# Information Highlighting by Color Dependent Depth Perception with Chromo-Stereoscopy

**Note to the reviewer:**
**to fully appreciate the effect of chromo-stereoscopy it is necessary to view the results with chromo-stereoscopic glasses. We have provided the program chair with such glasses. If you do not have them please ask him to send you such glasses.**


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## Abstract

*Due to characteristics of the human visual system different colors induce different depth perception. This chromo-stereoscopy has been already used for 3D data to enhance a third spatial dimension. We propose to use chromo-stereoscopy for 2D abstract data. Color coding introduces a depth cue which encodes relevance with chromo-stereoscopy. The focus information literally "stands out" as compared to the context information. We applied this technique on two-dimensional graphs and multi-layer representations. Our approach can also be easily combined with other focus+context methods.*



**Keywords:** chromo-stereoscopy, focus+context, graphs, multi-layer, animation


## 1. Introduction

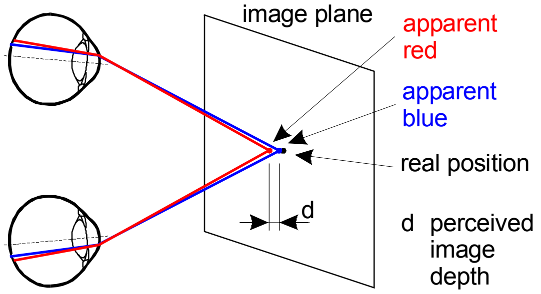
The use of color is a basic and essential technique for information visualization with a long history [18]. Color is usually used to separate groups or layers in order to distinguish information. Color should also be used according to pre-established cultural or professional meanings, e.g. red for heat or blue for water. Color is used in different ways in nearly every approach of information visualization, but there are few focus+context applications just with colors. The principle of focus+context is also important for information visualization, as it combines the detailed display of the most interesting data region and a less detailed overview of the remaining context.

Chromo-stereoscopy offers the possibility of a simple focus+context approach just by a special color encoding and a resulting color-dependent real depth perception. Chromo-stereoscopy is mainly used in entertainment, advertising, and art, whereas rarely in scientific visualization. All approaches up to now used the depth perception by chromo-stereoscopy in order to improve the spatial impression of three-dimensional data (Figure 5a). We present a new approach which utilizes the third dimension for the relevance of abstract two-dimensional data. Objects in focus are closest to, whereas objects in the context are remote from the viewer. The distance to the viewer is priority dependent, the higher the priority the smaller the distance.

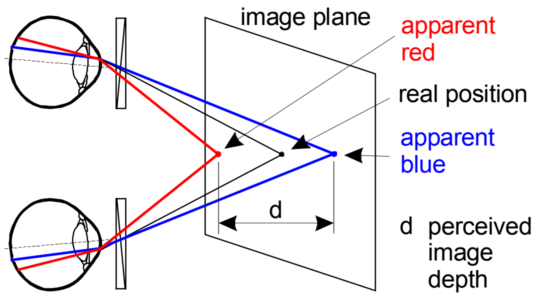
Chromo-stereoscopy [9, 10, 17, 19, 20] as an optical phenomenon, also known as color-stereo effect, was already described by Einthoven in 1885. The human eye refracts light in a color dependent manner, so that light rays with different wavelength (color) are projected onto different positions on the retina. The human brain interprets different positions on the retina as different distances of objects from the viewer (Figure 1a). This phenomenon makes it possible to perceive several depth levels of two-dimensional coplanar objects by using different colors. It can be utilized for stereoscopic effects with, e.g., printed images or monitor screens.

The effect of chromo-stereoscopy can be hardly noticed, but it can be amplified by double prisms, i.e. the perceived image depth will be increased (Figure 1b). With double prisms, one prism with low dispersion one with high dispersion, the apparent position of red objects seems to be in front and the apparent position of blue objects seems to be behind the real image plane. The background color of the image has to be black. The apparent position of yellow objects seems to be approximately between red and blue in the real image plane. Richard Steenblik invented a technology to produce inexpensive glasses consisting of a thin film, which has the same light refracting properties as double prisms. These so-called ChromaDepth™ glasses are trademarked by Chromatek [4]. Because of the simple image generation, the ChromaDepth™ glasses are a low-budget alternative to other stereoscopic methods [10] for various applications and fields. Chromo-stereoscopy offers a real depth perception in comparison to other 3D visualization techniques, which just project a 3D model onto a 2D image plane.

