Aesthetics in Information Visualization

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Abstract— The importance of visualization in conveying knowledge is undisputed. For example, the rise and fall of stocks is processed and understood faster by examining the corresponding line graph than looking at the raw underlying numbers. For the effectiveness of this cognitive process several factors have been identified in research, like for example the background knowledge, as well as its inherent aesthetics qualities. This text focuses on the latter. It has been argued that the higher the aesthetic value of the visualization is, the more engaged the viewer is in trying to decode its meaning. But what does "aesthetics" mean? Does an informative graphic have to be artistic to be effective? Since the perception of aesthetics is a highly subjective matter, what kind of effort should be put into creating a visualization? What connections between aesthetics and information visualization exist anyway? These questions are the subject of the following text. It starts with an introduction to the relevant terms and subfields of aesthetic information visualization research. It then proceeds with a discussion of several examples of information visualization that were created with a strong aesthetic concern. Since these results often resemble works of art, finally their artistic value is debated.

Index Terms—Information, Visualization, Aesthetics, Art

1 Introduction

Our society is defined by information. Every day we create vast amounts of data and transport them through many channels of telecommunication. In order to process the vast amount of data we rely on the power of visualization. With graphs we are able to gain insight in the data, by detecting patterns and trends and are able to check and verify the data.

As computers have become ubiquitous, so has the display of computer-generated and processed data.

Technological advancements in display technology have contributed to that development. The price of liquid crystal displays has fallen dramatically over the last years and even LC- and DLP projectors are affordable to many households. In the near future we can expect technologies like organic displays and E-ink based displays with advantages like less power consumption, less noise, richer contrast and colors and more.

> "The purpose of visualization is insight, not pictures."[28]

As true as this statement is, there has been a rising interest in creating visualization that should have an aesthetic quality. More and more people are able today to create visualizations that are more than bar and pie charts out of MS Excel data.

Software like Adobe *Flash* and the programming environment *Processing* are targeted at the designers with little programming experience and facilitate the process of creating a graphic representation.

Cheap hardware, easy-to-use software tools, growing internet communities and the availability and democratization of data[35] have all contributed to the fact that creating visualizations is as easy as never before.

But are these all *good* visualizations? By what means can the quality of a visualization be measured anyway? Edward Tufte discussed that matter already some 20 years ago in his groundbreaking book *The Visual Display of Quantitative Information*[33].

Aesthetics has been found as an important aspect. Several works of research propose that "enhancing the artistic merit of a visualization can result in a more effective and more productive visual analysis."[31]. There is more to the display than efficiency of communicating data. Visualizations can also be used to convey cultural and social messages and concerns.

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- *This research paper was written for the Media Informatics Advanced Seminar on Information Visualization, 2008/2009*

The following text presents an overview of the aesthetic and artistic aspects in information visualization. It first provides an overview of the terms *aesthetics*, *art*, and *information visualization* and then tries to combine them by explaining different models of information aesthetics that have been identified in previous literature. Several subfields with different aims and aspects are presented, namely *Artistic Information Visualization* and *Ambient Information Visualization*. Ambient Information Visualization is about making the display of information more *humane* and integrative to our lives. Several examples of information visualization with aesthetic or artistic concern are discussed. Finally the implications of Aesthetic Information Visualization on art and vice versa are explored.

2 Overview

2.1 Information Visualization

Information visualization is defined as the graphical representation of abstract data. It therefore differs from scientific visualization which visualizes real-world phenomena, like the human body or the flow of air[17]. Several key criteria for an information visualization have been proposed[17]:

- The data are external, that is they were not generated by an algorithm within the visualization program
- The source data are not an image itself
- The graphic must be readable, that is the viewer should be able to transfer the graphic representation back to the underlying values, (that process may require some learning effort, though)

In terms of intended aim two modes can be identified: exploratory and expository aim of use. If the visualization is used to explore the dataset, that is find new hypotheses, then the visualization should display the dataset in its entirety and offer interactivity by zoom and filter mechanisms. If the visualization has the aim to expose a certain issue, then interaction is often limited and only the data necessary to convey the intended message is represented. What qualities should a good visualization have and how can it be qualified? Traditionally, the value of information visualization is measured by how efficiently and effectively knowledge is conveyed [34].

