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Concise Image Maps - A Design Approach

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Abstract

Image maps represent a special map type that combines realistic and abstract visualisation of geoinformation. In a traditional image map, abstract map symbols are overlaid as figures on a remote-sensing image as background. A successfully designed image map should be able to render a visual hierarchy that guides the user´s attention immediately to the relevant information. However, no matter which figure is chosen, its visual saliency will be more or less weakened by the heterogeneous imagery background. This means a delicate task for map designers, because the image heterogeneity poses two challenges: (1) the visual hierarchy is more or less randomly set by the radiometric properties of the image objects, and (2) the visual figure-ground segregation is heavily obstructed.

This work proposes an approach of concise image map design according to which a differentiated visual hierarchy can be established and the visual figure-ground segregation improved so that the user´s attention can be effectively guided to the relevant information. The radiometric design of raster images is addressed in the same manner as the graphical design of map symbols. To achieve this, cartographic principles are transferred to the realism of imagery. At the same time the traditional assignment of map symbols for figure, and imagery for background is redefined by treating image objects such as landmarks as prominent figures.

The approach of concise image map design is composed of a set of highlighting strategies applicable to raster image objects and a set of highlighting strategies applicable to vector symbols on imagery background. The joint implementation of raster highlighting and vector highlighting strategies helps promote the user perception of contents in the image map at various visual layers. In addition to strategies that highlight the visual salience of map symbols as figures on a background, further strategies are developed to downscale map symbols to lower visual levels in a hierarchy, for example, beneath the image objects. The effectiveness and user friendliness of the strategies involved in the approach of concise image map design are validated in user tests.

The evaluation shows excellent user performances of the highlighting strategies for image objects. Furthermore it shows that a multi-layered visual hierarchy can be established and the highlighting strategies for image object can be gracefully combined with conventional vector symbolisation techniques, leading to a pleasant visual perception.

This thesis is dedicated to revisiting the concept of image map with extended or renewed design strategies. It makes contributions to form a theoretical basis for the design and use of image maps, containing the re-definition of the term of image map, its design processes and its usability issues. This reveals substantial benefits of using image maps as a visualisation tool and concludes with an agenda to improve concise image map design.

Zusammenfassung

Bildkarten sind ein besonderer Kartentyp, in dem realistische und abstrakte Visualisierungen von Geoinformationen kombiniert werden. In einer herkömmlichen Bildkarte überlagern abstrakte Kartensymbole als Figuren ein Fernerkundungsbild, das als Hintergrund fungiert. Eine gut gestaltete Bildkarte sollte durch eine visuelle Hierarchie die Aufmerksamkeit des Benutzers sofort auf die relevanten Informationen lenken. Doch unabhängig davon welche Figur die relevante Information visualisieren soll, die visuelle Salienz der Figur wird mehr oder weniger von dem heterogenen Bildhintergrund abgeschwächt. Die hohe Heterogenität einer Bildkarte stellt den Kartengestalter vor diffizile Gestaltungsherausforderungen, denn (1) die visuelle Hierarchie wird faktisch zufällig von den radiometrischen Eigenschaften der Bildobjekte bestimmt, und (2) die visuelle Figur-Grund-Unterscheidung ist erheblich eingeschränkt.

In dieser Arbeit wird ein Gestaltungsansatz für prägnante Bildkarten erarbeitet, in dem eine differenzierte visuelle Hierarchie aufgebaut und die visuelle Figur-Grund-Unterscheidung so verbessert wird, dass die Aufmerksamkeit des Benutzers wirksam auf die relevanten Informationen gelenkt wird. Dabei wird die radiometrische Gestaltung von Rasterbildern im gleichen Maße berücksichtigt wie die graphische Gestaltung der Kartensymbole. Zu diesem Zweck werden kartographische Gestaltungsregeln auf den Realismus der Bilder übertragen. Zusätzlich wird die traditionelle Zuordnung der Kartensymbole als Figuren sowie der Bilder als Hintergrund neu definiert, indem Bildobjekte wie Landmarken als prominente Objekte behandelt werden.

Der Gestaltungsansatz der prägnanten Bildkarte wird von einer Reihe von Designstrategien zum Hervorheben von Rasterbildobjekten, sowie von mehreren Designstrategien für Vektorsymbole auf einem Bildhintergrund gebildet. Die gemeinsame Implementierung von Rasterhervorhebungs- und Vektorhervorhebungsstrategien trägt zur Steigerung der Wahrnehmung von Karteninhalten in unterschiedlichen visuellen Ebenen bei. Zusätzlich zu den Strategien, die die visuelle Salienz von Kartensymbolen steigern, werden auch Strategien entwickelt, die Kartensymbole innerhalb der visuellen Hierarchie herunterstufen, z.B. unterhalb von Bildobjekten. Die Wirksamkeit und Benutzerfreundlichkeit der entwickelten Designstrategien wurden innerhalb von User-Tests validiert.

Aus der Evaluierung ergeben sich hervorragende Nutzerergebnisse für die Hervorhebung der Bildobjekte. Es wird gezeigt, dass eine vielschichtige visuelle Hierarchie aufgebaut werden kann. Die Hervorhebungsstrategien für Bildobjekte können ästhetisch mit konventionellen Vektorsymbolisierungstechniken kombiniert werden, und ermöglichen eine ansprechende visuelle Wahrnehmung.

Diese Arbeit dient der Überprüfung der Konzeptionierung von Bildkarten mit erweiterten oder erneuerten Designstrategien. Sie trägt zur Bildung einer theoretischen Grundlage für die Gestaltung und Nutzung von Bildkarten bei. Der Begriff Bildkarte wird neu definiert, und deren Gestaltungsprozesse sowie Usability-Fragen werden näher beleuchtet. Dabei werden erhebliche Vorteile für die Anwendung von Bildkarten als Visualisierungstool aufgezeigt.

Diese Arbeit schließt mit einer Agenda zur Verbesserung der prägnanten Bildkarten-gestaltung ab.

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Introduction

An image map is a composition of remote sensing imagery and cartographic symbolisation. Cartographic symbols with confined graphical space are integrated to the extensive image. The image map proves to be an effective communication medium because of its visualisation crossover. The intuitive natural appearance of the image is combined with cartographic abstraction, which complements, describes, clarifies, and classifies image objects. Common image map architecture arranges cartographic symbols onto remote sensing imagery. An image map example is shown in Figure 0-1.

Figure 0-1 - Example of an image map: a regeneration project of the Council of Walsall, UK © Mott MacDonald Group Limited 2013[1]

Image map use had its first peak in the late 1950´s till 1970´s. Technical progress had made it easy to geometrically correct aerial images and assimilate them into the cartographic production line. Together with the start of satellite imaging, this encouraged cartographers to use image maps as map substitutes. The hype around image maps was cooled down since the 1980´s and no extensive research works were reported on the design issues of image maps in the subsequent decades. The widespread of the Internet, however, has brought about a renaissance of image maps. An increasing number of image maps appear in applications such as disaster management, tourism, urban development and topographic mapping. The current image map renaissance is influenced by a series of factors.

[1] http://www.visualisation.mottmac.com/imagegallery/ (13.03.2014)

Firstly, the extensive availability of very high resolution (VHR) images, which can depict fine structures of the earth´s surface as well as objects upon it, has broadened the range of potential application fields. Remote sensing images are both fascinating and confusing for visual perception. The small details that form patterns, textures and colours in both man-made and natural structures reveal some surprising perspectives of geoinformation visualisation. The natural beauty of remote sensing imagery to present geoinformation is an essential ingredient of image maps.

In contrast to earlier times, today's users have become accustomed to remote sensing imagery with the ubiquitous access to various earth viewers on the Internet. The interpretation of remote sensing imagery was once a professional task of experts with the purpose to store the interpreted information in a database. This has become an everyday exercise for many users who have also become familiar with representations combining naturalistic images and map symbolisation. 'Augmented reality' can be found in everyday use applications of Location Based Services (LBS) and make the superimposition of reality and abstraction a common site to many smart phone users.

Image maps enable a faster production time. Many map making workflow steps and symbolisation decisions can be skipped when imagery acts as base map or prominent objects are presented as imagery. For this reason image maps are widely chosen for time-critical mapping applications. Image map production has become 'quick and easy' since geodata can easily be embedded into earth viewers, such as Google Earth. The popularity of these earth viewers has led to a huge number of image maps created by non-specialists.

In spite of the extensive use of image maps, the amount of scientific research on image map design lags behind. A few helpful, design guidelines concerning specific image map design applications exist (i.e. Albertz and Lehmann, 2007, Raposo and Brewer, 2013, Hoarau et al., 2013). But neither holistic design approach nor complete map design workflow is available. This work aims to revisit the concept of 'image map' and provide a cartographic framework for the production processes of image maps. Furthermore the benefits of image mapping will be analysed in order to strengthen the motives of spreading this visualisation medium.

The standard overlay of map symbols onto imagery has created and maintained the design default of map symbols being treated as the foreground or figures, and the imagery as background or context information. With this thesis, the author tries to question this design default and attempts to give the image map design a higher degree of flexibility, for instance, by emphasising landmark image objects as prominent foreground objects and visually downscaling the map symbols when needed. This can be achieved by addressing the radiometric design of raster images in the same manner as the graphic design of cartographic symbols.

The design of image maps is no trivial task. Important information should be visualised in the foreground and has to be visually segregated from the background. Figure-ground segregation is thereby best enabled when the figure is surrounded by empty void or a harmonic background. However, the background of image maps is seamlessly covered by remote sensing imagery, which is highly heterogenic as it is set by a collage of figures with varying sizes, colours and intensities. The noisy visual background impedes users to visually search for relevant information on image maps. Some prior studies have shown that visual searches with complex imagery backgrounds are significantly longer than searches done with simple imagery backgrounds (Lloyd and Hodgson, 2002). Facing the challenge of introducing a visual hierarchy despite the heavy visual burden of imagery, the designers of image maps therefore need to develop an approach towards the so-called concise image map design.

Concise image map design aims at attracting user's attention immediately and guiding the attention to the relevant information. It uses pre-attentive variables to make prioritised information more salient, thus allows the user to graphically rank features into vertical visual layers. Moreover, it embraces a set of image design strategies to inhibit distracting effects of the heterogeneous background imagery. The saliency of figures must thereby outweigh a reduced saliency of the background. The framework of concise image map design will serve as decision assistance for the designers, while users will be given an effective image design with a functional visual hierarchy and sufficient context information combined with an aesthetic, visually pleasing appearance.

The major tasks involved in this work are:

- Extend and renew the general design process of image maps,
- Redefine the term 'image map' by taking other references and practical applications into account,
- Analyse image maps following generally accepted cartographic principles,
- Formulate design principles and develop design strategies that meet the criteria of concise image map design, and
- Evaluate the new design strategies via user tests.

The work is structured as follows:

Chapter 1 outlines the technical production process of image maps and its evolution. Many historic and current image map examples illustrate their origin from different human inventions as well as the impacts of technical progresses leading to the state of the art of the digital production process. Two holistic image design workflows from the raw data input to the fully designed image map output are presented.

Chapter 2 is dedicated to the visual perception and cognition of image maps with the intention to understand how and what information can be extracted by the user. Theoretical concepts are given for the human interpretation of photographic representations as well as cartographic transcriptions of geoinformation. This theoretical foundation serves as the starting point for the development of a framework of concise image map design.

Chapter 3 contains the analytical part of this work. Starting from the essential differences between images and maps, this chapter addresses ambivalent views on image maps from different scientific fields. A definition of the image map reflecting the state of the art is then given. Different types of image maps as well as major application fields are presented, which allows the development of a conceptual framework for image map visualisation between realism and abstraction as well as the comprehension of the role of image maps between visualisation and communication. Furthermore, the benefits of image maps are outlined in comparison to holistically symbolised maps. Chapter 3 also includes the graphic implementation of image maps and introduces recommendations for the visualisation mode of features, symbolisation techniques and generalisation feasibilities for image maps.

Chapter 4 firstly demonstrates a publishing method to improve the user´s accessibility of online image maps. The framework of the concise image map design approach is then introduced. It is characterised on the one hand by a set of image object highlighting strategies that allow local and object-specific image manipulation, and on the other hand by a set of map symbol design strategies derived from the highlighting potentials of graphic variables on imagery. Research questions are formulated upon these design strategies and subsequently evaluated in a user test. The test results are statistically analysed.

1 Image Map Production Process and History

This chapter gives firstly an overview of the history of image maps (section 1.1). The origin from different human inventions as well as their blending in to early image map products is illustrated. Furthermore, it describes how technical progresses have improved the possibilities for displaying geodata with image maps. This is shown by a wide range of various historic and current image maps.

The major part of this chapter is dedicated to the production process of image maps. Section 1.2 proposes a holistic production process representing a complete up-to-date workflow from the raw data input to the fully designed and layouted image map output. This holistic processing workflow is named '*standard workflow of the image map design*'. Section 1.3 describes another image map workflow. The 'quick and easy' '*image map mashup*' has emerged in the context of neo-cartography. The background to mashups is described in section 1.3.1, before a typical image map mashup workflow is presented in section 1.3.2.

1.1 History of Image Maps

Image maps have emerged due to three inventions: cartography, photography, and aviation. Image maps count as a special type of maps, and are therefore addressed in cartography. The imagery part of image maps belongs to the field of photography, and is the result of photographic emulsion or nowadays rather, derived by electrical charge of an image sensor. And finally aviation has been necessary to uplift mankind and his remote sensing capability to a bird´s-eye view.

The map has a much longer history than the image. Like other significant early inventions the first maps were probably created in Mesopotamia around 2300 B.C. (Clark and Black, 2005). From there it took mankind a long time to invent photography as the breakthrough towards image maps. In 1826 Joseph Nicéphore Niépce was the first to make a permanent photography from nature (Gernsheim, 1977). Niépce´s photographs took several hours to expose so that further advances of his procedure were needed for usable applications. Louis-Jacques Mandé Daguerre who became a partner of Niépce invented photography based on silver-coated copper plates in the 1830s. This more sophisticated technique provided not only the basis for camera photography in the 20th century. Cameras became more and more manageable and inspired mankind to take pictures from a bird´s-eye view. The first proven attempt to take aerial photographs was made by Colonel Aimé Laussedat of the French Army Corps of Engineers in 1849 (Wolf and DeWitt, 2000). Laussedat experimented with cameras ascended by kites and balloons, but was unsuccessful. The first known aerial photograph was taken by the pioneer balloonist Gaspard Felix Tournachon (Jensen, 2007). Also known as '*Nadar'* he uplifted himself with a hot air balloon to take pictures from a village near Paris in 1858. Tournachon played an important role in the aerial photography initiation and established aerial survey. This is underlined by the fact that he applied for a patent for mapping the land from a series of overlapping aerial photographs

(Newhall, 1969). Even though an increased number of aerial photographs were made in the following decades with the help of kites and balloons, the remote image sensing was expanded to more sophisticated applications with the emergence of aviation. "*The development of heavier-than-air craft enabled man to move through the atmosphere as he wished and eventually they provided the capability of transporting the necessary equipment to produce excellent aerial photographs*" (Robinson and Sale, 1969). In 1908, five years after the invention of the airplane, a photographer accompanied one of the inventor brothers, Wilbur Wright, and took the first series of aerial photographs from an airplane (Lillesand et al., 2004). Further improvements on aircraft and photography technique and equipment made aerial photography a much more practical matter. Flight altitude, vertical camera orientation and therefore the control of scale became much better. These advances enabled that image maps became a more feasible visualisation possibility.

Remote sensing had a great effect on cartography, so able described by Kraak and Ormeling (2003, page 33): *"One of the most important moments for cartography was when the first satellite pictures became available. This created the opportunity to check whether the mapping activities of previous centuries, and especially the generalization from large-scale detailed maps to small-scale overview maps of larger areas, had been done in the right way".*

Since the 1920´s and 1930´s aerial photography provided data for mapping and was now used besides cartography for engineering, forestry, soil studies and other applications (Aber et al., 2010). The German geographer Carl Troll (1939) highlighted the capability of aerial photographs for viewing the landscape as a spatial and visual entity and strongly advocated their use in scientific studies.

Images as the straightforward reflection of the landscape are the foundation of most maps. The convention of remote sensing images passing topographic and thematic information on to the map-making process has become the default since about 1930 (Albertz and Lehmann, 2007). Remote sensing images can be regarded as a preliminary stage of the map design. But since the development of this map-production line, the image map has evolved as an alternative solution to the classical map, and established itself as an independent cartographic product. This even incited scientists to discuss how image maps could substitute traditional symbolised maps (i.e. Beck, 1966). This may not have happened, but image maps do act as map substitutes on certain occasions (Robinson et al., 1995b).

This excellent potential of visualising the earth´s surface with an aerial image was soon recognised by cartographers. A very early image map is the Economic Map of Sweden. It´s production started in 1937 at a scale of 1:10,000 (Jonasson, 1965). Administrative information, cadastral information and annotation was printed in black, contour lines in brown, arable land in yellow and the panchromatic aerial photo in green (see Figure 1-1). The Economic Map of Sweden was produced with a standard rectified image until 1966, when the orthophoto technique was adopted to improve the geometric accuracy (Jonasson and Ottoson, 1974).

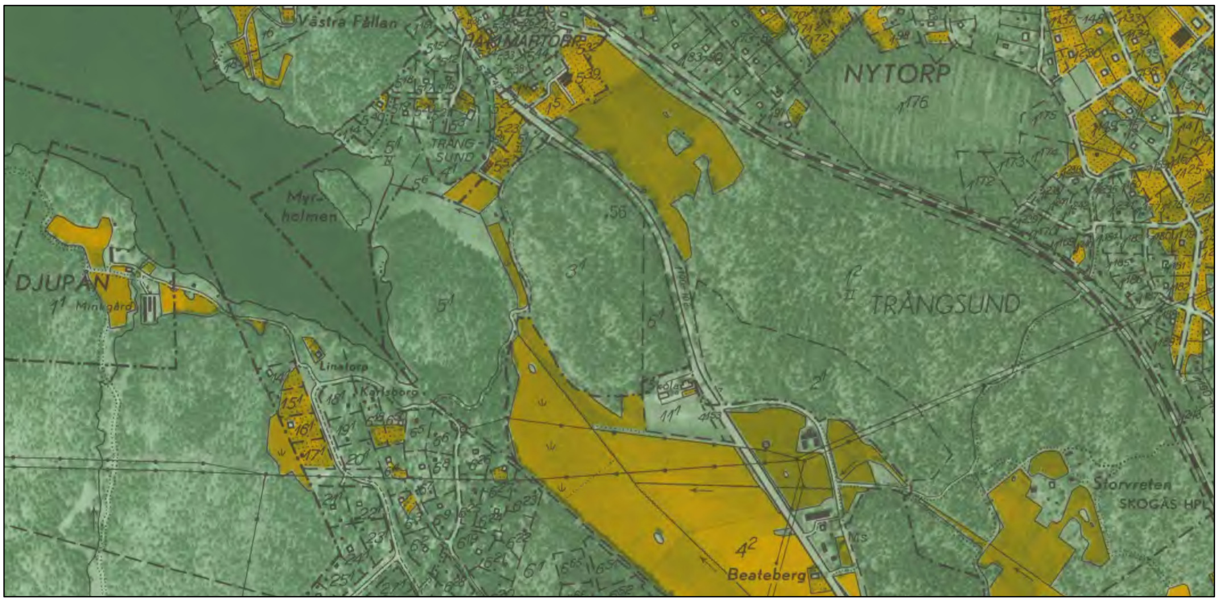

Figure 1-1 - Details of the Economic Map of Sweden, map sheet Dreviken 1951, © Rikets Allmänna Kartverk

The need for military intelligence in World War II contributed much in the way of methods and procedures in air photo interpretation (Robinson and Sale, 1969). It is therefore no surprise that image maps were available from military intelligence of that time. One example is shown on Figure 1-2. Image maps like this here, used for reconnaissance, displaying symbolised military circumstances on a vertically taken aerial photograph of Omaha Beach, were of immense tactical importance for the invasion of the Normandy.

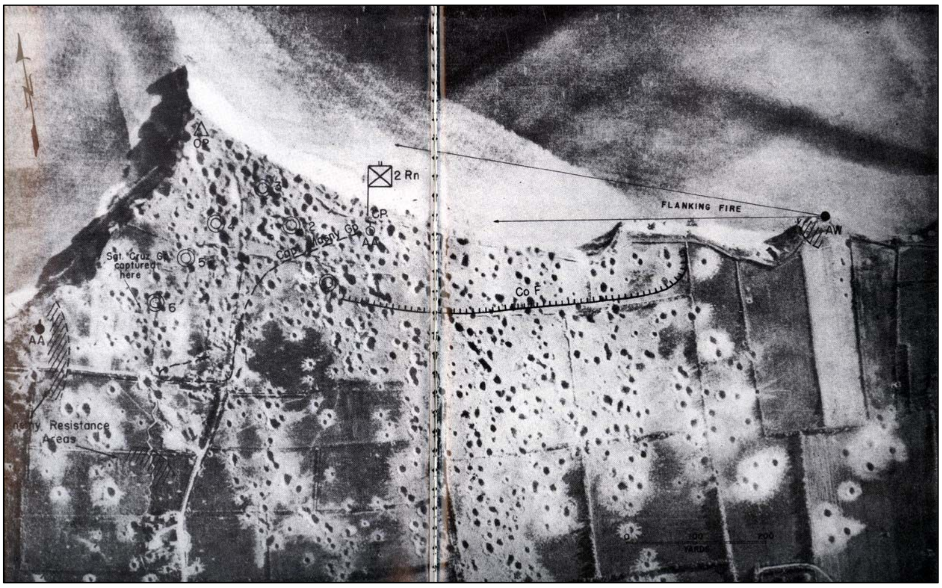

Figure 1-2 - Image Map of Omaha Beach produced by the U.S. Army in 1944 (United States Army Center of Military History, 2003)

After the Second World War, aerial photographs became the substitute of large-scale topographic maps for several parts of the world, where either the terrestrial surveying capacities were insufficient or maps were needed for certain time-critical applications. In Germany, aerial photo plans in a 1:5,000 scale eased the need for up-to-date topographic maps (Krauß and Harbeck, 1985, page 299).

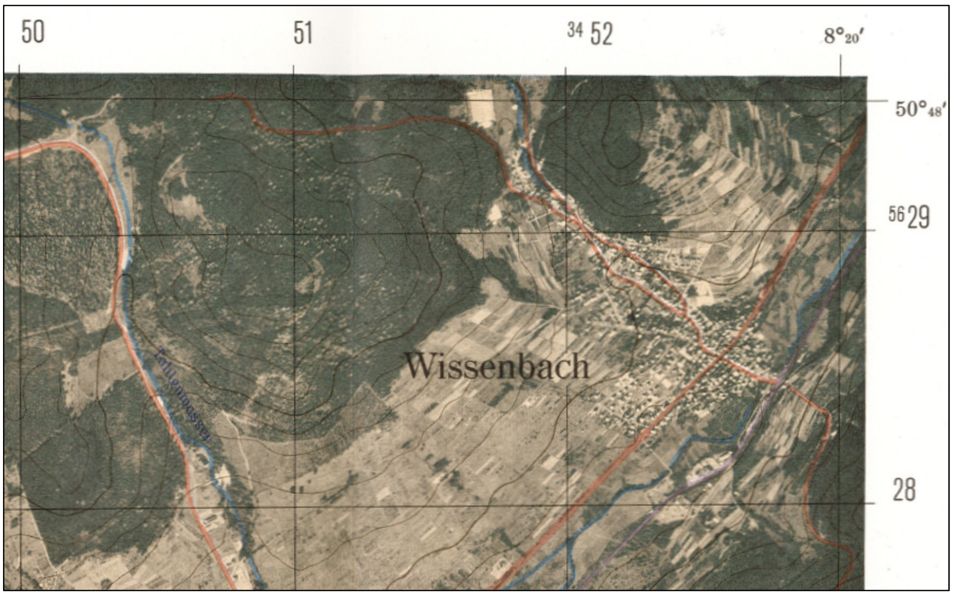

Figure 1-3 - Details of the map sheet Dillenburg 1974, 1:25000, © Institut für Angewandte Geodäsie

In the 1960´s, methods were introduced to geometrically rectify remote sensing images. Despite varying object distances between the camera and the recorded objects mainly due to the irregular topography and the central perspective position of camera, the scale on an image became uniform, and the rectified images were termed as orthophotos (Smith, 1995). The consistent scale was the key to allow the directly overlay of remote sensing images and orthographically projected map elements. Image maps could now be produced from a technical and economic point of view. In the early 1970´s the German Institute for Applied Geodesy (Institut für Angewandte Geodäsie) developed methods to produce and continue a topographic image map series 1:25,000 (Schmidt-Falkenberg, 1974). The default black and white orthophotos were overlaid with cartographic symbols from several object layers (see Figure 1-3).

A more widespread and global image coverage of the earth´s surface started with the advent of satellite remote sensing. The U.S. military space imaging reconnaissance programme *Corona* was launched in 1960. These first satellites to record vertical images were equipped with 70 mm cameras (Lillesand et al., 2004) to achieve a 40 ft. ground resolution (Jensen, 2007). In many following satellite missions, multi-spectral images and thermal infrared images complemented panchromatic images and the image resolution became higher. The current EROS-B earth observation satellite of the commercial Earth Resources Observation Satellite (EROS) programme, for instance, captures scenes of 7 km width and 150 km length and offers up to 70 cm (panchromatic) ground resolution (Lemmens, 2011).

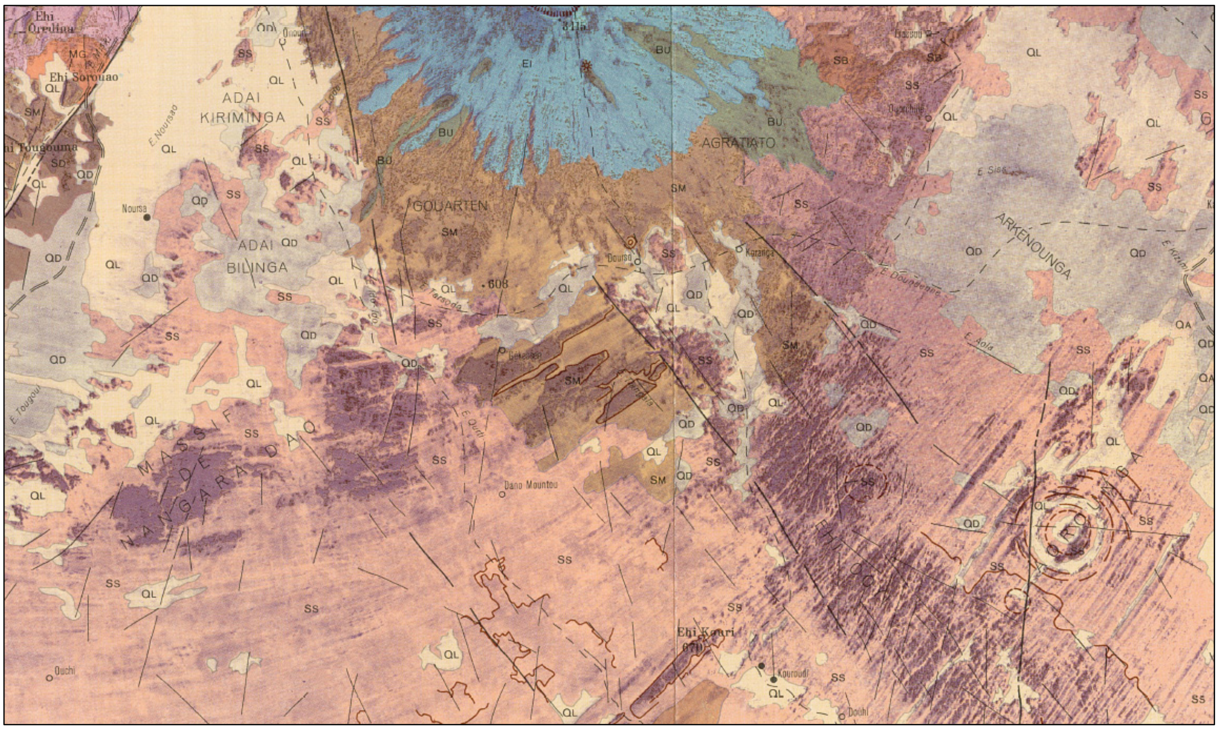

Figure 1-4 - Details of the image map Geological Interpretation of the Tibesti from LANDSAT-1 Imagery (Republik of Chad)

A good example showing how multi-spectral satellite images were used to create an image map is the geological map of the Tibesti from 1978. The Tibesti region (Central Sahara) was mapped by visual geological interpretation of LANDSAT-1 imagery and then printed in a seven colour offset (List et al., 1978). Besides geological thematic information and topographic symbols, the LANDSAT-1 imagery is printed in a dark brown layer (see Figure 1-4).

Figure 1-5 - Details of radar image mosaic Atka, Alaska Utah, produced by the United States Geological Survey, 1982

Other imaging methods have been used to complement cartographic symbolisation and to map the earth´s surface. Besides passive recording of visible and non-visible light imaging there are also active remote sensing systems. Light detection and ranging (lidar), sound navigation and ranging (sonar) as well as active Microwave (radar) can deliver the raster image basis for an image map. As non-visible light is recorded, the image´s pixel values are coded by a colour scheme in order to show the recorded spatial information on a map. The image map example on Figure 1-5 is based on radar imaging and visualises the topography of the Atka Island in Alaska by a set of grey tones.

Further advances were made to accelerate the image map-making process. Cameras used photographic films in the 19th and 20th century. In the 21st century, the age of digital handheld cameras entered photography. And in recent years pixel-based electronic image processing has now emerged in remote sensing. Either charge coupled devices (CCD) or complementary metal-oxide-semiconductor (CMOS) sensors were used (Lillesand et al., 2004). The evolution of Geographic Information Systems (GIS) has made it possible to store, manage, edit and visualise digital images and to integrate these images to separately surveyed geodata. This has led to nowadays omnipresent geodata with mixed raster and vector origin, resulting in the display and dissemination of omnipresent image maps.

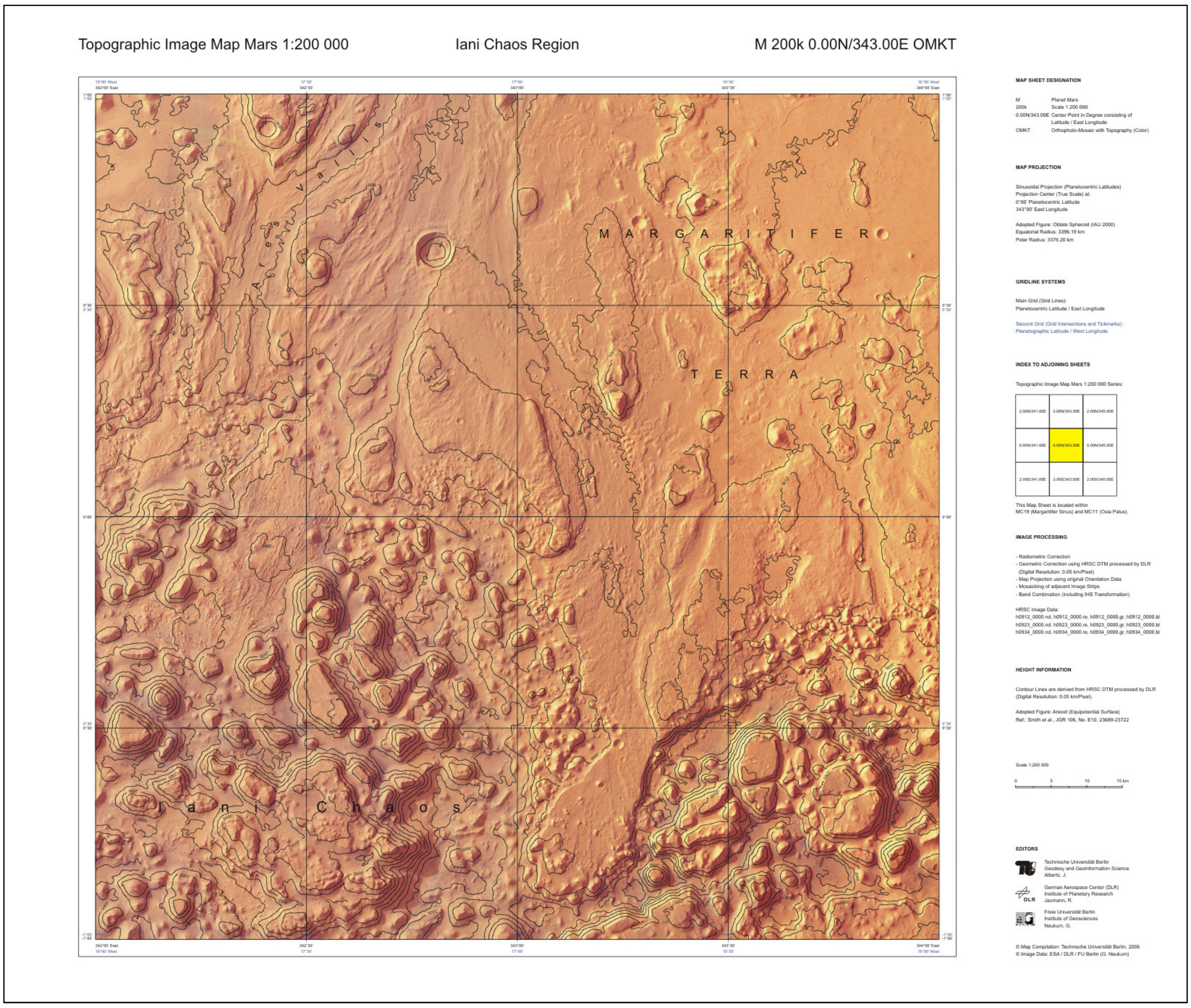

Figure 1-6 - Map sheet "Iani Chaos Region" of the Mars in the default scale 1:200,000 © Map compilation: Technische Universität Berlin, © Image Data: ESA, DLR, FU Berlin (G. Neukum)

Since space missions explore outer space, image mapping has accordingly extended its scope from the earth to other planets. Along with the Mars Express mission, imagery of a high resolution stereo camera (HRSC) was photogrammetrically processed to receive a digital terrain model (DTM) of the Mars´ surface (Gehrke et al., 2003). Contour lines were derived from the DTM and overlaid on coloured orthophotos together with automatically placed labels (Albertz et al., 2005). The digitally stored map sheets can be printed on demand (see Figure 1-6).

The presence of image maps reached a new horizon with the advent of earth viewers, such as Google Earth, Bing Maps, or Nokia HERE. These web mapping service applications offer free map services that have become part of our daily life. As all major providers have established an image map mode supplied with satellite imagery, aerial photography and mixed with street vector data, large parts of the population in the world have become accustomed to viewing image maps.

1.2 Standard Workflow of the Image Map Design

This section gives an overview of the standard workflow for the design of image maps. This workflow reflects the current state of ubiquitous GIS and digital processing. In the past, a number of image map-design workflows have been presented. Some of them originated from pre-computer era, therefore, no or little computer-aid was considered and non-digital sources were used. Schweissthal (1970), for example, considered aspects of the compilation of thematic image maps by discussing the production of an image map for hiking purposes. One of the most recent digital image map workflows was defined by Albertz et al. (1992) for satellite images with emphasis on photogrammetric aspects. None of these workflows, also not the standard one as shown in Figure 1-7 are intended to elaborate the design details subjected to technical and psychophysical constraints. The design stages such as '*problem identification*', '*preliminary ideas*' and '*design refinement*' proposed by Dent et al. (2009) and Hanks et. al (1977), or alternatively, the design stages '*planning*' and '*data analysis*' as proposed by Tyner (2010) can be adapted for the design process of image maps. Apart from the design issues related to symbolisation and layout, our standard workflow represents the composition of individual operations. It contains all required steps leading to the image map. The image map designer does not have to carry out all these steps by himself. For instance, the pre-processing of remote sensing images can be taken over by remote-sensing specialists.

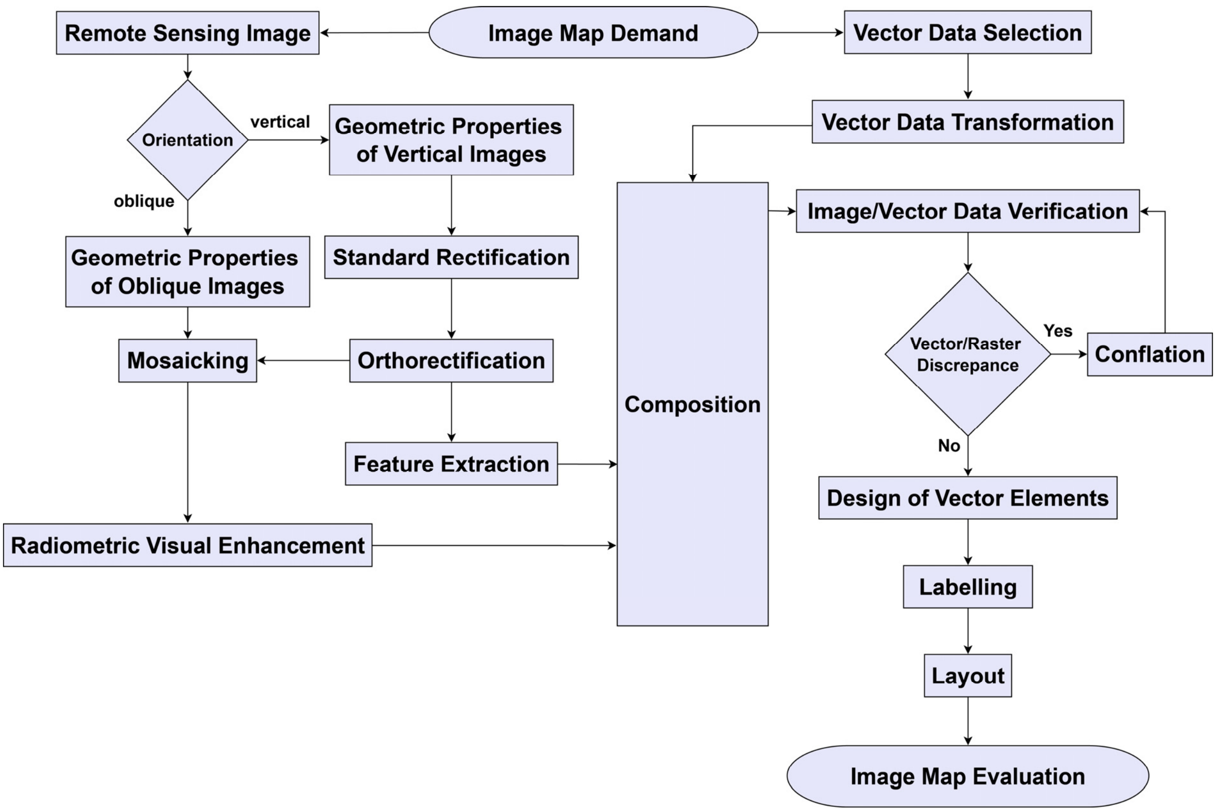

Figure 1-7 - standard workflow of image map design

This standard workflow deals with the implementation, or rather the construction of the image map. The '*image map demand'* marks the starting point of the workflow (Figure 1-7). The following workflow diagram will be explained, step by step, within this chapter. Due to the different data sources of image maps, the workflow diagram splits, in its beginning, into two sections. Here, the production of image maps start with the selection of suitable data in the steps '*remote sensing image*' and '*vector data selection*'. Both sources are merged within the step '*composition*' before an '*evaluation*' step concludes the workflow.

1.2.1 Remote Sensing Image

The image map workflow starts on one end with the extraction of images by means of remote sensing. In a broad sense, "*remote sensing is the field of study associated with extracting information about an object without coming into physical contact with it*" as stated in John R. Schott (2007, p. 114). In a narrow sense this field of research is "*the measurement of object properties on the earth´s surface using data acquired from aircraft and satellites*" (Schowengerdt, 2006, p. 2). When radiation hits an object, it may be transmitted, absorbed or reflected. Different materials reflect and absorb differently at different wavelengths. So, remote sensing makes airborne and spaceborne images of the earth´s surface by the recording of differently reflected or emitted electromagnetic radiation. These recorded images form the basis for image maps.