There are two types of ChromaDepth™ glasses, standard and high definition (HD). Standard glasses are recommended for printed images and laser light shows, high definition glasses are recommended for viewing images in TV and on monitors. Standard glasses have a stronger 3D effect but also provide blurred images. High definition glasses have a lower depth perception but sharper images. Because of their properties these glasses are preferred in our information visualization application.




**a) Natural chromo-stereoscopy**




**b) Amplification with a double prism or ChromaDepth™ glasses**

**Figure 1: Principle of chromo-stereoscopy without and with amplification**

In this paper a new focus+context technique using chromo-stereoscopy and its application on graphs and multi-layer representations is introduced. The perceived depth of objects will be used to represent their relevance. Focused objects are displayed in a special color (normally red), i.e., the apparent object position is closer to the viewer as the real image plane. Objects in the context are displayed with another color, i.e., the apparent object position seems to be behind the focused objects. With chromo-stereoscopy even the distinction of several depth layers is possible. This approach is well suited to highlight information, but can also be easily combined with other methods. Animation and interaction are also supported, because of a simple and fast image generation, just a special color table and ChromaDepth™ glasses for viewing are necessary.

## 2. Related Work

There are only few chromo-stereoscopic approaches in visualization, although ChromaDepth™ glasses have been available for years. So far chromo-stereoscopy has been used to get a real depth perception of data with three spatial dimensions. Bailey et al. [2] present the application of chromo-stereoscopy to landscapes, maps, three-dimensional CAD models and models of chemical substances. Toutin [17] and Petrie et al. [9] investigate the spatial perception improvement of remote sensing data by chromo-stereoscopic color encoding of elevation variances in maps. Verwichte et al. [21] utilize chromo-stereoscopy for numerical experiments with three-dimensional data in solar physics.

There are many approaches for focus+context visualization, just a few representants are described here. The fisheye view [5] displays the enlarged focus in detail, the context is displayed with gradually less detail with increasing distance to the focus. Sarkar et al. [13] describe the application of the fisheye view to graphs. The hyperbolic browser [7] uses hyberbolic geometry to magnify the focus and to minimize the context. In the bifocal display [15] the focus is displayed without distortion whereas the context is uniformly compressed and distorted in one direction. The stretching rubber sheet approach [14] expands the interesting regions and contracts the remaining regions. Focused table entries are displayed in detail by the Table Lens [11], the rest of the data is represented through line graphs. Lokuge et al. [8] highlight the results of user queries with opacity, color and size. Less important information is displayed more transparently and also smaller in size. The Information Cube [12] is a three-dimensional focus+context method, which represents hierarchical information by nested boxes. A recent focus+context technique is Semantic Depth of Field (SDOF) [6], which displays objects in the focus sharply, whereas objects in context are displayed blurred depending on their relevance.

## 3. Highlighting with Chromo-Stereoscopy

The idea of our approach is to use several perceived depth levels. The third dimension relevance is encoded with chromo-stereoscopy in order to highlight data in comparison to its context. The position of a two-dimensional object in three-dimensional space will be used to represent the relevance of the two-dimensional object, i.e. the focus literally “stands out” from the context. For the realization every object is assigned a priority. Objects with the highest priority are in focus, whereas objects with lower priorities are in the context with increasing distance. These priorities are mapped onto apparent distances from the viewer which correspond to respective colors. Objects with higher priorities seem to be closer to the viewer, less important objects are gradually receding in the background. A color table is used, which linearly maps a priority to a perceived depth, respectively color.

The basics for the generation of chromo-stereoscopic images can be found at Chromatek [4]. The selection of an appropriate color table is one criterion for a desired depth perception. But there are also some additional contributing factors like viewing distance, background color, object size and drawing order. The perceived image depth increases proportional to the viewing distance. We used a black background and the color order RGB (Red, Green, Blue) from near to far. It is also possible to work with other background colors like white and the color order CMY (Cyan, Magenta, Yellow) from near to far. The depth perception is the same for both orders, but for the white background one has to use more unnatural and less pleasing colors (see Figure 2 and Figure 6).