> "Effectively designed visual representations facilitate the understanding of complex phenomena by selectively emphasizing the most important features and relationships while minimizing the distracting effects of extraneous details." [26]

The graphic should present the information in a way that catches the viewer's attention, facilitates reading of the data and enables the user

to detect underlying patterns and trends. The key purpose of the graphical representation is thereby to enhance cognition by offloading "the mental internal representations onto an external medium to relieve the cognitive burden and speed up processing." [32] Although several guidelines exist, research strives for a better understanding of the creation of an efficient visualization.

2.2 Aesthetics

What is aesthetics? How is it defined and how can it be measured? No definite answer can be given, in fact these questions have been the topic of philosophic discussions since the 18th century. Kant, Adorno, Goodman, and many more elaborated on aesthetics and its role in society. The term "aesthetics" is well known in everyday-speech and we use it to refer to anything visually beautiful and pleasing our eyes. Aesthetics has been termed as "the measurement of beauty"[27]. Although aesthetics is not only about beauty or vision but of the stirring of any combination of the senses that causes pleasure in the viewer. Beauty has been regarded "as one of the many facets of an aesthetic experience" [8] with other key components being pleasantness, emotions and satisfaction[27]. It has been defined as "pleasurable subjective experience that is directed toward an object and not mediated by intervening reasoning."[24] Studies in perceptual psychology have identified several views on the aesthetic experience[24]:

- The *objectivist view* regards beauty as an imminent property of an object that produces a pleasurable experience to any viewer. Several features are thought to contribute to it and determine it, like symmetry, balance, complexity, figure-ground-contrast and more. For example a symmetrical object would be more beautiful than an asymmetrical one.

- The *subjectivist view* holds that anything can be beautiful, all depends on the viewer and his cognitive and cultural background.

Another view considered more modern is a combination of the previous two. It has been proposed "that beauty is grounded in the processing experiences of the perceiver that emerge from the interaction of stimulus properties and perceivers cognitive and affective processes."[24] The perception of beauty can therefore be explained as function of how fluently a viewer can process an object. Important are hereby the two phases of recognition that have been identified[10][36]:

- The *preattentive phase* denotes the low-level process that happens before the conscious attention and that processes sensory information and

- the *interpretative phase* that processes arbitrary information, that is representation that must be learned, for example the appearance of a word like "dog" has nothing to do with the appearance of the animal[36] or the metaphor color (red as hot/dangerous, green as safe, blue as cold)[6]

Aesthetics therefore has also been described as the "combination of cognitive and sensory modes of experience [..]"[8]. Several cognitive aspects have been proposed and examined, for example in graph design, symmetry, relations according to the Golden Ratio and a minimal number of bends and edge crossings are desirable[8][4]. A minimum of complexity is strongly favoured by E. Tufte. He rejects the use of "chart-junk", that is, elements in a graph that do not convey data. Other researchers argue, based on empirical testing, that the minimal designs are not the preferred ones, thereby indicating a lower aesthetic appreciation[12].

Above guidelines are only hints to follow while creating a visualization. Some like the Gestalt principles can be based on the very human perception. But in the end the highly subjective nature of aesthetic assessment renders it impossible to create a definitely measurable result that is equally appreciated. Integrating aesthetics in information visualization is yet one of the ten most important unresolved questions in this field[3].

So why is aesthetics an important factor in information visualization? Aesthetics has been identified as a key factor to engage a viewer[31]. Once the viewer is analyzing the graphic, it has been shown that a correlation exists between latency in task abandonment and erroneous response time (that is the time until a false information is extracted) in relation to the perceived aesthetic of visualizations [2]. Therefore the more aesthetically a graphic is perceived, the longer the viewer will try to decode the meaning of it or extract a certain information.