All remote sensing images have different characteristics depending on the general sensor type and exposure conditions. This sensing diversity leads to very different kinds of image maps. In the following a short overview is listed about the major remote-sensing configurations that have a decisive influence on the recorded image, and therefore, the appearance of image maps:

Active Sensor / Passive Sensor

Two general types of sensors are used within remote sensing: active and passive sensors. Active sensors radiate a beam to record the beam´s reflectance of the earth´s surface. Radar (radio detection and ranging) and Lidar (Light detection and ranging) are typical examples of passive sensors. For radar, microwave signals are emitted and scattered when they hit the earth´s surface. The backscatter, which is reflected back to the sensor, is then measured to receive the round-trip time and the strength of the reflected signal. The resulting image derives from the concept of radar imaging, in which a spatial distribution pattern of the target gives a spatial quantitative description of the earth´s surface (Pasmurov et al., 2005). A radar image example can be seen on Figure 1-8. Lidar systems work in a similar manner that they consist of a transmitter and a receiver. In this case, short light pulses with lengths of a few to several hundred nanoseconds and specific spectral properties are generated by a laser (Weitkamp, 2005). The received backscattered signal is processed in order to generate an image based on the runtime or the intensity of the backscatter.

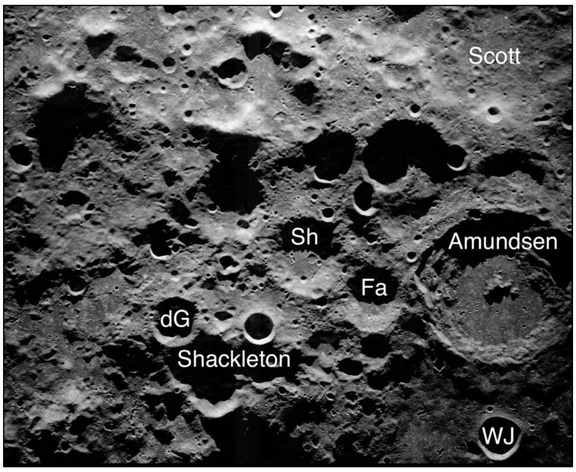

Figure 1-8 - Radar image map of the Moon's South Pole, © Arecibo Observatory and the Greenbank Telescope, 2005

Passive sensors receive radiation for imaging only. These sensors record electromagnetic energy that is either reflected or emitted (e. g. thermal radiation) from the surface of the earth (Jensen, 2007). The choice if active or passive sensors are to be used determines which electromagnetic spectrum can be recorded and therefore which objects are to be imaged. Table 1-1 gives an overview of the primary spectral regions used in remote sensing. When for instance forest damages are to be displayed, passive remote sensors with infrared bands fits this need best (Rock et al., 1986). But for instance when weather conditions like clouds and rain are to be bypassed, the choice falls onto active microwave (Weng, 2011).

Visible light	**0.4 – 0.7 μm**
Blue	**0.4 – 0.5 μm**
Green	**0.5 – 0.6 μm**
Red	**0.6 – 0.7 μm**
Visible-photographic infrared	**0.5 – 0.9 μm**
Reflected Infrared	**0.7 – 3 μm**
Nearer infrared	**0.7 – 1.3μm**
Short-wave infrared	**1.3 – 3.0 μm**
Thermal infrared	**3 – 5 μm, 8– 14 μm**
Microwave	**1 mm – 1 m**

Table 1-1 - wavelengths of major spectral regions used for remote sensing (Liu and Mason, 2009)

Single Band Images / Multiband Images

Regardless of if active or passive sensors are used, the remote sensing system can use one single spectral range or a variety of spectral ranges. If the remote sensor records the backscatter in one region of the electromagnetic spectrum, this is called single-band remote sensing. One spectral range equalises one band. The resulting single-band image holds the information of a finite set of quantised values. The information is typically stored in a set of grey shades. This principle is the same for latent images on photographic film as for digital images.

The presence of remote sensing latent images from analogue cameras will significantly drop in the near future. Just as digital cameras are the default in satellite remote sensing, digital cameras will also soon replace analogue cameras in areal remote sensing completely, due to their equal or superior geometric and radiometric properties (Jacobsen, 2008). Digital cameras record images with an electronic sensor. Light is turned into discrete signals by CCD sensor chips or complementary CMOS sensor chips.

In case of film-based photographic emulsions different sensitivities of spectral ranges have different descriptions. Orthochromatic, panchromatic, and near-infrared emulsions are sensitive to different spectral ranges, but all record solely black-and-white images (McGlone et al., 2004). An example for a panchromatic photographic emulsion is shown on Figure 1-9. Photographic film can also record energy in multi-bands and be then exposed to three dye layers. The most heavily used colour photographic emulsions in photogrammetry are normal colour photographic and colour-infrared. These could be considered as three-band multispectral sensors (Jensen, 2007). Normal colour photographic emulsions record three bands in blue green and red. Colour-infrared film also records three bands with one band in the reflected infrared spectral region.

Digital sensors can record a greater number of bands than hard copy film. These multispectral scanners can also sense light over a very wide range of spectral regions from approximately 0.3 µm to 14 µm (Lillesand et al., 2004) (compare with Table 1-1). For instance, the longest running enterprise for acquisition of satellite imagery, the Landsat programme, initially had a multispectral sensor of seven bands. The sensor suite consists of two spectral bands in visible light, two near-infrared bands, two shortwave infrared bands and a thermal infrared band (Williams et al., 2006). Multispectral remote sensing systems can record very narrow spectral bands, so that it can be expanded to hyperspectral remote sensing, in which hundreds of bands are recorded.

Figure 1-9 - SPOT 5 panchromatic image with a 2.5 m resolution of Toulouse (FRA), Cnes (2005)

1.2.1.1 Colour Composite Images

Remote sensing images are displayed on electronic visual displays. The digital image is therefore converted to an additive colour scale. If all primary colours red, green and blue have i.e. equal pixel values, this creates the colour grey. For each remote sensing band a primary colour can be chosen. This choice affects the appearance of the image heavily. Certain colour combinations are widely used in remote sensing and are described in the following.

Natural Colour Images

If a multispectral image consists of the three visual primary bands, the red, green and blue band can be combined to a natural colour image. The objects on the image appear then in very similar colours to how the human eye would directly see them. Sometimes natural colour images are referred to as 'true' colour images (Schowengerdt, 2006). Natural colour images are easier to interpret for non-remote sensing specialists.

False Colour Images

Unlike a natural colour image, a false colour image does not follow the natural colour rendition. A false colour image is used when at least one band is outside the visual spectrum. Then a minimum of one non-visible spectral band is linearly transformed to a displaying primary colour value. In this case, the displayed spectral band does not have any resemblance to its actual colour. The false colour composite does not look natural, like being seen with the naked eye (Patra et al., 2006). The colour infra-red composite (NIR band) is a commonly used false colour (Schowengerdt, 2006). In this case the red band is displayed as green the green band as blue and the near infra-red band as red. Vegetation has a high reflectance in the near infra-red band, so that colour infra-red images emphasize the conditions of vegetation.

Grey Scale Images

Grey scale images consist of one spectral band only. The spectral value is linearly transformed to a grey colour scheme. The displayed brightness is directly proportional to the sensed intensity. Panchromatic film emulsions as well as single bands from the non-visible spectrum are displayed as grey scale images.

Pseudo Colour Images

A pseudo colour image is derived from a single spectral band even though additive colours are used to display the image. The spectral band is linear transformed over a multi-colour scheme. The goal is to maximize the perceived difference of values by introducing a complex colour scheme. A typical application for pseudo-colour images is the display of thermal information.

1.2.2 Orientation

The remote sensing image can be obtained from vertical or oblique vantage points depending upon the area and geospatial information to be visualised on the image map.

Vertical images are gained when the sensor´s optical axis is roughly vertical to the earth´s surface. Photogrammetric principles are applied to rectify and orthorectify vertical remote sensing images (see sections 1.2.4 and 1.2.5). Vertical imaging is the standard remote sensing technique as vertical ortho-images are prevalent on geospatial information systems, because of the common georeferencing and blending with other two dimensional geodata and easiness to achieve two dimensional measurements.

Oblique images are obtained when the angle of view is tilted so that the camera´s optical axis deviates more than a few degrees from vertical (Wolf and DeWitt, 2000). Useful oblique image material is obtained only by airborne sensors. An overview of different technical approaches in collecting oblique images is given by Petrie (2009). An oblique view is commonly used for large-scale image maps in which building facades or mountain surfaces are presented. Deliberately remotely sensed oblique images are obviously not rectified. Nevertheless it is possible to georeference oblique images. The processing of oblique images for metric applications is considered in section 1.2.6.

1.2.3 Geometric Properties of Vertical Images

In order to utilise raw remote sensing imagery for the design of an image map in vertical view, it is necessary to know the relation of image coordinates to space coordinates. The interior and exterior orientation of the remote sensor has to be known to be able to assign the image pixels to georeferenced coordinates. The parameters of the interior sensor orientation are simply subject to camera calibration. The position and angular orientation of the sensor itself within a spatial coordinate system designates the exterior orientation. To capture the exterior orientation parameters, the airborne sensor carrier has an on-board global navigation satellite system (GNSS) and an inertial navigation system (INS) to record the sensor´s position and orientation in space when an image is taken. A direct orientation determines the exterior orientation solely by GNSS and INS is. Indirect orientation uses ground control points that offer known coordinates in both models (although this is not possible with row CCD sensors) (Kohlstock, 2011). The estimation of the exterior orientation is further improved by aerial triangulation (for further reading see Linder (2009)). The interior and exterior orientation parameters are then used to establish the transformation parameters between image coordinates and spatial coordinates. As soon as the transformation parameters become known, the image rectification can start.

1.2.4 Standard Rectification

A standard rectification removes the image distortions due to perspective effects. As remote sensing images are not taken in perfect nadir, the deviation to the central projection has to be compensated by rectification. This requires the transformation parameters between image coordinates and spatial coordinates. Digitally geo-rectified images are reprojected to a reference plane, or in the case of satellite imagery, the ellipsoid surface (Miller, 2004). Every pixel from the input image is assigned to the output image plane. As this assignment leads to an irregular distribution on the plane, the regular output pixel values are interpolated from neighbouring assignments. This process is called resampling.

Within the standard rectification processing step, distortions due to the curvature of the earth and refraction should be eliminated if necessary.

1.2.5 Orthorectification

The standard rectification is intended to remove the tilt impact of the sensor, but further rectifications may be needed to guarantee the image a uniform scale. While in flat areas standard rectification may be sufficient, the feature displacement increases with the growing terrain height. This is due to the perspective image. On a remote sensing image, the terrain and the objects on the terrain are affected by relief displacement. Features that are higher than the nadir are displaced outward from the centre of the photograph and features that are lower in elevation are displaced inward from their true position (Smith, 1995). This is the phenomenon of the apparent (building) lean (Society of Photo-optical Instrumentation Engineers, 2002). Orthorectification transforms the perspective projected image to an orthogonal projected image. The displayed features on the original image are forced into their geometrically true position. This end-product is an orthophoto. An orthophoto therefore differs from a standard rectified photograph in that only tilt has been removed from a rectified photo, whereas topographic displacement is also removed in an orthophoto (Paine, 1981). To remove the topographic displacement a digital elevation model (DEM) is needed. By combining the two sources, each image pixel has a geometrically true position and can be resampled, which leads to an orthoimage.

As objects on the ground like buildings, trees or bridges are not modelled within a DEM the orthoimage will show radial displacements around these objects (Konecny, 2002). This can be corrected by using a so-called ‘true orthophoto’ for which a digital surface model (DSM) rather than a DEM is taken to resample the output image. The DSM models not only the terrain, but also surface objects like buildings that show the apparent lean in standard orthophotos. Moreover, the true orthophotos also tackle the problem of occluded areas behind tall objects caused by the sensor perspective. The photogrammetric geometry is then used for the detection of occluded and shadowed areas in true orthoimage generation (Zhou et al., 2004). Occlusions that occur in single images can be filled up by combining several overlapping orthophotos (Braun, 2003).

1.2.6 Geometric Properties of Oblique Images

The established photogrammetric standard tools for vertical remote sensing images cannot be applied to oblique images. The footprint of an oblique remote sensing image has a trapezoidal shape instead of a rectangular one. This means that the scale of the pixels varies within the image due to perspective foreshortening. Oblique images are therefore not rectified. Even though oblique images cannot be processed to a standard planimetric ortho-image, georeferencing is possible. Firstly, the interior and exterior orientation of the remote sensor (see section 1.2.3) has to be known. The photogrammetric parameters important to relations between the image coordinates and the spatial coordinates of oblique images can be found in Graham and Read (1986). A calibrated camera, GPS/INS positioning and a DEM (or rather a DSM) enables georeferencing (Simmons and Karbo, 2007). Gerke and

Nyaruhuma (2009) address a multi-device calibration of parameters of oblique aerial images to support the stability of the overall geometry. However, the planimetric accuracy is lower than in orthoimages, although the elevation of objects can be determined more precisely (Höhle, 2008). The georeferenced oblique images can be integrated with a GIS environment. Special plug-ins can enable standard GIS software to view and to integrate oblique images with other geospatial data (Karbø and Schroth, 2009).

1.2.7 Mosaicking

A single remote sensing photo rarely covers the complete geographic area of interest. That is why the photo source of image maps often originates from multiple images which allow a seamless coverage of study area. Mosaicking is the merging of multiple images to one single image. The input images have to overlap for a mosaicking result. Mosaicking can solve three basic tasks – merging of multiple images of a single source, merging of multiple images of different sources, and merging of multi-temporal images recorded at different times (Albertz, 2009).

In case of vertical remote sensing images, an approximate merging result is reached within the rectification step. The aligning of multiple images produces better results when the apparent lean is avoided (see 1.2.4). For this reason orthoimages or better true orthophotos are used as a mosaicking input. Every single input image shares the same coordinate system and can therefore be aligned into a preliminary result. Mosaicking is the geometrical transformation of all images by using identical points in the overlap. The result can be improved if joining images have shared control points in their overlap.

Mosaicking of oblique images is a more complex task. Changing perspectives and differing scales of objects in the overlapping area add to the difficulties. For this reason, some image maps were created from multiple oblique images in a straightforward manner by using stitching algorithms (Kerle and Stekelenburg, 2004). These simple mosaic results cannot be georeferenced and seam lines can be noticeable in the join of the different images. Recently, some methods have been developed to improve oblique mosaics. Oblique mosaics can be georeferenced, if the mathematical sensor model of interior and exterior orientation is used. These products, named orthorectified-oblique mosaics (Karbø and Schroth, 2009), offer a continuous projected image from an oblique perspective. Under usage of a DSM, the imagery is draped onto the surface of a 3D model and treated as a photorealistic 'skin' (Kalinski, 2012). The method captures the geographic location of each pixel in each image. Then each pixel can be reprojected from the 3D model by resampling in any requested perspective angle to create an oblique-mosaic image.

1.2.8 Radiometric Visual Enhancement

In addition to geometric aspects, radiometric aspects are also considered in the digital image processing of remotely sensed imagery. Along the image map processing chain, the step of visual enhancement deals with the improvement of the visual image quality by manipulating pixel lightness, colour and contrast. Depending on the origin of image errors or the processing objective, it is separated into three digital processing tasks (i.e. Jensen (2005)) - image restoration, image enhancement and radiometric mosaicking.

Image Restoration

Image restoration, sometimes referred to as radiometric corrections, aims to reduce noise and eliminate errors in the image that were introduced by the sensor system or by atmospheric influences. The sensor system may feature unwanted effects due to limitations in optical sensing, spectral digitization, or data recording. Atmospheric influences lead to a brightened image and a reduced contrast (Albertz, 2009). The atmospheric impact depends on a number of variables which have to be taken into account to run a detailed correction. The variables important to atmospheric corrections are:

- sun elevation,
- earth-sun distance,
- sensor viewing geometry,
- atmospheric haze, and
- surface physiography.

A good overview of classical image restoration techniques is given by Banham and Katsaggelos (1997).

Image Enhancement

Image enhancement is concerned with the modification of images to make them more suited to the capabilities of human vision. Image enhancement is mostly performed after image restoration with the goal to improve the visual interpretability of an image by increasing the apparent distinction between the features in the scene (Lillesand et al., 2008). The readability is improved by visually accentuating slight radiometric differences of objects that otherwise are veiled to the human eye. Image enhancement is a crucial step to produce a user-orientated visualisation. Improving the overall interpretability of the remote sensing image is not the only goal for image map applications. Depending on the specific application, the image map designer should also decide which feature class is to be highlighted and made visually distinct from other image space. However, no matter which image enhancement procedures are applied, they have a holistic impact on the remote sensing image. Image enhancement is not applied to selected image parts or specific object footprints.

Image enhancement is achieved by applying numerous possible radiometric operations. Image enhancement radiometric operations can either have a global or a local nature. Global operators modify all image pixels under the same rules, whereas local operators modify pixels on the basis of their neighbouring pixels. A rather popular global operation is contrast manipulation, which may improve the visual interpretability by making use of the maximum pixel value range. A thorough overview is given amongst others by Chuvieco and Huete (2010). Spatial filtering belongs to a visibility-improving set of local operations. Common filters are the high-pass filter and the low-pass filter. While a high-pass filter enhances details by emphasizing high frequencies, a low-pass filter removes details by image smoothing. Another useful filter, the median-filter, has the ability to remove speckle from the image while preserving the edges. For further information on spatial filtering see (Mather and Koch, 2011)

Radiometric mosaicking

In addition to geometric mosaicking (section 1.2.7) a further radiometric correction is often necessary to combine single images to a mosaic. Even if image enhancement has been applied, lightness, contrast, and colour differences remain between single images (Albertz, 2009). Figure 1-10 shows an example. Radiometric mosaicking aims to balance tonal differences between single photos to enable a seamless appearance.

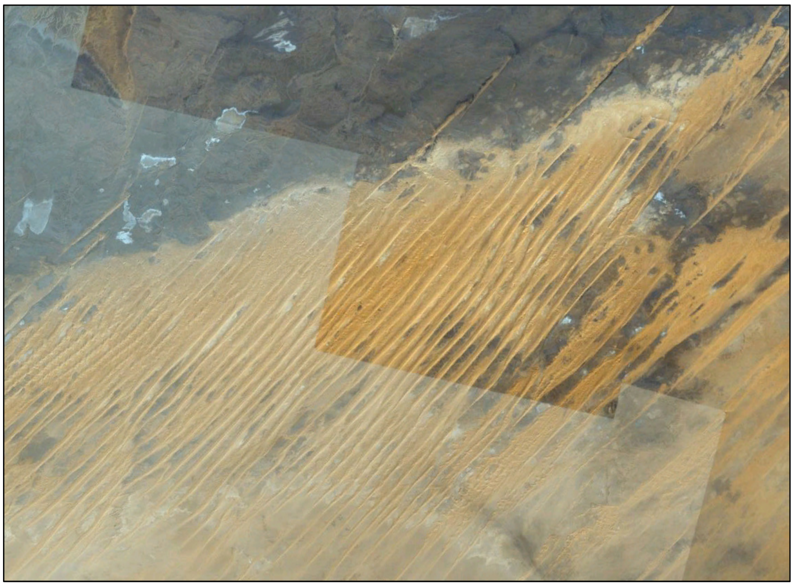

Figure 1-10 – Tonal differences between merged images; © CNES / SPOT images from north Mali (2013) in Google Earth

Therefore, the redundant information in the overlapping image parts is used to compensate radiometric differences. The objective is hereby to average the intensities and contrasts of both images (Afek and Brand, 1998).

1.2.9 The Raster Base Map

The previous sections have dealt with the pre-processing of remote sensing images. Starting from the raw remote sensing image, many digital image processing steps are applied that result into the completed image part of the image map. These steps are necessary to enable a good visual distinction between depicted image objects and enhance the semantic interpretation of these. Figure 1-11 illustrates the visual impact of pre-processing steps on the image.

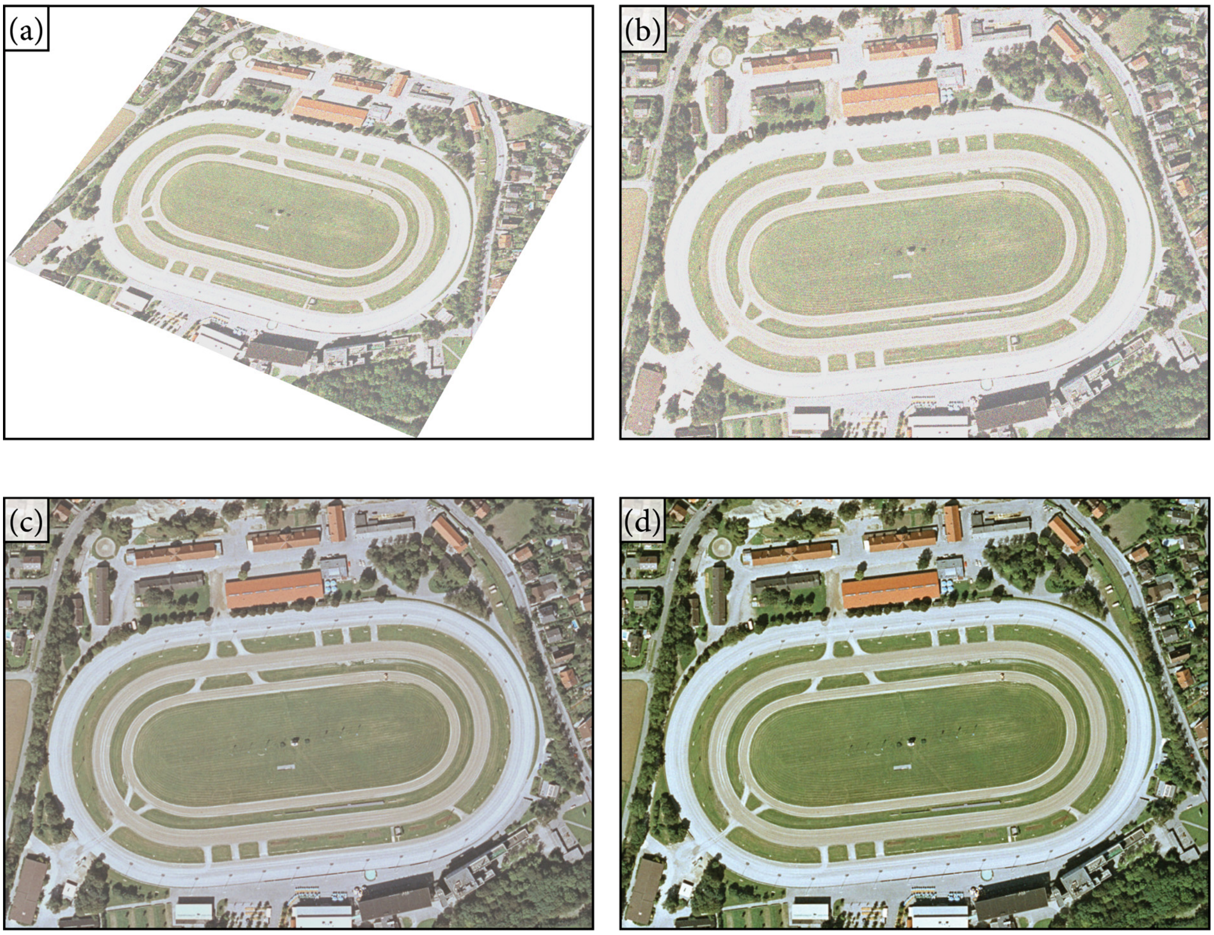

Figure 1-11 - From remote sensing recording to raster base map:
(a) represents the untreated remote sensing imagery, (b) represents the rectified image, (c) shows the image after image restoration, and (d) shows the image after further image enhancements procedures. (Depicted landmark: trotting course in Munich-Daglfing)

After the composition of image and vector data (in section 1.2.13), the raster image is not only physically beneath map symbols, it undertakes the task of a base map. As a base map the raster image "*provides a geographic frame of reference*" (Slocum et al., 2009, p. 191), and thereby puts the presented map theme into a spatial and semantic context. This is of course the main difference to holistically symbolised maps. Map designers producing holistically symbolised maps have to add base map data, such as boundaries, coastlines, rivers, landmarks, roads and other infrastructure. The time necessary to individually acquire base map data of these object classes, to symbolise them, and then to evaluate the design of the various object classes is much more time-consuming than digital image processing steps. Pre-processing steps of remote sensing have a very high degree of automation, which considerably decreases the effort for creating a base map. However, when remote sensing imagery is externally acquired, normally the pre-processing of remote sensing images have already been carried out by the provider, which simplifies image map making to an even greater amount.

1.2.10 Feature Extraction

Remotely sensed images can be analysed to extract thematic information. As stated in section 1.2.1, a fundamental part of remote sensing is the extraction of information. Thematic information is derived by the assigning of each image element to a certain class by digital interpretation. Thematic classification is either pixel-based, when each pixel is assigned by its spectral content to the most appropriate thematic class (Chuvieco and Huete, 2010), or object-oriented, in which image objects or segments are identified by considering shape, size, and context as well as spectral content (Congalton and Green, 2002). The land-use/land-cover classification has been performed for decades and is one of the most frequently used analysis methods (Jensen, 2005). Thematic classification is performed on multispectral or hyper spectral images, with single band images also having the potential to be classified (i.e. Murphy, 2001). This implies that feature extraction is not necessarily only based on the provided visual spectral band of the images, as additional spectral ranges are also useful to complement the spectral bands used for display.

With nowadays available very high resolution (VHR) images that offer ground resolution of 1 m or less, it has also become possible to extract the geometric entities of single objects such as streets and buildings. The automated extraction of topographic objects is an active field of research. Although feature extraction from VHR images remains a challenging task, there have been promising approaches (Rottensteiner, 2009). The various existing approaches for road detection share the common techniques that make use of spectral, geometric, topologic, and contextual road properties (Fortier et al., 2001). Mayer et al. (2006) tested several road extraction approaches and came to the conclusion that road extraction is useful for scenes with limited complexity. More complex areas would need human supervision. Similar results have been achieved for building extraction approaches, where either lines and corners or areas are extracted from VHR images (Shorter and Kasparis, 2009, Dahiya et al., 2013).

The results of thematic classification, as well as topographic feature extractions are initially in raster format, but can be converted to vector objects for the further image map processing steps.

1.2.11 Vector Data Selection

All image maps need additional spatial information to supplement the remote sensing images. The supplementary spatial information can be topographic or thematic geo-information. In contrast to the remote sensing image that depicts all visible objects from a birds´ eye view, the further spatial information is symbolised and merged with the image. Symbols are graphic marks tied to concepts (Krygier and Wood, 2011). In the symbolisation process, the spatial data is usually encoded as points, lines and areas. These symbols overlay partly the remote sensing image. As the image has a graphical continuous nature, the supplementary spatial information has a graphical discrete nature. For this reason, supplementary spatial data is mostly two dimensional vector data. The supplementary spatial data will therefore be referred to as vector data in this chapter.

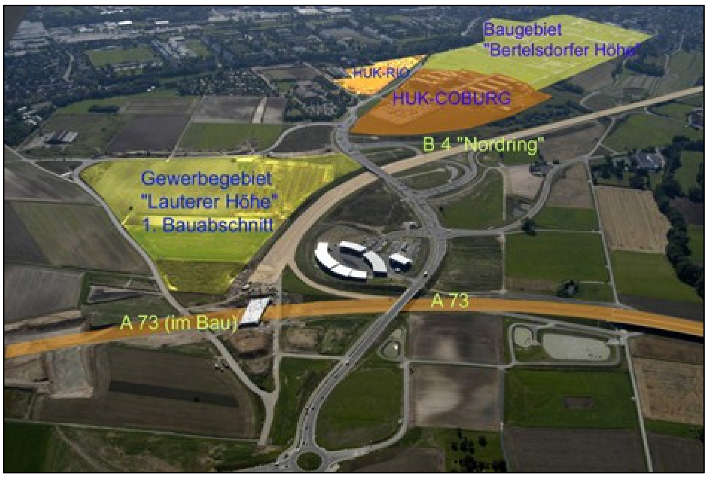

Figure 1-12 - image map for town-planning purposes, © City of Coburg[2]

Figure 1-12 shows example uses of vector data features on image maps. Point symbols can visualise locations, line symbols are suitable representations of street data and area symbols can highlight thematically significant zones. Like in all other map-making projects the first workflow step is to select the important vector data depending on the mapping objective. Vector data is stored in object classes that can be retrieved independently. The vector data is selected regarding spatial and semantic needs.

1.2.12 Vector Data Transformation

The vector data transformation of the image map workflow has two tasks. The first is to harmonise all chosen object classes of vector data. As the object classes may originate from multiple spatial data sources, these may be based on different coordinate systems. Therefore, one function is to integrate different vector data sources. The other task is to harmonise the coordinate system of vector data with that of the image. Therefore, either one of these coordinate systems is taken as the target coordinate system or a new target coordinate system can be introduced. In either case, coordinate transformations are necessary.

1.2.13 Composition

Composition is the blending of remote sensing images with symbolised mapping features. This procedure is also named superimposition, mixing, blending, merging or scrambling, depending on the reference (i.e. Hoarau et al., 2013). Any common GIS can superimpose orthophotos with two dimensional vector data, when both sources have been transformed to the same coordinate system. Both can then be projected. The remaining displacements and occlusions, due to geometrically inaccurate objects on the image, can be reduced by employing true orthophotos (Amhar et al., 1998). But this straightforward work step is valid only for vertical images. The composition of vector data and oblique images proves a non-

[2] http://www.coburg.de/desktopdefault.aspx/tabid-899/882_read-3462/ (23.12.2013)

trivial endeavour. However, the growing supply of remote sensing oblique images in recent years has largely stimulated the research interest to reduce misalignment between the oblique images and superimposed vector data sets. Mishra et al. (2008) validate vector data by using combined cues of colour, intensity gradients, texture and image filter outputs. Whereas Nyaruhuma et al. (2010) extract building outlines as evidence for the verification of two dimensional vector data sets of buildings. A fully automatic registration approach of oblique aerial images with cadastral data is given by Habbecke and Kobbelt (2012) (see Figure 1-13).

Figure 1-13 - A set of oblique aerial images (a), a cadastral map (b), and the registration of images (c), (Habbecke and Kobbelt, 2012).

Even though the basic research on this topic has achieved some promising results, there is presently no proven automatic work step for the composition of vector data with oblique images. The assignment and adjustment of the vector data will often have to be carried out manually. Commercial GIS software can facilitate this step. For instance, the Pictometry International Corporation provides an extension for ESRI ArcGIS to get GIS capabilities for georeferenced oblique images (Pictometry®, 2011).

1.2.14 Image/Vector Data Verification

The composition is followed by the evaluation of its quality. It is necessary to verify the spatial and semantic relationship between vector elements and the image and solve the possible conflicts. Image/vector data verification is hereby the identification of features in the image and the vector data that represent the same real-world features. As both data sets originate from different sources and are processed independently prior to the composition, spatial discrepancies can occur between the homologous features. They can either be global over the entire image map or local on confined areas of the image map. They can either be displacements or inconsistencies. The displacement refers to a spatial offset between the homologous features. It is a consequence of translations, rotations or scale errors. The inconsistency refers to the degree of logical conflict between the image and vector datasets. For instance, an incomplete vector street network would result in inconsistency (see Figure 1-14). The following scenarios of displacement and inconsistency are relevant for the verification of vector objects on the basis of the image:

- global displacement between image and vector data caused by incorrect or imprecise transformation parameters,

- global displacement caused by incorrect or imprecise image rectification,
- local displacements of vector data and image depicted manmade objects caused by DEM-based orthorectification (see 1.2.5),
- local displacements caused by either locally inaccurate or imprecise vector data,
- global or local inconsistency caused by incorrect classification of vector data,
- local inconsistency caused by incomplete vector data, and
- local inconsistency caused by different observation times of image and vector data.

The composition quality can be visually verified by symbolising vector point, line and area features with a provisional symbolisation. The discrepancy screening is typically performed manually together with any required corrections. Automated correction approaches are discussed in the following.

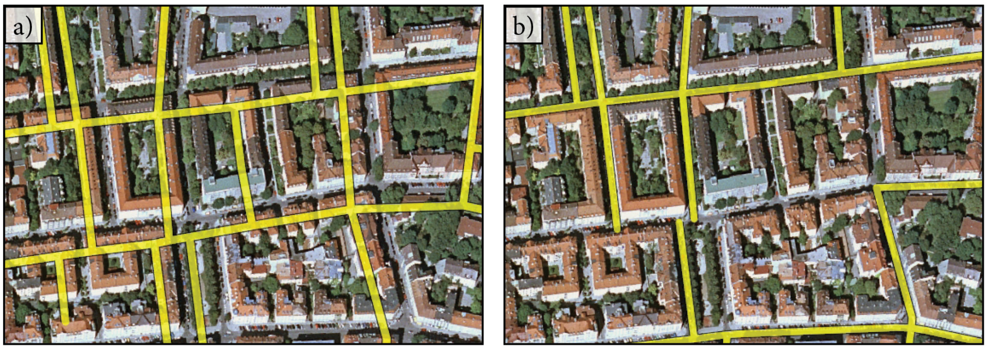

Figure 1-14 - Examples of a) displacement (global translation), and b) inconsistency (incomplete vector data)

The verification of vector elements on the basis of the image can be partly automated. Various automatic or semi-automatic detection approaches have been introduced to validate a vector data set on the basis of remote sensing images in the context of map updating, map revision, change detection or verification of vector datasets. The approach of image/vector data verification generally contains the following fundamental procedures: (1) objects are extracted from the image, (2) partner objects of both datasets are searched and assigned to each other, and (3) all identified partner objects are listed along with the relevant discrepancies. Promising methods have been introduced to detect discrepancies in solitary object classes like buildings (i.e. Matikainen et al., 2010) and streets (i.e. Becker et al., 2011). Some holistic approaches to automate the detection of discrepancies for all vector features and model objects have been also carried out (i.e. Müller and Heipke, 2009). Since these approaches do not detect all discrepancies, a human operator is required to complete the screening and to eliminate all critical displacements and inconsistencies.

1.2.15 Conflation

Conflation goes a step further than the sole image/vector data verification. Conflation is the compilation or alignment of two different geospatial datasets covering the identical geographical area (Saalfeld, 1988). The term conflation is also referred to as data matching, integration or fusion. Which conflation techniques are adopted depends on the type of input spatial datasets. With raster graphics and vector data as input the conflation is performed as vector to raster conflation. A vector to raster conflation basically performs an image/vector verification (see 1.2.14) at first. Then, the misalignments between the data sources are rectified. The alignment is performed by using a transformation function (i.e. Rubber-Sheeting). In general, the proposed approaches take the imagery as reference and align the vector dataset towards the imagery (Eidenbenz et al., 2000, Chen et al., 2006, Zhang, 2013). Automatic conflation is a challenging research area. The object-wise conflation of a complete vector data set to a georeferenced image remains very limited. The street networks have been so far the most frequently addressed object type for conflation approaches. All conflation approaches require VHR Images. No commercial products to provide vector to raster conflation are yet available (Chen and Knoblock, 2008).

1.2.16 Design of Vector Elements

In the vector design process, geographic objects are selected based on their relevance for the usage context of the image map. Rendered vector data is added to the image to increase the legibility and highlight certain image information. The symbolisation of vector elements in points, line and areas can add essential meanings to the image. Dependent on the purpose of the image map, these vector elements can be topographic or thematic features, of qualitative or quantitative nature. Any vector data can be symbolised by means of vector design operations and serve the following functions according to Hake et al. (2002, page 180):

- complement,
- declaration,
- clarification, and
- classification.

The complement vector data has the highest potential of adding more information to the map. Declaration refers to labelling and will be dealt with in section 1.2.17. Some examples to the functions of complement, clarification and classification are depicted in Figure 1-15.

Figure 1-15 - Cartographic design operation examples for a) complement, b) clarification, and c) classification

Complemented vector elements can visualise non-visible phenomena like elevation and thematic information. Furthermore, complemented vector elements can reveal objects that are otherwise obscured on the image, i.e. a playground hidden under trees. If image objects are difficult to identify, the vector elements can clarify them. Typical applications for clarification are the overlay of roads with road network data or the tracing of water bodies with vector lines and areas. Classification, on the other hand, can harmonise and accentuate depicted objects of the image. When for instance, objects of the same land use have a visually different appearance, they can be superimposed with a uniform symbolisation. On the basis of the gestalt law ‘similarity’ (see section 2.1), similar symbols will be perceptually grouped into one class. An example for the use of classification is visually separating residential estates from vegetation areas by using different colours for both classes.

1.2.17 Labelling

Dahlberg (1993) states that image maps are “*visually interesting and highly informative, though at times puzzling to uninitiated viewers*”. He points hereby to the additional information on required image characteristics which should be given by sufficient labelling and other associated explanations. Image maps can hardly be understandable to map readers without any typographic design. “*Typography is the art or process of specifying, designing and arranging type*.” (Wolff, 1999, page 202). Type has different functions, specified and categorized by various cartographers. One holistic approach classifies type into designative text, that reflects features that are portrayed on the map face, analytical text, that links the user with attributes of features or interpretations, and positional text to describe or confirm locations of objects or events in space and time (Fairbairn, 1993). As type can be found on all map elements, labelling is here the placing of type onto the map face. The labelling has the essential task to indicate the location of objects and to assign a name or a description to an object. Furthermore, with the use of type design, labels can also categorize objects and establish hierarchies (Brewer, 2005). A comprehensive overview on the elements of type can be found in Dent et al. (2009) and Robinson et. al. (1995b).

Labelling image maps is a challenge. Due to nature of the raster image, no ‘empty’ graphical spaces exist to place labels, and the usual heterogeneous pixel value distribution combined with strong colours hampers the figure-ground segregation (see section 2.2). The labels become illegible when the contrast between single letters and the image is insufficient. When a black or dark coloured label is placed over the image, letters that hover over dark pixel spots are illegible. White text will be readable in these areas, but are difficult to read over light spots. A remedy to this problem is to frame the labels with callouts, rectangle boxes, drop shadows or halo effects in order to maximize the contrast between the type and its proximate background (Figure 1-16). Rectangle boxes place the label inside the box. Callouts are like rectangle boxes, but have attached connecting lines to link a label to a point location (Krzywinski, 2013). Drop shadows apply the shadow effect on the letters to give the impression of a raised label in front of the background. Halos are rendered with a buffer around each letter. The use of the halo effect has been recommended over the use of rectangle boxes as readability is maintained while less background is occluded (Hodler and Doyon, 1984). All contrast improving type effects are for the given reasons widely-used on image maps.

Figure 1-16 - Contrast improving type effects; from top to down: rectangle box, callout, halo, drop shadow

The placement of labels is an important task, as the readability, the connection to the object and the overall understanding of the reader depend heavily on the legibility of labels. Established guidelines for the placement of type have been introduced among others by Raisz (1962), Imhof (1975) and Robinson (1995b). All these guidelines are specified in point, linear and areal features. Manual labelling can be a very time-consuming task (Yoeli, 1972). To save time in the labelling process, the so-called 'expert systems' (Zoraster, 1991) have been designed to create algorithms based on the established type placement guidelines (i.e. Freeman, 2005, Wolff, 1999). On this basis automatic labelling software has been developed over the last few decades. An overview to labelling software is presented by Slocum et al. (2009). All automatic type placement algorithms are based on vector data input. To automatically label raster image objects, structured information on the depicted image objects would be necessary. To this present day, little research on automatic labelling of raster images has been reported.

1.2.18 Layout

Up to this workflow step, the processing of raster images, geographical vector elements and labelling has been discussed. This geodata is portrayed within the map field. Image maps, just as all other maps, do need further various map elements. Most maps are created from a common set of map elements (see Slocum et al. (2009)). Map layout elements like titles, legends, north arrows, scale bars, etc. are embedded to locate, explain, orientate or estimate the extent for the map user. The map elements add contextual information to the map field and are therefore vital parts for communication with the map user. The choice of layout elements and design decisions should be made on the basis of how each element is to function in the communication (Dent et al., 2009, page 207).

1.2.19 Image Map Evaluation

The final workflow step is to evaluate the image map. A very basic way to evaluate the image map is to check the legibility. Further guidelines how to evaluate a map is given, among others, by Southworth and Southworth (1982). Usually, the steps involved in the workflow can be iteratively adopted as long as further improvements in terms of effectiveness and efficiency of image map design are possible. Fundamental modifications like the change of extent or scale of the mapped area or change of the orientation require a complete new cycle. As geometrical conflicts are eliminated in the working step

"Image/Vector Data Verification", possible modifications are to be found in the graphic design of the image map. The radiometric characteristics of the images, the symbolisation of vector elements and the labelling are hereby subject of improvement. For map reading, these map features interact with each other. This means that, for instance, a refinement of the radiometric image enhancement will often result in an adaption of the symbolisation of vector elements.