The 3D effect cannot be seen with thin lines or small objects and a high resolution, so a minimum object size is necessary. It is also possible to use text, but also a minimum font size and a bold style are recommended. The drawing order has to consider hidden lines and hidden surfaces. Apparent near objects covered by apparent remote ones result in a confusing spatial perception. The human perception can be further supported by a perspective display.

With our method it is also easily possible to determine several foci, since all objects in the focus only have to have the same focus color, i.e., they have the smallest distance to the viewer.

### 3.1 Color Tables for Chromo-stereoscopy

There are only few sources to get information about the general structure of a color table for chromo-stereoscopy. Chromatek [4] lists several rules, the so-called Open CyberHolographic™ Standard, in order to create images with a desired color dependent 3D effect. It is possible to derive several requirements for such a color table from these rules, the principle of chromo-stereoscopy and other chromo-stereoscopic approaches [2, 17]. Red is always perceived to be closest to the viewer, whereas blue is always in the background, the colors in between are the rainbow colors. The RGB color model is not very helpful for these requirements. A more intuitive color model is necessary like the HSV (Hue, Saturation, Value) color model [22]. Bailey et al. [2] use the HSV color model and Toutin [17] uses the similar IHS model for their application of chromo-stereoscopy. We use the similar HSB (Hue, Saturation, Brightness) color model from Java [16].

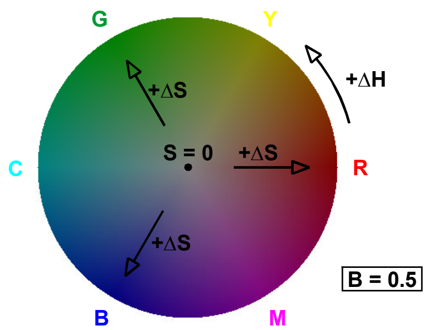



**Figure 2: HSB color model with B = 0.5**

Figure 2 shows a part of the three-dimensional HSB color model. The hue changes from red (0°) to green (120°) to blue (240°) and back to red (360°). The saturation changes from the center (S = 0.0) of the disk to the edge (S = 1.0). The brightness changes orthogonal to this disk from 0 to 1. For our color table the last third of this model (240° - 360°) will not be used, since the mixture of red (foreground) and blue (background) of these colors leads to a confusing depth perception. The three-dimensional perception of this table can be amplified by a (linearly) changing brightness. Closer objects are displayed brighter than remote ones. In some examples also a constant brightness was used. The selection of constant or variable brightness depends on the requirements. A low brightness of remote objects amplifies the distinction of depth levels, but decreases also the perceptibility of the less important context. The saturation remains constant, the other color parameters are linearly interpolated. The color table can be described as follows ($1 \le i \le n$), n is the number of entries in the color table and a smaller i corresponds to a color perceived closer to the viewer.

Hue: $$H_i = \frac{H_{\max} - H_{\min}}{n-1} \cdot (i-1) + H_{\min}$$

Saturation: $S$ const.

Brightness: $$B_i = B_{\max} - \frac{B_{\max} - B_{\min}}{n-1} \cdot (i-1)$$

The higher the assigned priority of objects the smaller the perceived distance. We used for our color table mainly the following parameters:

$H_{min} = 0$ (0°, red) and $H_{max} = 0.667$ (240°, blue)