2.3 Art

In this section the relation between aesthetics and art is examined. Aesthetics has been termed as the theory of art, as a "critical reflection on art, culture, and nature"[14]. These terms are not to be used interchangeably:

> "Aesthetics is concerned with the theory of sensual perception, while art is a social practice involved in certain forms of research and investigation processes and in the construction of particular types of artifacts." [23]

The aesthetic pleasure, that is the perceived beauty is not be be confused with the aesthetic value. A beautiful object may have little or no aesthetic value: it does not provoke thought or create a new view on culture or society. Accordingly, an object may have aesthetic value without producing aesthetic pleasure [24]. The "subversive and questioning power may act as a substitute for the pure beauty to rate the quality of art."[21].

3 Aesthetic Information Visualization

This section brings the previous sections of information visualization, aesthetics and art together and examines the implications.

Following framework has been created for an assessment of the comprehension of an aesthetic information visualization[30]:

- *That* data are visualized, that is the display is recognized as a visualization, not just as a decorative picture.

- *What* is being visualized, e.g. weather, e-mail traffic, etc.

- *How* to read the visualization, e.g. which metaphor within the visual denotes what

Only if all three criteria are clear to the viewer the visualization is of use to the viewer as information visualization.

It is possible, though, that the data is not readable anymore by the viewer, that is the purpose of the display is not to communicate information but it only uses data to create the picture. This is for example the case in the visualization of music, popularized by the *Winamp* media player [1].

Based on these qualities, aesthetic information visualization therefore can be placed on a continuous scale, ranging from *readable* and *recognizable* and *not readable* and *not recognizable*[17].

Another, more exhaustive model has been created, based on different quantities: According to this, information aesthetics can be placed on a continuous scale based on artistic intentions and interpretative engagement with the extremes of *functional information visualization* (little aesthetic concerns) and *information art* (high aesthetic concerns)[19].

The contrast in their aims and attributes is explained with *Figure 1* displaying a functional representation of stock market data and *Figure 2* displaying an artistic visualization of the same data:

- *Objectiveness vs. subjectiveness*: *Figure 1* is an objective portrayal of facts. It is universal and not based on a personal, subjective point of view. It has been argued, though, that true objectiveness or neutrality is in fact impossible since every visualization is a form of distortion. [35]

[1] `http://www.winamp.com/`

Fig. 1. Market Maven, from the company Ambient Devices.[23]

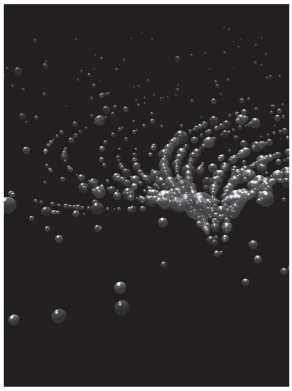

Fig. 2. Kamila B. Richter and Pavel Němec, I Deal Solution, 3D visualization and sonification application, 2005–2006 [23]

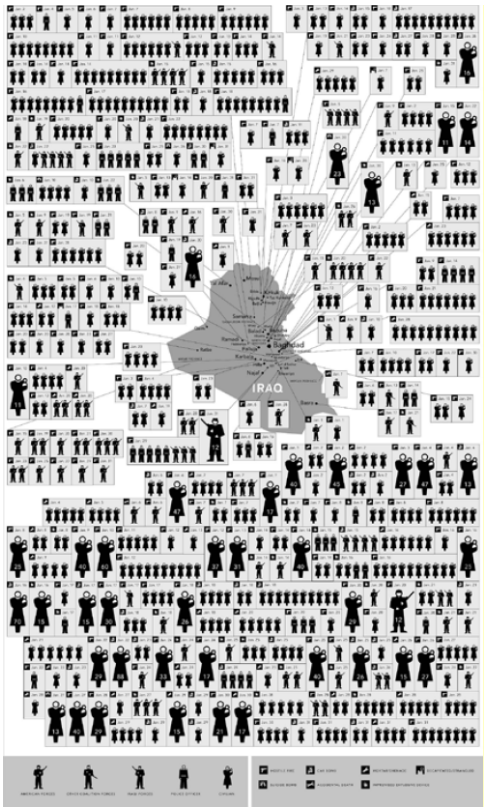

Fig. 3. Adriana Lins de Albuquerque and Alicia Cheng, Iraqian civil losses during January 2007 [5]