1.3 Image Map Mashup

In this section the term 'image map mashup' is explained and brought into context. The motivation and potential of making image maps on a geobrowser is illustrated. Finally, an example workflow is shown by mapping KML data on Google Earth.

1.3.1 Image Map Mashup Background

The standard image processing workflow is carried out mostly by agencies with remote sensing and cartographic expertise. Beside this standard workflow another image map workflow has emerged in recent years in the context of neocartography. "*Neocartography facilitates data capture, processing and publishing using social software, available via Web 2.0*" (Cartwright, 2012). In other words, neocartography empowers a web user to collect geo-referenced data, to remix different sources and to visualise this on the web. It typically results in a quickly-made 'map mashup'. Here, an 'image map mashup' is a compilation of geodata sources, with one or more sources depicting remote sensing imagery combined with added symbolised features. Today's networked internet users, trained or not trained on geoinformation studies, have unlimited access to all kinds of geo-referenced data and have open source solutions available to visualise geodata. In particular, the Volunteered Geographic Information (VGI) has considerably influenced the amount of available geodata and the handling of geodata on the web. VGI is the harnessing of tools to create, assemble, and disseminate geographic data provided voluntarily by individuals (Goodchild, 2007). The OpenStreetMap (OSM) project has been a major driving force in the creation of VGI. On OSM the geometries of streets, railways, waterways, public places and other object classes are crowdsourced and stored in vector data format. It is released under a license that allows the user to copy, change and redistribute the data (Bennett, 2010).

Different from the acquisition of geographic data in vector data format, is that the acquisition of free remote sensing imagery remains limited. That means, open vector data is often easier obtainable than aerial and satellite images. At this point, web mapping services are an interesting alternative. Geobrowsers, such as Google Earth, Bing Maps or Nokia Here all offer geographic base data and remote sensing imagery as a free service. These mapping services have a number of restrictions, like impossible offline mapping, but it is possible to customize the maps using an application programming interface (API) or to customize by extensible markup language (XML) scripting. Within a given, restricted framework, it is possible to style the map, add content and embed the map on third-party web pages. For this reason, geobrowsers have provided the basis for a high number of published image map mashups.

1.3.2 Image Map Mashup Workflow

Mapping with the Keyhole markup language (KML) is a very popular way to produce an image map mashup. KML is an XML grammar used to encode and transport representations of geographical data for display in a geobrowser (Wilson, 2008). KML is maintained by the OGC (Open GIS Consortium) as an OGC-standard. Sandvik (2008) gives an overview for how and which geobrowsers support KML. A full support of KML is given by the popular geobrowser Google Earth. The popularity of Google Earth can be highlighted by the fact that 80% of the German students use this geobrowser (Ditter et al., 2012). In the following, an image map mashup workflow is given how it would be performed when using KML and Google Earth.

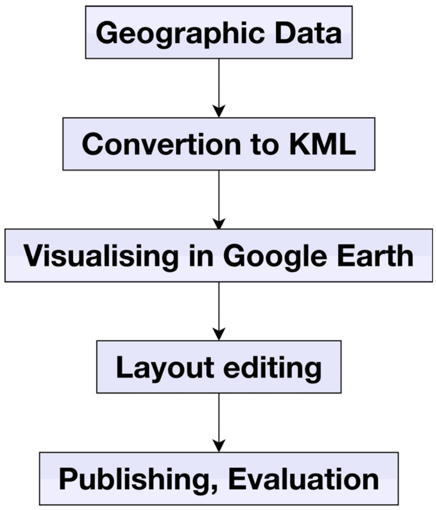

Figure 1-17 - Image map mashup workflow

The workflow overview is given step by step on Figure 1-17. In the first step the geodata is collected either from customary geodata resources or online. Then the geodata has to be converted to the KML syntax. Many commercial GIS software packages (i.e. ESRI ArcGIS) enable a KML export and many freeware solutions exist to convert ubiquitous spatial data file formats like shapefile, DXF (drawing interchange file format) and GML (geographic markup language) to KML (for converting GML, see Stefanakis and Patroumpas (2008)). KML supports all commonly used 2D vector feature types. 3D models can also be included when linked and converted to the COLLADA interchange file format. The geodata has to be referenced in long/lat WGS84 coordinates in order to place the objects at their true location and the object styles are also defined within the KML syntax. All objects are specified in a XML based format of KML elements to be displayed on Google Earth. When loaded in Google Earth the KML elements are rendered into a virtual environment set by a digital terrain model and overlaying remote sensing imagery. An example is given in Figure 1-18.

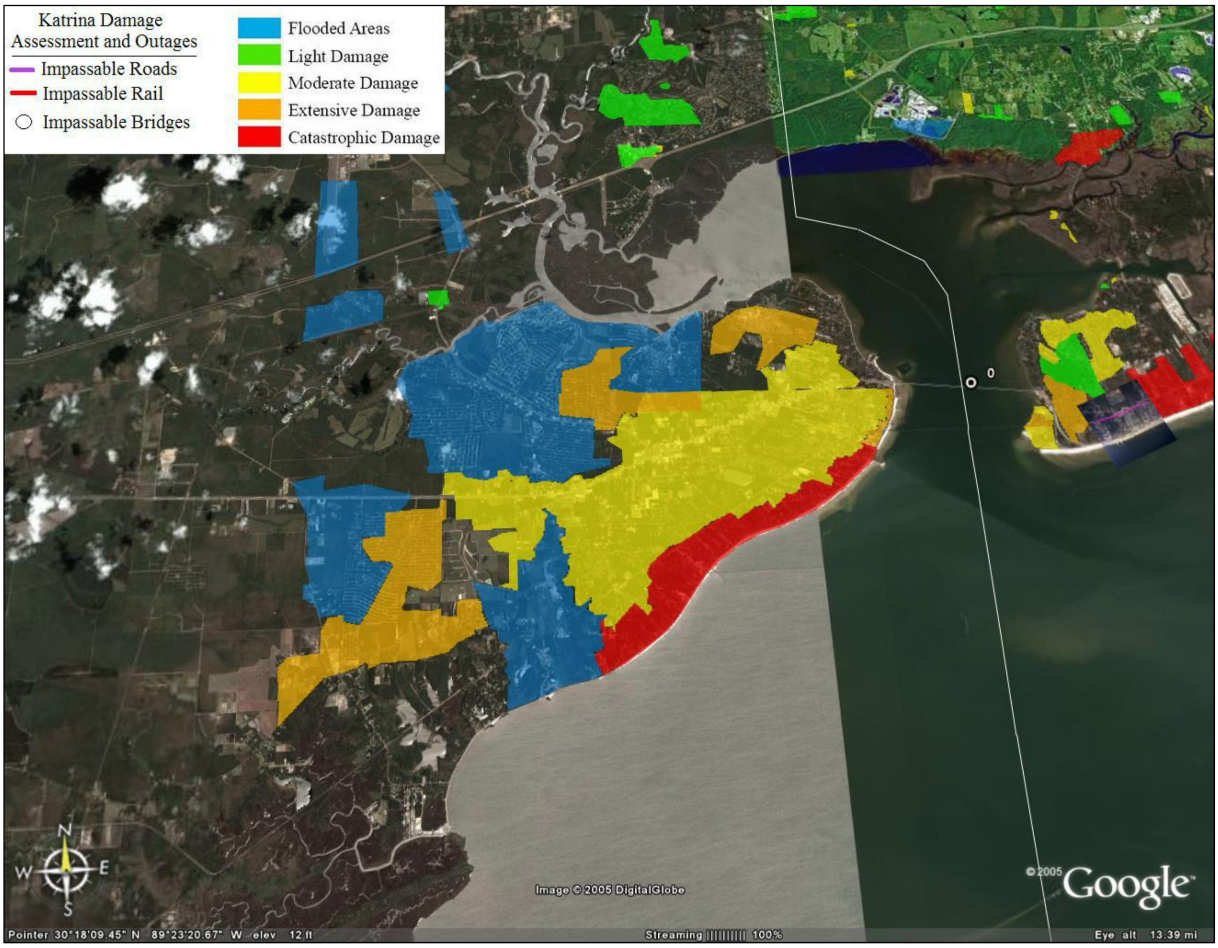

Figure 1-18 - Hurricane Katrina – Impact Assessment; KML application for Google Earth by the National Geospatial Agency (2005)

Layout elements can be added to Google Earth by displaying legends and titles as 'screen overlays'. These KML elements are drawn as layers over the underlying images and fixed to the screen. A ready-to-publish image map mashup is completed by defining the position of the virtual camera in relation to the map objects that are being viewed within the KML syntax. This ensures every user the same initial view onto the map. The image map mashup can be published as a downloadable KML-file for the standalone geobrowser or embedded on a website in full view. The users simply need the Google Earth plug-in to view the map on a standard web browser. The publication on the World Wide Web enables a direct user feedback. With the aid of Web 2.0 technologies, one can use social media dialogues such as forums, like buttons, etc. to receive user feedback. The assembled feedbacks are useful for the evaluation and improvement of the image map mashup.

2 Image Map Perception

The visual perception and cognition of image maps is based upon the scientific findings of human perception. Human perception via the visual channel plays a major role for human information processing and communication. Visual perception is hereby the transformation of a pattern of light on the retina into awareness of the visible world (Marr, 2010). It is important to understand the basics of visual perception, i.e. what information can be extracted by the user.

Like all visual representations, the visual perception and cognition of the rasterised and symbolised objects of an image map is based on Gestalt psychology which explains how users tend to cognitively organise visual elements into groups. An overview of Gestalt principles is given in section 2.1. It is vital for human perception to recognise important objects on the map by visually separating them from insignificant objects. This perceptual ability is referred to as figure-ground segregation, and is discussed in section 2.2. Section 2.3 discusses simultaneous contrast, which affects the visual perception of map symbols on an imagery background. The basic terms of visual interpretation in the context of image maps are then discussed in section 2.4.

The historic separation of theoretical concepts for human interpretation of photographic representations and cartographic transcriptions of geoinformation, is taken into account in the subsequent sections. The elements of image interpretation are presented in section 2.5. An introduction to the elementary representation of cartographic objects by the visual variables is given in section 2.6. Furthermore, a comparison between these two concepts is discussed in section 2.7.

This chapter is concluded by two sections concerning the depth perception of images. Section 2.8 introduces the human ability to have a three dimensional impression from a simple flat photograph. Section 2.9 presents further depth cues, which particularly play a role in remote-sensing photographs.

2.1 Gestalt Principles

Structured sensory stimuli separate a signal from background noise and can be perceived as an object. In visual perception research, something we perceive as a unit or an object is called a gestalt. The German word “Gestalt” means figure or shape. Gestalt principles were introduced by Max Wertheimer (1923) and (1925). In the following the gestalt laws were founded and extended under assistance of other German psychologists of the Berlin School (King and Wertheimer, 2005). The gestalt laws describe how people cognitively organise visual elements into groups or assemble them to a unified whole. The Gestalt laws easily translate into a set of design principles for information displays (Ware, 2012).

The gestalt theory is composed of a number of gestalt laws, among which the following laws are fundamental:

- **Law of Proximity:** Objects that are close together are likely to be perceived as a group.
- **Law of Similarity:** Objects with similar looking are perceived as a group.
- **Law of Closure:** When an object is incomplete or is not completely enclosed it can be closed to one shape. If a shape is sufficiently indicated, its missing information can be filled.
- **Law of Continuity:** Objects that follow straight or curved lines without abrupt changes are perceived as belonging together.
- **Law of Good Gestalt:** Complex objects are perceptually decomposed into basic geometries. The perceptual decomposition is strengthened by similarity.
- **Law of Symmetry:** Objects are grouped in some symmetrical manner, if the order of objects offers this option. Unconnected symmetrical objects are then perceived as a coherent shape.
- **Law of Common Fate:** Objects that move together or lie in the same direction are perceived as a group.
- **Law of Connectedness** (Palmer and Rock, 1994): Objects that are connected by lines are perceived as a group.

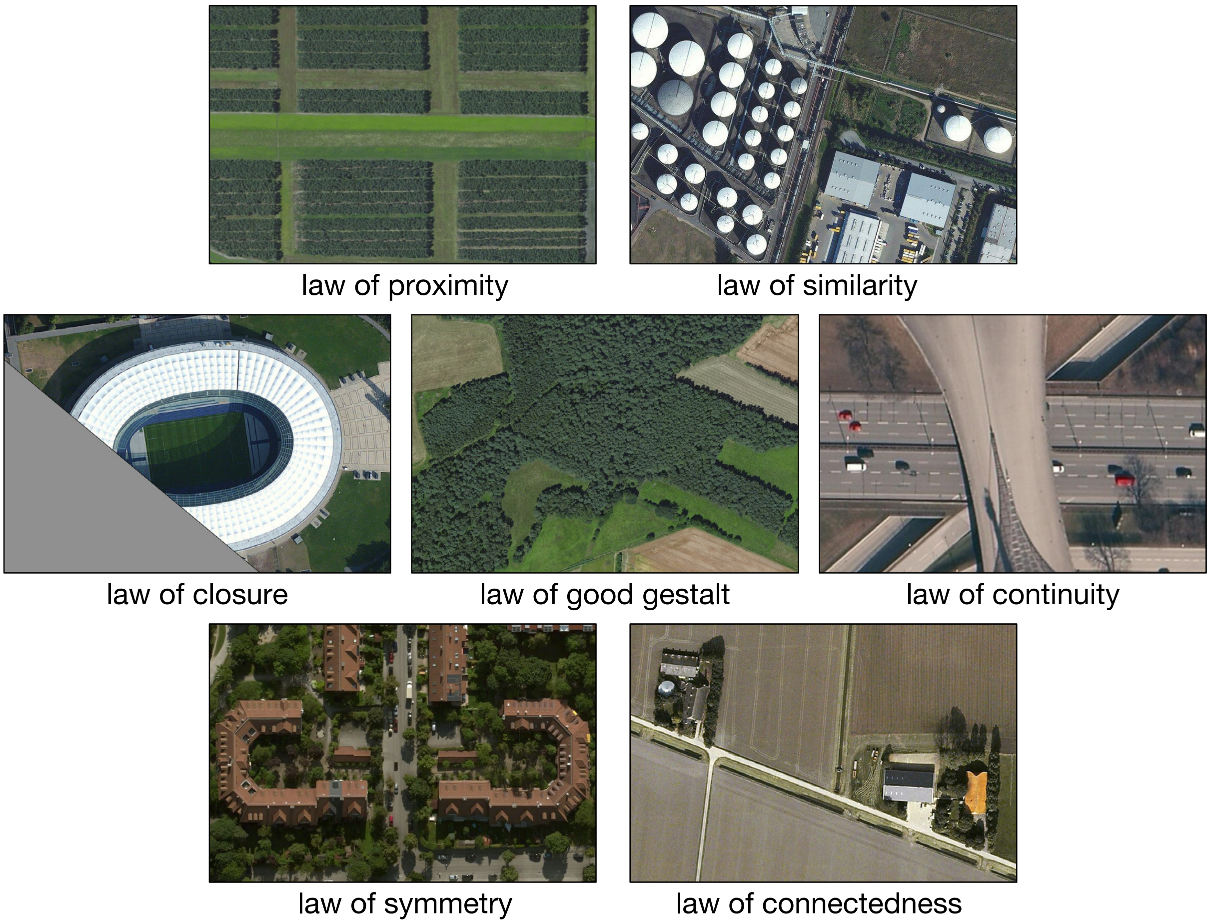

Figure 2-1 – The gestalt principles in the context of image maps (© Bing Maps)

All listed laws play an essential role for the perception of static image maps with the exception of the law of common fate. The law of common fate has an impact when a movement occurs, and therefore plays a role in animated maps only. Figure 2-1 exemplifies how the gestalt laws influence the perceptual organisation in image maps.

There are many other Gestalt laws based on Wertheimer´s work, and psychologists detect more all the time (Lauesen, 2005). The Gestalt laws help to understand how and what objects on visual representations are perceived. The Gestalt laws have been used by cartographers for establishing logical guidelines for map design and they influence the visual grouping of map elements (MacEachren, 1995, page 77).

2.2 Figure-Ground Segregation

“When we see a separate object, it is usually seen as a figure that stands out from its background, which is called the ground” (Goldstein, 2013, page 104). The figure-ground segregation is another concept arising from Gestalt psychology. Its importance for map design can be derived from the need to structure geoinformation into a visual hierarchy. The visual hierarchy orders information due to their relevance. The attention of a user should be guided along the visual hierarchy to assure map communication and avoid confusion. The objects should be organised in vertical visual levels with important information perceived as figures and less important context information as ground. Figure and ground have to be designed in a way that ambiguity is avoided. That remote sensing imagery can provide an ambiguous figure-ground relationship is shown in Figure 2-2. In this example, either the water or the land can be perceived as figure.

Figure 2-2 - Ambiguous figure-ground relationship on remote-sensing imagery: detail of the Isla del Trocadero, Spain (© Google Earth)

All Gestalt laws contribute to creating a figure that stands out from the background. Elements are grouped as a figure over a ground. The figure-ground relationship is more stable when other factors are introduced. The main factors of these are listed in the following (MacEachren, 1995, pp 108-110):

- **Heterogeneity:** A visual difference must be created between figure and ground. Brightness differences are seen as a useful tool. In addition, focus is a strong heterogeneity maker. It was found by Wong and Weisstein (1983) "*that when a segment was sharp, it was detected better in figural regions, but when it was blurred, it was detected better in ground regions*". On this research work MacEachren postulates, that "*blurred patterns will be seen as ground, because they appear to be physically in the three-dimensional background*".
- **Contour:** Figures can be easier segmented from ground, when separated by a clearly visible edge.
- **Surroundedness**: Figure formation is enhanced, when the figure has a closed contour.
- **Orientation:** Objects that are aligned horizontally, vertically, or symmetrically are likely perceived as figure (Bruce et al., 2003).
- **Relative Size:** The more the ground dwarfs the figure in size, the likelier is the segregation of the two.
- **Convexity:** Convex surfaces have a tendency to be perceived as figure.

The Figure is seen hereby by MacEachren as 'object' and ground as 'non-object'. Other researchers designate the ground as empty space (Hochberg et al., 2007), or negative space (Lupton and Phillips, 2008). Among others, Ware (2012, page 196) states that a surrounding white area will contribute to the perception of the figure. In terms of image maps, there is no such thing as non-objects. The remote-sensing image base ensures there are no empty spaces, as one object borders the next. The figure-ground segregation is affected strongly by this fact.

2.3 Simultaneous Contrast

Another perception effect that has to be carefully taken into account within image map design is simultaneous contrast. Uniform coloured map symbols that are composed around heterogenic imagery will not be visually perceived as identically coloured. The inconsistent visual appearance of graphically identical map symbols on image maps is caused by the simultaneous contrast effect. This effect has been described first as the '*simultaneous contrast of colours'* (Chevreul, 1860, p. 7). The simultaneous contrast effect is considered separately by lightness and chrome. Simultaneous contrast shifts the apparent lightness and chromaticity into direction opposite from those of the proximal imagery. This means, that simultaneous lightness causes that dark surrounding colours make the map symbol´s colour appear lighter, and in opposite, lighter surrounding colours will make the map symbol´s colour appear darker. The colour of one stimulus is seen differently when placed against alternative objects of other colours. Because the stimuli of imagery and map symbol are presented simultaneously the user perceives map symbols by 'optically mixing' map symbol colours with surrounding colours. This influences besides simultaneous lightness also simultaneous chrome contrast. Simultaneous chrome contrast makes map symbol colours apparently shift towards the proximal complementary colour (Kuehni, 2012, p. 74).

The complementary colour is derived from colour wheel theory. The simultaneous chrome contrast effect is most intense when the two colours (from map symbol and surrounding imagery) are complementary colours (Rossotti, 1985, p. 135).

The impact of simultaneous contrast is also influenced by connectivity. This was described by another German psychologist of the Berlin School of experimental psychology. Kurt Koffka (1935) introduced the '*Koffka Ring*' to illustrate the influence of connectedness on simultaneous contrast (see Figure 2-3). When the two halves of the ring are connected, the human visual system attempts to assign a uniform grey colour to the entire ring. Here, the simultaneous contrast effect is more or less nullified. But when the two halves are disconnected, simultaneous lightness contrast causes a much different visual perception of the rings´ two halves. The graphically identical grey values are perceived as different.

Figure 2-3 - The Koffka ring illusion: The connected ring on the left is perceived as uniform on light/dark backgrounds. Whereas the disjoint ring on the right is perceived quite different.

2.4 Visual Interpretation

Perception has to be differentiated from cognition, with perception being the initial processing and interpreting of information, and cognition the continuative processing including understanding, memorising, and decision making. Slocum et al. (2009, page 15) described it as follows: "*Perception deals with our initial reaction to map symbols. In contrast, cognition deals not only with perception but also with our thought processes, prior experience, and memory*".

The human perception and feature extraction of image maps brings two scientific theories together. The heterogenic image map with rasterised and symbolised objects requires addressing the cartographic terms, perception and cognition as well as visual image interpretation. Photo or image interpretation is defined as "*the act of examining photographic images for the purpose of identifying objects and deducing their significance*" (Colwell, 1952, page 566). This can be seen as equal to Slocum´s definition about the cognition of map symbols as both terms extract information by perception. The "*prior experience*" equals hereby the "*skills of photo interpretation*" (i.e. Paine, 1981) in remote sensing. The elements of image interpretation will be addressed in section 2.5.

Cartographic objects are symbolised by the geometric primitives (see section 1.2.16). They are made perceptually distinctive from each other by the visual variables. The first to describe a comprehensive theory on the visual variables and their uses was Jacques Bertin (1967/1983). His formalized visual variables can be related to psychological theories of perception (Wilkinson et al., 2005). A full overview of visual variables is given in section 2.6.

2.5 Elements of Image Interpretation

The visual interpretation of images requires the user to systematically utilise several characteristics of features, called the *elements of image interpretation* (Bossler, 2002). The elements of image interpretation have evolved empirically. These include colour/tone, shape, size, texture, pattern, shadow, height, site and association (Olson, 1960, Paine, 1981, Estes et al., 1983, Bossler, 2002, Jensen, 2007, Lillesand et al., 2008, Chuvieco and Huete, 2010). The elements of image interpretation are illustrated in Figure 2-4 and described in the following:

- **Colour/Tone:** By applying additive colour-combining techniques the element colour falls apart into intensity, hue, and saturation. They all contribute to the ability to differentiate objects. In case of interpreting natural colour images, water surfaces are i.e. often depicted in shades of blue, and woodland in green. When interpreting grey scale images the element colour is known as tone.
- **Shape** refers to the two dimensional outline or form of an object. Shape can be a very distinctive object identifier. Buildings have often a rectangular shape on orthoimages. Railways are narrowly shaped with smooth curves. In contrast, streets are also narrow, but street junctions can have sharper curves.
- **Size** complements the identification of objects. Absolute size is a hint for object identification when taking the map scale into account. For example, the large size of a football pitch helps to identify this object. Relative size helps distinguish between different objects depicted on the image. Size can then assist the human in classifying cars from trucks and buses (on large scale images).
- **Texture** is the periodic changes of colour that form a characteristic arrangement on a discreet object. Texture also helps to identify single objects. The texture has a bandwidth from coarse (i.e. tree crowns of a forest) to smooth (i.e. grasslands).
- **Pattern** refers to the spatial arrangement and spacing of multiple objects. In general, objects are arranged systematically in geometric patterns when being man-made. Natural patterns have a more unsystematic appearance. Pattern helps i.e. identifying a housing estate and separates natural vegetation from an orchard.
- **Shadows** are a visual criterion for extracting the profile and structure of objects. Furthermore, they provide clues for the size of an object. Shadows reveal the structure of steel bridges, monuments, trees, etc. in a very useful manner.
- **Height** can aid image interpretation in combination with size and shape. Depth cues enable the estimation of the height of objects. Stereoscopic views are therefore not necessary. The flat, two dimensional image map has monoscopic cues that gives the user a three dimensional impression. Especially in oblique images, the three dimensional visual impression of the imaged objects is high.

- **Site** relates to the location information of the remotely sensed image. The geographic and topographic location offers clues about depicted image objects. For example, certain tree species would be expected to occur in one climate zone but not in the other, or the known location 'Egypt' would make it easier to recognise a pyramid complex.
- **Association** addresses the probable occurrence of certain objects in relation to others. A simple example is the following: objects, which are considered as manmade and lie over a water body, are likely to be boats.

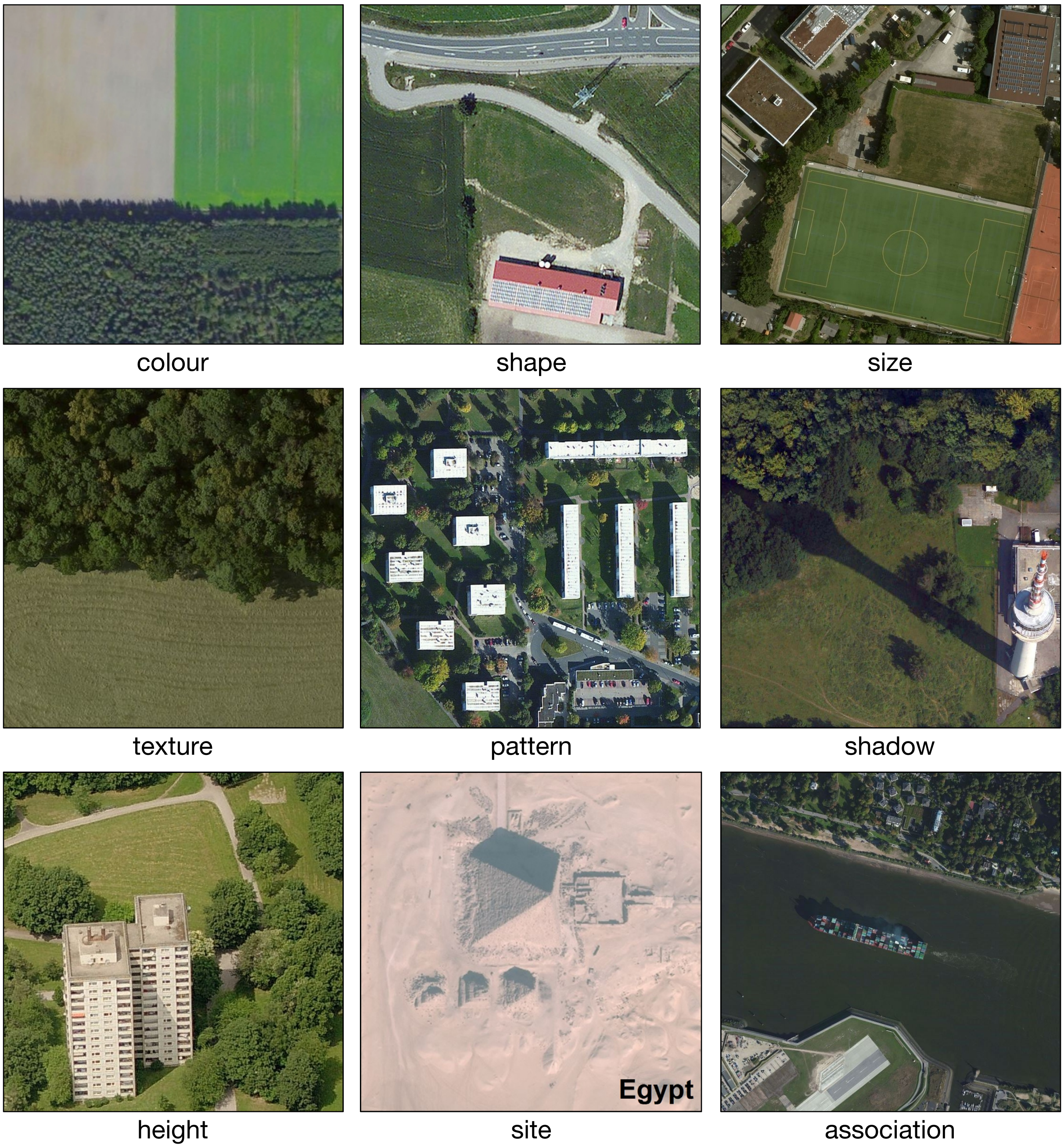

Figure 2-4 – Elements of Image Interpretation (image details from Bing Maps)

Some researchers also include **resolution** as an element of image interpretation (Lillesand et al., 2004). Resolution is merely seen as a practical limit on interpretation, as small objects need to be represented by a certain amount of pixels to be recognizable.

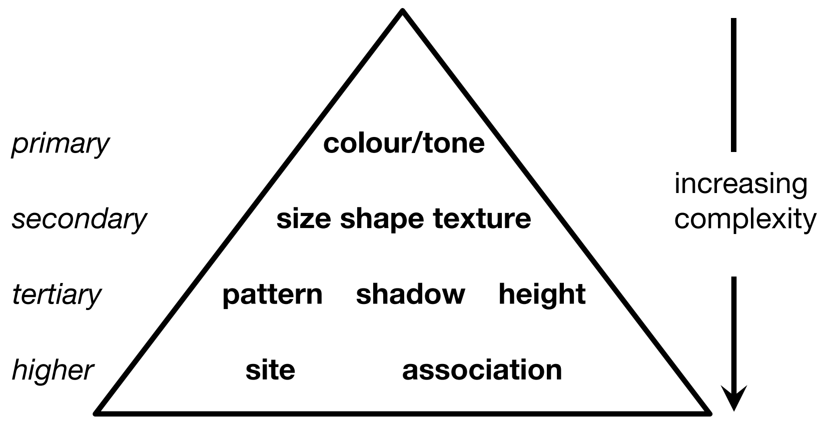

Figure 2-5 - Elements of Image Interpretation; adapted from Estes et al. (1983)

Images are made of pixels that have unique pixel values. These basic values set the element colour. **Colour/tone** is therefore considered as the *primary* order element. *Secondary* elements are spatial arrangements of coloured/toned pixels, and *tertiary* elements add context to spatially neighbouring objects. The interpretation of the *higher* order elements **site**, and **association**, are based on prior knowledge of the user. The degree of interpretation complexity increases with the order (see Figure 2-5).

2.6 Visual Variables

The visual nature of image objects is set by reflectance of the object surfaces and the recording of lights. In contrast, the visual nature of cartographic objects is subject to map design. Geospatial information can be graphically represented on two dimensional displays as point, line, or area. Hake et al. (2002, page 11) describes these three geometrical primitives as elementary signs of the sign system. A sign is made to represent some information other than itself. It is also referred to as a mark. Bertin (1967/1983) describes marks as basic graphical units and developed a given number of modes through which these units can be modified. These predefined modes are called the visual variables. Apart from variations in position of a visible mark, Bertin described that a mark can vary in **size**, **value**, **texture**, **colour**, **orientation** and **shape**. He further orders these visual variables into four levels of organisation, determined by perceptual properties. These levels are (Bertin, 1967/1983, page 48):

- **Selective (≠):** A variable is selective, when all marks are perceived as different, while also perceiving them as belonging to a family.
- **Associative (≡):** A variable is associative, when all marks are perceived as similar.
- **Ordered (O):** A variable is ordered, when varying marks are perceptually ordered into categories.
- **Quantitative (Q):** A variable is quantitative, when varying marks are perceived as proportional to each other.

Bertin´s visual variables are based entirely on graphics for analogue paper maps. The digital age of maps granted more possibilities of graphical variations. Several authors have proposed extensions to Bertin's visual variables. Morrison (1974), for example, forwarded the visual variable **saturation** as an ordering variable. It extends Bertin´s colour variables value and hue, to a three dimensional colour model in computer graphics. In addition, Morrison adds pattern **arrangement**. MacEachren (1995) studied the visual variables in the context of visualising uncertainty. Based on an earlier publication (MacEachren, 1992), he proposed a set of variables, ranked under the term '*clarity*'. These visual variables are **crispness**, **resolution**, and **transparency**. Furthermore, Slocum et al. (2005) expanded the list by the variable **perspective height** which refers to a perspective three dimensional view of the size or height of simple geometric figures, drawn on the two dimensional graphical base. The extended visual variables are depicted in Figure 2-6.

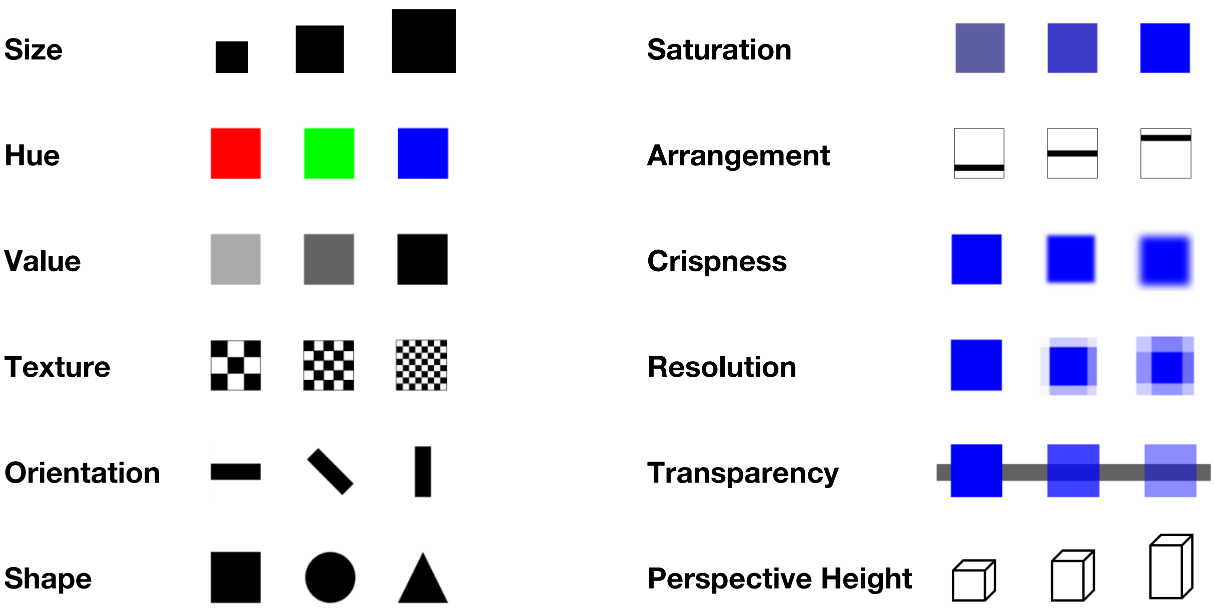

Figure 2-6 - The Visual Variables – assembled from Bertin (1967/1983), Morrison (1974), MacEachren (1995), and Slocum et al. (2005)

All contributors featured here are consent regarding the visual variables. But, terminological differences do exist. The categorization of texture-related variables varies among scientists. Slocum et al. (2005) use the term '*spacing'* to describe the variable **texture**. Others have divided texture into sub-variables. For example, Caivano (1990) classifies **texture** into the three dimensions '*directionality*', '*size*' and '*density*'. Wilkinson et al. (2005) splits texture into '*granularity*' and '*pattern*' and includes the texture variable '*orientation*'. And in a similar approach, Andrienko and Andrienko (2006) divides **texture** into the sub-variables '*arrangement*', '*density*', '*size*', '*shape*' and '*orientation*'. The diverse treatments of **texture**, or **pattern**, are due to the fact that texture is not an individual mark, but rather a spatial arrangement of multiple marks. MacEachren (1995, page 273) considered **pattern** as a set of visual variables at a higher level than other variables.

Dynamic map display introduces the dimension of time, which further expands the number of visual variables. DiBiase et al. (1992) suggest dynamic variables for map animation that were then complemented by MacEachren (1995). Dynamic visual variables are not presented in this work which is dedicated to the static visual variables.

2.7 Comparison of Image Interpretation Elements and Visual Variables

Image maps are simultaneously photographic representations and cartographic transcriptions of geoinformation. One visualisation method has the pixel, or pixel cluster as the graphical basic unit, the other graphic signs. For the further study of image map design it is necessary to compare the possibilities of graphical variation for both visualisation methods. Either graphical basic unit is described by given attributes that derive from two different fields of research. A basic comparison of graphical attributes in the concepts of the elements of image interpretation and the visual variables is made in Table 2-1.

ELEMENTS OF IMAGE INTERPRETATION			VISUAL VARIABLES
	Size	<->	Size
	Shape	<->	Shape
	Texture	<->	Texture
	Colour/Tone	<->	Hue Value Saturation
Equivalent	Pattern	<->	Arrangement, Orientation, Texture
	Height	<->	Perspective Height
	Site	<->	X,Y
	Resolution	<->	Resolution
Correlated	Shadow	<->	(shading)
	Association	<->	(interaction of marks)
Exclusive		->	Crispness
		->	Transparency

Table 2-1- The elements of image interpretation vs. the visual variables

At the first view of Table 2-1 both lists of graphical variations have many attributes in common. Many ***equivalencies*** can be found. **Size**, **shape** and **texture** have congeneric definitions for the elements of image interpretation and the visual variables. Furthermore, these three attributes have identical terminologies. The colour related attributes also refer to the same graphical principle. The spatial arrangement in **pattern** and spacing of multiple objects is ***equivalent*** to the visual variables **arrangement**, **orientation** (to some degree), and to the sub variables of **texture** discussed in section 2.6. The element **height** and the visual variable **perspective height** have substantial graphical commonalities. The element **site** refers to the variation in location and can be seen as equivalent to Bertin´s (1967/1983, page 42) *two planar dimensions* (**X,Y**). The attribute **resolution** plays slightly different roles in both concepts. On the one hand, **resolution** is seen as an imaging graphical constraint, although in some cases a pixelated depiction of an object helps the user estimate its size.

On the other hand, within cartographic symbolisation, **resolution** is not only a result of spatial imprecision, as it can depict uncertainty (MacEachren, 1992).

The elements of image interpretation **shadow** and **association** have no corresponding visual variable, but are widely used in cartography. Artificial shading effects for relief depiction have a long history in the use for topographic maps (Hurni, 2010). Hill shading, or other shading techniques, are used to imitate natural shading effects, and to create a three dimensional impression, thus make the morphology easier understandable (Imhof, 1982). The user associates spatially close objects in image and in map interpretation. **Association** that does not occur in the lists of visual variables can be seen as a higher level visual variable, because it is an interaction of multiple marks. **Shadow** and **association** for visual image understanding are therefore ***correlated*** to those for map reading.

Crispness and **transparency** are ***exclusively*** visual variables. They have no corresponding partner in the elements of image interpretation. These are two mainly unwanted variations in remote sensing imagery. Therefore, all recording techniques aim to eliminate their occurrence. In terms of **crispness**, the goal of recording remote-sensing images is to display the entire visual plane as fully focussed photographs. The intentional including of blur in remote sensing is unknown to the author. **Transparency** occurs in remote sensing when the recorded light passes through material without being scattered. This applies mostly to clouds and smoke between the sensor and the earth´s surface. In most cases, meteorological effects are removed by atmospheric corrections (see 1.2.8). Note, that transparency resulting from haze, may act as a visual criterion for estimating the depth in an oblique image (see atmospheric effects in section 2.8).

2.8 Image depth cues

The ability to perceive a scene as three dimensional is due to depth perception. Depth perception arises from a variety of depth cues. There are four classes of depth cues (Sherman and Craig, 2003, page 118):

- monoscopic image depth cues,
- stereoscopic depth cue
- motion depth cues, and
- physiological depth cues.

Monoscopic image depth cues can be perceived when looking at a static, two dimensional scene. The stereoscopic image depth cue (stereopsis) is a depth cue from binocular vision, which is based on the parallax between different images received from both eyes. Motion depth is perceived by the same parallax of different images, this time derived by changing the relative position between viewer and scenery. Physiological depth cues are generated by the sensation of the eyes´ muscle contractions, when focusing an object into sharp view.