$S = 0.85$

$B_{min} = 0.15$ and $B_{max} = 0.75$

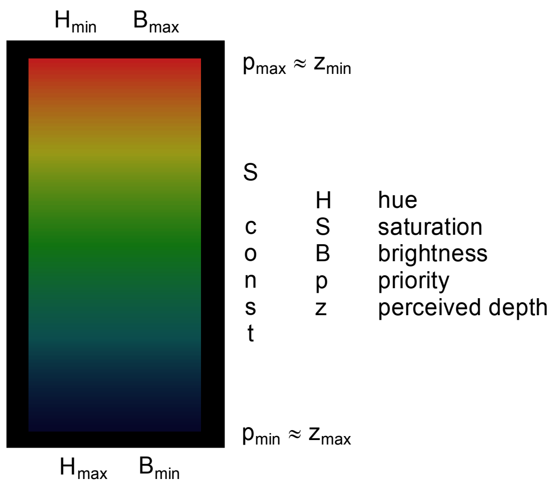



**Figure 3: Continuous color table for color dependent depth perception**

Figure 3 shows the resulting color table. For this figure a high number of color table entries was used in order to get continuous color transitions, but usually only a small number of depth levels can be distinguished. At least three depth levels can be recognized, red in front, blue in the background and a level in between. This number can be slightly increased by for instance distance-dependent object size, variable line width, or varying brightness. There are no general rules, but solutions depend on the application and need some experiments.

### 3.2 Interaction and Animation

A high number of color-table entries has no direct influence on the number of recognizable depth levels. More depth levels are important for smooth transitions between different apparent positions after an interactive priority change. We implemented a prototype for graph and multi-layer representations. In the prototype for graphs you can interactively select nodes and edges and change their priority by a slider. The prototype for layers makes it possible to select one or more layers and to change also their priority with a slider. Every change of a priority is followed by an immediate update of the display. For instance one can see moving an object from the foreground to the background, if the priority is modified. This results in a better understanding of focus and context and their changes. A fast repainting of the display is supported after a new selection of a focus, since only the color of objects changes. For an interactive usage of our approach immediate and animated updates after modifications are an essential factor. The parameters of the used color table can be always changed in order to adapt the depth perception to actual requirements.

### 3.3 Properties of chromo-stereoscopy for information visualization

The use of chromo-stereoscopy for focus+context is well-suited for many applications, but there are also some limitations.

The technique is simple and results can be calculated fast, therefore it is appropriate for animation and interaction. Chromo-stereoscopic images can also be viewed without special glasses albeit with much reduced depth perception. Stereoscopic techniques often need special hardware arrangements. With chromo-stereoscopy there is only one image necessary, other stereoscopic methods use two images from different viewing positions. ChromaDepth™ glasses are inexpensive, they cost less than 1$ per piece and are easily obtainable from American Paper Optics [1]. Depth can be perceived on monitors, on printed images, on overheads and at laser shows. Color-blind persons can also perceive depth, since with chromo-stereoscopy depth depends on the projected position of light on the retina but not on the ability to recognize colors.

A restricted assignment of colors to objects is one of the biggest drawbacks of the method. Colors are priority dependent, so it is not possible for instance to assign blue to rivers or lakes, or red to warm regions. In our approach of using chromo-stereoscopy for information visualization this is, however, not a big problem. We are primarily dealing with abstract data where pre-established color meanings are less important. Chromo-stereoscopy is not very well suited for photorealistic images or shaded objects. Continuous color changes do not always result in a desired continuous depth perception. The perceived distances are not linearly proportional to the priority respectively to linearly changing entries in the color table and a calibration is difficult. This disadvantage should be in general no important restriction for information visualization. Further it is necessary to know the distance of every object to the observer, which is no problem for our approach, since we use two-dimensional objects and the depth is determined by their priority. For other applications the determination of explicit depth information might incur difficulties and expensive calculations.

## 4. Applications

This chapter illustrates several results of our technique. Only slight 3D effects are recognizable without glasses, but ChromaDepth™ glasses are required to see the impressive focus+context properties of chromo-stereoscopy.

### 4.1 Graphs

One can use our method for the exploration of two-dimensional graphs. It is possible to highlight for instance graph relevant functions like subgraphs, spanning trees or interesting paths in a focus+context manner. Nodes which fulfull desired criteria are shown highlighted in the focus, the rest of the nodes are in the context. An example is shown in Figure 4.

### 4.2 Multi-Layer Representations

The use of layers is helpful for instance for geographical data (Figure 6) or technical drawings (Figure 7). In modern plans a high number of hardly distinguishable layers is used. With our method it is simply possible to focus only on the interesting layer like public transport, hospitals, drugstores and so on. A method just with colors, e.g. our results viewed without special glasses, works only with few non-overlapping data. With an increasing amount of data a reasonable distinction between different layers is not possible (Figure 6). Our method in combination with ChromaDepth™ glasses moves the layer of interest closer to the viewer, so an adequate distinction between layers is possible.