- *Obscuring vs. revealing information*: With *Figure 1* the viewer is able to draw conclusions from the underlying data, whereas *Figure 2* does not allow this. With *Figure 2* not only the underlying values are unclear but even the fact it is a visualization of data.
- *Analysis vs. Emotion*: *Figure 1* is task- and usability-oriented. Emphasis is placed on the efficient transfer of knowledge (that is stock market data). *Figure 2* invokes curiosity and interest because of the enigmatic quality.

3.1 Artistic information visualization

Often when placing emphasis on the aesthetic aspect, the sublime component is very important. It is thought to invoke feelings of awe and inspiration on the viewer. On the one hand, the graphic can be left intentionally ambiguous and thereby open for interpretations. On the other hand, the creator of the visualization is able to communicate a concern by displaying the data in a way a certain trend is made clear or a message is conveyed. It is then more important for the viewer to understand the concern instead of being able to read the data [17][23] The creator can form a statement[35] with strong implications on society and culture. *Figure 3* was displayed in the New York Times in February 2007. It illustrates the deaths of the Iraqi civilians in the month of January. While there would certainly have been a more effective way to show the names or numbers, by this means the immense extend of losses is communicated as an accuse.

> "The task of artistic information visualization is not to resolve but to question or restructure issues pertaining to a topic in a manner that is not possible through any other means, medium or cultural artifact.."[23]

An artistic visualization is therefore defined by the artist's intention to create a work of art [18] [35] and does not have to be beautiful to be artistic [35].

3.2 A model on information aesthetics

A recent publication has identified two dimensions for information aesthetics[19]:

- *Mapping Technique* represents the methods by which the visualization was created
  - Direct: the viewer is able to infer the underlying data.
  - Indirect: the viewer is not able to infer the underlying data, that is the graphic is interpretative.
- *Data Focus* represents what is communicated by the graphic.
  - Intrinsic: the graphic facilitates the insight to data by cognitively effective means. The graphic could be considered as a mere tool for analysis.
  - Extrinsic: the graphic facilitates the communication of meaning implied by the data.

Several data visualizations with artistic concern have been arranged according to the their perceived focus on each of the dimensions (see *Figure 4*). It has been observed that a correlation between the mapping technique and the data focus exists: the chosen mapping technique often determines the data focus and therefore resulting in a continuum of information aesthetics between information visualization and information art (see *Figure 5*).

3.3 Ambient Information Visualization and Informative Art

The research field of ambient visualization is closely related to information aesthetics. Ambient visualization researchers try to integrate the display of information in a non-obtrusive, almost unconscious way into our environment. The premise is that in order to communicate non-critical information users should not have to actively search for and stare at a computer screen. Instead, information could be encoded