Even though image maps have no physical depth, the remotely sensed images can show an illusion of three dimensions. So, even being two dimensional, image maps do offer depth perception. As image maps are in this work static and two dimensional visualisations, singly monoscopic image depth cues can be considered for their depth perception. The monoscopic image depth cues are described in the following and illustrated in Figure 2-7. These image depth cues include linear perspective, texture gradient, size gradient, occlusion, depth of focus, cast shadows, shape-from-shading (all Ware, 2012), atmospheric effects, geometric figures, (both Albertz, 1997), and height in the visual field (Kumke, 2011):

- **Linear perspective:** In the geometry of linear perspective, the image projection lines converge to a single vanishing point (not orthorectified). Thus, the user can reconstruct the depths of objects in relation to the vanishing point and to each other.
- **Atmospheric effects:** The atmosphere contains always a certain degree of haze, or mist. Therefore objects that are nearer are seen in high contrast, in opposition to distant objects that are seen in low contrast, and dyed in blue
- **Size gradient:** Objects in perspective view vary in size on the image in inverse proportion to their distance from the vanishing point. As humans have developed a set of size expectations for known objects, the object´s relative size is an indicator for its depth.
- **Texture gradient:** Based on perspective, texture gradients provide depth information. The elements of uniformly textured objects become smaller with distance, from coarse to fine.
- **Occlusion:** When one object occludes the other, it appears closer to the point of view. This depth cue is sometimes referred to as interposition (Howard and Rogers, 2012).
- **Depth of focus:** Image blurring can be used in images to establish the impression of depth. If the depth of the focussed (sharp) object is predictable, blurred image regions are ordered as behind or in front.
- **Cast shadows:** A cast shadow is detached from the object and gives information about the object´s height over a surface.
- **Shape-from-shading:** The shading of an object body gives information about its shape.
- **Geometric figures:** Pictured simple geometric figures are observed as three-dimensional. This phenomenon is based on the viewer´s prior experience and is frequently used to predict the height of remotely sensed buildings.
- **Height in the visual field:** The nearer an object is imaged to the horizon line the farther away it is perceived. This depth cue is sometimes interpreted as relief displacement (i.e. Jensen, 2007, page 142).

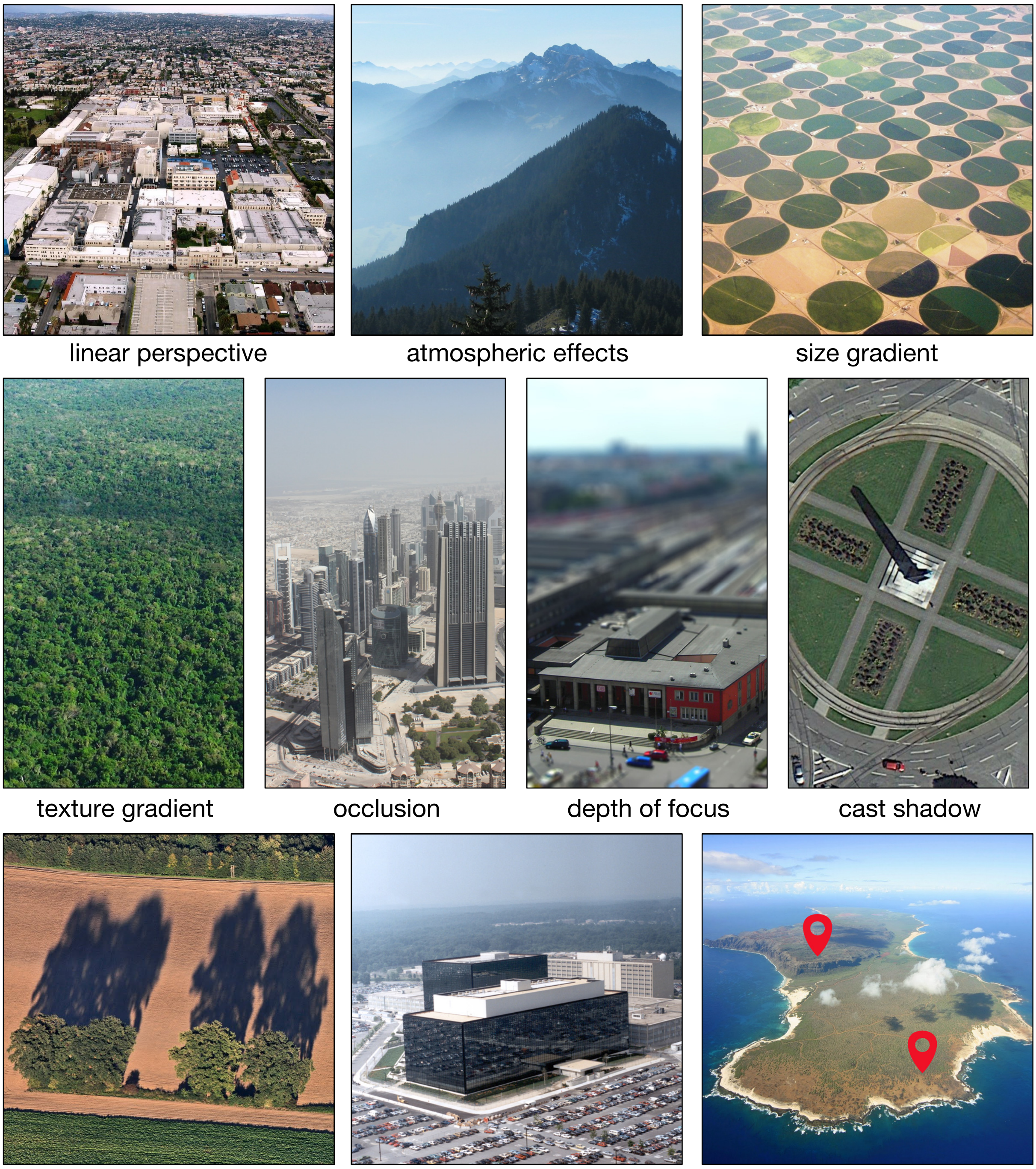

Figure 2-7 - Monoscopic image depth cues (copyrights in order: MyWestlake.com, author, 2011 Valley Pro Irrigation, Valerie Druguet, unknown, I. Mattes, Bing Maps , 2008 K. Leidorf, National Security Agency, 1997-2011 Aloha from Hawaii)

The combinations of many depth cues may enhance the three dimensional impression. The main depth cues for vertical remote sensed images are related to shading and geometric figures. Images recorded in oblique view offer much more depth cues than vertical images, and therefore enable a much better depth perception. Also, the resolution influences the depth perception. Objects have to be identifiable to allow object-based depth cues. That is why VHR images are required to provide a sufficient three dimensional impression.

2.9 Indirect depth cues

When the remote-sensing image is in a small map scale and with a low resolution, none of the depth cues described in section 2.8 can sufficiently support the three dimensional visual perception. An example is shown in Figure 2-8. Nevertheless, the image may provide alternative hints to understand the landforms. An experienced image map user obtains information about the surface shape using indirect depth cues. Schweissthal (1967, page 57) enumerates the following indirect depth cues:

1. the traffic infrastructure alignment,
2. the course of water bodies, and
3. the configuration of agricultural area.

Figure 2-8 - Indirect depth cues in remote-sensing imagery

The geometric configurations of these objects do not arouse a three dimensional perception, but rather give indications to the user about the morphological type.

3 Analytical Approach to Image Maps

Starting from the essential differences between images and maps (section 3.1), this chapter addresses ambivalent views on image maps from different scientific fields. A definition of the image map reflecting the state of the art is then given (section 3.2). Different types and applications of image maps are presented (section 3.3), which lead to outlined benefits of image maps in comparison to holistically symbolised maps (section 3.4). This allows an analysis of the image maps that are either dedicated to special usage or designed following generally accepted cartographic principles (section 3.5). The remaining parts of the chapter (3.6 to 3.8) are dedicated to the graphic implementation of image maps that includes the process and techniques of symbolisation and generalisation.

3.1 Image vs. Map

In order to utilize the advantages of images and vectorised mapping data which constitute an image map, it is necessary to acknowledge their visual differences. Images and maps both visualise spatial data, but in different manners. Remote sensing images are the representation of optical recordings of reflected or emitted light. Remote sensing images in the visible spectrum (see Table 1-1) visualise all objects that the human eye would visually perceive from above. Especially when the image is a composition of natural colours (see section 1.2.1.1), it mimics the human´s view. Remote sensing images of the invisible spectrum extend the representation of object properties hidden from the eye, like moisture or heat. Nevertheless, all images visualise seamlessly tangible objects on or belonging to the earth´s surface by representing their surface structure. Represented image objects have a realistic appearance. This is not the case with maps. Maps are graphic representations composed of symbols and labelling. Visible and non-visible spatial data can be presented respectively. But, not all spatial information is presented continuously. Maps are selective (Tyner, 2010, page 9). They are designed by a map maker, who decides which information is to be visualised. To conclude, the main characteristics are that the image is realistic, and the map is abstract. This leads to several disparities which are discussed in the following.

Figure 3-1 illustrates the visual differences of image and map. The image displays the physical surface and shows all objects that are large enough to be visible from the sky. The level of detail depends on the geometric and radiometric resolution of the sensor, as well as the resolution of the human eye (Kohlstock, 2011, page 160). The image a) displays topographical objects, such as houses, woodland, fields, but also non-topographic, moveable objects like boats. Maps display a selection of spatial information that is conditioned by the purpose of the map. The map content is generalised. Beside topographical information, thematic information can be displayed, i.e. the ferry routes on map b).

Similar image objects do not always have the similar appearance in the image. In fact, they frequently appear to be different due to different surface materials. The varying appearance can lead to defective image interpretation. In contrast, similar map objects may be grouped together and uniformly symbolised. A good example for this is the uniform, blue coloured water body on map b), and the varying visual appearance of the water body on image a), due to different depths of water.

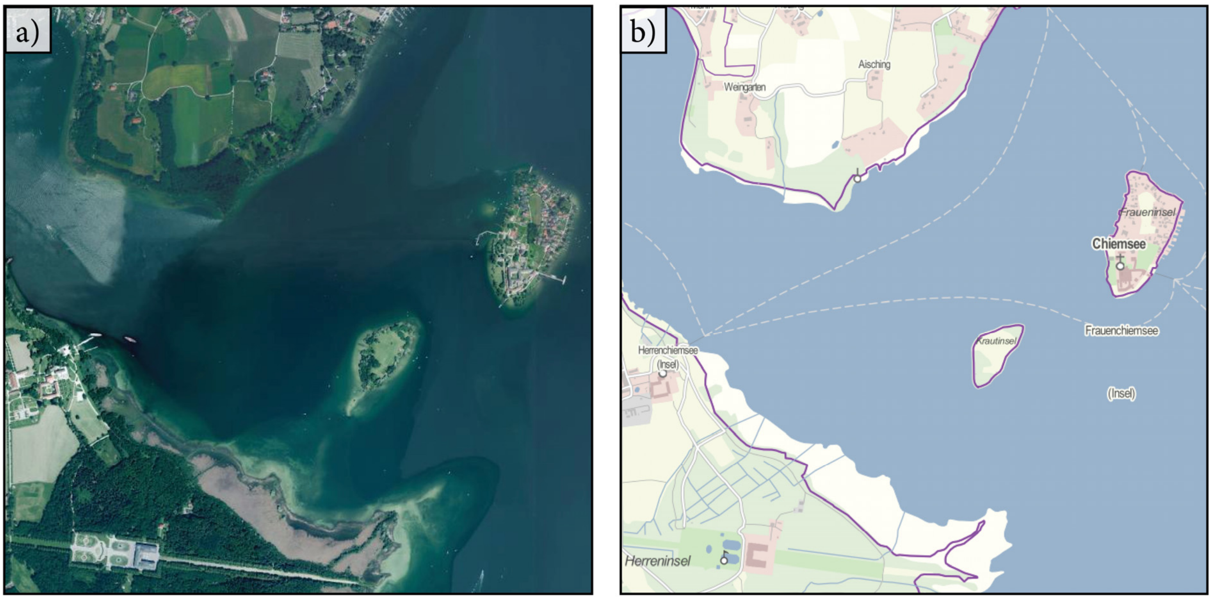

Figure 3-1 - Image vs. Map: details of a) an orthophoto, and b) an internet map series of the Chiemsee, © 2013 Bayrische Vermessungsverwaltung

The image is not structured. It has no visual hierarchy. Therefore, unimportant information may stand out, where as important information may be obscured. In contrast, map objects are structured. A visual hierarchy is achieved by visually emphasizing important symbols, and playing down base information. Intellectually important symbols are rendered with the greatest contrast to their surroundings (Dent et al., 2009, page 216), to achieve a figure-ground segregation (see section 2.2). This leads to another difference between maps and images. In maps, spatially neighbouring, but diverse objects are designed to be clearly distinguishable from each other. In images it is often more difficult for the user to visually separate adjacent objects. In image a) of Figure 3-1 it is difficult to visually separate water from land, due to the floating colour gradient in the shore area. The distinct symbolisation of map b) makes this task much easier.

Images have to be self-explanatory. An image cannot give answers to important geographical questions, such as street relevance and place names (Radlinski, 1968). Maps can help the user understanding the phenomenon by describing features. Labels are included to explain map objects, as well as legends, that can designate the symbol classes.

Images and maps have different temporal aspects. The remote sensing image displays the earth´s surface at a single moment of time. Remote sensing images are heavily influenced by the date of recording. Images from the winter season can feature snow covering and leafless tress, while images taken during summertime show more vegetation. The map, however, is based on various sets of spatial data, such as field measurements, statistical surveys, or information extracted from maps and images. All these sources will correspond to different dates of data collection. Usually, one map data source is collected over a time period. Therefore, the map objects originate from multiple time periods.

A summary of the discussed basic characteristics of image and map is shown in Table 3-1.

Characteristic	**Image**	**Map**
nature	realistic	abstract
general appearance	photographic	symbolised
coverage	seamless	selective
information	tangible objects	tangible and intangible
appearance	individual	classified
visual hierarchy	random	structured
visual object separation	vague	distinctive
declaration	unexplained	explained
temporal representation	moment	period

Table 3-1 - Basic characteristics of images and maps

A further essential difference between the image and the map addresses the scale of representation. "*The larger the scale of the representation, the more the advantages of the aerial photograph outweigh those of the map. The smaller the scales, the more the power of expression and legibility move in favour of the map*" (Imhof, 1982). That scale does matter, is illustrated in Figure 3-2. The large-scale image c) shows a richness of detail that map d) with its uniform symbolisation cannot match. Not only image objects can be identified, but also object properties, for instance the landscape architecture, are presented. Moreover, depth cues offer a three dimensional impression (see sections 2.8 and 2.9). These advantages demise with decreasing scales. Remote-sensing textures begin to coalesce at scales smaller than 1:50,000 (Imhof, 1982). The small-scale satellite image e) merely enables the distinction of water bodies, forest, other vegetation, as well as large residential areas. Infrastructure is not visible. Also, there is no three dimensional impression. In contrast, the large scale map f) additively visualises arterial roads and marks specific locations.

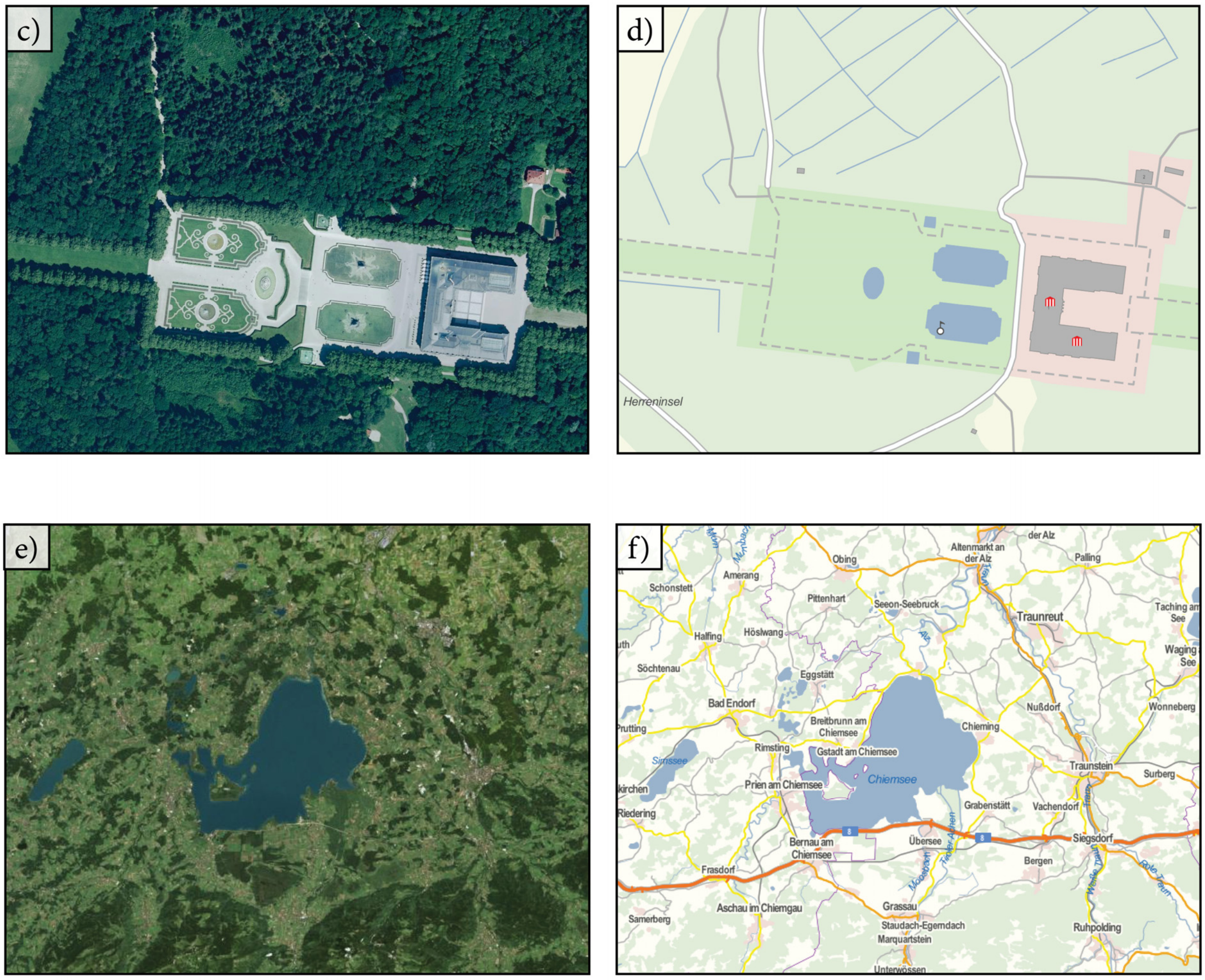

Figure 3-2 – Castle Herrenchiemsee as c) large scale aerial image, and d) large scale map; Regional area of the Chiemsee as e) small scale satellite image, and f) small scale map; © 2013 Bayrische Vermessungsverwaltung

Geometric differences are not discussed here, as rectification methods are part of the digital image processing (see sections 1.2.4 and 1.2.5) which ensures that the image becomes a geometrically correct representation with a uniform scale.

3.2 The Definition of Image Map

Before the author attempts to define image maps, various aspects of the term ‘image map’ shall be examined, mainly from a cartographic point of view, but also from other scientific perspectives. But first, we try to review the essential components ‘image’ and ‘map’ separately.

3.2.1 Image

In one of its first occurring definitions dated in the 17th century, the word ‘image’ is described as “*an artificial resemblance either in painting or in sculpture*” (Blount, 1656). The term '*artificial resemblance'* could be used here as an antique synonym for a photograph. The 'photograph' may be called 'image' in a more generic view. Lillesand et al. (2008, page 30) see the term 'image' as a generic term for any pictorial product. That means that beside aerial photographs, all remote sensing products, such as radar and lidar images, belong to the category of image. From an airborne or spaceborne sensor, electromagnetic radiation is recorded onto a storage medium as an analogue, latent image from emulsion, or as digital image. Nowadays, analogue cameras are rarely used, and even when they are used, the analogue images are converted to digital form by a scanner math (Mather and Koch, 2011, page 3). On this account, this work refers to an image as a remotely sensed digital image, mostly as a raster graphic with its image pixels, carrying the binary information of the colour depth. The pixels are orthogonally ordered into rows and columns, which set up the full image (for a good overview on digital images, see Burger and Burge (2010)).

3.2.2 Map

Maps are used to visualise geodata. The importance of maps is nicely emphasized by Dodge et al. (2011, page xxi), who see them as "*a key component of visual culture*". In a general view from Robinson and Petchenik (1976), maps are seen as "*graphic representations of the milieu*". '*Milieu*' connotes hereby surrounding or environment. A map can be also considered as a geospatial information system that gives answers to many spatial questions (Kraak and Ormeling, 2003, page 33). Such maps can be in printed physical form, or they can be virtual maps. A virtual map is a map without physical reality that is viewable on an electronic visual display (Dent et al., 2009, page 4). This work will not differentiate between paper maps and virtual maps, as mapmaking is nowadays a digital process worked on computers and displays, with the final step either being the presentation of the map on an electronic visual display, or a printed hardcopy. This point of view is similar to the view of Longley et al. (2010, page 302), who see maps as the final outcome of a series of GIS data processing steps.

Maps use graphical map symbols to visualise geospatial data. This is emphasised in the agreed map definition of the International Cartographic Association (ICA, 2003): "*A map is a symbolised image of geographical reality, representing selected features or characteristics, resulting from the creative effort of its author's execution of choices, and is designed for use when spatial relationships are of primary relevance*". These aforementioned definitions are all valid for image maps. Maps are in most cases divided into general reference maps and thematic maps. General reference maps are referred to as topographic maps, which depict the location of visual objects of and on the earth´s surface. Thematic maps on the other hand, use a reference base to visualise the statistical pattern of geographic variables. Image maps can justify both roles of acting as topographic maps or visualising thematic phenomena.

3.2.3 Crossover Visualisation

The image map is a synthesis of an image and a map. Both components are mandatory. While the image map possesses all characteristics of a map, it also is an image to some degree. Remotely sensed imagery is combined with cartographic symbols and supplemented by explanatory information, such as legends, grids, etc. Spatially seamlessly covered imagery and cartographic symbols are composed (for a detailed workflow see section 1.2). Graphical symbols with confined graphical space thereby overlay or substitute the extensive image. Because of the required confined graphical space for symbolisation, it is reasonable to have these in a vector format. Vector data is stored in a set of spatially referenced points. These points can be connected to other points to create lines and areas. Each element in this space is discrete and can hold thematic and topological attributes. Most mapping applications are based on vector data, as vector models are well-suited for representing maps (Bonham-Carter, 1994).

3.2.4 Terms and Meanings of Image Map

The term ‘image map’ has various meanings in science. There is no congeneric definition. In particular, different fields of science adopt their own interpretations. Even in the same specific field, judgements over the term ‘image map’ are not necessarily conforming. An overview of the most frequently used synonyms is shown in Figure 3-3, which will be discussed in the following sections.

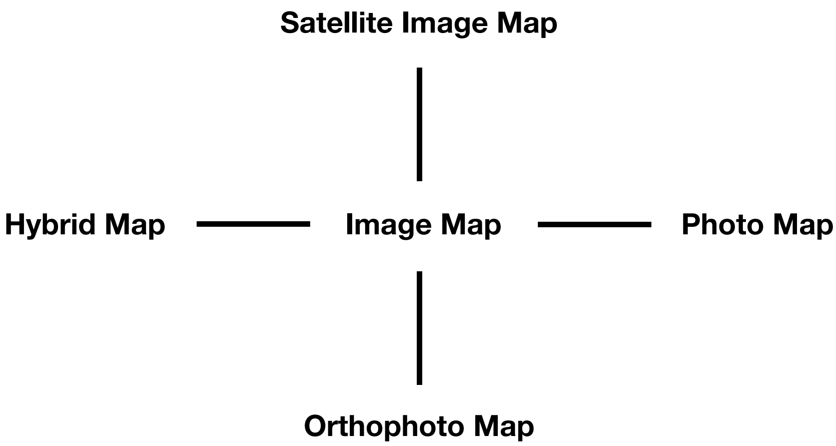

Figure 3-3 - Frequently used synonyms for Image Maps

3.2.5 Terms Distinguished by the Sensory Systems

Image maps are frequently referred to as ‘*photo maps*’ or ‘*satellite image maps*’. The distinguishing feature is hereby the sensory system. Older references (i.e. Heavey, 1942) refer to ‘*photo maps*’, instead of ‘*image maps*’, because earlier image mosaics were made from aerial photographs only. When satellite images entered into the image mapping process the term ‘*satellite image maps*’ was introduced. This does not obviate the term ‘*photo maps*’ being used for all remote sensing sources. For this reason, Weimer (1999) refers to these ‘*photo maps*’ and ‘*image maps*’ as subdivisions for the term ‘*remote sensing maps*’. Another term that often includes all remote sensing sources is ‘*orthophoto map*’ (i.e. Petrie, 1977), which refers to the mosaicking of orthorectified images (see section 1.2.7).

However, the term '*photo map*' is also used as a simple synonym for '*orthophoto map*' (Kraus, 2007, page 366).

3.2.6 Definitions Excluding a Symbolisation Component

In remote sensing, image maps are often defined as '*orthorectified image mosaics*'. Many references treat orthophoto maps as solely orthorectified images, without mentioning the symbolisation (i.e. United Nations Statistical Division, 2000). These orthorectified image mosaics are set into a cartographic frame with a map grid, but no cartographic symbols or labelling is included. Jensen (1996) follows the same logic, although he does mention the possibility of merging image data with a topographic map.

3.2.7 Definitions Including a Symbolisation Component

Many definitions of image map do include a symbolisation component. They present the image map as a montage product of an image with cartographic symbolisation. Some of these are tied to the concept of a specific use. One example is the definition of the image map as a topographic map substitute. For instance the American Society of Civil Engineers (1968) state that, "*contours, names, notes and all other editorial information appear on the photo map exactly as they do on the more standard topographic map*". Lillesand et al. (2008) introduce a '*topographic orthophotomap*' as an orthophoto overprinted with cartographic contour lines. This product has also been described as *orthophoto map* by Pedrotti (2013). In the scope of remote sensing, orthophoto based maps are sometimes referred to as '*topographic maps*'. To linguistically differentiate between the conventional topographic maps and orthophoto maps the term '*line map*' (i.e. Jensen, 1996) has been introduced to address conventional topographic maps. The definitions of image map have also been tied to the concept of thematic map use. Misra and Ramesh (1989) introduce the term '*photomap*' as a map for military use. Here, the *photomap* is an air photograph with strategic and tactical data superimposed on it.

However, definitions of the image map exist for a more general image symbolisation approach, without being tied to a specific application. Kraus (2007) described '*orthophoto maps*' as orthophotos with added graphical elements. In the textbook of Robinson et al (1995b), '*orthophotomaps'* were defined as orthophotos with "*overprinted map symbols*".

In the German-speaking region, image map is termed '*Bildkarte*', which is rather unambiguously known as a rectified mosaic in a map sheet system supplied with cartographic design of a considerable extent (Hake et al., 2002, pp 178-179). This definition corresponds to other definitions of '*Bildkarte*' in German literature, such as Albertz (2009), and Kohlstock (2011).

There are more terms for image map products. Arctur and Zeiler (2004, p 282) define the background images combined with vector data as '*hybrid maps*'. Since 2005, Google Maps users have become accustomed to this term when looking at the '*hybrid map view*' mode. Google´s '*hybrid*' mode blends their original street map tiles with transparent backgrounds over Google´s satellite tiles (Gibson and Erle, 2006). Other earth viewers have introduced the same image map mode with similar design approaches. Here again, names vary for image map modes of different earth viewers. Bing Maps use the term '*Aerial View*', and in Nokia´s geobrowser HERE it is simply called '*Satellite*' (with *Labels* enabled).

3.2.8 Image Maps as Clickable Images

Even in cartography, some confusion remains over the term image map. A considerable amount of cartographic references take an image map as a clickable HTML-image (i.e. Kraak and Brown (2001), Dent et al. (2009) and O'Rourke (2013)). Like in many parts of computer science, here an image map is a graphic object embedded in a HTML (hypertext markup language) or XHTML (extensible hypertext markup language) document and possesses designated regions that are hyperlinked. The World Wide Web Consortium (W3C), who develop fundamental open standards for the World Wide Web, defines image maps as images or objects with specified regions to which actions are assigned (W3C, 2012).

3.2.9 Definition of Image Maps

Selected sources share the author's interpretation of '*image map*' as a merging of remote sensing images and cartographic symbolisation. Monmonier (1987) regarded the '*image map*' as a synonym to '*photomaps*', that integrate an image with "*cartographically accurate grids and existing map data*". Harris et al. (1994) describe *image maps* as produced by digital cartographic map methodologies combined with remote sensing and image processing methodologies. These image maps have an orthophoto base overlaid with geographical information. And a more recent and analytical definition of the image map addresses the image map *"as a special map portraying geographical space in a particular cartographical projection and map scale, where its content consists of two basic components – image and symbol components. Image component is represented by remote sensing image(s), while symbol component is represented by cartographic symbols*" (Bělka and Voženílek, 2013).

The author aims not to limit the definition of image map to classic orthogonal maps, rather to extend it to 3D and perspective maps. In cartographic literatures, 3D maps are not always regarded as maps, but rather as map-related representations (Hake, 2002). Other sources do make references to '*perspective maps*' as maps (i.e. Robinson et al., 1995b). Häberling (2005) defines a 3D map as a "computer-generated perspective view with cartographic content". These are perspective views of a three-dimensional geo-data model. A perspective map is very close to the 3D map, with the difference of not being derived from a three-dimensional geo-data model. The term '*perspective map*' originates from the pre-digital era. Cartographers or artists mapped what they could see from high elevation in an oblique view (Smith, 2005).

If maps include perspective views derived from three-dimensional geo-data models, we would regard a perspective derived from a virtual camera snapshot as a map. In this thesis, however, we would not include the overall virtual reality in the definition of image map, and rather leave it as a field of computer simulation that creates a realistic-looking and interactively accessible virtual world (Burdea and Coiffet, 2003).

Based on the analysis in the preceding sections, the author defines image maps as *a composition of remote sensing imagery and cartographic symbolisation, which creates a crossover visualisation, designed to reap the advantages of presenting naturalistic images while providing easily recognisable cartographic symbols. Image maps visualise spatial phenomena in an orthogonal or in a perspective view, and are complemented by cartographic layout elements.*

3.3 Types of Image Maps

3.3.1 By Orientation

Holistically symbolised maps can be classified according to their orientation. Standard planimetric maps are formed by a parallel projection of the top view of the landscape onto a horizontal surface. Maps obeying the law of central perspectives served as a complementary representation in pre-computer era. They fall under the generic term *perspective pictorial maps* (Robinson et al., 1995b), or *oblique views* (Slocum et al., 2009). Perspective maps do not have a uniform scale, as the scale decreases from foreground to background. The principle of the perspective projection is shown in Figure 3-4.

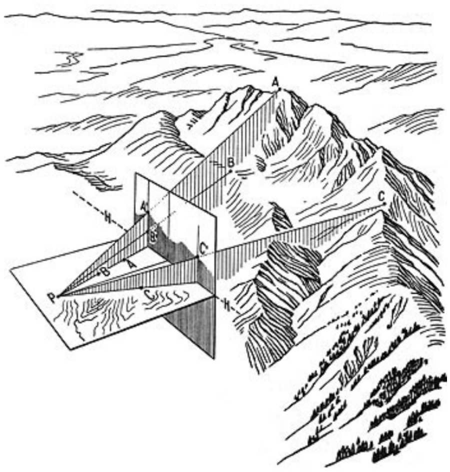

Figure 3-4 - Illustration of the perspective projection by Imhof (1963); Projection lines between the focal point P and the real world points A to C intersect with the map points A' to C'.

Remote sensing images are classified according to their orientation. In this case, they are classified due to their basic geometry (see Figure 3-5). As explained in section 1.2.2, vertical images are gained when the sensor´s optical axis is roughly vertical to the earth´s surface and oblique images are obtained when the angle of view is tilted. Oblique images are further divided into two sub sections. A *low oblique image* is acquired with the sensor aimed to the side or the front of the aircraft, and it does not show the horizon (Campbell and Wynne, 2012). In contrast, the *high oblique image* is obtained when the horizon is visible.

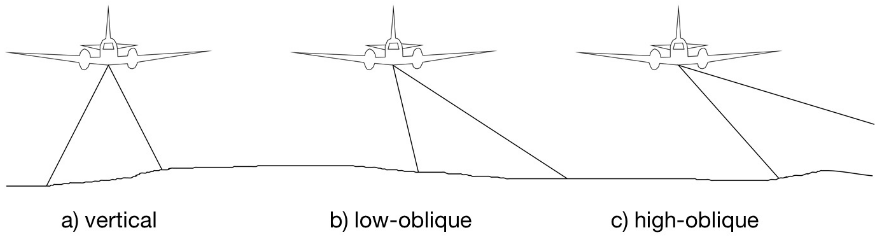

Figure 3-5 - Orientation of Images

In the following the categorisation by orientation is adapted to image maps including 3D image maps derived from three-dimensional geo-data models (see section 3.3.5).

3.3.2 Vertical Image Maps

Image maps in vertical view are the most usual, because most geodata is stored as planimetric data, and it is easy to handle in common GIS-software.

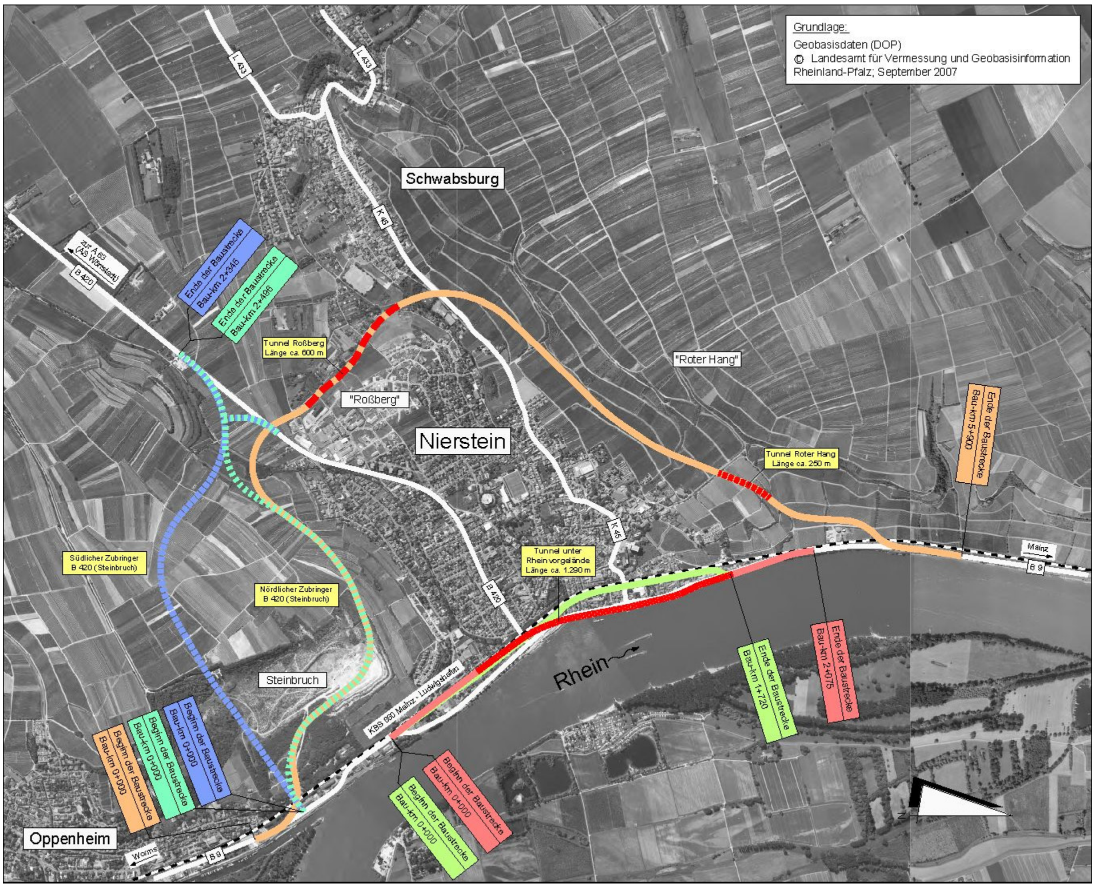

Figure 3-6 - Ring road alternatives in Nierstein, Germany; ©Landesbetrieb Mobilität Rheinland-Pfalz, and ©Landesamt für Vermessung und Geobasisinformation Rheinland-Pfalz (2007)[3]

[3]http://lbm.rlp.de/icc/OU_Nierstein/nav/a42/a4260047.htm (20.08.2013)

All national mapping programmes invariably base their mapping series on vertical images, because they can be examined stereoscopically and scale distortions can be easily corrected (Gibson and Power, 2000). Vertical image maps are used for analytic purposes. Basic photogrammetric methods can be applied to vertical images in order to directly determine geometric properties. The scale is then the ratio of the camera´s focal length to the height above the surface. While aerial imagery can also be used for oblique image maps, satellite imagery is almost always rectified for vertical view applications. An example for vertical image maps is shown in Figure 3-6.

From the point of view of map reading, vertical image maps have an unfamiliar human perspective. Many image objects are difficult to recognise from above. This is why vertical images are more challenging to interpret (Campbell and Wynne, 2012).

3.3.3 Low-Oblique Image Maps

A low-oblique image map is based on an image with the optical axis tilted for more than 3 degrees from the nadir line while recording. This recording geometry generates much different image map characteristics compared to a vertical view (see Figure 3-7). A relatively large area is displayed by a low-oblique image map compared to a vertical image map. The shape of the displayed geographic area is thereby trapezoidal. An oblique image map possesses distortion. No constant spatial relationships are depicted, as the scale size reduces from the foreground to the background. That means objects in the foreground are depicted larger, than objects in the background. Low-oblique image maps are applied to illustrate detailed scenarios in which the height of image objects (mainly buildings and vegetation) can be perceived. These objects appear to lean away from the viewer. The visual variable *perspective height* (see section 2.6) enables a figural presentation of objects. The map reader becomes a three-dimensional impression of the scene. Also, more pictorial details of the object faces, such as building facades, are added. Both perspective height and pictorial detail act as cues for object identification (Warren, 1994). But at the same time more occlusions are introduced, and therefore potentially important information may be hidden compared to maps in vertical view (see Figure 3-7). That is why the orientation of the oblique image becomes important. The viewing angle determines which objects are to be depicted larger, which object faces are visible and which objects are hidden, or partly hidden. The importance of orientation, or uprightness, in oblique maps, has been highlighted by Warren (1994).

Oblique perspectives provide a more intuitive perspective for visual interpretation (Campbell and Wynne, 2012). They are favourable for site mapping, as the viewer receives vivid overviews. It is often confirmed in remote sensing literatures that humans are better able to interpret oblique imagery than vertical images (i.e. Jensen, 2007). That is due to the fact that looking at the side of objects is the standard human visual experience. Because of the intuitive nature, oblique images are very attractive to decision makers, as well as to the general public (Grenzdörffer et al., 2008). However, low-oblique image mapping is seldom used for measuring and analytic purposes.

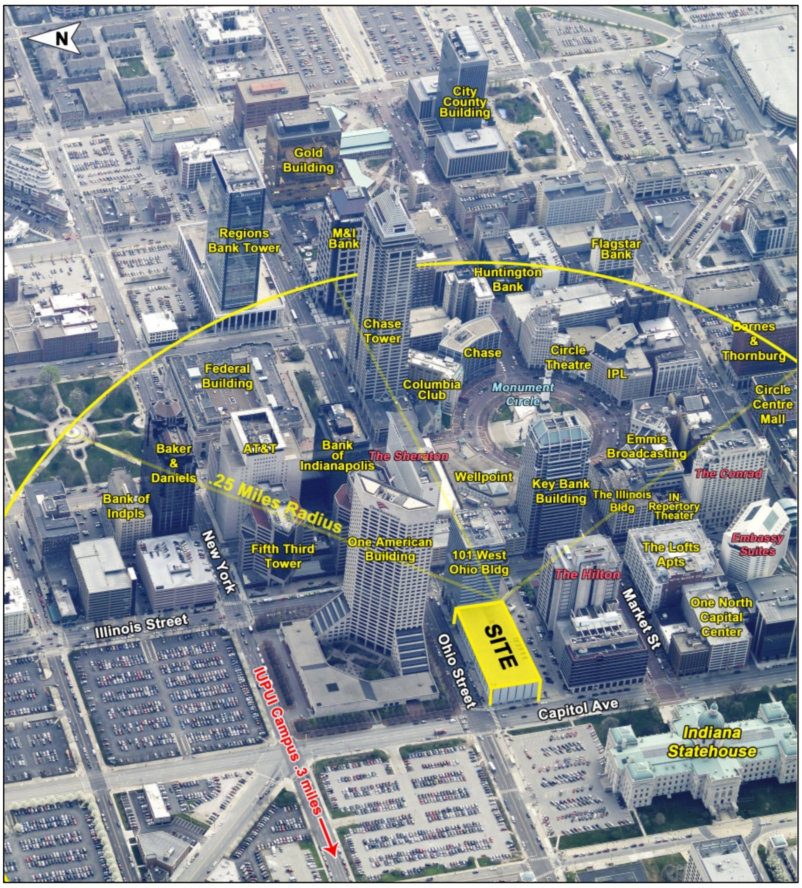

Figure 3-7 - Image map showing real estate information, (©2013 Sitehawk Retail Real Estate[4])

For holistically symbolised maps, research has been done on the cognition of oblique maps in contrast to planimetric maps. Plester et al. (2002), and Liben and Yekel (1996) showed that preschool children are better able to identify locations and referents on an oblique perspective map than on a planimetric map. This makes the assumption that oblique representations are more consonant with perceptual experiences (Liben et al., 2008).