The layer approach can also be used in order to visualize the segmented part of three-dimensional medical data. The whole data is shown in context, whereas segmented partion is displayed as focus in the foreground. This application can be used for a virtual medical showcase to show different organs highlighted, e.g. for medical education (Figure 5b and 5c). Figure 5a shows a traditional usage of chromo-stereoscopy where three spatial dimensions are encoded. Figure 5b and 5c on the other hand show two spatial dimensions. The third, importance dimension is used for selected features (in this case vessel trees), which are highlighted and “stand out” as compared to the background context information.

### 4.3 Other Applications

It is possible to combine chromo-stereoscopy with other focus+context approaches. The application of chromo-stereoscopy just highlights the information depending on its priority, but it is often necessary to increase the detail of the focused objects and to decrease the detail level in the surrounding context. A space-efficient representation of hierarchical data can also be used from other approaches. Therefore it is advicable to control the size and the arrangement of objects with techniques like fisheye views [5, 13] or stretching rubber sheet [14]. The color of objects is selected priority dependent to achieve a strong chromo-stereoscopic effect. This combination would simply improve the distinction of focused objects and objects in the context.

## 5. Conclusion and Future Work

A new focus+context approach was introduced, which utilizes chromo-stereoscopy in order to spatially highlight information. We used the third dimension to encode the relevance of two-dimensional abstract data. The perceived apparent distance of objects to the viewer depends on their color. The chromo-stereoscopy phenomenon is amplified with inexpensive and easily obtainable ChromaDepth™ glasses, which results in a good depth perception. It is also possible to use several foci. The main contribution of this paper is to show that chromo-stereoscopy can be used advantageously for information visualization. Previous usage of chromo-stereoscopy concentrates on visualizing three spatial dimensions. In our case we visualize 2D abstract data. The third dimension (encoded in color) specifies the importance of objects. With chromo-stereoscopy important objects in focus “stand out” as opposed to the surrounding context.

We applied this technique on graphs and representations with several layers like plans or segmented medical data, but it can also be easily combined with other focus+context methods in order to benefit from both. Further information, results and animations can be found at the page http://www.cg.tuwien.ac.at/research/vis/infovis/chromadepth.

Application examples for our technique are: layered abstract information (e.g. drawings); graph data with interactive exploration of various properties; virtual showcases with cheap 3D effects; medical illustrations, where different segmented objects in a 2D representation might be successively moved to the foreground; explosive views of complex machinery.

## 6. Acknowledgements

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## 7. References

[1] American Paper Optics, Inc., Memphis, Tennessee, http:\\www.3dglassesonline.com.

[2] Bailey, M., Clark, D., "Using ChromaDepth to obtain Inexpensive Single-image Stereovision for Scientific Visualization", Journal of Graphics Tools, Volume 3, Number 3, 1998, pp. 1 - 9.

[3] Card, S. K., Mackinley, J. D., Shneiderman, B., "Readings in Information Visualization", Morgan Kaufmann Publishers, 1999.

[4] Chromatek Inc., http:\\www.chromatek.com.

[5] Furnas, G. W., "The FISHEYE View: A New Look at Structured Files", Bellcore, 1981. Reprinted in [3].

[6] Kosara, R., Miksch, S., Hauser, H., "Semantic Depth of Field", Proceedings Information Visualization 2001, 2001, pp. 97 - 104.

[7] Lamping, J., Rao, R., "The Hyperbolic Browser: A Focus+Context Technique for Visualizing Large Hierarchies", Journal of Visual Languages and Computing, 7(1), 1996, pp. 33 - 55. Reprinted in [3].

[8] Lokuge, I., Ishizaki, S., "GeoSpace: An Interactive Visualization System for Exploring Complex Information Spaces", Proceedings CHI '95, 1995.

[9] Petrie, G., Toutin, T., Rammali, H., Lanchon, C., "Chromo-Stereoscopy: 3D Stereo with Orthoimages & DEM Data", GeoInformatics, Vol. 4, No. 6, 2001, pp. 8 - 11.

[10] Petrie, G., "3D Stereo-Viewing of Digital Imagery", GeoInformatics, Vol. 4, No. 10, 2001, pp. 24 - 29.