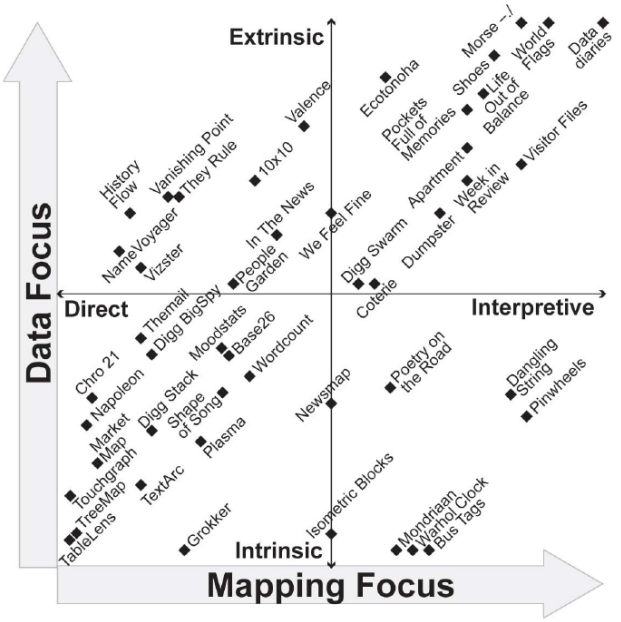

Fig. 4. The proposed model of information aesthetics with *Mapping Technique* mapped on the X-axis and the *Data Focus* mapped on the Y-axis [19]

into things that surround our public or personal daily life: physical elements of architecture or art objects. The off-screen attribute is in fact a criterion for a subfield of ambient information visualization termed *informative art*.

Like a painting the user should be able to hang a display on his living-room wall that tells him, for example, stock market data. The attractiveness is therefore an important factor for the acceptance of these objects. To facilitate this acceptance the metaphors of information that are displayed are often not designed from scratch but based on well-known artistic styles, which creates "art" works that are augmented by information that are interesting to us, therefore termed *amplified* or *augmented art*. [25].

The visualization thereby does not have to be a flat image, physical sculptures with tangible quality have been introduced, too. [20]

Following premises should be considered when designing an ambient visualization: If the display is to be non-distractive, information must be conveyed "at a glance"; the complexity of the data is to be

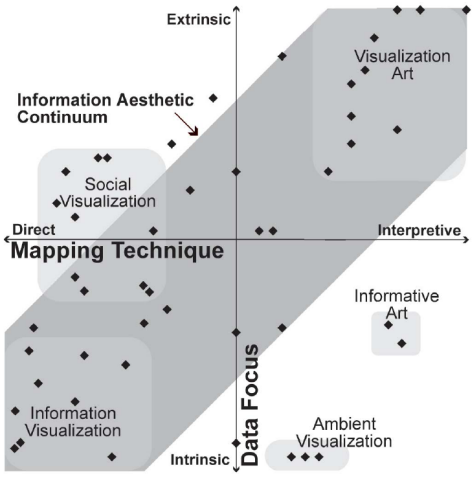

Fig. 5. The various subfields of information aesthetics, [19]

kept simple. Possible quantities to be displayed are mass (e.g. the number of e-mails), growth (e.g. stock market index) and flow (e.g. ratio of incoming vs. outgoing e-mails) [25].

It is often not possible or desirable to display exact numerical values. Therefore the visualization should only present an overview of the data or show trends. [11] And finally, the visualization application has to update the data itself, probably in a regular interval. The interval should be high enough, otherwise a rapid change would appear as animation and would distract the user. It is possible to integrate a slow interpolation between two consecutive values.

Unlike in artistic visualization, ambient visualization systems do not convey meaning beyond the visualized data, they are not to be used to communicate a concern for a certain agenda.

A taxonomy for ambient displays was introduced based on the four dimensions [22]:

- *Information capacity*: holds the number of sources of information conveyed by the visualization.
- *Notification level*: The "designer-intended level of alert" [22] measures how distractive the visualization is. Does the visualization demand for attention e.g. through animation, flashing or blinking or does it blend into the environment?
- *Representational fidelity* represents the degree of how much the graphic metaphor abstracts the underlying data.
- *Aesthetic emphasis* represents perceived importance of the artistic intentions behind the visualization. Does the design follow the style of a certain artist or art movement?

Figure 6 shows the ranking of 19 ambient visualization systems according to aforementioned dimensions.