3.3.4 High-Oblique Image Maps

High-oblique image maps share many characteristics of low-oblique image maps (see section 3.3.3), but they reveal some specific properties. A high oblique image is obtained when the horizon is visible. An example is given in Figure 3-8. The nadir line is usually tilted by about 70 degrees (Aber et al., 2010). On one hand, the high-oblique image map has the ability to cover a large geographical area, compared to the other two image map types. On the other hand, high-oblique image maps have major occlusions. The visual appearance is therefore highly dependent on the image orientation. High-oblique image maps are very illustrative. They are particularly good for visualising 3D landscapes. Because of the near horizontal view, map readers can easily understand elevation differences and topographic features (Schobesberger and Patterson, 2008).

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[4] http://www.sitehawkretail.com/wp-content/uploads/Michael-Downtown-Indy.jpg (20.08.2013)

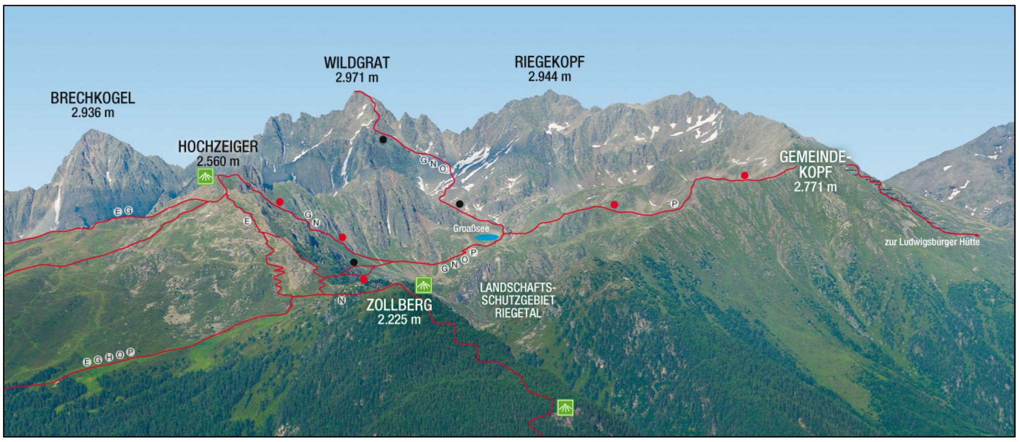


Figure 3-8 - Detail of a high-oblique image map of the Hochzeiger hiking area[5]; © Pitztal Activ

3.3.5 3D Image Maps

3D image maps are perspective views derived from a three-dimensional geo-data model, in which a remotely sensed texture is draped over the virtual ground. Typically, orthorectified image mosaics texture the ground that is either a plane surface, or a 3D surface set upon an extruded digital terrain model. Other topographic objects like buildings can also be extruded. The cartographic symbols can be 2D or 3D. Lighting and shading effects are added to the geo-data model in order to give the model a realistic look, and in order to give the user visual cues for the shape, the relative position of symbols, and terrain landforms. 3D image maps are rendered images from a 3D geo-data model. The perspective is generally oblique. An inclination of 30° to 60° is hereby preferable (Häberling et al., 2008).

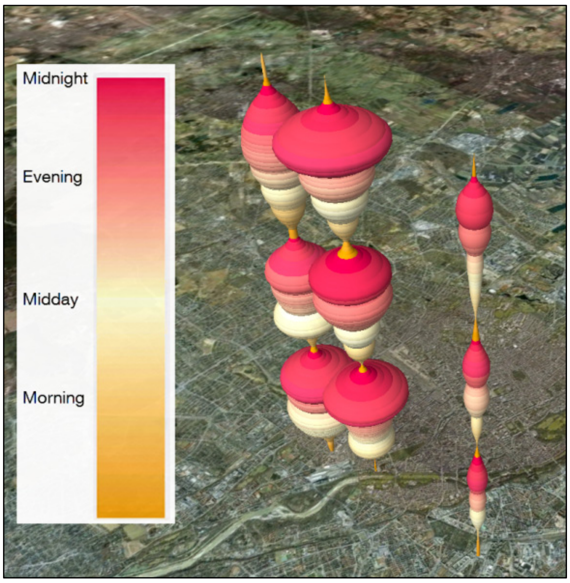


Figure 3-9 - Image map rendered from Google Earth visualising mobile phone call intensities with 3D symbolisation (Murphy, 2013)

[5] http://www.pitztal.at/wandern-am-hochzeiger.html (21.08.2013)

Many 3D image maps have been created with geobrowsers, such as Google Earth. When vector data from other sources is rendered on the virtual globe, these products are sometimes referred to as map mashups (see section 1.3.2). An example for the visualisation of mobile call intensities with 3D symbols on a virtual globe is shown in Figure 3-9.

3.3.6 By Application

In can be perceived from the general survey of image maps as map series appearing on the web or published on printed media that image maps are targeted to certain applications. In particular, they are predominately used in disaster management, tourism, urban development, topographic mapping, and visual analytics. In the following, selected examples from these fields are presented to reflect on the typical applications.

3.3.7 Disaster Management

Disasters adversely affect population and environments. Disaster management aims to reduce the harm of life, property, and environment (Coppola, 2011). In the event of a disaster, massive alterations of the geographic space along with the infrastructure take place. Especially the emergency response phase requires a fast reconnaissance of the aftermath. Damage information should be obtained within hours by rapid mapping as a fast procedure to collect basic information on the contents of remote sensing images (Dell´Acqua and Gamba, 2010). Remote sensing imagery can be obtained quickly by satellites with short revisit times (Broek et al., 2009). The remote sensing images are usually mapped to planimetric image maps. A damage assessment of buildings or infrastructure is often included as a thematic vector layer (see Figure 3-10). This can be a polygon symbolisation of damaged / not damaged areas, or an isarithmic layer for the visualisation of damage classes. Relevant infrastructure and other objects important for crises response are often highlighted using cartographic symbols.

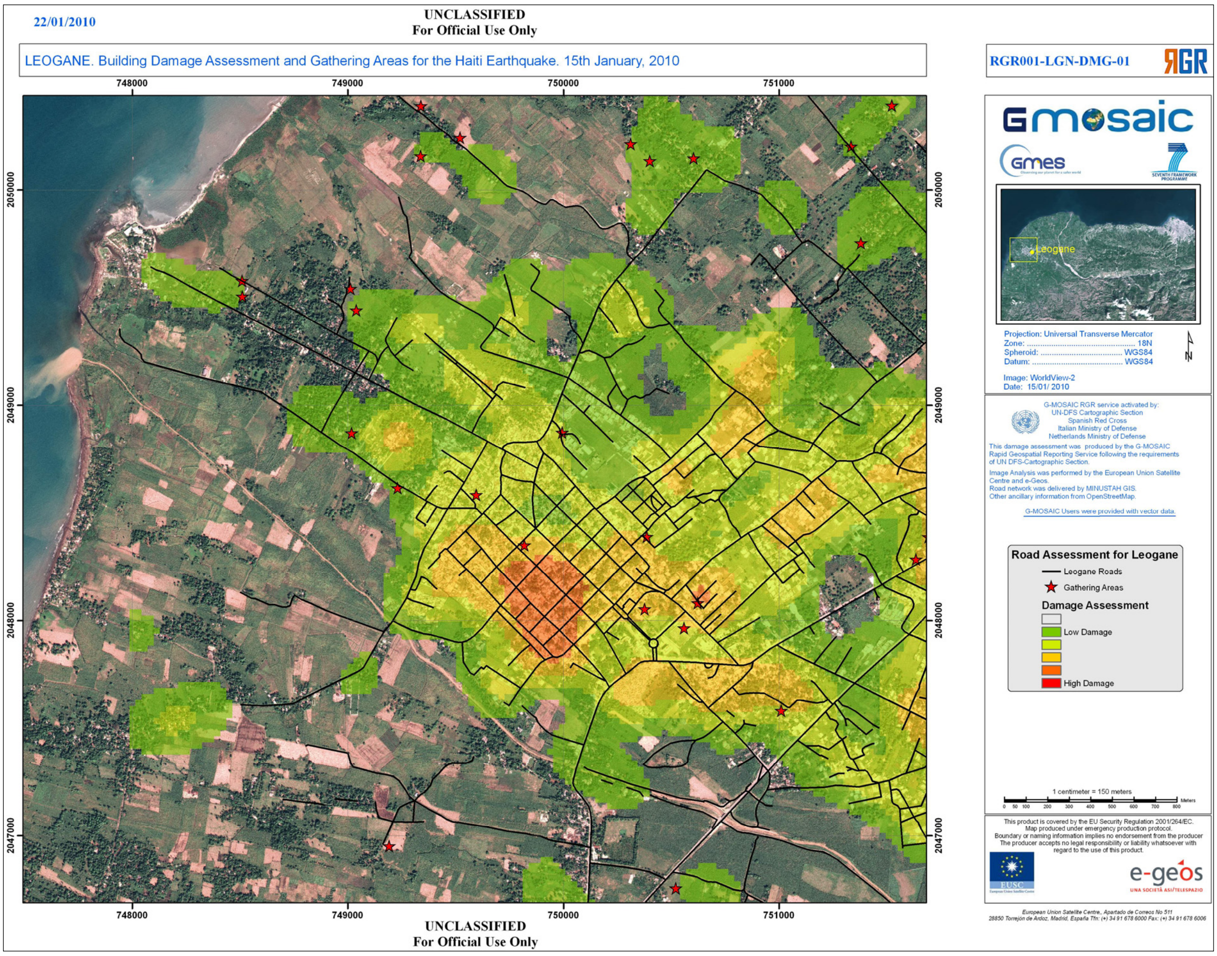


Figure 3-10 – Assessment of Building Damage after the Haiti Earthquake 2010, © G-MOSAIC 2010

3.3.8 Tourism

Tourists travel for recreation, leisure and business. In order to visit unknown places, they need maps for orientation and navigation purposes. Exploring tourist destinations with the help of maps is also an important issue. Touristic places are sometimes mapped as image maps to indicate the location of tourist´s points of interest. This is most common when tourists seek leisure activities in natural areas. In this case local tourist agencies are enthusiastic in exhibiting the attraction of their natural resources. They choose the image map visualisation to show natural landscapes in a naturalistic way, while offering the tourists easy readable map symbols for hotspots (see Figure 3-11).

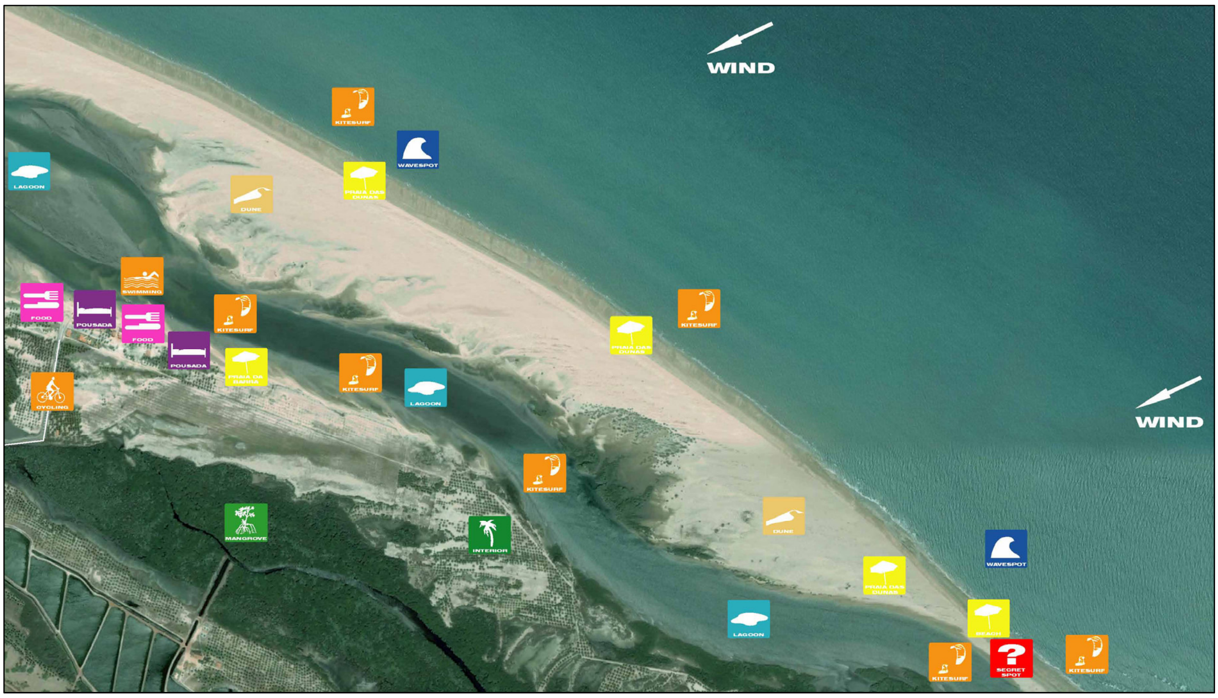


Figure 3-11 - Detail of a tourist map of the Ilha Do Guajirú, Brazil[6], © 2008 Beachlife Imóveis do Brasil ltda.

A considerable number of image maps for touristic purpose are connected to the leisure activities hiking and skiing. A large survey of North American ski maps showed that 6% of all ski maps were image maps (annotated aerial photographs in oblique view) (Tait, 2010). These image maps highlight hiking or skiing routes as polyline symbols. The mountainous areas are mostly mapped in perspective view, while the flat areas are mapped in orthogonal view (see Figure 3-8 and Figure 3-12).

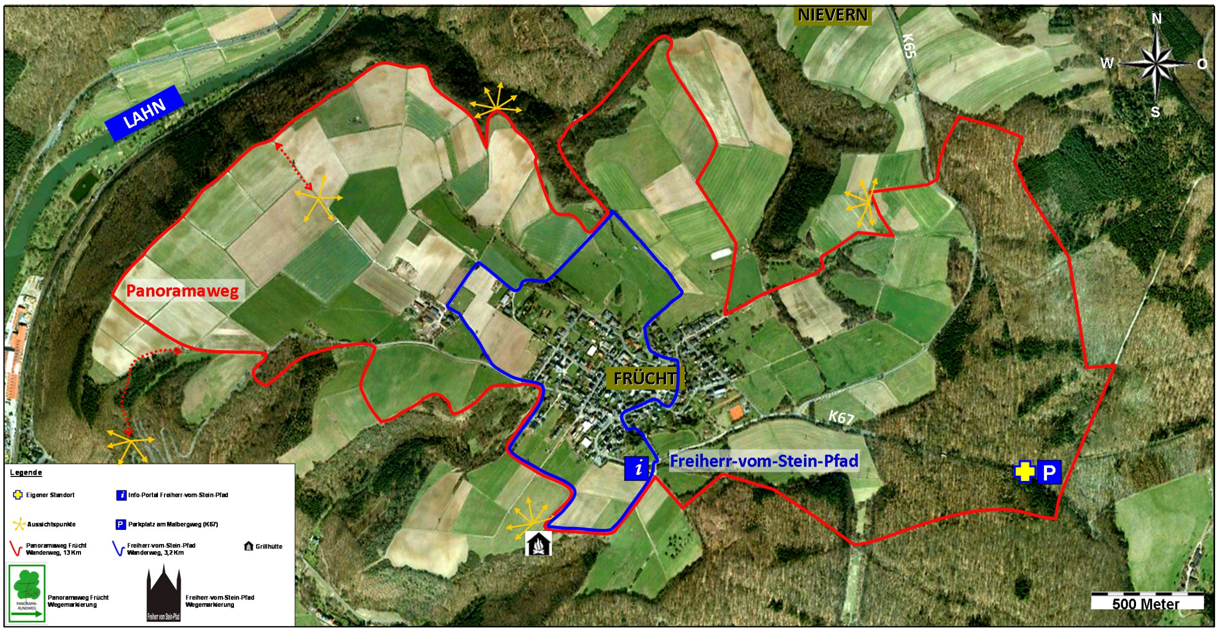


Figure 3-12 - Hiking map of Frücht[7], © Gemeinde Frücht

[6] http://www.theflatwatersea.com/maps_touristmap.html (09.09.2013)

3.3.9 Urban Development

Urban planning (or town planning) is known as "*the art and science of ordering the use of land and siting of buildings and communication routes so as to secure maximum practicable degree of economy, convenience and beauty*" (Keeble, 1952, p. 9). Urban planners formulate plans for the structural change of city districts, blocks, and for major building projects. The development of urban areas is accompanied by administrative procedures that involve public participation. For this reason, information about the urban development is important for the implementation of urban planning projects. Affected citizens and parties gain a much easier project understanding with the aid of visualisation. Image maps are keenly used. They allow the users to perceive the presented built environment with remote sensing images as orientation. In fact, the realistic impression of the built environment makes the planned structural changes more comprehensive. Many image maps of urban development are in a perspective view that reveals both building facades and heights familiar to the local observers. Often they also highlight and classify certain areas by transparent polygon overlays (Figure 3-13), or by polylines enclosing an area of interest.

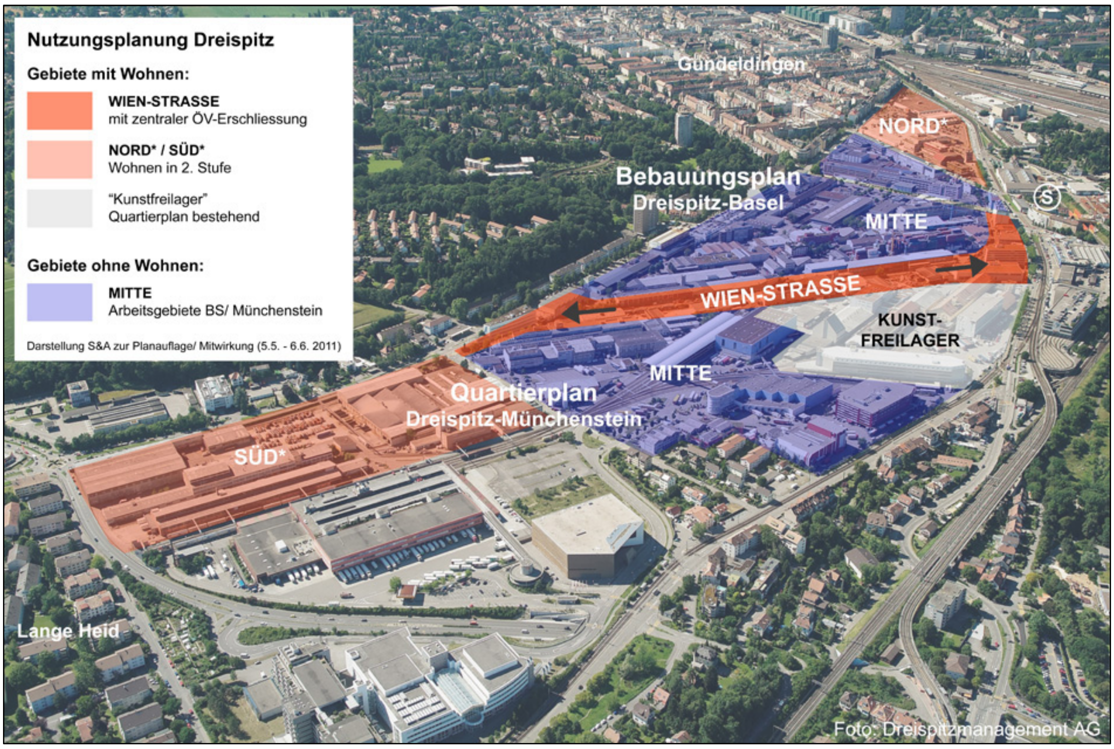


Figure 3-13 - Municipal land use planning of Dreispitz in the City of Basel[8], © 2011 Planungsamt Basel-Stadt

3.3.10 Topographic Mapping

Topographic image maps show both natural and man-made features just as conventional topographic maps do. Topographic image maps act at as map substitutes for non-existent

[7] http://www.fruecht.info/index.php/landschaft-wandern/panoramarundweg (09.09.2013)

[8] http://upload.sitesystem.ch/5524DDE7FB/F6B8BF5BAD/B3AE0D3DAF.jpg (09.09.2013)

topographic maps or as completion for topographic map series (Kohlstock, 2011). Especially in developing countries, topographic image maps are an interesting alternative as orthophotos are easy to acquire and can make up for non-existent topographic object class data (i.e. buildings and water bodies). Topographic image maps can be completed with fewer vector objects (i.e. solely road network data and contour lines). Which from holistically symbolised topographic maps and topographic image maps are more useful has not yet been proven. Smith (1977) showed in a user test, that the readability of a standard topographic map compared to a topographic image map (orthophotomap) differs little.

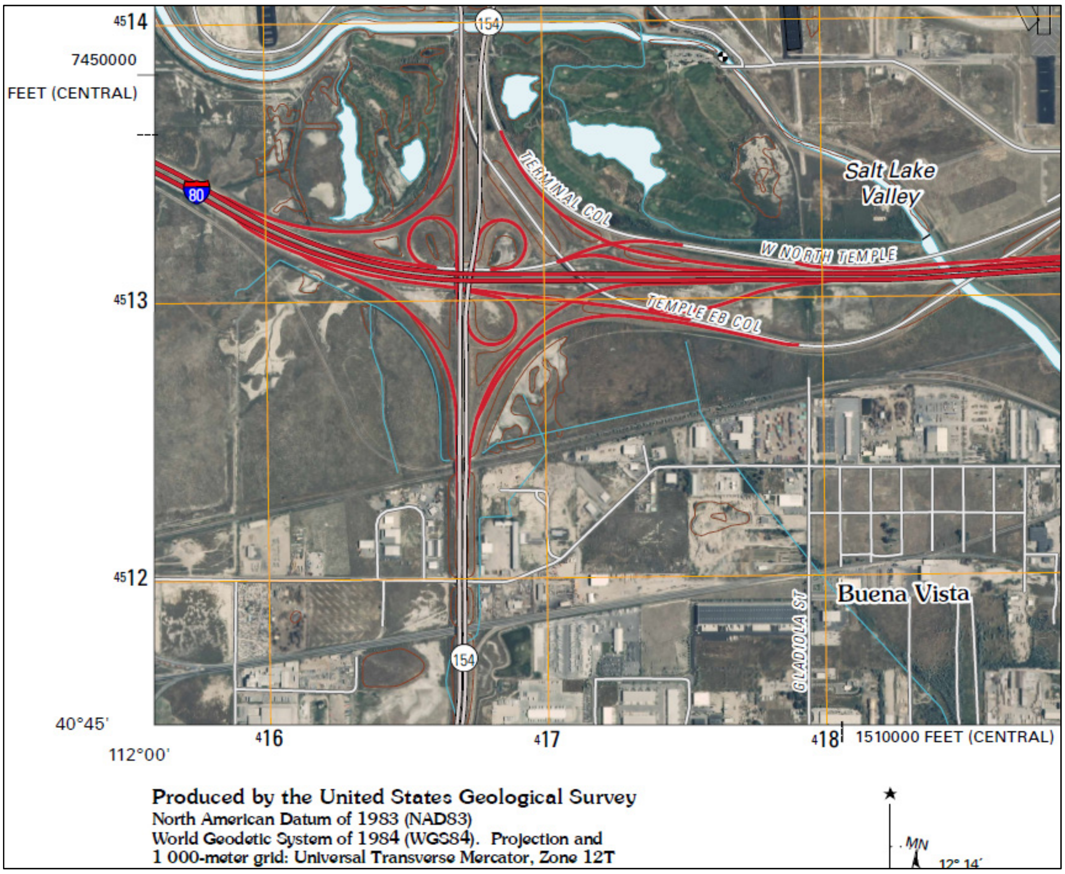


Figure 3-14 - Detail of map sheet Salt Lake City North, Utah, of the US Topo Map 1:24,000, © 2012 USGS

Developed countries also map their topography with image maps. In 2009, the United States Geological Survey (USGS) released the US Topo, which consists of nationwide topographic maps in a 1:24,000 scale (USGS, 2010). These governmental maps provide consistent and seamless geographical base data. US Topo maps are composed of road networks, geographical names, representation of altitude, water bodies and orthophotos (Schoppmeyer, 2011). As essential base data such as railway lines or land use are not symbolised as cartographic layers, the orthophoto completes the base data representation. The orthophoto map example of Figure 3-14 shows the graphical design of the US Topo maps.

3.3.11 Visual Analytics

Visual analytics has been introduced and specified as the science of analytical reasoning facilitated by interactive reasoning techniques (Thomas and Cook, 2005). Computational tools are combined with human understanding to visually explore spatial databases. Visual analytics is about visual data mining and statistical analysis. Since the emergence of virtual globes, it has become increasingly easy to visualise and disseminate geodata as image map mashups (see section 1.3). Supported by XML notations such as KML, virtual globes can visualise spatial data in a 3D view. The remote sensing imagery of virtual globes provides the orientation and localisation of the visualised data. The comprehensive set of navigation tools allows the analyst to freely navigate to any view and analyse the visualised data from every angle and distance. For instance, hotspots of spatial phenomena can be analysed in detail. Many examples on how spatial and spatio-temporal data are analysed can be found in the realm of visual analytics via image map mashups (i.e. Dransch et al., 2010, Murphy, 2013). The visualisation end products are hereby 3D image maps (see section 3.3.5). These are used to document visual analytical results for a single professional analyst or a group of scientists. An example is shown in Figure 3-15.

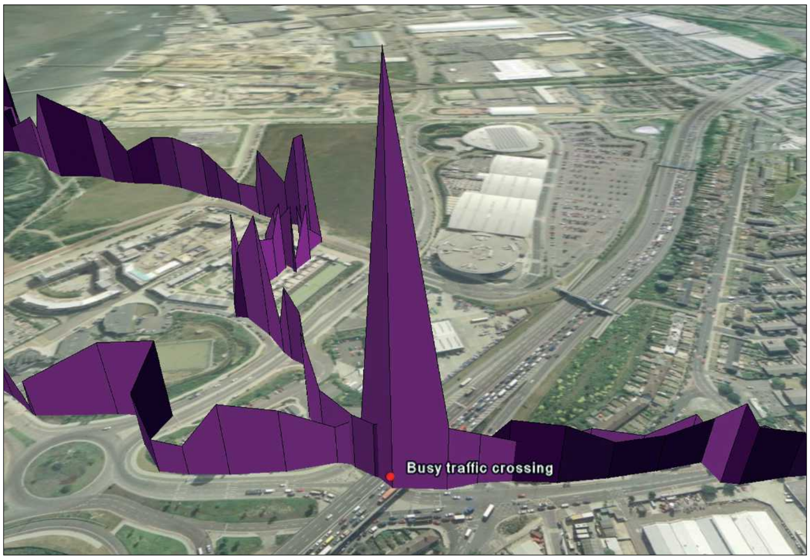


Figure 3-15 - Visual analysis of physiological arousal (Nold, 2009)

3.4 Benefits of Image Maps

In this section the benefits of image maps are pointed out compared to the default holistically symbolised maps. These benefits constitute reasons why image maps have established themselves as a popular visualisation type.

Firstly, image maps enable a ‘quick and easy’ map production. Many map making workflow steps and symbolisation decisions and can be skipped when imagery acts as base map or prominent objects are presented as imagery (see section 1.2.9). For this reason image maps are widely chosen for time-critical mapping applications, for instance as ‘rapid mapping’ (see section 3.3.7). Directly connected with a faster production time is the reduction in map making costs as the workload is cut down. Both costs and workload are considerably shortened a further when the image map mashup (see section 1.3.2) type is chosen.

Imagery adds beauty to the map. 'Beauty' is a not to be overlooked design aspect for the overall map appearance (i.e. Tyner, 2010). Users often find bird´s eye views with such intensity of detail beautiful, and are fascinated by naturalistic visualisations. The attention-gripping and immersive experience of remote sensing imagery supports the distribution and the use of image maps. Furthermore, users´ tend to prefer realistic visualisations even when the realism shows no relevant information. They fall for a behaviour dubbed '*naïve realism*', which is the paradoxical behaviour of the user´s misplaced faith in the perception´s ability to extract information from realistic information display (Smallman and St. John, 2005). VHR images can boost the attractiveness of a map and make it more interesting and captivating to the user.

The naturalistic imagery also adds user confidence to the image map´s assets. Realism improves the map reader´s confidence in the credibility of spatial data. User tests have shown that the more realistic a display is, the higher are the participant's confidence ratings (Fabrikant and Boughman, 2006, Zanola et al., 2009). The reader´s higher confidence in naturalistic visualisations is maintained even when the performance noticeably drops. Again, user tests reveal that user´s need more effort for identifying relevant objects on realistic displays in comparison to abstract displays (Hegarty et al., 2009, Hegarty et al., 2008, Canham et al., 2007). Image map designers can utilize this stalwart belief in realistic imagery to hand a trusted message onto the user.

A major benefit from the image map concept is that the designer can choose a convenient balance between the information visualisation of reality and abstraction, without having to go for one extreme (see section 3.5.1). Vector elements complete the map design by adding and explaining information with several design operations (see section 1.2.16). Thorough labelling supports the reader´s overall understanding (see section 1.2.17). By symbolising a portion of the map frame, a visual hierarchy is introduced to enhance information communication by the image map. The designated symbols achieve a clear, unambiguous transfer of information, which the image alone cannot achieve.

The image map proves to be an effective visualisation type because of this image/map composition. An intuitive natural appearance is combined with cartographic abstraction. One visualisation mode is surely not responsible for a single task, but the image largely attracts the user, while symbolisation and labelling transfer the message.

3.5 Conceptual Analysis

3.5.1 From Realism to Abstraction

Representations are not reality. This in one way obvious fact is sometimes not always clear to the user. Alfred Korzybski´s (1958) statement "*the map is not the territory*" tries to emphasize that the map is not the real object. It is an abstract reflection of the territory.

Human perception keeps interceding between reality and ourselves. Our environment is visually scanned to produce a mental image. As both, real physical objects and visual representations are perceived in the same manner, semantic uncertainness remains in human cognition over the reality of this mental image. The Belgian surrealist artist Rene Magritte highlighted this semantic uncertainness in his famous work “The Treachery of Images” that featured a drawing of a pipe with the label “*Ceci n'est pas une pipe*” ("This is not a pipe"). In fact, it is only a picture of a pipe (see Figure 3-16).

Figure 3-16 - Rene Magritte´s artwork (1929): “*Ceci n'est pas une pipe*” ("This is not a pipe")

Photographic representations are likelier to be confused with reality, than abstract representations. This is due to images being a reflection from reality. Their appearance is closer to the reality, just as humans visually scan the environment. Kelly and Nace (1994) state that “*people believe photos if they make sense - if the information they provide fits comfortably within their existing understanding of the world - […]*”. Most remotely sensed images fit comfortably within people´s understanding of the world, and are therefore seen as more truthful representations of a geographic scene than abstract maps.

For the following concept of image map visualisation, realism does not correspond to the artistic understanding of realism, but as visual scenes, just like humans visually perceive reality. Realism can here be equated with photographic imagery. On the other hand, abstraction is about reflecting the essence of a subject rather than the detail. The subject is reduced to the dominant attributes to echo the subject´s character. Abstraction can here be equated with holistically symbolised maps.

Image maps are defined as a crossover visualisation in section 3.2.9. They do not reflect a discrete type of visualisation. In fact, from a design point of view, image maps fill a whole visualisation continuum between realistic images and abstract maps. This theoretical model can be explained by means of the *image map visualisation continuum* in Figure 3-17. In this figure, three visualisation dimensions or variables constitute a cube, the *image map cube*, in which one corner represents the image representation and its opposite corner the map representation. The open space between these opposing corners represents the realm of image maps. Image maps blend two extreme visualisation types together. One could also say that image maps are geographic visualisations between realism and abstraction.

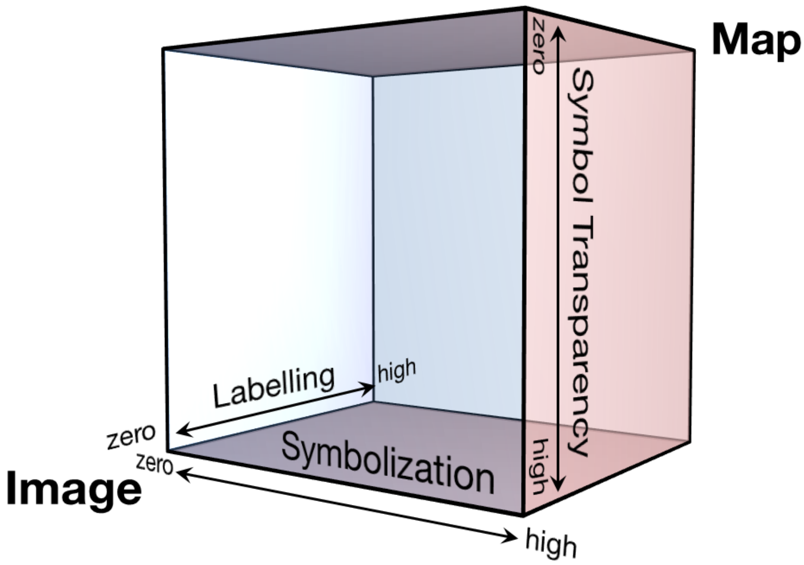


Figure 3-17 - Image map cube

The *image map cube* of Figure 3-17 has three axes. All three axes have a range from zero to high. They reflect the degree of three fundamental design variables,

- Labelling,
- Symbolisation, and
- Symbol transparency.

Labels indicate the location of image objects and assign names or descriptions to the image object. The amount of labelling of an image map defines its place along the labelling axis. Cartographic symbols add meaning by complementing, clarifying, and classifying image objects (see section 1.2.16). Symbolisation refers to abstraction with symbols. The amount of symbolisation is reflected by the proportion of map space covered by map symbols (in contrast to the image proportion). Symbol transparency reflects the level of opacity concerning cartographic symbols. The symbol transparency is a useful variable for blending stacked cartographic symbols and imagery in order to make both visible. The higher the symbol transparency, the more clearly is the imagery to be seen. This visualisation continuum implies that a completely symbolised and labelled representation with zero transparency is a map, and that an image is neither labelled nor symbolised.

Figure 3-18 - Different design examples of image maps between realism and abstraction: a) high degree of labelling – zero symbolisation, b) medium degree of labelling – high symbolisation degree – zero symbolisation transparency, and c) medium degree of labelling – high symbolisation degree – high symbolisation transparency

As the *image map cube* contains all possible design cases. Every image map can be located at a distinctive place. Three examples shall clarify this concept. Figure 3-18 a) shows an image map in which solely labels are used to enhance the understanding. This image map has a high degree of labelling, but zero symbolisation, therefore, corresponds to the blue point placed in the *image map cube* (see Figure 3-19). Figure 3-18 b) shows an image map, in which labels are used to a medium degree. Its symbolisation covers the major part of the map face, which means high symbolisation, while the symbolisation transparency is zero. This map corresponds to the green point placed in the *image map cube* (see Figure 3-19). Figure 3-18 c) shows an image map on two axes analogue to b), in which labels are used to a medium degree, and symbolisation is high. The difference is only set by the high symbolisation transparency. Consequently, it is placed as a yellow point under the green point (see Figure 3-19).

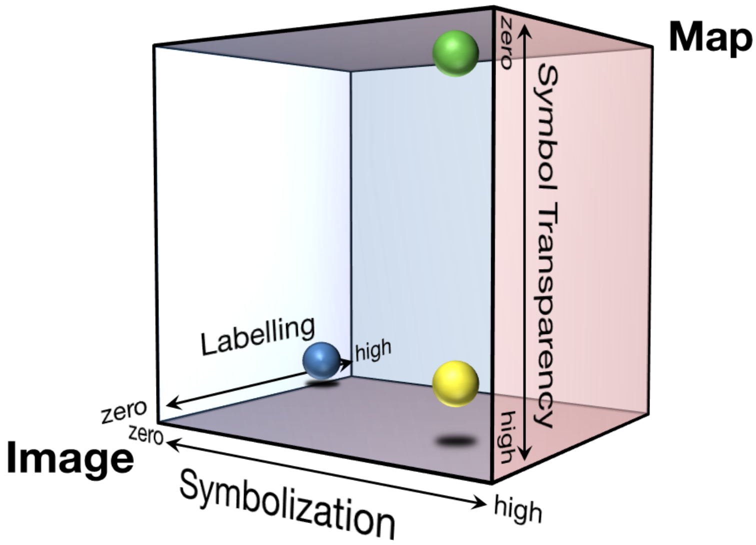


Figure 3-19 - The image map cube demonstrating the relative locations of the three examples from Figure 3-18

3.5.2 Image Maps between Visualisation and Communication

This section tries to relate the role of image maps with the map-use cube developed by MacEachren (1994), who stated that any category of map might occupy a position within his map-use cube, originally named *(Cartography)*[3]. The map-use cube as shown in Figure 3-20 is developed from the perspective of the mapmaker. It occupies three dimensions with their meanings explained as follows (MacEachren, 1994, pp. 6-7)*:*

- *"map use that is private (where an individual generates a map for his or her own needs) versus public (where previously prepared maps are made available to a wider audience)*
- *map use that is directed toward revealing unknowns (where the user may begin with only the general goal of looking for something "interesting") versus presenting knowns (where the user is attempting to access particular spatial information); and*
- *map use that has high human-map interaction (where the user can manipulate the map(s) in substantive ways - such as effecting a change in a particular map being viewed, quickly switching among many available maps, superimposing maps, merging maps) versus low interaction (where the user has limited ability to change the presentation)."*

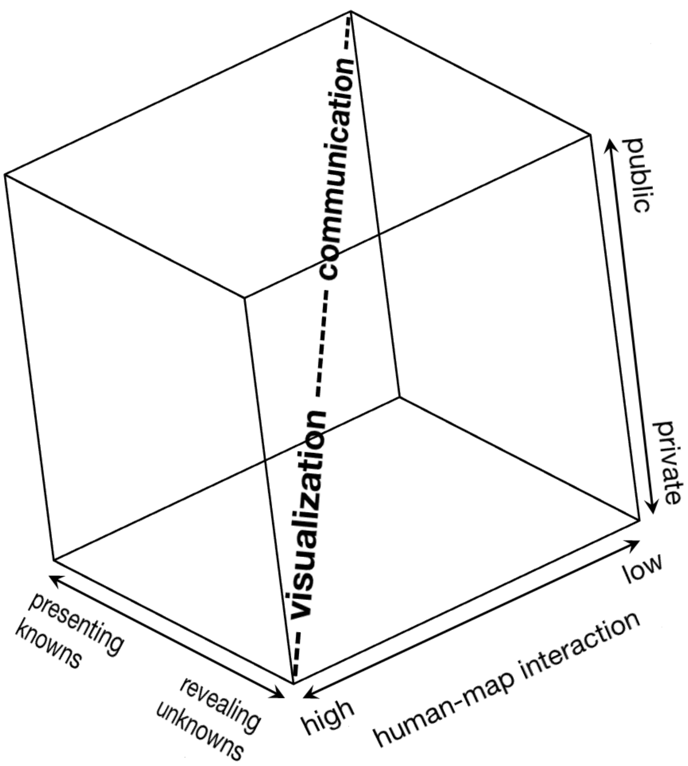


Figure 3-20 – (Cartography)^3, the Map-Use Cube, MacEachren (1994)

The map-use cube makes a distinction between *cartographic visualisation* and *communication*. *Visualisation* and *communication* are hereby defined as the two subcomponents of cartography. *Cartographic visualisation* is aided by computer graphics to "*produce scientific insights by facilitating the identification of patterns, relationships, and anomalies of data*" (MacEachren and Ganter, 1990). Further, *cartographic visualisation* is seen as a cognitive process, which qualifies its role inside the map-use cube. The extreme *visualisation* of this concept reveals unknowns in a highly interactive representation for spatial data exploration of an individual. The other subcomponent, the term *cartographic communication*, has been discussed for many decades within theoretical cartography. The several existing definitions usually involve the process of information transfer from a map percipient, who decodes spatial information into map symbols, to a map viewer, who reads and interprets the map symbols. A good overview to the existing map communication theories is given by Board (2011). According to the map-use cube, the maps of cartographic communication are produced for a larger public audience, presenting more general spatial information, with less interaction.