[11] Rao, R., Card, S. K., "The Table Lens: Merging Graphical and Symbolic Representations in an Interactive Focus+Context Visualization for Tabular Information”, Proceedings CHI '94, 1994, pp. 318 - 322. Reprinted in [3].

[12] Rekimoto, J., Green, M., "The Information Cube: Using Transparency in 3D Information Visualization", Proceedings of the Third Annual Workshop on Information Technologies & Systems (WITS '93), 1993, pp. 125 - 132.

[13] Sarkar, M., Brown, M. H., "Graphical Fisheye Views of Graphs", Human Factors in Computing Systems, CHI '92 Conference Proceedings: Striking A Balance, ACM Press, 1992, pp. 83 - 91.

[14] Sarkar, M., Snibbe, S. S., Tversky, O. J., Reiss, S. P., "Stretching the Rubber Sheet: A Metaphor for Viewing Large Layouts on Small Screens", Proceedings User Interface Software and Technology (UIST) '93, 1993, pp. 81 - 91.

[15] Spence, R., Apperly, M., "Data base navigation: an office environment for the professional.", Behaviour and Information Technology, 1(1), 1982, pp. 43-54. Reprinted in [3].

[16] Sun Microsystems, Java Development Kit (JDK), http:\\www.javasoft.com

[17] Toutin, T., "Qualitative Aspects of Chromo-Stereoscopy for Depth Perception", Photogrammetric Engineering & Remote Sensing, Vol. 63, No. 2, 1997, pp. 193 - 203.

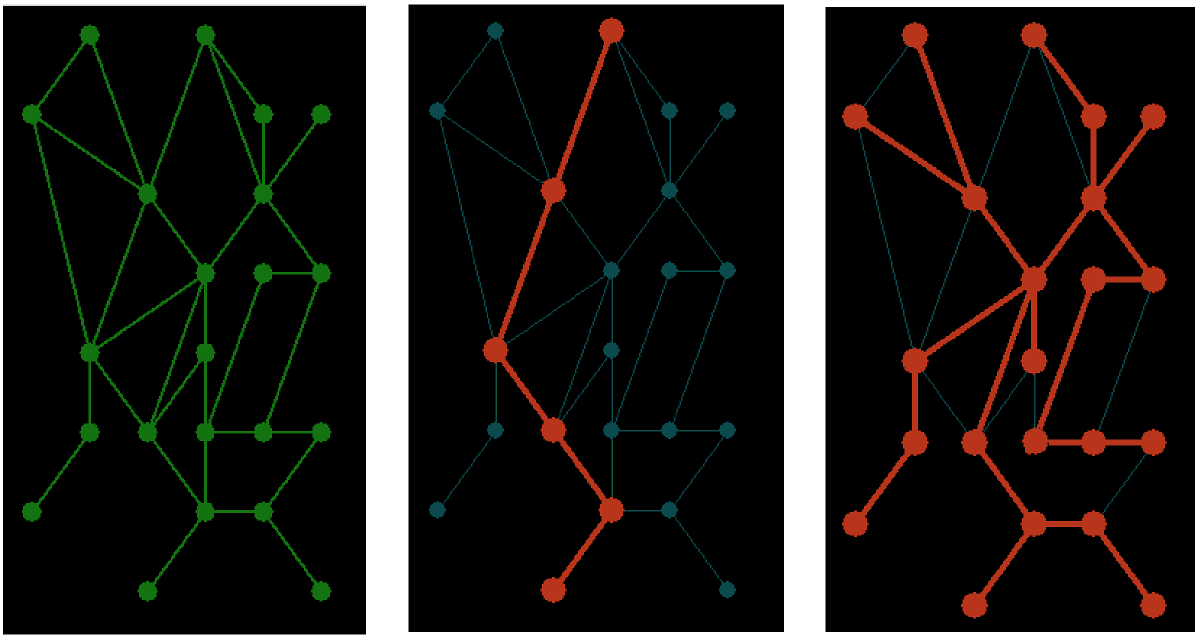
[18] Tufte, E. R., "Envisioning Information", Eighth Printing, June 2001, Graphics Press, 1990.