The map-use cube does not deal with types of map products, but with types of map use. Here, the usage of image maps shall be shortly examined. Table 3-2 summarises the general map use built in all cases upon typical image maps of the respective fields of application mentioned in section 3.3.6.

	Audience	Interaction	Known to Unknown
Tourism	**public:** tourists and hikers, skiers, etc.	**low:** nothing typical	**presenting knowns:** i.e. representing points of interest or hiking trails
Urban development	**rather public:** affected and interested citizens	**low:** nothing typical	**presenting knowns**: i.e. representation of blocks to be redeveloped
Topographic mapping	**public**	**low:** panning and zooming	**presenting knowns:** i.e. relief representation
Disaster management	**public to private:** emergency managers, interested people	**low:** nothing typical	**closer to revealing unknowns:** i.e. damage assessment
Visual analytics	**rather private:** the analyst and scientists of the research field	**high:** data model changing, full navigational set	**revealing unknowns:** i.e. exploring spatial patterns

Table 3-2 - Map-uses of typical image map applications

Obviously, differences exist depending on the application field. Image maps do not fit into one single map use category. However, a majority of the image maps for these application fields are predominately for *communication* use. The applications 'tourism' and 'topographic mapping' have a *low interaction*, a *public audience*, and the *presenting of knowns* in common. According to the map-use cube their uses are highly *communicative*. 'Urban development' is not far off the latter two applications, as the only reduction arises from the slightly smaller *audience*. The image maps used in 'disaster management' are further up the *audience* axis to *private*, as disaster mapping is mainly for emergency managers. The typically represented damage assessment is closer to *revealing unknown*, than *presenting known*. As interaction tools are scarcely found in disaster management, this field of application would be somewhere between *communication* and *visualisation*. This kind of observation is valid for the map-use cube as MacEachren (1994) suggests that the dividing line between communication and visualisation is becoming fuzzier all the time. It can be noted that a major part of image maps on the web are view-only maps. They become interactive only in the field of the visual analytics (see section 3.3.11). Image maps for visual analytics aim to explore and visualise spatial data. They allow the users to examine the *unknowns* or manipulate *knowns*. Together with the *high interaction* and *private* attributes, visual analytics is located at a corner of the map-use cube (see also MacEachren and Kraak, 1997).

3.6 Symbolisation Process

Once the relevant geographic objects have been assessed and selected based on their relevance for the usage context, the selected data are symbolised. In general, the process of map symbolisation involves the mapmaker's decision how to graphically design objects. Symbols must be designed in a way that they are connected to a specific meaning. An ideal symbolisation would allow one single semantic interpretation only.

The mapmaker faces a second design decision for image maps, namely which selected objects should be represented by cartographic symbols and which should be represented by their images. This second decision leads to a different appearance of the image map. In case of symbolising an object, the differing symbol appearance from its image appearance is a major concern. While each image object has its unique appearance, map symbols usually represent classified objects, i.e. objects of the same class share a uniform symbol. The following discussions are dedicated to the question which map objects are suitable for image (singular) symbolisation and which for map (uniform) symbolisation.

3.6.1 Objects Suitable for Image Symbolisation

Objects that are selected to be visualised by remote sensing imagery have to meet some general requirements. Of course, only the characteristics of physical objects that are visible or made visible in the imagery can be chosen. According to the empirical cartographic research and the practice of image mapping so far, two object classes can be chosen predominately for image symbolisation:

- Landmarks, and
- Land cover objects.

The cartographic visualisation of landmarks deviates from the standard uniform symbolisation of map symbols. Landmarks are prominent objects like buildings or mountain peaks that stand out from their surroundings. They have been used for wayfinding tasks in pedestrian navigation (i.e. Gartner, 2004, Elias, 2007), and for tourism mapping applications (i.e. Grabler et al., 2008). Landmarks have two essential abilities. They are capable of attracting attention, and they can be commonly recognised by many people (Golledge, 1999, p. 17). They attract attention because of their striking visible form. Landmarks are visualised in their own specific singular symbolisation. Moreover, landmarks can be visualised in a whole bandwidth of abstraction levels between geometric symbols and photographs. Especially, the photographic depiction of landmarks is of particular interest for image mapping. An example of landmark visualisation is shown on Figure 3-21. Hereby, the individual landmarks act as the visual anchor points for the map reader.

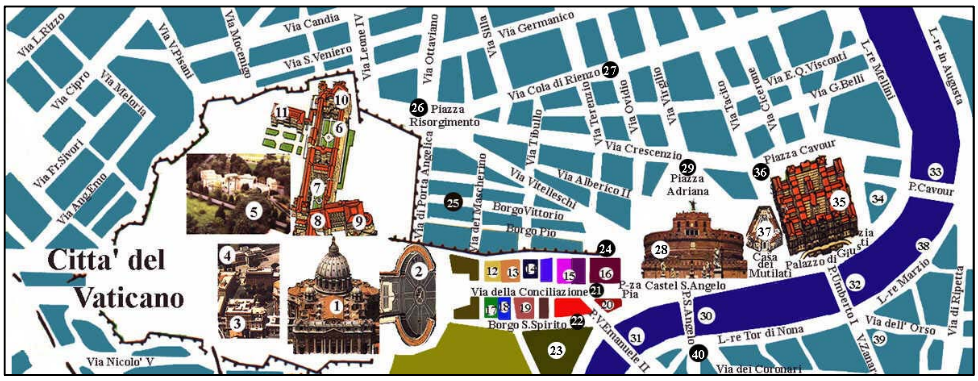


Figure 3-21 - A tourist map of the Vatican[9] featuring landmarks in a photographic depiction

[9] http://www.rometour.org/places-rome-shown-map-d-zone.html (22.10.2013)

The easy recognisability of landmarks without needing further visual information and their function of acting as orientation points make them highly suitable to be visualised as photos. For this reason, objects that play the role of landmarks can be better represented by the image. The effectiveness of landmark recognition increases with an oblique view familiar to the user (see 3.3.3).

Not only objects that sort themselves into the visual foreground are fit for image representation. Areal land cover objects, such as arable land, extensive water bodies, urban area and forests can also be adequately depicted by image or photorealistic symbolisation. Singular symbolisation of land cover objects aims to achieve a natural impression of these land cover objects. Examples how cartographers successfully attempt to mimic natural phenomena can be found in landscape painting and in old topographic maps. Here, an individualized topographic symbolisation creates textures closer to the forms of natural phenomena (see Figure 3-22 for an example). More recent examples on use the of singular symbolisation to develop a more engaging and expressive map style are described by Jenny (2012).

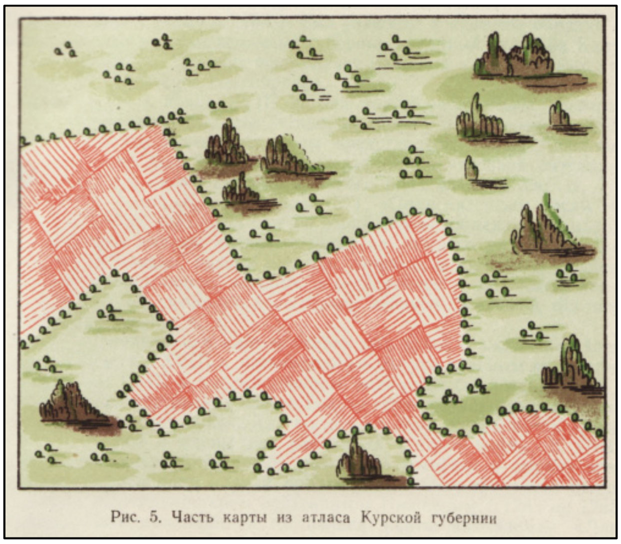


Figure 3-22 - Land cover symbolisation on old Russian maps of the 18th and 19th century[10]; highlighted by Krygier and Wood (2011); original figure from Shaposhnikova (1957)

One realism step further than mimicking natural phenomena is directly using remote sensing imagery for land cover objects. Patterson (2002) has done so for the look of national park service maps. He substitutes hereby areal map spaces with aerial photographs to make the whole map more eye-catching and fascinating to a map reader. The image representation of land cover objects give visual cues for differentiating land cover objects and provides a tactile appearance to the map reader. The same user appearance also applies to sky visualisation in high-oblique maps (see section 3.3.4). But, not all land cover types are suitable for singular image symbolisation. The imagery has to characterise the land cover accurately. The image texture needs to consist of a rather homogenous pattern. This is especially an issue for depicting urban area. The land cover suitability will also depend on the scale (see section 3.1). The best way to address the suitability of image representation

[10] http://makingmaps.net/2009/01/13/map-symbols-trees-forests-on-old-russian-maps (23.10.2013)

of land cover objects is simply to visually evaluate its appearance on the image map in terms of recognisability and aesthetics.

3.6.2 Objects Suitable for Map Symbolisation

After assessing which objects are suitable for image representation it becomes obvious that all remaining spatial information, which is to be included into the image maps, has to be encoded as map symbols to some degree of abstraction. Two main spatial information groups can be defined that require holistic map symbolisation, namely:

- Thematic information, and
- Non-visible or poorly visible physical objects.

Thematic information is in most cases not visible or not immediately recognisable in remote sensing images. Therefore, it is mandatory to graphically symbolise this information to complement or classify the imagery (see section 1.2.16).

Relevant non-visible or poorly visible image objects can be substituted by map symbols. Certain physical objects are invisible in the image either when their geometric dimensions do not reach the minimum discernible dimensions to the human eye, or when the radiometric configuration does not perceptually differentiate them from the surrounding. Non-visible physical objects can also result from total occlusion (i.e. roads in a tunnel). Map symbols can complement spatial information gaps left by invisible physical objects. Poorly visible physical objects either reach the geometric and radiometric requirements partially, or they are partially occluded, for instance by trees or cast shadows. The visibility of image objects in dependence on the scale has been discussed in section 3.1. Non-visible or poorly visible physical objects generally have a linear shape or are marked as spots in the image. Prominent examples are roads, railway lines, rivers and trails on one hand, and points of interest, such as public transport stations or parking spaces, on the other hand. These objects can be better clarified by substituting their image depiction with vector graphics point/polygon symbolisation.

3.6.3 Objects Suitable for Hybrid Symbolisation

Objects suitable for hybrid symbolisation are mostly areal objects that require a higher rank in the visual hierarchy. While linear and point information may remain hidden to the user without graphical clarification, areal image objects generally remain visible to the user. They are often large enough to the human eye. However, similar radiometric properties in their neighbourhood often produce a too weak contrast. Especially, when these areal objects show important information destined to be highlighted in the image map, two usability goals can be reached by a combined symbolisation of imagery and vector graphics: (1) the saliency of the object is improved in order to gain a better attention from the user, and (2) the object´s spatial extent is clarified. Areal objects to be visually highlighted are zones of concern, i.e. settlement blocks indicating the urban development (see section 3.3.9). The hybrid use of image and map symbols means that both symbol types are visible simultaneously. The map symbols graphically trace the image objects by using three symbolisation techniques:

- Transparent polygon area,
- Distinct polygon outline, or
- Transparent polygon combined with distinct outline.

All three techniques accentuate an image object and thereby rank it higher in the visual hierarchy. Depending on the symbolisation technique, a segment around the outline of an areal object can be covered, or the pixel values of the object may be combined with a monochromatic layer by means of transparency. Either way will enhance the degree of saliency of the object. The hybrid symbolisation also applies to linear objects on larger scale image maps (≥ 1:1000). In those scale ranges, linear objects, such as infrastructure, are decomposed into areal objects.

3.7 Symbolisation Techniques

As a well-known fact, image enhancement techniques have a considerable impact on the readability of image maps. How the legibility of remote sensing images is globally enhanced is explained in section 1.2.8. This section focuses on a survey of existing symbolising techniques to improve the saliency and legibility of vector elements.

If vector elements represent important information to be visualised in the foreground, it is necessary to enable a good figure-ground segregation (see section 2.2). This is a very difficult task when the background is seamlessly covered by a remote sensing imagery. The image is a collage of coloured objects with varying pixel values in terms of intensity, hue and saturation. The image objects can appear in dark or light tones, their colour values can change quickly over short distances. Moreover, the imagery can have rather homogenous coloured areas adjacent to areas possessing high radiometric fluctuations. This challenges cartographers who should find design solutions to maintain the readability of vector and label designs upon imagery. The vector design for image maps is mostly concerned with point and line features. *Size* is a visual variable that draws much attention (Wolfe and Horowitz, 2004). Without any accentuation, however, relatively small points and thin lines are more likely to fade into the ground. Special symbolisation strategies for image maps include *saturated colouring*, *casing*, *brightened seam*, and *adaptive colouring*. Each symbolisation technique is shown in Figure 3-23.

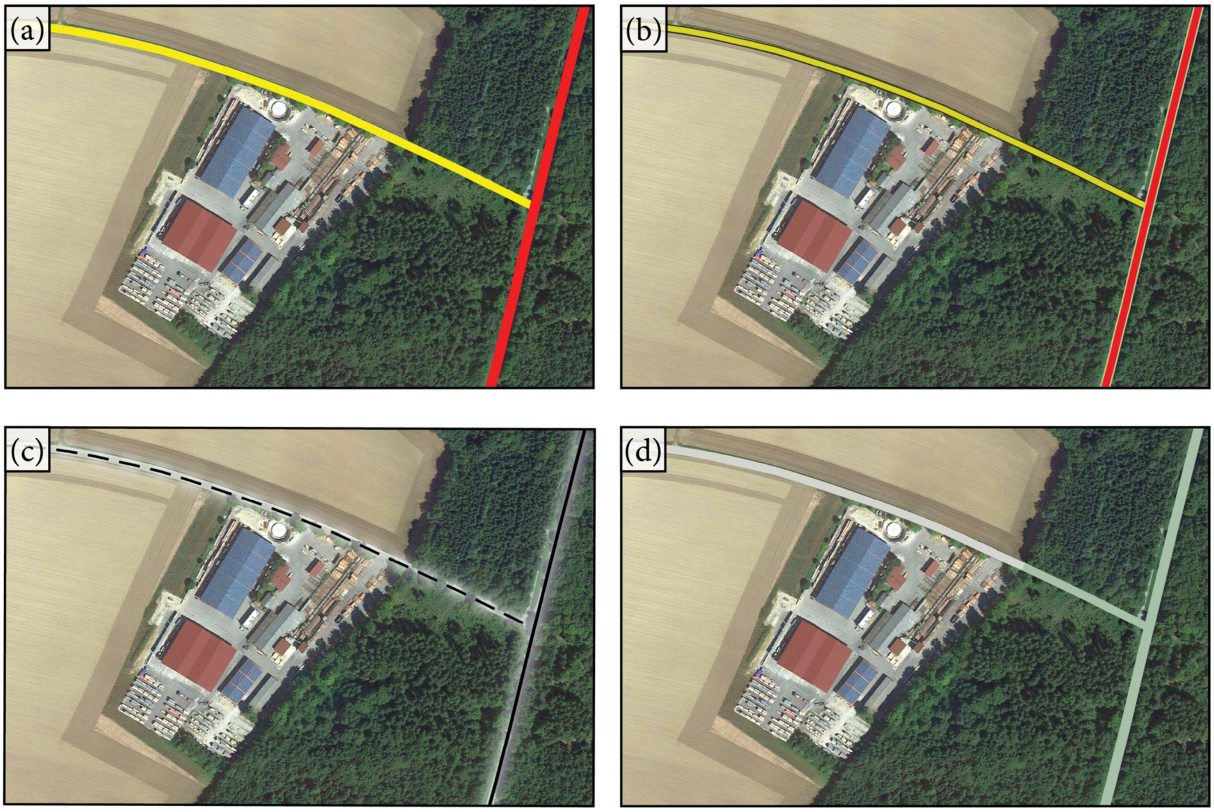


Figure 3-23 - Image Map Symbolisation Techniques: (a) Saturated Colouring, (b) Casing, (c) Brightened Seam, and (d) Adaptive Colouring

3.7.1 Saturated colouring

The gestalt psychologist Edgar Rubin stated that figures, besides appearing closer to human perception, also appear more saturated and higher in contrast than their background (as found in Gordon and Jon, 1995). We may interpret this law as a support to the use of high saturation to enhance the figure-ground perception. This is what most effective image map designs have in common. Point and line symbols are often depicted using saturated colours. They remain legible over full-colour imagery. This strategy has been applied and tested by Raposo and Brewer (2011).

3.7.2 Casing

Another strategy to enhance the visual segregation of points and lines from the ground or adjacent objects is *casing*. The interior symbol is delineated with a drawn border, the casing. This is a technique used in many map products, not just image maps. Symbols are usually drawn in a light colour in the interior, cased by darker coloured lines. This opposed colour assignment can be flipped for image maps in order to make colour matches on dark coloured image grounds more unlikely. *Casings* can be further adjusted to the image ground. They can be coloured with related mean colours of the image to create a more aesthetic appeal of the casings (Raposo and Brewer, 2013). The same technique can also be applied to label halos.

3.7.3 Brightened seam

The *brightened seam* is a more individual approach than casing, even though this symbolising strategy of image maps has been known for quite a while. Albertz and Tauch (1994) describe a method of generating a brighter ground around dark vector symbols, thus a similar effect to casings. But they achieved the casing effect by manipulating the image. Digital image processing techniques help to improve the legibility in dark areas. Pixel regions of the image within a buffer around the symbol are modified by reducing the intensity. This strategy has been described later as a '*brightened seam'* (translated from the German term 'aufgehellter Saum') (Albertz and Lehmann, 2007). Of course, this strategy can be applied only when the imagery can be manipulated. Therefore, the legibility improvement of symbols for image map mashups has to rely mainly on casings.

3.7.4 Adaptive colouring

The adaptive colouring strategy is a technique proposed by Hoarau et al. (2013). It aims at providing visually segregated vector symbols from the image, and gaining a harmonic appearance. Vector objects are visualised in accordance to their image background. They are symbolised with the same hue of the underlying pixels, but with a brighter intensity. This new and more experimental design strategy has not been applied in other maps than in Hoarau´s et al. work. One setback to the viewer´s understanding could hereby be the heavily varying appearance of symbols and symbol parts of identical classes. Hoarau et al. (2013) also suggests other image map design techniques for map symbols based on the radiometric characteristics of the image.

3.8 Generalisation of Image Maps

The International Cartographic Association (ICA) defines cartographic generalisation as "*the selection and simplified representation of detail appropriate to the scale and/or the purpose of a map*" (ICA, 1967). More generally, generalisation selects information and adjusts the symbolisation to create a suitable and readable map. Because of the existing geometric reduction ratio between the real world and the target map scale, the mapmaker has to make compromises between:

- legibility,
- geometrical correctness, and
- completeness (Hake et al., 2002, p. 166).

Legibility has the highest priority, while the geometrical correctness and object completeness should be preserved as far as possible. To achieve this, a number of raster-based and vector-based generalisation operations have been established. The approaches to raster-based and vector-based generalisation are entirely different and therefore, it is necessary to treat imagery and vector data separately in image map generalisation.

3.8.1 Raster-based Generalisation

Naturally, the generalisation of an image can only be raster-based. The number of raster generalisation operations for image maps are limited. An overview of raster-based generalisation is given by Muller (1991). The most basic raster generalisation operation is resampling. When the scale and resolution of a map is to be reduced, resampling reduces the image´s resolution to a coarser level. This increases the size of the smallest legible object. Other raster generalisation approaches are related to image enhancement techniques like filtering (see section 1.2.8). Filtering can only be applied to a limited extent, which preserves the naturalistic look of the image map. This also inhibits the use of raster-based generalisation based on categorized pixels. When raster images are set up by categorized pixels, further techniques like the eroding and the thickening of objects are possible. This has been used for thematic land-use raster maps (i.e. Peter and Weibel, 1999). However, the imagery of image maps is not categorized. The author claims that although it is possible to categorize pixels by automatically extracting features (see 1.2.10), this does not seen reasonable for image maps, as categorizing results would be insufficient and the generalisation would completely destruct the naturalistic image look. This leaves merely resampling and filtering (to a limited extent) as meaningful operations for generalising image maps. They have a global effect only. In other words, the raster-based generalisation cannot individually address the legibility of important map objects. The object completeness is directly dependent on resolution, while the geometrical correctness of objects is preserved to a pixel-size degree.

3.8.2 Vector-based Generalisation

In contrast to raster-based generalisation, vectors are generalised by an object-oriented approach. The generalisation process is accomplished through a number of logical operations, which vary in terms and in number, depending on the theoretical concept. The first detailed operation typology was described by Shea and McMaster (1989), who attempted to accommodate the requirements of digital generalisation by addressing all 2D vector features (Weibel and Dutton, 1999). In line with the generalisation goals, legibility is ensured by cutting down the geometrical correctness. Within vector-based operations, metrics and topology is affected to a great extent.

When vector data represents geoinformation with a direct connection to a depicted image object, it becomes important to comply with the geographical extent of each other. The different impact of vector-based operations compared to raster-based generalisation leads to inevitable spatial conflicts. Vector objects are omitted, displaced or distorted. Raster objects are (more or less) spatially preserved. To support the usability of image maps, the visual matching of image and map objects has to be maintained. Image maps leave much less room for generalisation compared to fully symbolised maps. This has also been emphasized by Schweissthal (1967). As a consequence, the use of some vector-based generalisation operations has to be restricted in order to avoid spatial conflicts between imagery and vector elements. In general, the vector-based generalisation operations have to comply with the following rules:

- perceivable individual image objects of an object class should not be omitted,

- topological relations have to be preserved, and
- geometrically modified vector data must spatially cover the corresponding image objects completely.

In some cases the generalisation operations *aggregation* and *amalgamation* try to follow the equal-area principle. This means the size of the generalised vector object is depicted in proportion to its initial size. In many cases the equal-area principle has to be violated, in order to spatially cover the corresponding image objects. For the same reason, the generalisation operation *collapse* should be applied with some restriction. For the generalisation operation *collapse* (sometimes referred to as symbolisation), area and line features are decomposed to line and point features. A recommendation, for which vector feature type is practical for which image map scale, is attempted by Keskin et al. (2013) on the basis of administrative maps.

This thesis attempts to classify the vector-based generalisation operations with regard to their applicability for image maps in Table 3-3. The enumerated generalisation operations are based on the work from Shea and McMaster (1989).

Generalisation Operator	**Feasibility for Image Maps**	**Operator Explanation (short)**
Simplification	restricted	shapes are simplified by maintaining the their character
Smoothing	restricted	the sharp angularity of shapes is reduced
Aggregation	restricted	a group of point objects is represented by a symbol
Amalgamation	partly restricted	neighbouring individual area objects are represented as one single object
Merging	partly restricted	individual linear objects are merged to one linear object
Collapse	restricted	line and area features are decomposed to point and line features
Refinement	restricted	objects are selected or eliminated whilst retaining the general characteristics
Typification	restricted	objects of similar sizes and shapes are replaced by a representative pattern.
Exaggeration	party restricted	characteristic shapes and sizes of an object are exaggerated
Enhancement	partly restricted	objects are symbolised to maintain legibility
Displacement	very restricted	objects are displaced to avoid spatial conflict caused by other operation
Classification	full	statistical or thematic generalisation

Table 3-3 - The feasibility of vector generalisation operations for image maps (operations based on Shea and McMaster (1989))

4 Image Map Design and Use

Starting with a section concerning image map publishing, a new *interlace method* is proposed to reduce the data size without deterioration of the visual quality (section 4.1). Section 4.2 introduces the concise design of image maps aiming to enhance the communication and aesthetic appearance of image maps. A number of highlighting strategies are used to rank image objects in vertical visual layers (section 4.2.1). Recommendations of symbol design for image maps are extracted from the design potentials set by the image (section 4.2.2). This chapter concludes with an evaluation of many design strategies of the approach of concise image map design (section 4.3).

4.1 Image Map Publishing by Interlace

A large portion of all image maps is distributed as internet maps which are directly embedded into web pages as HTML-elements. They are provided as downloadable files, and in many cases generated as georeferenced maps by a Web Map Service (WMS). Online map users, especially mobile users with a wireless device, have a limited and sometimes inconsistent bandwidth connection, but they expect a fast accessibility of geoinformation with quick retrieval and an instant visualisation. "*Long download times will cause users to lose interest*" (Kraak and Ormeling, 2003, p. 18), and in the worst case, a delayed loading time may impede the entire image map design. Therefore, it is a common task for map designers to produce online maps with the smallest possible file size. In other words, the file size is an important design constraint for internet maps (Lobben and Patton, 2003). For holistically symbolised maps this issue is rather simple. Geospatial vector data features can easily be described as vector graphics that provide a high quality of graphical representation while enabling small file sizes. Vector graphics such as the W3C-standard SVG (Scalable Vector Graphics) can be directly viewed in a web browser or serves as the map data format for a WMS.

Online image maps need a more diversified approach for publishing than fully symbolised maps. High resolution image maps require a broad transmission bandwidth due to their large file sizes, because raster images can rarely be reasonably vectorized. The pictorial file formats adopted by a WMS are typically Graphics Interchange Format (GIF), Portable Network Graphics (PNG), and Joint Photographics Expert Group (JPEG), all of which can be displayed by web browsers (Open Geospatial Consortium (OGC), 2004). In order to assure a desirable transmission speed, the file size of the imagery part of the image map should be kept as small as possible. Nevertheless, the quality of the image for cartographic use is critical. Straightforward methods such as resolution reduction and lossy compression may cause quality deterioration, disfigure the image, and thus dilute beauty of the image map with its richness of naturalistic remote sensing imagery. To maintain the richness of detail, the imagery can therefore only be rendered in a (nearly) lossless compression format.

To enable small file sizes of image maps for a fast access, we propose a coexistence of imagery and symbolisation side by side instead of a stacked configuration over each other.

That means we propose an *interlace method* rather than the default *superimposition* of vector and raster information. In a traditional composition of the image map, vector graphics overlay raster graphics, i.e. map symbols are arranged on top of imagery. That means some parts of the image map feature occupy two information layers of which only one is presented. The part of raster imagery covered by vector objects is redundant, and therefore should be discharged in order to reduce the file size. The concept is illustrated on Figure 4-1 and can be achieved with spatial analysis tools of standard GIS software. It involves the following steps:

(1) The spatial extent of the map symbols are joined to a clipping layer

(2) Covered raster image pixels are removed by performing a clipping function

(3) The clipped image is stored in a lossless compression image format

The resulting clipped image features reveal only the regions that will be visible in the published image map. The discharged image regions are set by pixels with a uniform value (normally black or white). The reduction of file size is achieved mainly by means of the run-length encoding according to which the consecutive pixels with uniform values are represented by ordering pairs of the value and the length of its run (Chanda and Majumder, 2000). The run-length encoding is part of the lossless compression algorithms for all common image file types, among them GIF, PNG, and JPEG. Large discharged image regions enable large run-lengths. For this reason, image regions discharged by areal vector features and large symbols have the greatest potential for the reduction of file size, and should be prioritized for constructing the clipping layer.

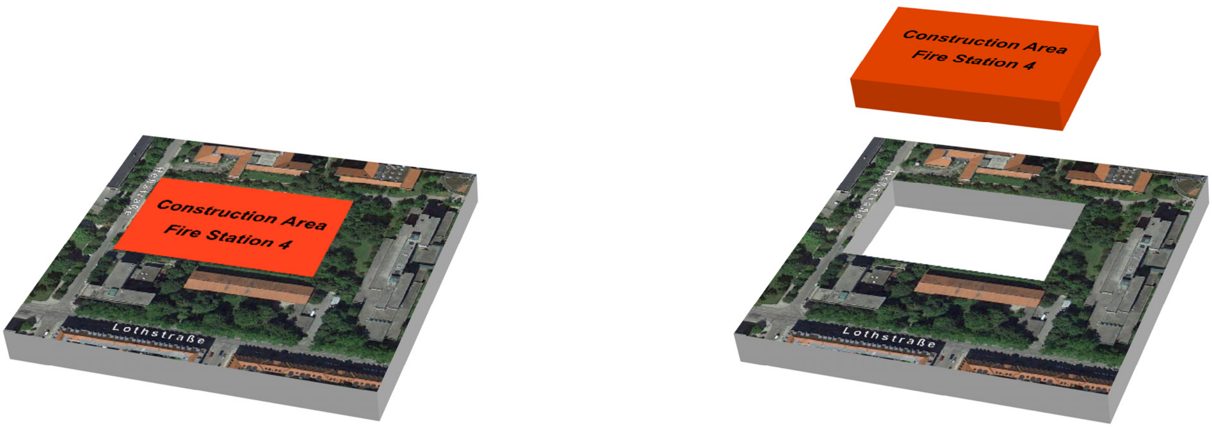
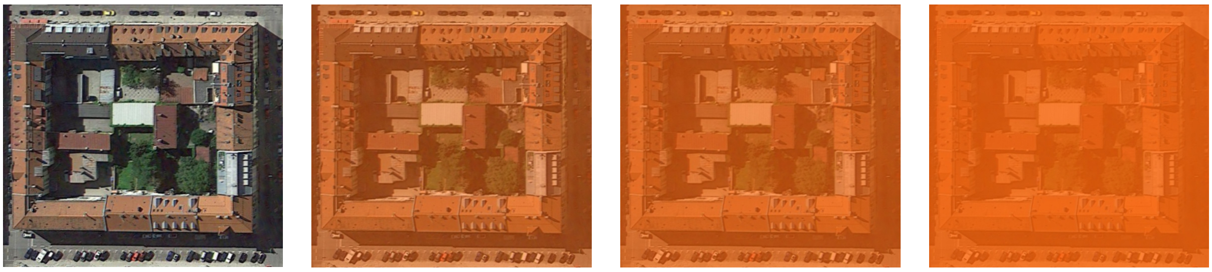


Figure 4-1 – Reducing the file size of an image map: the hidden image region covered by the map symbols is subtracted from the overall image extent

For this workflow, the map symbols must have a full opacity. However, the interlace method can be also applied to reduce the file size of image regions covered by transparent symbol features. Hereby, the file size reduction potential is smaller, and a slightly different spatial analysis workflow is necessary. Transparent map symbols are embedded in their target image parts and exported as a merged image file containing the complete image. As the translucency-effects are included to the imagery, the transparent vector features from the map symbol layer can be omitted. The merged image file should substitute the original double-layered image map file and have a smaller file size for publishing.

Data compression is achieved in the image´s regions covered by transparent symbol features, as similar valued pixels have a greater compression potential. The file size of these image regions decreases exponentially with increasing opacity of the superimposed vector feature (see Figure 4-2). This example is carried out in the PNG raster graphics file format. In this case, the file size is reduced because of two raster graphics algorithms - PNG´s filtering algorithm and the 'deflate' compression. PNG´s filtering algorithm assigns the value of each pixel based on the values of previous neighbouring pixels (W3C, 2003). That is why smaller variations of pixel values take a smaller number of bits. The deflate algorithm achieves compression by replacing equal pixel values with references to a single pixel value (Koranne, 2010, p. 156). Image regions superimposed by transparent vector features are likelier to have more equal pixel values. Therefore, the deflate algorithm compresses these regions into a smaller number of bits.



445 KB	340 KB	295 KB	231 KB
vector opacity 0%	vector opacity 50%	vector opacity 65%	vector opacity 80%

Figure 4-2 -The lossless image compression potential for transparency influenced map regions (here the PNG image format was used)

The *interlace method* makes use of the separate handling of vector features and raster graphics on image maps by either omitting redundant imagery or compressing the file size of imagery covered by transparent vector features. As a result, it leads to a reduced file size without deteriorating of the visual quality.

4.2 Concise Image Map Design

Cartographers share a common ground on what good design is. The literal definition of visual principles may differ, depending on the source, but (more or less) all visual principles that are put into words target equal goals of map design. Robinson et al. (1995b), as a frequently cited source, names *legibility*, *visual contrast*, *figure-ground*, and *hierarchical structure* as design principles. These design principles are valid for all mapping products and therefore also for image maps. However, the implementation of the four listed design principles to the realm of image maps differs from their implementation to conventional (holistically symbolised) maps. The exclusive design constraint for image maps is set by the highly heterogenic and colourful imagery. How can spatial information be effectively designed on a map covered with this imagery? So far, this question has been solved only partly. The improvement of legibility and visual contrast of vector elements has been shown in section 3.7, based on existing image map symbolising techniques. This chapter addresses the issues related to the legibility and visual contrast for image objects, as well as the conception of symbolisation techniques that provide an improved figure-ground segregation, and enable a more sophisticated visual hierarchical structure for all image map objects. The approach of concise image design aims to reduce the visual complexity of image maps and to guide the user´s visual attention promptly to the relevant information. All image map features are designed respecting the pre-attentive properties of applied visual variable attributes. Concise image map design should visualise important information in a salient way that requires little visual effort. Therefore, the saliency of important information is increased, whereas the saliency of context information is reduced. A visual hierarchy guides the user´s attention successively in a predetermined order and improves thereby the user´s visual scanning efficiency. The approach of concise image design intends to enhance the image map communication and to improve the aesthetic appearance of image maps. Despite the heavy visual burden set by the radiometric heterogeneity of images, the goal of facilitating a concise image map design remains unchanged.

4.2.1 Image-Object Highlighting

Not all mapping objects are of equal importance. A visual hierarchy is composed of visual levels where important features are graphically emphasized on the top layer and less important features are retreated into lower layers or background. Non-relevant features are omitted.

When important image objects (i.e. landmarks) are to be highlighted, the map design follows the principle of visually emphasizing the map symbols representing these objects. A convention of map design is that the possibilities of graphical variation should be utilized extensively (Hake et al., 2002, page 111). However, this is hardly possible for the common image map design. The image processing procedure does not highlight the important image objects. To make use of all possibilities of graphical variations, image map designers have to treat the radiometric design of raster images in the same manner as the graphic design of cartographic symbols.

Although the remote-sensing imagery is visually enhanced during the image processing (see section 1.2.8), these radiometric modifications pursue a completely different goal than modifications from a cartographic design. In the field of remote sensing, image enhancement aims to increase the visual distinctions between features in a scene (Kumar, 2005, p. 111). The apparent distinction between all objects of the image´s extent is increased. This global approach does not go well with map design. To create a structured visual hierarchy within the image, further graphic design operations are required. These must not be performed as global image manipulations. Local and object-specific image manipulations are needed so as to introduce vertical visual layers.

The possibilities of enhancing graphical variations are limited within the image. The naturalistic reflection of reality and the geographic footprints of image objects should remain. Otherwise, the image may become illegible and highly confusing. For this reason, the graphical variables *size*, *orientation*, *shape*, *arrangement*, and *perspective height* (see section 2.6) cannot be applied. Other visual variables can only be applied to a limited degree that does not disguise the naturalistic reflection. To compensate the limitations, we develop highlighting strategies which utilise the pre-attentive variables to make prioritised information more salient, and thereby, graphically rank image objects into vertical visual layers. These highlighting strategies include:

(1) *Selective Brightening*

(2) *Spotlight Highlighting*

(3) *Light Beam Guidance*

(4) *Semantic Focusing, and*

(5) *Tilt-Shift Focusing*

4.2.1.1 Selective Brightening

A straightforward approach to create a visual hierarchy between different image objects is to use colour related visual variables (see section 2.6). Figure 4-3 shows two images of the identical geographical space, differentiated by colour related visual variables. Image (a) depicts the scene after image enhancement procedures. No cartographic design has been applied. The visual hierarchy is solely set by radiometric properties of object surfaces. In terms of importance, the visual structure is randomly set by the natural scene.

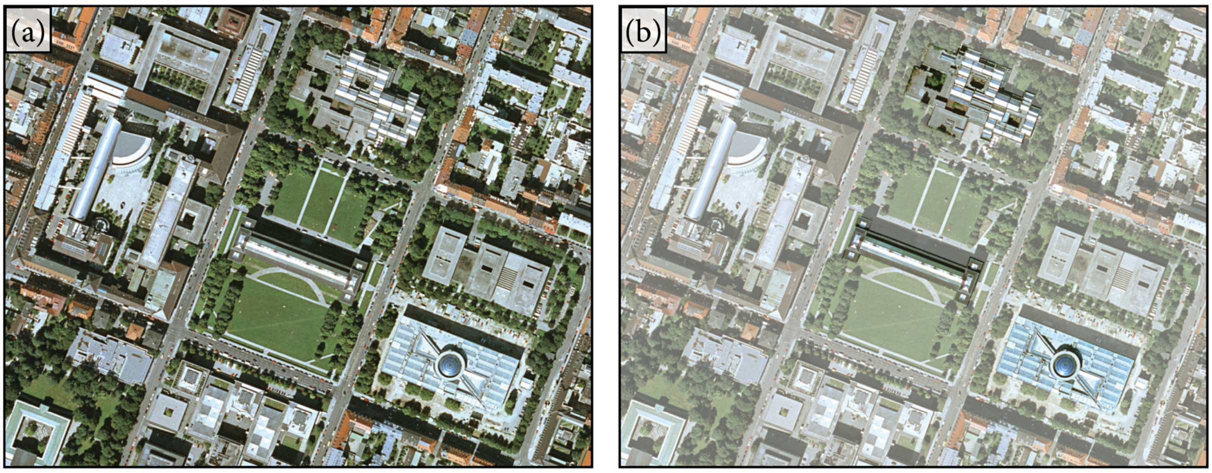


Figure 4-3 - Two images depicting the downtown area of Munich containing three Pinakothek-buildings: (a) after image enhancement procedures, and (b) brightness highlighting of the Pinakotheks by deemphasizing the surrounding area.

In contrast, image (b) highlights three objects by graphically deemphasizing the remaining geographic space. The three highlighted Pinakotheks appear salient. The saturation of the Pinakotheks has been slightly increased. Their graphical variation is minor because the image enhancement already supplies strong colours. The deemphasizing of surrounding objects has a much greater effect. A simple compression of the tonal values of the surrounding towards lightness makes it look more neutral and the Pinakothek buildings visually stand out from their background. The simple double-layered visual hierarchy is made by two perception principles. Firstly, brightness differences are seen as a useful tool for figure-ground segregation (see section 2.2). Secondly, the low contrast of the background stresses the *atmospheric effects* for depth perception (see section 2.8). The simulated haze lets the surrounding objects to be perceived as distant objects, in opposition to the high-contrast Pinakotheks. In addition, image (b) exemplifies some basic map design rules of *colour composition* by Imhof (1982, p. 72), namely: (1) that "*pure, bright and very strong colours have loud, unbearable effects when they stand unrelieved over large areas adjacent to each other, but extraordinary effects can be achieved when they are used sparingly between dull background tones*", and (2) that "*large area background or base-colours do their work most quietly, allowing the smaller bright areas to stand out most vividly*". The highlighting effect of *Selective Brightening* can be further improved in some cases by also emphasising the shadows.

4.2.1.2 Spotlight Highlighting

Visual hierarchy can also be established by changing brightness conditions. First, the light-dark assigning of figure and ground can be inversed (in comparison to Figure 4-3b). Second, the highlighting contour can be spanned in a more natural manner. Figure 4-4 and Figure 4-5 show respectively an original reference image and the same scene with the *Spotlight Highlighting* of some image objects. The *Spotlight Highlighting* creates a familiar highlighting effect known from the theatre stage where a small area is illuminated to centre the attention to the stage performer. The spotlight effect has been successfully tested in geo-visualisation to guide the users´ attention to intended areas of large wall-sized displays (Khan et al., 2005).

Figure 4-4 - Oblique aerial photo of the Giza pyramid complex[11]
© Raimond Spekking / CC-BY-SA-3.0

Figure 4-5 – Spotlight highlighting of the three main Giza pyramids
(original photo © Raimond Spekking)

[11] http://commons.wikimedia.org/wiki/File:Giza_pyramid_complex_from_air_(2928).jpg (16.03.2014)

To imitate the spotlight effect of the theatre stage in image map design, we use round spotlights to push the important objects to the top of the visual hierarchy, thus make them more prominent. The spotlights are introduced using a raster graphics editor. Radial or elliptic filter areas are defined, with their contours enclosing the objects of concern. The colours within the contours are brightened and given greater contrast. To model the spreading of light, a fuzzy contour edge encloses the spotlight to let the illumination decay in a natural manner. All remaining image area has its tonal values compressed and darkened. As with the previous design approach, the deemphasizing of surrounding objects has a much larger visual effect.

4.2.1.3 Light Beam Guidance

The *Spotlight Highlighting* can be further enhanced with beams of light. The design idea originates from a natural phenomenon. When a light beam travels through the air, it is partly scattered by particles in the atmosphere and creates a cone of light. The effect is commonly known from narrow sunbeams in the sky and can be transferred to highlight image objects especially when strong visual cues are necessary that should quickly guide the users´ attention to important information. Figure 4-6 illustrates the *Spotlight Highlighting* extended by *Light Beam Guidance*.

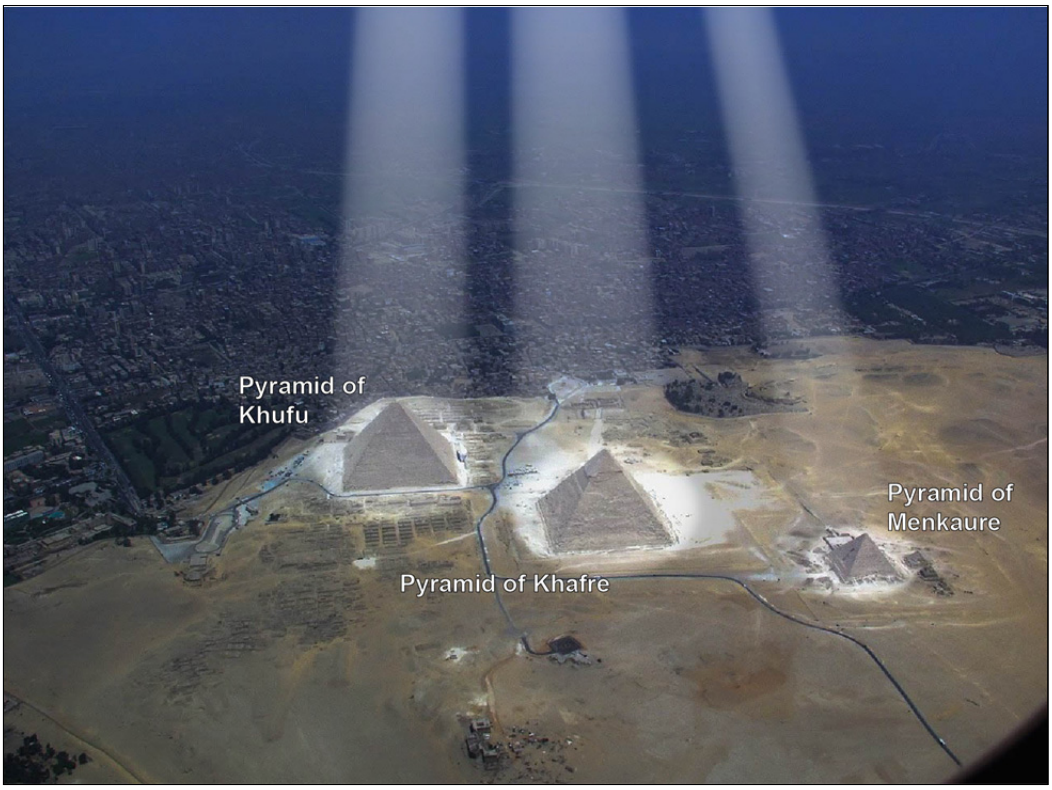


Figure 4-6 – Image map with spotlight highlighting and additional light beam guidance to the three main Giza pyramids (original photo © Raimond Spekking)

To graphically create the light beams, a separate graphical white coloured and translucent layer is overlaid that decays horizontally from the middle to the fringe of the beam, and vertically from the top image border to the spotlight. The application of a blurring filter imitates the natural spreading of light on the fringes of the beams. Because of its advantageous orientation within the image, the *Light Beam Guidance* does not conceal important information. The dominant parts in the light beam cover, in general, far distant and very small patches of terrestrial information in low oblique images, and mainly sky parts in high-oblique areas. The intensity of the beam along with the angles of the beams in Figure 4-6 mimics a source of light, thus invokes a natural effect. The light beam may guide the users´ attention to the spotlighted objects very effectively, and as a strong visual cue, it may distract from non-spotlighted information. However, *Light Beam Guidance* can be reasonably added only in oblique images.

4.2.1.4 Semantic Focusing

Semantic Focusing is yet another graphical variation suitable to organise specific spatial information into vertical visual layers. The image in Figure 4-7 takes design advantage from the varying depth of focus that allows the user to visually segregate and order the surrounding area behind the Pinakotheks. In terms of visual variables, this graphical variation is called crispness (see section 2.6), or blur. Technically they are realized by firstly segmenting the important objects from the background image space into separate image layers. Then, a low-pass filter is applied to the background image layer, while minor raster editing (i.e. an increase of colour saturation) can be applied to the important object image layer.

Figure 4-7 - Semantic Focusing on the three Munich Pinakotheks; the blurring effect is made by applying a Gaussian filter to the background.

Image maps are suitable test beds for the defocus approach to visually order different features. This fact is rooted in photographic technology for directing the viewer's attention within a photograph. In object photography, for instance, the foreground and background around the main object is blurred to visually highlight and segregate the object from the remaining image space. Although, the depth of focus is a visual cue naturally known from three dimensional presentations, it works amazingly well for semantically structuring two dimensional visualisations. Kosara (2001) showed that blur is very well suited for guiding the viewer's attention onto sharply depicted objects among blurred geographical space. He further showed in this work that when different blurring levels are established, depending on the relevance of image objects, several visual levels can be created.

For image map design, the degree of relevance for image objects, combined with its given pixel size sets the reasonable defocusing impact. Priority objects are given no blur. The objects along the hierarchy are assigned values of an ascending blurring curve with decreasing relevance. However, the use of semantic focusing has three main restrictions. (1) The defocusing variable can only be used within a certain bandwidth. Less important, but nonetheless relevant information must be kept recognisable. (2) Defocusing can be applied to an image space of considerable sizes only. Blurred, segregated point and linear features are likely to become illegible. And (3), the use of defocus can possibly impede the three dimensional perception in oblique image maps.

4.2.1.5 Tilt-Shift Focusing

Tilt-Shift Focusing is a further approach for graphical variation related with the blurring variable. It is derived from the use of 'tilt-shift' lenses in photography, in which the plane of focus is tilted, so that a small image band remains sharp, while other image parts recede into blur (Schulz, 2012, p. 154). *Tilt-Shift Focusing* is advisable for oblique images only. The image plane in the sensor device and the object plane (surface of the earth) are not parallel in oblique images (see section 3.3.1). *Tilt-Shift Focusing* makes use of this given optical setting and artificially reduces the depth of focus.

When *Tilt-Shift Focusing* is applied, an imaginary horizontal focal plane is introduced that intersects with semantically important information. The important image objects are focused, while all other image parts in the fore- and background are blurred. The farther the object is away from the focal plane, the more blurry is its appearance. The image is manipulated by defining a horizontal focal plane area and introducing linear blur gradients above and beneath this image space. That way, the blurring effect increases with growing vertical distance from the focal plane. An example is shown in Figure 4-8 (the full tilt-shift effect can be better perceived when compared with the original Figure 4-4). The focused image area is visually highlighted in analogy with the semantic focusing approach. Other depth cues such as *linear perspective* and *height in the visual field* (see section 2.8) help to disseminate between figure and ground.

Figure 4-8 - Tilt-Shift Focusing of the three main Giza pyramids (original photo © Raimond Spekking)

Graphically, *Tilt-Shift Focusing* is simply generated by two linear blur gradients, which diverge vertically from the focal plane. A drawback of *Tilt-Shift Focusing* is its miniaturisation effect. The amount and magnitude of blurring within the image influence the perception of size and distance between depicted image objects. The higher the tilt-shift effect, the smaller the image objects are perceived. Experiments show that users tend to estimate the apparent scale of the image content by interpreting the blurred pattern together with relative depth cues (Held et al., 2010). High resolution remote-sensing imagery that depicts high buildings may have to take building heights into account, in order to guarantee a visually harmonic appearance. However, *Tilt-Shift Focusing* is suitable for oblique image maps where the prioritised image information is arranged around a horizontal line.

4.2.2 Map Symbol Design

Map symbol design is given far more creative space in image maps, because (1) map symbols have, in displaying thematic and topographic data, discrete and continuous data, as well as quantitative and qualitative data, a greater information visualisation spectrum, and (2) in opposition to image object design, map symbols are not tied to a fixed geographic footprint (see section 4.2.1). These two facts allow the usage of all visual variables (see section 2.6). Nevertheless, the symbolisation task for image mapping is far from being easy. The challenging visual segregation of graphical symbols from their surrounding imagery discussed in section 3.7 makes the design problem very complex. A visual design rule of thumb is to highlight some information by making it considerably different from the remaining information. In other words, the strongest 'pop-out' effects occur, when a single target object differs in some graphical dimension from its surrounding (Ware, 2010, p. 29). To make the symbol stand out best from the image, it either has to be visualised with entirely differing visual variables, or it has to show considerably different value ranges of collective visual variables.

To choose different visual variables as well as different value ranges for symbolic design, the designer needs to know which visual variables compose the imagery. Although every imagery composition will be unique, many universally applicable principles can be extracted to guide the design of image maps. Table 4-1 demonstrates the typical characteristics of different graphic variables found on images, as well as the assumptions about their potential of highlighting important information. These assumptions are based on natural colour images (see section 1.2.1.1) after radiometric visual enhancement (see section 1.2.8). The highlighting potentials may differ on other spectral image composites or vary with different display scales of the image and the individual image appearances. Nonetheless, these assumptions provide some useful guide and may lead to the derivation of a holistic design approach that is applicable for a large number of remote sensing images.

According to Table 4-1, the highlighting potentials of the graphic variables reveal three levels. *Low* means little potential of a variable in making a visually unique or outstanding symbol, as it frequently occurs or occurs with a full range of its values throughout the imagery. *Medium* is associated with a variable which has only certain values or value ranges occurring in the imagery. *High* means that a variable typically does not appear, or exhibits with only one fixed value. *Crispness* and *transparency* have a high design potential because they seldom occur and their limited occurrence is regarded as unwanted and artificially introduced to the remote sensing imagery (see section 2.7). *Resolution* is naturally constant within the image. The pixels have identical sizes due to customary image record settings. If a different resolution is introduced, it may catch much attention. *Saturation* and *texture* also have a high design potential. Image objects almost always appear as textured and with low saturations. For this reason the map symbols of image maps are often drawn non-textured and in saturated colours to give a good contrast to the image base.

The remaining two colour variables *hue* and *value* also show some potential. The colours of the recorded image are harmonised by sunlight (Imhof, 1982, p. 72). Therefore, extreme colour values may be used to draw attention. The following sections are dedicated to deriving design recommendations for image maps based on the approaches that make use of the highlighting potentials of the visual variables.

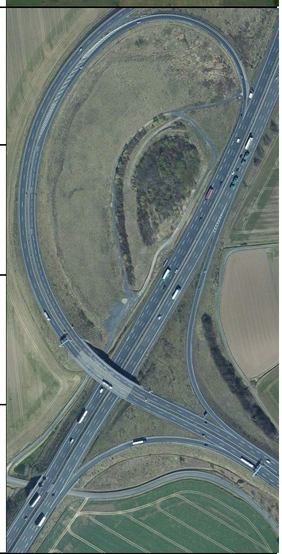
Visual Variable	**Characteristic on Images**	***Highlighting Potential***	**Example Image**
Size	a full range occurs and dependent on visual grouping	*low*	
Hue	varies with object types such as vegetation/urbanity level and climate zone; but mainly greyish, greenish, brownish and sometimes reddish colours	*medium*	
Value	a wide range occurs with the exception of black	*medium*	
Saturation	predominantly lower saturations	*high*	
Shape	various polygons, polylines and smooth curves	*low*	
Orientation	a full range occurs and can be correlated with regular street networks	*low*	
Texture	spread throughout the whole image with hardly any non-textured spaces	*high*	
Resolution	constant throughout the image	*high*	
Perspective Height	occurs as vegetation and building heights	*medium*	
Crispness	occurs only as focussed objects	*high*	
Transparency	occur by meteorological effects only, but mainly removed within image restoration techniques	*high*	
Arrangement	a full range occurs	*low*	

Table 4-1 – Highlighting potentials of visual variables in remote sensing imagery (Example Images from Bing Maps)

4.2.2.1 Glow Segregation

This technique aims to enhance the visual segregation of cartographic symbols from the imagery by using the glow effect. Glowing (or blooming) simulates a known effect of the human visual system, in which a bright light source appears to bleed beyond its natural borders. For instance, the optical recording of a scene with candles on a Christmas tree produces a glowing halo around the light sources. The artificial creation of the glowing effect is very popular in painting and computer gaming. Here, the glowing effect is used to make objects visually prominent. Figure 4-9 adapts this concept to cartography, by using it for concise image map design. The surrounding polygon contour of the 'security area' and the 'Hotel Bayerischer Hof' are complemented by the glowing effect. Graphically, a second translucent polygonal layer is designed enclosing the line, based on the contour and a blurring filter. The glow radius determines hereby the blur amount around the object. The contour itself remains intact.

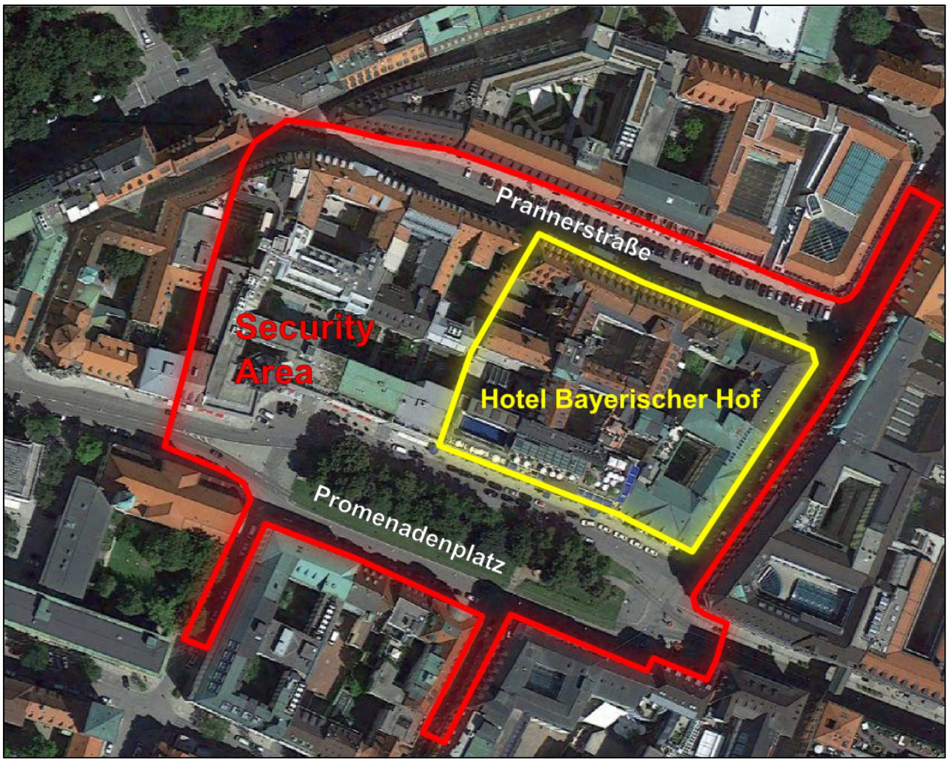


Figure 4-9 - Glowing effect that highlights a prohibited area during the Munich Security Conference 2013 (imagery: ©Google Maps 2013, thematic information: City of Munich[12])

Note that some variable with *medium* potentials can also be compiled in Figure 4-9. Non-textural polygon lines are styled in highly saturated hues that largely differ from the imagery. The glowing effect may be not so visually striking, but it increases the highlighting effect for the contours and provides a visually smooth transition between the contours and the imagery.

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[12] http://www.muenchen.de/verkehr/aktuelle-verkehrslage/muenchner-sicherheitskonferenz.html (10.12.2013)

4.2.2.2 Visual Downscaling of Cartographic Symbols

Imagery has a somewhat contradictory influence on cartographic symbols. On the one hand, it is difficult to visually highlight cartographic symbols in an image. On the other hand, the inhomogeneous texture of imagery is a hindrance to suppress or downscale the visual salience of symbols. So far, the following three strategies prove helpful to visually downscale map symbols and their design examples can be found in existing image maps:

- Simulated Occlusion
- Map Symbol Transparency
- Alignment of Symbols with the Image´s Appearance

Although these strategies are not entirely new, they are revisited here in the context of concise image map design.

Simulated Occlusion

One of the difficulties of assigning map symbols a suitable visual level within a visual hierarchy of imagery is related to occlusion. As discrete map symbols are technically drawn over remote sensing imagery, they appear visually in front of the image. Not only visually, also many references have reported image maps as an overlay of vector features on imagery rather than a vector-image composition (see section 3.2.7). For this reason, the assignment of vector-foreground and image-background has become a tradition. The graphical overlay of discrete vector symbols on continuous imagery leads to the *interposition phenomenon* (Dent et al., 2009, p 221). Because the imagery display is interrupted by map symbols, the symbols seem to appear on top of the image. This *interposition phenomenon* is a very effective depth cue that visually sorts map symbols to the visual foreground and imagery to the background, if no further design artefact is applied.

An effective way to countermeasure the interposition depth cue is to utilise image objects that visually stand out from the depicted surface. Due to many other monoscopic and indirect depth cues (see sections 2.8 and 2.9) objects like buildings, vegetation or elevated places seem to visually stick out. To enable the downscaling of a map symbol within the visual hierarchy, its anticipated position relative to the positions of image objects in the field of view has to be carefully considered. That means, map symbols should not be drawn in spaces where their anticipated positions would be occluded by image objects. Occlusion is hereby simulated by erasing these map symbol parts. Simulated occlusion is a helpful strategy for overturning the traditional the vector-foreground and image-background assignment.

Map Symbol Transparency

The power of *transparency* to simultaneously depict both visualisation modes on the same space has been discussed in the realm of the *image map cube* (see section 3.5.1). Symbol transparency is the key to ‘*bivisual*’ map communication, as both visual sources are mixed together, while remaining independently perceivable. This simultaneous visualisation is the reason for being the most applied design strategy for visually degrading the prominence of cartographic symbols. With the decreasing opacity of a vector symbols, the salience of imagery in the visual hierarchy increases. However, the designer of an image map should choose the transparent colour carefully, as image parts that happen to have similar colour values are either difficult to recognise for the map reader or may vanish completely.

Alignment of Symbols with the Image´s Appearance

The strategies of highlighting symbols can be inversed to downscale the salience of map symbols. Using the image-like visual variables and their value ranges may order map symbols onto lower levels along the visual hierarchy. A general guide to which variables, and which value ranges can be applied to visually downscale cartographic symbols, can be extracted from Table 4-1. The typical characteristics of visual variable can be adopted, while the inverse of the '*highlighting potential'* in Table 4-1 expresses the potential for symbolisation in alignment with the image appearance.

Figure 4-10 - Reduced saliency of map symbols in an image map of the TUM main campus

In Figure 4-10 all three described visual downscaling design strategies are unified. This example visually degrades the map symbols in order to make the imagery more prominent. The street symbols are translucent and with image-like grey-bluish hues. The simulated occlusion of road symbolisation by the two bridges in the centre of the middle vertical street (the 'Theresienstraße') adds to the background perception of the symbolised streets.

4.2.2.3 Simultaneous Contrast

One significant advantage of image maps is its possibility to complement, declare, clarify, and classify imagery with uniform map symbolisation (see section 1.2.16). The consistent appearance of symbols in the same class makes it is easier for map readers to identify kindred spatial objects, and to understand their meanings. However, the heterogenic image that surrounds the symbols affects the uniform appearance heavily. On imagery, map symbols with physically identical colour do not appear to have the identical colour. Apparently varying map symbols can cause confusion. Figure 4-11 illustrates the varying appearances of physically uniform map symbols, as the left flower symbol on Figure 4-11 appears to be darker and having a stronger red colour than the right flower symbol.

The visual perception of map symbols is affected by simultaneous contrast (see section 2.3). The proximal imagery changes the apparent lightness and chromaticity of the map symbols. Ware (1988) confirmed with a user experiment that simultaneous contrast is the major source of error for visually estimating quantitative values from colour-coded maps. Being aware of this fact, the designer of image maps has to provide perceptually consistent map symbols by compensating the bias caused by simultaneous contract. Therefore, the radiometric properties of image objects must be taken into account for the symbolisation.

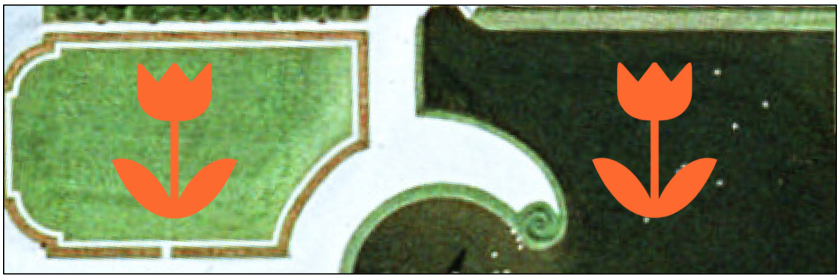

Figure 4-11 - The simultaneous contrast effect on imagery: Both flower symbols have the same colour hue, tone, and saturation. Nonetheless, their visual appearance is different.

Section 2.3 describes the simultaneous contrast effect and points to the compensating influence of connectedness. If map symbols are connected, the visual appearance is not affected much by simultaneous contrast. This means that joint shapes, such as large areal and line symbols, are less sensitive to simultaneous contrast than point symbols would be. Therefore, a particular measure to reduce simultaneous contrast is necessary when designing point symbols which should look consistent in spite of varying background imagery.

A reasonable solution to counteract simultaneous contrast would be an automatic tool that can (1) analyse the surrounding image radiometry of map symbols, (2) predict the magnitude of simultaneous contrast, and (3) customise the colour value for each individual map symbol in relation to its imagery. To implement such a software algorithm, profound and more specific research is needed. Although many research works have addressed the simultaneous contrast problem, none of them can be applied for image map design tasks. In the field of cartography, the effect of simultaneous contrast on map colours has been examined by Brewer (1996, 1997). These works contribute to the prediction of simultaneous contrast for the design of effective colour schemes. But they are not adaptable to forecast simultaneous contrast and to equalise visual appearances of uniform map symbols on image maps. Some influence factors of simultaneous contrast can hardly be modelled. For instance, the simultaneous effects are more intense, the longer the background is viewed (Itten, 1970, p. 54). In addition, most research on simultaneous contrast starts with the assumption of a uniform background colour. Obviously, this does not apply to the highly heterogeneous remote sensing imagery. One could take an average radiometric value from the proximal imagery, but the question remains where to confine the influencing image area surrounding the map symbol. Furthermore the heterogeneous surrounding does not have the same simultaneous contrast as a uniform surrounding has. The imagery has a diminishing impact on simultaneous contrast. Wolf (2011) showed that texture reduces the strength of simultaneous contrast for uniform symbols compared with homogeneous backgrounds. But again, no colour magnitudes are predictable. Further fundamental research on simultaneous contrast on textured backgrounds as well as empirical studies to quantify the effects of simultaneous contrast are required in order to implement an innovative algorithm that can counteract simultaneous contrast for map symbols in image maps.

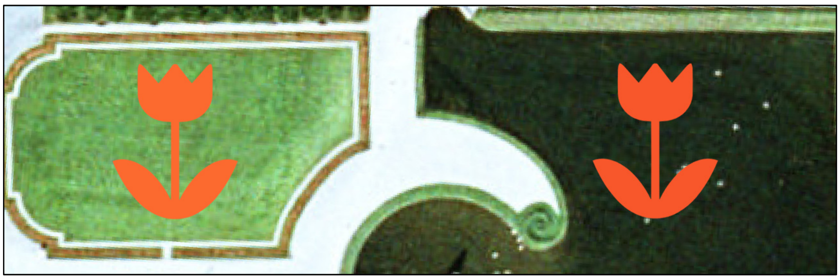

Figure 4-12 - Compensating the simultaneous contrast effect of image maps: Both flower symbols are perceived as equally coloured, but physically they are not equal. The colour values of the right flower symbol have been modified to match the appearance of the left flower symbol.

For now, the simultaneous contrast effect can only be counteracted manually by visual assessment of the map designer. Figure 4-12 illustrates the result of counteracting refinement of the simultaneous contrast. In comparison to Figure 4-11, the right flower symbol in Figure 4-12 has been customized to provide a perceptual constancy between the two. For this design refinement, the map designer can follow the rules derived from research findings of simultaneous contrast (see section 2.3). The inverse of these rules make guidelines to diminish the simultaneous contrast on map symbols, and can be applied as follows:

(1) shift the symbol hue towards the mean proximal colour,

(2) shift the lightness of the symbol into direction of the average proximal lightness, and

(3) shift the saturation of the symbol into direction of the average proximal saturation.

Note that iterative customizations and visual assessments of the result are necessary.

4.2.2.4 3D Symbolisation

Symbols that render the three-dimensional impressions are either 2½ dimensional symbols or true 3D symbols. 2½D symbols appear in oblique image maps. They are in line with the projection of the imagery (see section 3.3.1) and drawn in respect to the tilted imagery plane and the presented topography. All areal and linear, as well as many symbolised point features, are transformed into the oblique central perspective projection, so the symbols visually fit onto the image. Even though 2½D symbolisation enhances the 3D perception of oblique imagery, it is merely perspectively drawn 2D vector features. Therefore, the guidelines for concise design do not differ much from 2D symbolisation. Consequently, their design ideas can be taken from the previous sections, as well as section 3.7.

True 3D symbols are part of a 3D geo-data model. They are created in a 3D environment in order to be rendered as part of a 3D image map (see section 3.3.5). Many of these maps are image map mashups (see section 1.3). The 3D symbols of these maps are either created simply by extrusion of 2D symbols, or as more sophisticated 3D objects with a high number of edges and surfaces. 3D symbols in image maps are mainly used to highlight thematic information. They often display quantitative information by variations of *size*, *orientation*, or *colour*. A few design guidelines should be followed when creating 3D symbols, so that they stand out from the background imagery and can be easily perceived.

Firstly, all highlighted symbols should stand out by making it considerably different from the imagery. The potential for highlighting by perspective height is considered *medium* according to Table 4-1 because the designer must make sure that the 3D symbols are considerably higher than the perspective height of image objects giving a 3D impression. Moreover, 3D symbols should be segregated from the imagery assisted by other visual variables. The surfaces of the 3D model should be easily differentiated from the imagery. One straightforward approach to make 3D symbols visually stand out from the image is therefore to favour non-textured surfaces on 3D symbols. Furthermore, the surfaces should be drawn in saturated colours that give a good contrast to the image base (see section 3.7.1). An example taken from a visual analytics application is shown in Figure 4-13.

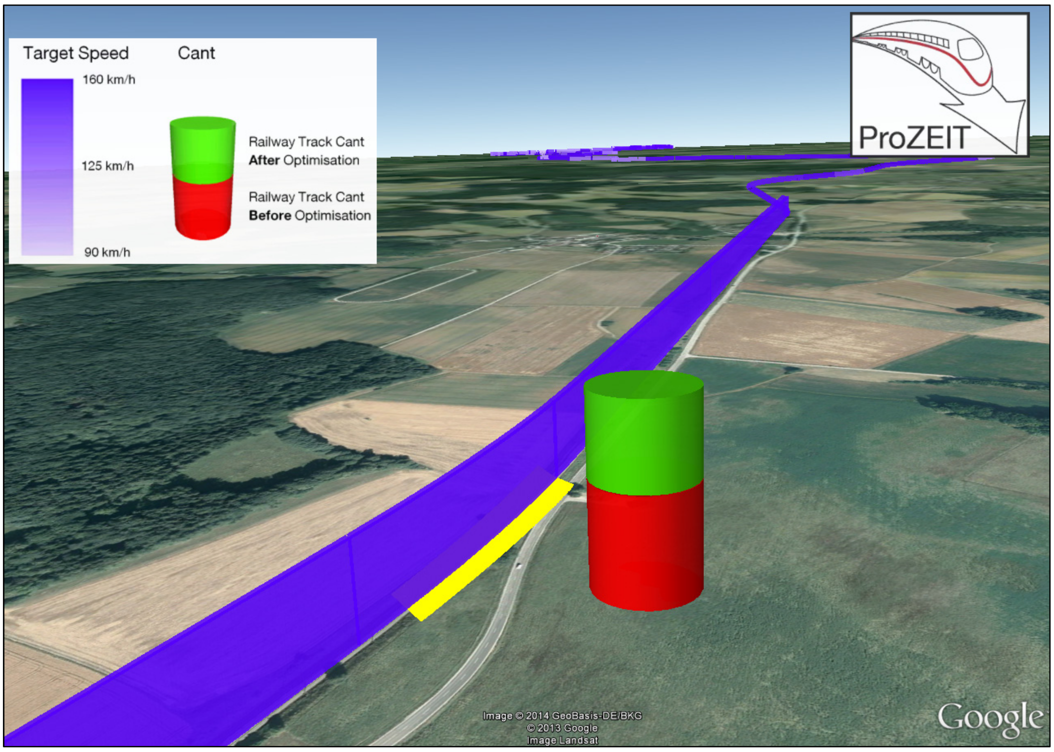

Figure 4-13 - 3D image map as part of the travel time optimisation of railway infrastructure project 'ProZeit' (rendered in Google Earth) (Meng et al., 2013)

The visual detection and identification can be further enhanced by using strongly accentuated edges for the 3D symbols. A clear-cut edge achieves a good delimitation from the image background and good identification of the symbol itself. These were the findings of a user test comparing various 3D symbol types on Google Earth imagery (Frank, 2013). That accentuated edges guide the user´s interest is also known from non-photorealistic rendering (Halper et al., 2003).

Shading techniques can be recommended as they are easily implemented in 3D geo-data models. Cast shadows act as a visual cue for the positions of 3D symbols relative to the imagery, whereas shading directly on the symbol surfaces enhance the 3D perception and act as a visual cue for the symbols shape (see section 2.8).

Apart from the design of the 3D symbols itself, it is important to choose the correct 3D scene motive for within the geo-data model. 3D image map designers have to choose a viewpoint that puts the most important 3D symbols into a prominent place, while avoiding as much occlusion as possible and ensuring sufficient image presentation. 3D models are best perceived when the viewing inclination is chosen relatively high. Further 3D symbol issues regarding the influence of the viewpoint are given by Shepherd (2008).

4.3 User Test on Design Strategies

This section is devoted to a paper-and-pencil test we developed to evaluate many design strategies of the approach of concise image map design. When graphical sign variation is tested on its usability, most empirical work has been done with isolated graphical signs on harmonic backgrounds (i.e. Wolfe and Horowitz, 2004). This makes sense, as the user´s vision is guided by anomalies that visually pop out, and therefore should not be distracted by the background. Further studies feature evaluations on map displays. The effectiveness and efficiency of map symbolisation based on the visual variables was investigated by Swienty (2008), and Garlandini and Fabrikant (2009). For image maps this approach has to be modified. This user test is based mainly on the evaluation of highlighting strategies of image objects, as (1) they result from a potpourri of visual variables that cannot be investigated in isolation, and (2) they represent a completely new design approach for image maps.

What is to be evaluated is the hypothesis that highlighting strategies of image-objects make highlighted objects most salient on the image map. Furthermore, it has to be proven if highlighting strategies of image objects can be applied to create a multi-layered visual hierarchy, thus allow the communication of more complex information. For the evaluation of image object highlighting, the interaction of highlighted image objects with vector symbolisation has to be considered, which means that concise image map design must be functional. For this reason, the highlighting strategies of image objects are design compromises that should guide the user´s attention to highlighted objects with a minimum visual scanning effort, while also providing sufficient context information. That means the important objects can only be highlighted to a degree that keeps necessary background objects readable. Since the image object highlighting may reduce the readability of background features, the evaluation should answer the question of whether the users find the context information sufficient.

Furthermore, a successful image map design should make the map visually appealing for the audience. It is therefore necessary to evaluate how users rate the attractiveness of the highlighting strategies of image objects. The user test needs to answer the following essential questions:

(1) *Does image-object highlighting allow users to promptly locate the most relevant information?*

(2) *How effective do the highlighting strategies guide the users' attention to the most relevant information?*

(3) *Can the image-object highlighting strategies establish a multi-layered visual hierarchy?*

(4) *Which of the image-object highlighting strategies guides the users' attention best?*

(5) *Can they be combined with conventional vector highlighting operations to establish a multi-layered visual hierarchy?*

(6) *Which image highlighting/vector highlighting combination is most effective?*

(7) *Are image-object highlighting strategies visually pleasing?*

(8) *Does context information (background objects) remain legible?*

4.3.1 User Test Structure

The creation of a test scenario with images is no simple task. Images cannot serve as a harmonic background, and unwanted background stimuli will affect the user´s attention to the test objects. In order to minimize this distracting background effect, remote sensing images were chosen as test beds that exhibit very similar image objects in a homogeneous environment. The visualisations created for this user test are based on two remote sensing images, one in an oblique view, and one in a vertical view. The oblique view image depicts similarly looking houses, while the vertical view depicts very similarly looking blocks of houses (see Figure 4-14). Both images were slightly manipulated to dismiss remaining eye-catching objects, and to improve the visual quality. As image maps have to clearly highlight the relevant information while providing readable background information, the visualisations of this paper-and-pencil test were designed in a way that visually a good balance is created between highlighting and providing sufficient context information.

Figure 4-14 - Test scenarios for the paper-and-pencil user test. With (a) an oblique photo[13] taken in Huaxi Xun (China), and (b) remote sensing imagery from Mexico City ©Google Earth

The prepared visualisations were printed onto a DIN A4 landscape page with 16 x 21 cm dimensions for the oblique test cases and 16 x 19 cm dimensions for the vertical test cases. To validate the wide-ranging research questions formulated in section 4.3, the user test is structured into four parts, addressing different scopes.

4.3.1.1 Part 1

The first part of the paper-and-pencil test was designed in order to answer the research question (1) "*Does image object highlighting enable users to promptly locate the most*

[13] http://emilyhartley.wordpress.com/2010/11/22/applied-learning/ (18.02.2014)

relevant information", as well as (2) "*How effective do they guide the users' attention to the most relevant information?*". The design strategies that enable the highlighting of a single object were implemented to the oblique test scenario to create a collection of test visualisations. Only one object was highlighted. A single building of the similarly looking houses was highlighted by *Selective Brightening*, *Spotlight Highlighting*, *Light Beam Guidance*, or *Semantic Focusing* (see Figure 4-15).

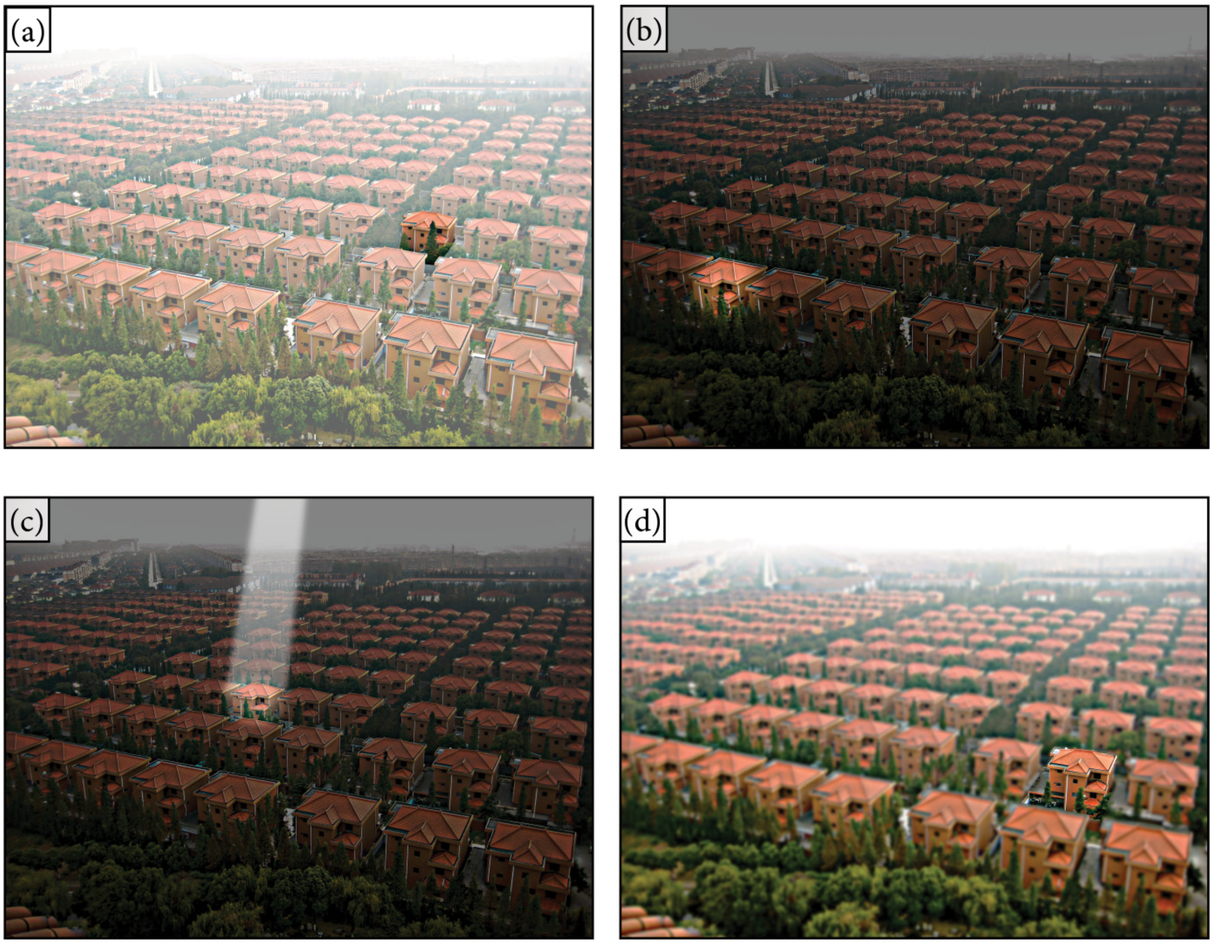

Figure 4-15 - Image object highlighting: (a) Selective Brightening, (b) Spotlight Highlighting, (c) Light Beam Guidance, and (d) Semantic Focusing

In the oblique view the scale is not fixed. Foreground objects are depicted larger than background objects, due to the size gradient (see section 2.8). To take the depicted object size into account, the paper-and-pencil test includes three variations of each highlighting strategy. The highlighted houses vary randomly from foreground to background in order to monitor the scale influences.

Given these design strategies, the test persons were asked to locate the most eye-catching object. It was not further specified what type of 'object' it can be. To record the immediate attention, the time for the task completion was fixed to four seconds (including page turning) respectively. All fixed time spans of the user test were derived from a prototype evaluation.

While test persons viewed one of the prepared visualisations, the given task was:

- "*Please mark the most eye-catching object!*"

Hereby, ’eye-catching’ is used as a commonly understood synonym to ‘salient’. After marking salient objects in a visualisation, the test persons were instructed to rank the degree of task difficulty on the following page by this instruction:

- “*Rank the degree of task difficulty!”*

The predefined rating scale has a range from 1 = ‘very easy’ to 5 = ‘very difficult’ (see Figure 4-16).

1	2	3	4	5

Figure 4-16 – Task difficulty ranking scale:
1 = very easy, 2 = easy, 3 = moderate, 4 = difficult, 5 = very difficult

4.3.1.2 Part 2

The second part of the user test was designed to evaluate the research questions (3) “*Can image-object highlighting strategies establish a multi-layered visual hierarchy?*”, and (4) “*Which of the image-object highlighting strategies guides the users’ attention best?*” The same image-object highlighting strategies were used as in part 1, but this time encoding a primary and a secondary highlighted object. The primary object is highlighted in the same manner as in the first part. The secondary object is also highlighted, but with a lower intensity. In this approach the simple foreground-background hierarchy case is extended to a multi-layered hierarchy, in particular, the primary object, the secondary object and the background image space (see Figure 4-17). As with part 1, varying object sizes due to the perspective were taken into account, with the primary and secondary objects for each highlighting strategy implemented into two user test visualisations, once perspectively in front, and once behind the secondary object.

To record the immediate attention, the time for the task completion was fixed to five seconds (including page turning) respectively. While test persons viewed one of the visualisations, the task given was:

- “*Please mark the most eye-catching object with a ‘1’ and the second most eye-catching object with a ‘2’!*”

After marking salient objects in two visualisation variations, the test persons were instructed to rank the degree of task difficulty on the following page by this instruction:

- “*Rank the degree of task difficulty!”*

As in part 1, the predefined rating scale has a range from 1 = ‘very easy’ to 5 = ‘very difficult’ (see Figure 4-16).