[19] Ucke, C., "3-D Vision with ChromaDepth Glasses", Proceedings of ICPE(International Commission on Physics Education)/GIREP(Groupe International de Recherche sur l'Enseignement de la Physique) conference 'Hands-On Experiments in Physics Education', 1998.

[20] Ucke, C., Wolf, R., "Durch Farbe in die 3. Dimension", Physik in unserer Zeit 30, No. 2, 1999, pp. 50 - 53.

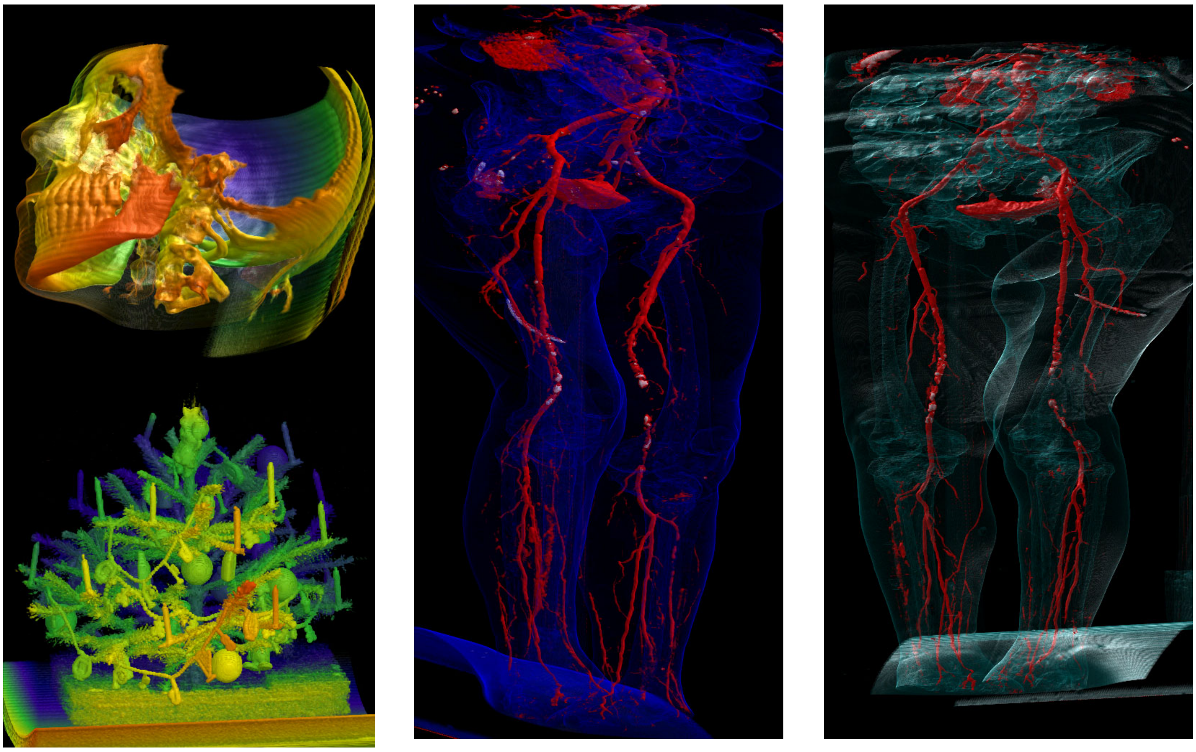
[21] Verwichte, E., Galsgaard, K., "On the visualization of three dimensional datasets", Solar Physics, 183, 1998, pp. 445 - 448.

[22] Watt, A., "3D Computer Graphics", Third Edition, Addison-Wesley, 2000.



a) b) c)

Figure 4: a) A random undirected graph. b) Shortest path between two nodes. c) Spanning tree of this graph.



a) b) c)

Figure 5: Chromo-stereoscopic color coding applied to medical data and a christmas tree.
a) A head and a christmas tree are shown. Depth information is encoded by color (3 spatial dimensions). b) and c) In red color the vascular tree (focus) of the peripheral arteries of the abdomen and the lower limbs (context) is shown. Relevance is encoded in color (2 spatial dimensions, 1 importance dimension).