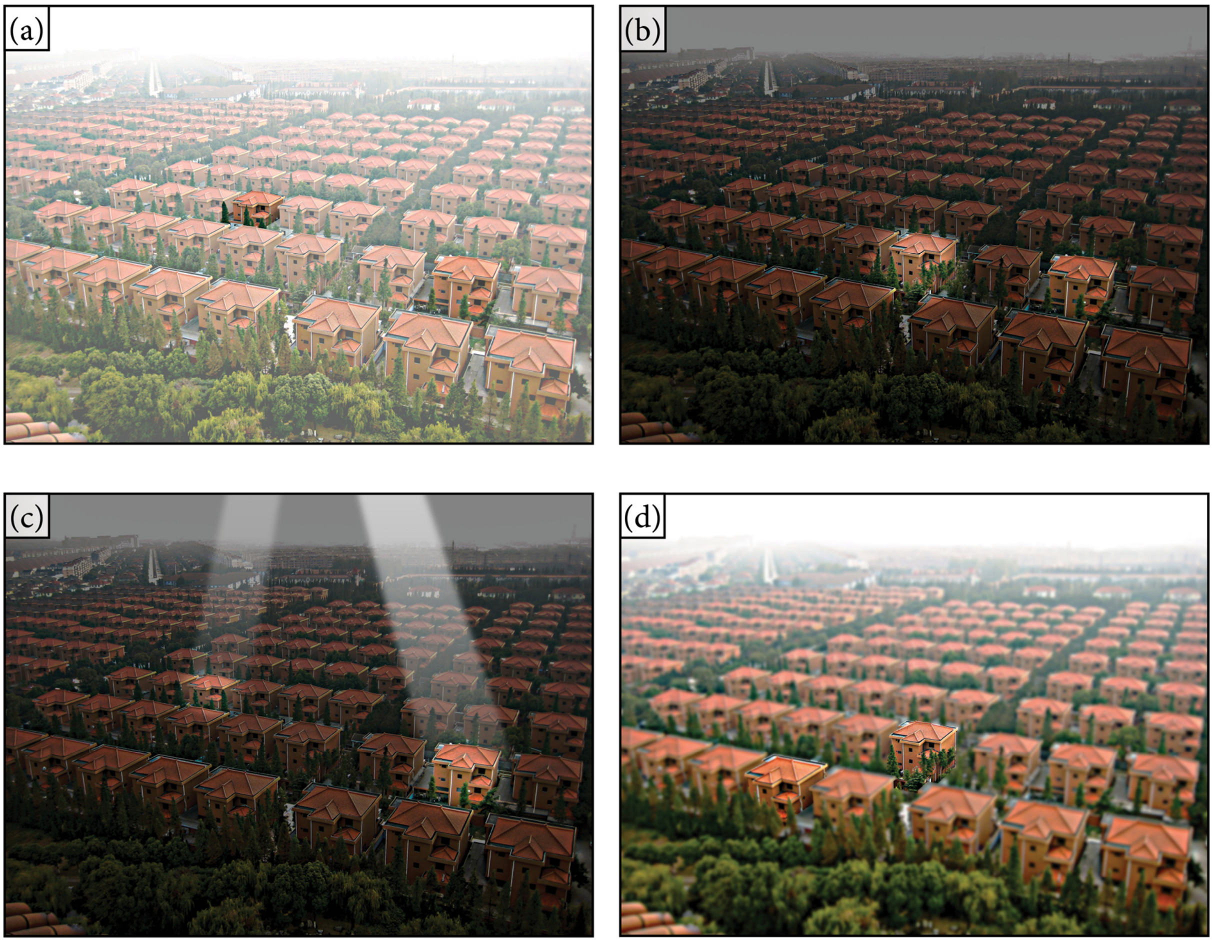

Figure 4-17 - Layered image-object highlighting: (a) Selective Brightening, (b) Spotlight Highlighting, (c) Light Beam Guidance, and (d) Semantic Focusing

4.3.1.3 Part 3

The third part of the user test was devoted to the research questions how image object highlighting strategies interact with simultaneous vector highlighting. The exact research questions are (5) "*Can they be combined with conventional vector highlighting operations to establish a multi-layered visual hierarchy?*", and (6) "*Which image highlighting/vector highlighting combination is most effective?*".

A series of various image-object highlighting strategies and vector highlighting combinations were created to examine if a multi-layered hierarchy can be established when comparable vector highlighting is differentiated by image object highlighting. As in part two, a multi-layered hierarchy shall be created containing a primary and a secondary object. The primary object consists of the interaction between an image object highlighting strategy and a vector highlighting technique. The secondary object is solely highlighted with a comparable vector object.

The two image-object highlighting strategies that only apply to the oblique image basis, namely *Tilt-Shift Focusing* and *Light Beam Guidance* (see sections 0 and 4.2.1.5), are implemented onto the oblique image template (see Figure 4-14a). For these user test visualisations, labelling is selected as an appropriate vector highlighting, because the use of contouring and transparent overlays is not homogeneously applicable within the crowded oblique image. As with part 1 and part 2, varying object sizes due to the perspective were taken into account, with the primary and secondary objects for each highlighting strategy implemented into two visualisations, once in front, and once behind the secondary object. One of each visualisation variations is shown in Figure 4-18.

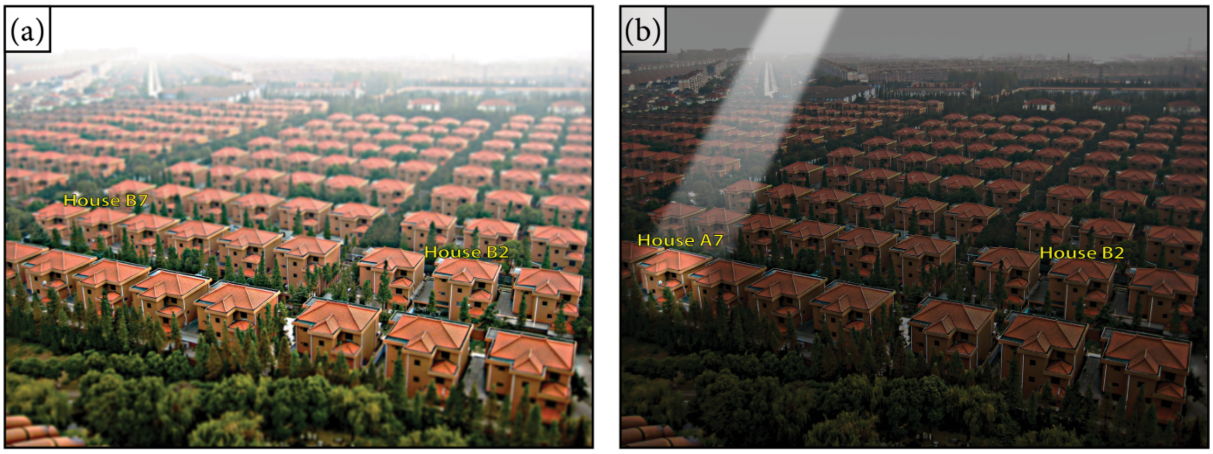

Figure 4-18- user test visualisations implemented as tilt-shift focusing with labelling (a), and light beam guidance with labelling (b)

All other image-object highlighting strategies, namely *Selective Brightening*, *Spotlight Highlighting* and *Semantic Focusing*, are implemented onto the vertical image template (see Figure 4-14b). These were combined with the three vector highlighting techniques, contouring, transparent overlays, and labelling. Figure 4-19 shows two implemented examples.

Figure 4-19 – examples of user test visualisations on the vertical image template: (a) semantic focusing with contouring, and (b) selective brightening with transparent overlays

To record the users´ immediate attention, the time for the task completion was fixed to five seconds (including page turning) respectively. The test persons were given the same tasks as in part 2. While test persons viewed one of the visualisations, the task given was:

- *"Please mark the most eye-catching object with a '1' and the second most eye-catching object with a '2'!"*

After marking salient objects in a single visualisation, the test persons were instructed to rank the degree of task difficulty on the following page by this instruction:

- "*Rank the degree of task difficulty!"*

As in part 1 and 2, the predefined rating scale has a range from 1 = 'very easy' to 5 = 'very difficult' (see Figure 4-16).

4.3.1.4 Part 4

The fourth part of the paper-and-pencil test was designed differently to the previous parts in order to investigate the map communication regarding context information, as well as the map reader´s subjective impression rather than the evaluation of sensory stimulus-driven control of visual attention. The exact research questions to be evaluated are (7) "*Are image object highlighting strategies considered as visually pleasing?*" and (8) "*Does context information (background objects) remain legible?*". Because of these completely different experimental requests, the user tasks of the user test were much different than those in the previous parts. The test persons were instructed to view and assess the whole visualisation and to rank the design strategy itself regarding its attractiveness of highlighting. Furthermore, the users were instructed to rank the supply of sufficient context information when image object highlighting was applied. The tasks were formulated as follows:

- "*Do you consider the highlighting as visually appealing? Rank its aesthetic appearance!*", and
- "*Does the background provide sufficient context information? Rank the background´s context information!*"

The ranking scale had to change for the completion of these tasks. Hereby, the predefined rating scale has a range from 1 = 'excellent' to 5 = 'fail' (see Figure 4-20).

1	2	3	4	5

Figure 4-20 – Assessing ranking scale:
1 = excellent, 2 = good, 3 = satisfactory, 4 = sufficient, 5 = fail

The test persons were permitted ten seconds for the assessment of an image object highlighting strategy example visualisation, and a further eight seconds to rank their assessment of both asked questions. The fixed time spans were again derived from a prototype evaluation.

4.3.2 Experimental Conditions

The test persons of this user test were recruited in two groups. Together 41 under-graduate students (17 female, 24 male) with a mean age of 24 (range: 20-36) took part in the study. All test persons are studying in an earth science related programme. Of the two groups, one was carried out in an original English version and the other in a precisely translated German version. Both parts of the user test were carried out at the Technische Universität München in lecture rooms under similar conditions.

The test persons are assumed to have optimal visual acuity and visual scanning performance within the visual field. Test persons were allowed to wear glasses (or contact lenses). To avoid visual distraction as much as possible, every test person was placed in the lecture room so that the seat left and right to them was vacant. Furthermore, test persons were asked to keep their desk clear, apart from the test itself and the pen in their hand.

4.3.3 Results

To provide a good overview on the results of the user test, the results are presented in the same number of parts as the test structure itself (see section 4.3.1).

4.3.3.1 Results of Part 1

All four image-object highlighting strategies enabled the test persons to almost always promptly locate the highlighted object. Table 4-2 shows the results, whereby 'winners' represent successful localising efforts of the test persons. Only a very low number of test persons either marked an alternative spot on the image, or failed to complete the task in the given time span. A series of McNemar-Tests were applied to statistically investigate if a significant difference exists of successful object user localising between the highlighting strategies. At the $\alpha = 0.05$ level of significance, there exists no evidence to conclude that there is a difference in the user performance between the four image object highlighting strategies.

Image-Object Highlighting	**Winners (3 test variations)**	**Mean**
Selective Brightening	40 (97.6%) 41 (100%) 41 (100%)	99.2%
Spotlight Highlighting	40 (97.6%) 40 (97.6%) 41 (100%)	98.4%
Light Beam Guidance	41 (100%) 39 (95.1%) 41 (100%)	98.4%
Semantic Focusing	40 (97.6%) 41 (100%) 41 (100%)	99.2%

Table 4-2 – User test results of image-object highlighting strategies to highlight a single image-object

After perceiving the variations of each highlighting strategy, the test persons were instructed to rank the degree of task difficulty. Table 4-3 shows mean ranks of close to 'very easy' (1). This result suits the outcomes that test persons promptly localise the highlighted object. An applied Friedman Test showed no significant differences in the user ranking of these image-object highlighting strategies (at $\alpha = 0.05$ level of significance). In fact, users find it very easy to promptly locate a single highlighted object with any of these four featured design strategies.

Image-Object Highlighting	Arithmetic Mean Rank
Selective Brightening	1.1
Spotlight Highlighting	1.2
Light Beam Guidance	1.2
Semantic Focusing	1.1

Table 4-3 - Task difficulty ranking results of image-object highlighting strategies to highlight a single image object

4.3.3.2 Results of Part 2

Table 4-4 shows the test results of the second part. Winners are here defined as the successful localising and correctly chosen order of the primary and the secondary objects. When *Selective Brightening* was applied, the percentage of successful localisation of primary and secondary objects dropped in comparison to the other strategies. Nevertheless, this observation is not statistically significant, as a McNemar-Test revealed (with $\alpha = 0.05$). Missing cases that would complete 100 % are largely cases in which the order of primary and secondary order were chosen in reverse order by the test person.

Image-Object Highlighting	Winners (2 test variations)	Mean
Selective Brightening	36 (87.8%) 35 (85.4%)	86.6%
Spotlight Highlighting	38 (92.7%) 37 (90.2%)	91.5%
Light Beam Guidance	38 (92.7%) 39 (95.1%)	93.9%
Semantic Focusing	38 (92.7%) 38 (92.7%)	92.7%

Table 4-4 – User test results of image-object highlighting strategies to create a multi-layered visual hierarchy

The distribution of rankings assigned to the multi-layered application of the image object highlighting strategies is shown in Table 4-5. The task difficulty drops slightly for *Spotlight Highlighting*.

Ranking	Image-Object Highlighting Strategy			
	Selective Brightening	*Spotlight Highlighting*	*Light Beam Guidance*	*Semantic Focusing*
very easy	19 (46.3%)	15 (36.6%)	21 (51.2%)	21 (51.2%)
easy	16 (39.0%)	17 (41.5%)	14 (34.1%)	15 (36.6%)
moderate	5 (12.2%)	7 (17.1%)	6 (14.6%)	5 (12.2%)
difficult	1 (2.4%)	2 (4.9%)	0	0
very difficult	0	0	0	0

Table 4-5 – Distribution of rankings assigned to the multi-layered application of the image-object highlighting strategies

A Friedman-Test was applied to calculate the mean rank (see Table 4-6), and to statistically investigate if a significant difference exists between the given user rankings. At the $\alpha = 0.05$ level of significance, there exists enough evidence to conclude that there is a difference in the true mean task difficulty of the four image object highlighting strategies. That means, *Spotlight Highlighting* is ranked as more difficult, although successful user localisations with *Spotlight Highlighting* do not show a reduced percentage (see Table 4-5).

Image-Object Highlighting	Mean Rank
Selective Brightening	2.46
Spotlight Highlighting	2.85
Light Beam Guidance	2.38
Semantic Focusing	2.30

Table 4-6 - Task difficulty mean ranks of a Friedman-Test of image-object highlighting strategies to create a multi-layered visual hierarchy

4.3.3.3 Results of Part 3

Table 4-7 to Table 4-14 show the results of the third part. The winners of the image-object highlighting strategies *Tilt-Shift Focusing* and *Light Beam Guidance,* which were implemented as oblique visualisations, are shown in Table 4-7.

Image-Object Highlighting	Vector Highlighting	Winners	Mean %
Tilt-Shift Focusing	labelling	16 (39.0%)	50.0%
	labelling	25 (61.0%)	
Light Beam Guidance	labelling	36 (87.8%)	87.8%
	labelling	36 (87.8%)	

Table 4-7 - Comparison of successful user localisation of layered important information highlighted by tilt-shift focusing with labelling and light beam guidance with labelling

Here again, winners are defined as the successful localisation and correctly chosen order of the primary and the secondary objects. It can be seen that the *Tilt-Shift Focusing* with *labelling* only produced mean winners of 50 %. *Light Beam Guidance* with *labelling* was far more successful. These results are somehow reflected in the task difficulty rankings (see Table 4-8). Here, a Friedman-Test reveals a significantly lower task difficulty ranking of *Tilt-Shift Focusing* with *labelling* (α = 0.05 level of significance).

Ranking	***Tilt-Shift Focusing***	***Light Beam Guidance***
	labelling	labelling
very easy	12 (29.3%)	23 (56.1%)
easy	19 (46.3%)	14 (34.1%)
moderate	10 (24.4%)	4 (9.8%)
difficult	0	0
very difficult	0	0

Table 4-8 - Task difficulty rankings for tilt-shift focusing and light beam guidance with labelling

Table 4-9 confronts all image object highlighting strategies and vector highlighting combinations that were implemented into the vertical test bed (see section 4.3.1.3). The overall winner-ratio is high. McNemar-Tests with continuity correction were applied to statistically investigate if a significant difference exists between the changing vector highlighting combinations of image-object highlighting strategies. The image-object highlighting strategies were tested in separate. *Selective Brightening* and *Spotlight Highlighting* show no significant difference (α = 0.05) depending on the applied vector highlighting combination. Though, at the α = 0.05 level of significance, the *Semantic Focusing* combined with transparent overlay reveals a statistically significant decreasing task completion.

Image-Object Highlighting	**Vector Highlighting**	**Winners**
Selective Brightening	contour	37 (90.2%)
	transparent overlay	37 (90.2%)
	labelling	39 (95.1%)
Spotlight Highlighting	contour	38 (92.7%)
	transparent overlay	39 (95.1%)
	labelling	38 (92.7%)
Semantic Focusing	contour	40 (97.6%)
	transparent overlay	34 (82.9%)
	labelling	38 (92.7%)

Table 4-9 - Comparison of successful user localisation of important information encoded by various image-object highlighting/vector highlighting combinations

The task difficulty analysis is done here separately by image-object highlighting. Table 4-10 shows task difficulty rankings of *Selective Brightening* combined with the three conventional vector highlighting techniques. The labelling combination achieves the most '*very easy*' scores followed by *contouring* and *transparent overlay*.

Ranking	*Selective Brightening*		
	contour	transparent overlay	labelling
very easy	23 (56.1%)	14 (34.1%)	29 (70.7%)
easy	11 (26.8%)	18 (43.9%)	6 (14.6%)
moderate	6 (14.6%)	5 (12.2%)	5 (12.2%)
difficult	1 (2.4%)	4 (9.8%)	1 (2.4%)
very difficult	0	0	0

Table 4-10 - Task difficulty rankings for selective brightening with vector highlighting combinations

A Friedman-Test was applied to calculate the mean ranks (see Table 4-11), and to statistically investigate if a significant difference exists between these user rankings. At the $\alpha = 0.05$ level of significance, there exists enough evidence to conclude that there is a difference in the true mean task difficulty of *Selective Brightening* combined with vector highlighting. *Selective Brightening* with a transparent overlay is ranked as more difficult to localise.

***Selective Brightening* +**	**Mean Rank**
contour	1.98
transparent overlay	2.33
labelling	1.70

Table 4-11 - Task difficulty mean ranks of a Friedman-Test of selective brightening combined with vector highlighting

Table 4-12 shows the task difficulty rankings of *Spotlight Highlighting* combined with the three conventional vector highlighting techniques. Here the difficulty ranking results look fairly even.

Ranking	*Spotlight Highlighting*		
	contour	transparent overlay	labelling
very easy	26 (63.4%)	26 (63.4%)	23 (56.1%)
easy	8 (19.5%)	8 (19.5%)	11 (26.8%)
moderate	5 (12.2%)	4 (9.8%)	4 (9.8%)
difficult	1 (2.4%)	3 (7.3%)	2 (4.9%)
very difficult	1 (2.4%)	0	1 (2.4%)

Table 4-12 - Task difficulty rankings for spotlight highlighting with vector highlighting combinations

A Friedman-Test was applied to statistically investigate if a significant difference exists between task difficulty rankings. *Spotlight Highlighting* shows no significant difference ($\alpha = 0.05$ level of significance) in the task difficulty depending on the applied vector highlighting combination.

Table 4-12 shows the task difficulty rankings of *Semantic Focusing* combined with the three conventional vector highlighting techniques. The *contouring* combination achieves the most '*very easy*' rankings.

Ranking	***Semantic Focusing***		
	contour	transparent overlay	labelling
very easy	30 (73.2%)	23 (56.1%)	22 (53.7%)
easy	7 (17.1%)	10 (24.4%)	10 (24.4%)
moderate	3 (7.3%)	6 (14.6%)	7 (17.1%)
difficult	1 (2.4%)	2 (4.9%)	2 (4.9%)
very difficult	0	0	0

Table 4-13 - Task difficulty rankings for semantic focusing with vector highlighting combinations

A Friedman-Test was applied to calculate the mean ranks (see Table 4-14), and to statistically investigate if a significant difference exists between these user rankings. At the $\alpha = 0.05$ level of significance, there exists enough evidence to conclude that there is a difference in the true mean task difficulty of *Semantic Focusing* combined with vector highlighting. *Semantic Focusing* with transparent overlays and labelling reveal an increased localising difficulty.

***Semantic Focusing* +**	Mean Rank
contour	1.74
transparent overlay	2.09
labelling	2.17

Table 4-14 - Task difficulty mean ranks of a Friedman-Test of semantic focusing combined with vector highlighting

4.3.3.4 Results of Part 4

This section covers the results of part 4, in which the aesthetic appearance and the context information were ranked by the test persons. The aesthetic appearance ranking results are shown in Table 4-15. *Selective Brightening* seems to be the most visually appealing strategy, while *Tilt-Shift Focusing* receives the least '*excellent*' ranks.

Ranking	**Aesthetic Appearance**				
	Selective Brightening	*Spotlight Highlighting*	*Light Beam Guidance*	*Semantic Focusing*	*Tilt-Shift Focusing*
excellent	22 (53.7%)	12 (29.3%)	12 (29.3%)	10 (24.4%)	5 (12.2%)
good	16 (39.0%)	16 (39.0%)	8 (19.5%)	14 (34.1%)	11 (26.8%)
satisfactory	1 (2.4%)	11 (26.8%)	9 (22.0%)	9 (22.0%)	7 (17.1%)
sufficient	2 (4.9%)	2 (4.9%)	11 (26.8%)	7 (17.1%)	11 (26.8%)
fail	0	0	1 (2.4%)	1 (2.4%)	7 (17.1%)

Table 4-15 - Distribution of rankings assigned to the aesthetic appearance of the image object highlighting strategies

A Friedman-Test was applied (see Table 4-16) to statistically investigate if a significant difference exists between the given user rankings. At the $\alpha = 0.05$ level of significance, there exists enough evidence to conclude that there is a difference in the true mean aesthetic appearance of the five image object highlighting strategies. The Friedman-Test mean ranks show that *Selective Brightening* was chosen to be the most appealing image-object highlighting strategy.

Image-Object Highlighting	Mean Rank
Selective Brightening	2.09
Spotlight Highlighting	2.84
Light Beam Guidance	3.20
Semantic Focusing	3.09
Tilt-Shift Focusing	3.79

Table 4-16 – Evaluated aesthetic appearance mean ranks applying a Friedman-Test

The distribution of rankings regarding the context information from the background is shown in Table 4-17. 35 test persons (85.4 %) rate the context information of the *Selective Brightening* strategy as ‘*excellent*’ or ‘*good*’.

Ranking	Background Context Information				
	Selective Brightening	*Spotlight Highlighting*	*Light Beam Guidance*	*Semantic Focusing*	*Tilt-Shift Focusing*
excellent	15 (36.6%)	12 (29.3%)	4 (9.8%)	1 (7.3 %)	5 (12.2%)
good	20 (48.8 %)	11 (26.8%)	10 (24.4%)	10 (24.4%)	10 (24.4%)
satisfactory	4 (9.8%)	15 (36.6%)	17 (41.5%)	13 (31.7%)	11 (26.8%)
sufficient	1 (2.4%)	2 (4.9%)	7 (17.1%)	11 (26.8%)	8 (19.5%)
fail	1 (2.4%)	1 (2.4%)	3 (7.3%)	4 (9.8%)	7 (17.1%)

Table 4-17 - Distribution of rankings assigned to the background context information of the image-object highlighting strategies

A Friedman-Test was applied to calculate the mean rank (see Table 4-18), and to statistically investigate if a significant difference exists between the given user rankings. At the $\alpha = 0.05$ level of significance, there exists enough evidence to conclude that there is a difference in the true mean background´s context information of the five image object highlighting strategies. The test persons assessed that *Selective Brightening* provides the best context information followed by *Spotlight Highlighting*. Between these two and the following image object highlighting strategies *Light Beam Guidance*, *Tilt-Shift Focusing*, *and Semantic Focusing* exists a large margin in the ranking results.

Image Object Highlighting	Mean Rank
Selective Brightening	1.84
Spotlight Highlighting	2.33
Light Beam Guidance	3.45
Semantic Focusing	3.85
Tilt-Shift Focusing	3.52

Table 4-18 - Background context information mean ranks applying a Friedman-Test

4.3.4 Discussion

The evaluation of this user test helps to answer many research questions regarding image-object highlighting. It confirms the assumption that the image-object highlighting strategies *Selective Brightening*, *Spotlight Highlighting*, *Light Beam Guidance*, and *Semantic Focusing* enable a clear figure-ground segregation. Despite the inhomogeneous nature of images, the use of pre-attentive variables makes prioritised information more salient. The user test confirms this hypothesis with a significant result. Both, the localisation of highlighted objects on test scenarios (Table 4-2), as well as the rankings of task difficulty (Table 4-3), have confirmed that image-object highlighting strategies allow users to promptly locate the most relevant information. These empirical tests support the statement that image-object highlighting strategies may guide the users´ attention very effectively.

Another interesting finding from the user test concerns oblique image maps. The perspective-conditioned size gradient has no significant influence on the highlighting performance. That means image map designers do not have to take special measure to counteract the size gradient.

The evaluation also shows that image-object highlighting not only enhances the visual segregation of fore- and background objects, but also supports the perception of a multi-layered visual hierarchy. Although the localisation of highlighted objects on test scenarios with primary and secondary objects was not as efficient as with solely primary objects, the results remain positive (see Table 4-4). Without surprise, the task difficulty increases when image-object highlighting strategies were targeted to establish a multi-layered visual hierarchy (Table 4-5). However, the overall difficulty is ranked as between 'easy' and 'very easy' for all test scenarios, which shows, the localisation is still efficient enough.

The question "*which image-object highlighting strategy guides the users' attention best?*" cannot easily be answered by this user test evaluation, partly because the vision guiding effectiveness of *Selective Brightening*, *Spotlight Highlighting*, *Light Beam Guidance*, and *Semantic Focusing* turned out to be so excellent, that no significant differences could be identified between them. Although, *Spotlight Highlighting* was ranked as significantly more difficult to localise (see Table 4-6), no negative impact was detected on the localisation of primary and secondary objects (see Table 4-4).

The test results show that *Tilt-Shift Focusing* was not suited to highlight information in the chosen oblique image. As *Tilt-Shift Focusing* can only highlight a continuous horizontal focal plane and not a single spot of the image (see section 4.2.1.5), it had to be combined with labelling to highlight one particular object. *Tilt-Shift Focusing* achieved only an average 50 % of successful localisation of primary and secondary objects (see Table 4-7). These poor results were also reflected in the rankings of much increased task difficulty (see Table 4-8). The secondary object that featured a sharply drawn label over blurred image space was often perceived as more salient. The observation that strong blurring contrasts immediately catch the user´s attention was also made in studies by Kosara (2001). Therefore the secondary object can be more salient than the sharply drawn primary object, even though the intention was to highlight the primary image object. However, this does not mean that *Tilt-Shift Focusing* always fails to have the desired effect. Apart from the precondition of having relevant objects in a horizontal focal plane, the image should only contain sparsely distributed objects that feature a large spacing between all individual objects. Under these test circumstances further experimental results may deliver much different test results.

The evaluation also shows that image-object highlighting can be combined with conventional vector highlighting operations to establish a multi-layered visual hierarchy. Similar vector objects that are highlighted become more salient when the image-object highlighting is simultaneously applied. The users perceive these highlighted vector objects predominately as being primary. The percentage of successful localisation was over 90 % in all combinations (except one) of *Selective Brightening*, *Spotlight Highlighting*, and *Semantic Focusing* with the vector highlighting techniques *contour*, *transparent overlay*, and *labelling* (see Table 4-9). Only the *Semantic Focusing* with *transparent overlay* showed a significantly lower amount of successful localisation. Here the statistic pattern continues as *transparent overlays* that are applied simultaneously with *Selective Brightening* and *Semantic Focusing*, showed a significantly higher task difficulty (see Table 4-13 and Table 4-14). It can therefore be assumed that *transparent overlays* reduce the image highlighting effect.

Semantic Focusing with simultaneously applied *labelling* showed an increasing task difficulty, similar to *Tilt-Shift Focusing* with *labelling* (see Table 4-14). This can be similarly reasoned as mentioned before that strong contrasts of blur are very salient to the human eye. Image map designers have to consider that when either *Semantic Focusing* or *Tilt-Shift Focusing* is used to visually structure the image, any labelling placed on blurred background image space will have a higher saliency than on the focussed image space.

As all image-object highlighting strategies restrict the visibility of the background image space, it is important to evaluate if the background remains readable in order to provide sufficient context information to the highlighted features. Among the image-object highlighting strategies, *Selective Brightening* was assessed by the users to have the best background legibility (see Table 4-18). *Spotlight Highlighting* came next in the ranking. *Semantic Focusing and Tilt-Shift Focusing* were at the bottom of the user ranking. This means, backgrounds that have their tonal values shifted towards lightness (*Selective Brightening*) are ranked as being better legible than backgrounds with tonal values shifted towards darkness (*Spotlight Highlighting* and *Light Beam Guidance*). *Light Beam Guidance* achieved lower rankings than *Spotlight Highlighting*. This confirms the hypothesis that the light beams for all their excellent highlighting abilities are a dominant visual cue which distracts from background information. Backgrounds that have been blurred (*Semantic Focusing* and *Tilt-Shift Focusing*) were evaluated as least legible. This last finding has been described by Ware (2012, p. 157) who stated that blurred information is likely to become illegible. This should be considered when applying these two image-object highlighting strategies.

The aesthetic appearance of the image-object highlighting strategies showed quite different user evaluations. Significantly different rankings were assigned to the highlighting strategies (see Table 4-15). *Selective Brightening* was ranked as visually most appealing followed by *Spotlight Highlighting*, *Semantic Focusing*, and *Light Beam Guidance* (see Table 4-17). Last of this ranking was *Tilt-Shift Focusing* which is no surprise, given its worse localisation performance. On the basis of this evaluation it can be assessed that *Selective Brightening* is seen by users as the best strategy. *Spotlight Highlighting*, *Semantic Focusing*, and *Light Beam Guidance* also achieved positive user rankings. But the specific aspects of design cannot be addressed with this evaluation. *Selective Brightening* could have achieved excellent rankings because it is perceived as *intuitive*, *useful*, *unobtrusive*, *innovative* or *clarifying*. It is more likely that a blending of these enumerated design aspects has an impact on the user rankings, but it cannot be ultimately resolved which design aspect has the greatest impact. Nevertheless, the designer of the image map does not necessarily have to know which aspect enhances the design, as long as the design is effective and users find it visually pleasing. The evaluation confirms that a whole set of concise image-object highlighting strategies are perceived as visually pleasing.

To summarise, the following list features simplified conclusions made on the prior formulated essential research questions of section 4.3:

(1) Do image-object highlighting strategies allow users to promptly locate the most relevant information? ***Yes!***

(2) How effective do the highlighting strategies guide the users' attention to the most relevant information? ***Very effectively!***

(3) Can the image-object highlighting strategies establish a multi-layered visual hierarchy? ***Yes!***

(4) Which of the image-object highlighting strategies guides the users' attention best? ***No clear statement possible.***

(5) Can they be combined with conventional vector highlighting operations to establish a multi-layered visual hierarchy? ***Yes, but transparent overlays may reduce the image highlighting effect, and labelling over blurred image space may distract the attention from the highlighted image object.***

(6) What image highlighting/vector highlighting combination is most effective?
Selective Brightening and Spotlight Highlighting combined with contouring, transparent overlays, and labelling, as well as Semantic Focusing with contouring and Light Beam Guidance with labelling all show very good user test results.

(7) *Are image-object highlighting strategies considered as visually pleasing?*

Yes, especially Selective Brightening followed by Spotlight Highlighting, Semantic Focusing, and Light Beam Guidance.

(8) *Does context information (background objects) remain legible?*

Yes, the Selective Brightening background is rated as being best legible. Spotlight Highlighting also achieves good legibility. Semantic Focusing, Light Beam Guidance, and Tilt-Shift Focusing all achieve (in average) satisfactory legibility.

Furthermore, this evaluation delivers criteria of Bertin´s (1967/1983) described *levels of organisation* for image-object highlighting (see section 2.6). One can assume from the test results that highlighted objects with varying intensities are perceived as being different, but belonging to a family. The correct ordering of primary and secondary objects by the user shows that they can be perceptually ordered into categories. In terms of the *levels of organisation*, image-object highlighting strategies produce *selective*, *associative*, and *ordered* highlighting. This might be no surprise, as all highlighting strategies are largely influenced by the visual variable 'value'. And, 'value' can display ordinal data, but has limited application to quantitative data (Bertin, 1967/1983).

The image-object highlighting strategies introduced in this thesis work are proved being effective in terms of guiding the user´s attention. They are experienced as well designed and provide sufficient context information. Still, some aspects of the research questions could not be sufficiently solved.

The evaluation revealed excellent user performances of image-object highlighting strategies to promptly locate the most important information. Since the performances were high and the user tasks were easy, little distinctions in the results from the individual image-object highlighting strategies could be detected. For a comprehensive comparison that should reveal the relative advantages and weaknesses of these strategies, further user tests under visually more challenging conditions must be carried out.

This evaluation showed the fitness of the image-object highlighting strategies for establishing a multi-layered visual hierarchy. However, the test scenarios were limited to three levels of a visual hierarchy. From a research point of view, it would be interesting to evaluate how many further levels can be incorporated. For instance, Bertin (1967/1983) advises six or seven steps of 'value' – black and white included. As image object highlighting is very influenced by 'value', but a complete black and white would disguise the object, four to five levels of visual hierarchy at most could be conceivable.

The image highlighting strategies empowers users to promptly locate the most important information, to understand the degree of relevance, and probably, to assign the information into a geographical context. However, no evidence exists that the users encode the semantics of highlighted image objects. As the radiometry of image objects is manipulated by these design strategies as well as the context information, it remains unclear how the modification of object representation may influence its recognition. If the map objects are not appropriately encoded, users have to employ more mental efforts to decode the underlying meanings, and therefore, the usage efficiency of geovisualisation will decrease

(Swienty, 2008, p. 28). This requires that the semantics of image maps should be encoded in a way to allow a clear comprehensibility for the user.

5 Conclusions and Outlook

5.1 Summary of Achievements

Since the introduction of image maps into the cartographic typology in 1970´s, the imagery component of an image map has been mainly treated as background for highlighted cartographic symbols. Such a background remote-sensing imagery with no target-oriented graphic enhancement, however, challenges the legibility of map symbols and causes an unstructured visual hierarchy among image objects. The author of this thesis has addressed the radiometric design of raster images in the same manner as the graphic design of cartographic symbols, with the aim to effectively guide the user´s attention to relevant image information. Five strategies of highlighting image objects were developed and evaluated. The conducted user tests have verified the desired user performances of these highlighting strategies in terms of immediately locating the most important information, and confirmed that the image highlighting strategies can effectively support the construction of a multi-layered visual hierarchy. A combinatorial application of image highlighting strategies and conventional vector highlighting techniques is also possible. Some differences between image and vector highlighting were revealed with regard to the legibility of context information, but with the help of highlighting strategies rated between sufficient and excellent in the user tests, readers of an image map are able to associate the information with its geographical context. The evaluation results have confirmed that a whole set of concise image-object highlighting strategies introduced in the thesis is perceived as visually pleasing.

Not only the design issues related to image objects in raster format, but also those related to map symbols in vector format are addressed. Based on the review of existing symbolisation techniques, particular symbolisation strategies were derived from their highlighting potentials on remote sensing imagery. In addition to approaches that highlight the visual salience of map symbols as figures on a background, further strategies were developed to downscale map symbols to lower visual levels in a hierarchy, for example, beneath the image objects. Moreover, guidelines were set to help the image map designer diminish the inconsistent appearance of point symbols caused by simultaneous contrast on an imagery background.

In this work, the concept of image map with extended or renewed design strategies was revisited to develop the concise image map design approach. Contributions are made to form a theoretical basis for the design and use of image maps, containing the re-definition of the term of image map, its design processes, and its usability issues.

Two production processes of image map design were presented. At first, a standard workflow of image map design was demonstrated alone with the in-depth discussions of all required steps from the raw data input to the image map output. It was then extended by a step of the image map mashup emerging in the context of neocartography. The results of chapter 4 suggest a further adaption of the standard workflow where the step ‘*design of vector elements*’ should be supplemented to the step of a holistic ‘*image and map symbol* *design'*. In order to achieve a higher degree of automation for image object highlighting, the vector footprints of image objects could be utilised for graphical editing. The image space of important objects such as landmarks could be spatially clipped by means of vector polygons, for example, from a cadastral database. Therefore, the step of '*vector data selection'* should be included in the workflow whenever necessary.

These workflow adaptions cannot be entirely transferred to the image map mashup. The imagery of the image map mashup is shown by a fixed web service and therefore not directly modifiable. Here, the remote sensing imagery can only be manipulated by draping a transparent layer on the earth models surface. The transparent layer of raster or vector nature spatially covers the background information and is matched to the geobrowsers imagery. It optically mixes with the imagery, but can only compress the tonal values or shift the hue values towards a monochromatic layer. Therefore, the highlighting possibilities of image objects in image map mashups are more limited and it has to be reviewed if reasonable solutions are possible.

The review on the nature of image maps has shown that the term image map remains so far ambiguous. By taking other views into account, the author gave a definition of the image map that can better reflect its use in practice and help establish itself to be commonly known as a visualisation technique composed by remote sensing imagery and cartographic symbolisation in and beyond the cartographic community.

The '*bivisual'* image map has the ability to simultaneously visualise geoinformation by realism and abstraction. The theoretical framework presented in this thesis shows that the image map fills a whole visualisation continuum between realistic images and abstract maps. The designer can choose a convenient balance between reality and abstraction, without being forced to choose one extreme or the other.

The benefits of image maps explain the growing popularity of image maps. The complexity of imagery in combination with the simplicity of symbolisation offers a high potential for visualising geoinfomation. Users tend to prefer realistic visualisations, while realism also adds user confidence in a visualisation message. Negative impacts of realistic visualisations are compensated by the abstraction of map symbols and labels that explain the imagery and add information with several design operations.

5.2 Outlook

The historical separation of photogrammetric image processing and map making has led to the separate implementation of raster graphics editing and vector graphics editing. Commercial software solutions can either provide digital photo manipulations or they are vector graphics editing programmes that provide required cartographic effects, such as advanced labelling and relief shading. Until now, no commercial software can apply image object highlighting strategies while also providing the symbolisation of geographic primitives as well as the design of map layout elements. In future, cartographic production software has to assimilate local image editing to facilitate concise image map design in a practical way.

This thesis put forward some fundamental principles for image map design and tried to answer questions such as which information should be represented as map symbols, which information is suitable for image representation, and which information is suitable for hybrid symbolisation. The recommendations for a reasonable design were derived from the given object attributes and scientific findings of other research works. Nevertheless, further research is required to validate or refine the recommendations so as to provide the map designer with an elaborated decision assistance.

On the basis of this work an agenda can be formulated to improve image map design and to promote the usage of image maps. The agenda should comprise the following requirements and missions:

(1) Image map designers should be given possibility of local and object-specific image processing in order to organise image objects of different importance into different visual layers,

(2) Cartographic production software needs to assimilate raster graphics editing, thus enables more design freedom to graphically configure individual image objects as well as symbolic objects, and

(3) Dedicated user tests are required to evaluate the fundamental question of what and how much information the user can effectively and efficiently derive from various combinatorial highlighting strategies of image objects and vector symbols that jointly constitute an image map.

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Abbreviations

2D	two dimensional
2½D	two and a half dimensional
3D	three dimensional
API	application programming interface
CCD	charge coupled device
CMOS	complementary metal-oxide-semiconductor
COLLADA	COLLAborative design activity
DIN	Deutsches Institut für Normung
DTM	digital terrain model
DEM	digital elevation model
DSM	digital surface model
DXF	drawing interchange file format
EROS	Earth resources observation satellite
GIS	geographic information system
GML	geographic markup language
GNSS	global navigation satellite system
HRSC	high resolution stereo camera
HTML	hypertext markup language
ICA	International Cartographic Association
INS	inertial navigation system
KML	Keyhole markup language
Lidar	light detection and ranging
OGC	Open Geospatial Consortium
OSM	OpenStreetMap
Radar	radio detection and ranging
Sonar	sound navigation and ranging
SVG	scalable vector graphics
USGS	United States Geological Survey
VGI	volunteered geographic information
VHR	very high resolution
W3C	World Wide Web Consortium
WMS	web map service
XHTML	extensible hypertext markup language
XML	extensible markup language