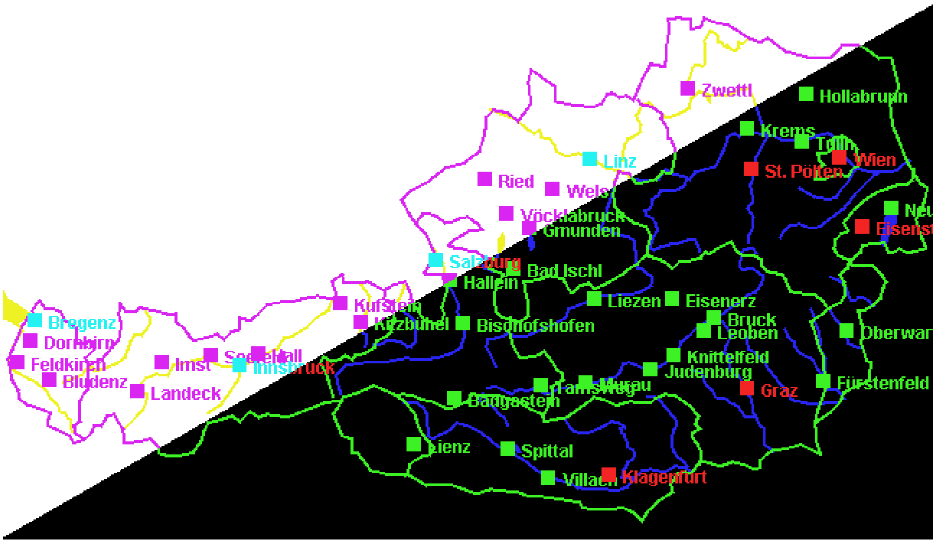



**Figure 6: Map of Austria with 3 layers. The left side uses the color order CMY with white background, the right side uses the color order RGB with black background. The focus are the capitals of the federal states (cyan/red). The border, the inner borders of the federal states and non-capital cities are in the context with medium priority (magenta/green). The third layer are rivers and lakes with a low priority (yellow/blue). A constant line width and brightness were used. The layers provide the same depth perception in both image parts!**

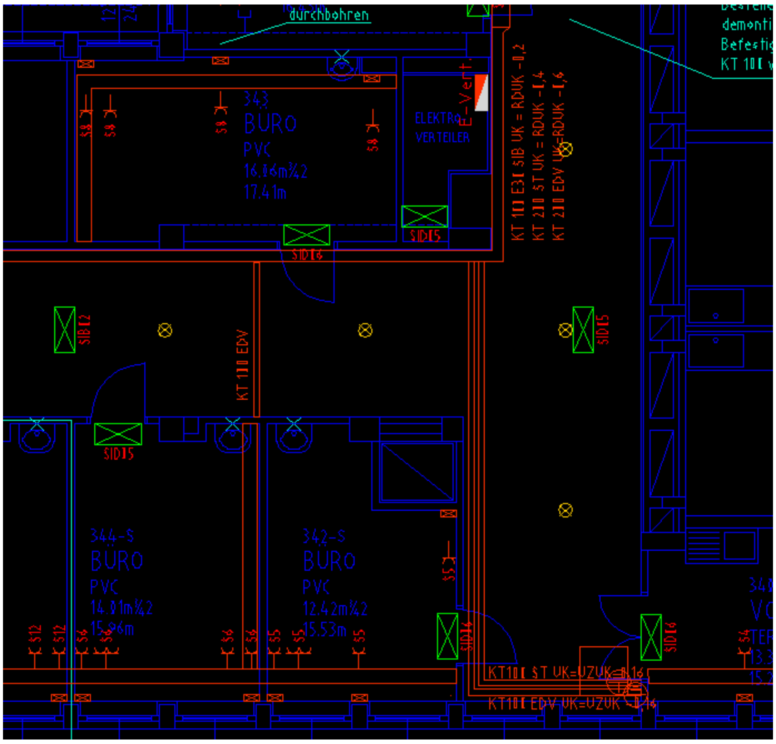



**Figure 7: In the background, blue, a floor plan with utilization information for each room is shown. In the middle layer lights for escape routes in green, and annotations in cyan can be seen. The power outlets, cable conduits and annotations in the red foreground make the supply structure easily perceiveable.**