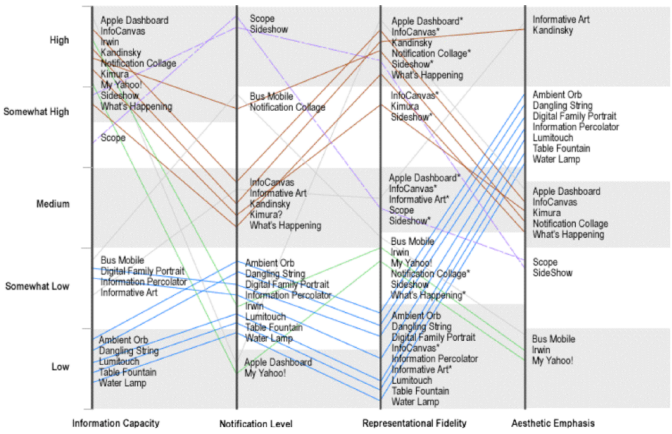

Fig. 6. Parallel coordinate plot of 19 existing ambient information systems across four design dimensions. [22]

Most ambient visualization systems are designed in a fixed way according to the perceived aesthetic of the designer. The effect is evaluated but the aesthetic considerations that went into the design are often not made clear [11]. Some hold that since the perceived aesthetics is so important for the acceptance and appreciation of the display, the user should be integrated in the design process. The user should have full control over which metaphors are used for the display of information and therefore several scientists try to create a system that allows full customization [7].

In ambient visualization research, several additional uses and effects have been examined. Ambient systems have been used as a means for informal communication where, for example, users in a work environment are made aware of the activities of their colleagues [25]. The monitoring of people's activity has also been examined in the *Activity Wallpaper* project [29] that observed the guests of a public café over the time of a week and displayed the number of visitors at

a certain time of a day, therefore providing insight about peak-hours, people's habits etc.*(see Figure 7)*.

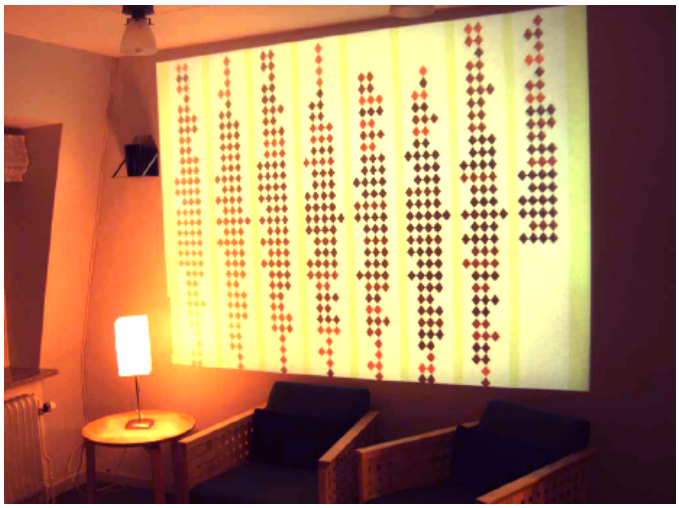

Fig. 7. A projection of the Activity Wallpaper: each day of the week is mapped to a column, each timeslot is mapped to a row, the amount of people is mapped to the amount of symbols [29]

Works by Skog et al. [11][30] examined the display of bus arrival times and global weather reports. They used the style of Piet Mondrian to create the visualization, encoding information in the color and size and position of the rectangles *(see Figure 8)*.

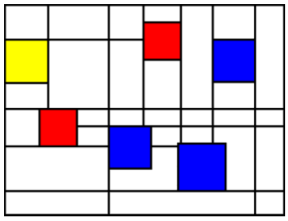

Fig. 8. A visualization of the current weather in six cities around the world: Los Angeles, Gotheborg, Tokyo, Rio de Janiero, Capetown and Sydney. Cities are represented by rectangles, weather is represented by color (red: cloudy, blue: rain- or snowfall, yellow: sunny) [30]

Kosara criticized that these mappings were not easily comprehended, as well as even the fact that the image underlay data [16].

Another use of ambient information visualization has been proposed: persuasive ambient visualization. Like the film *An inconvenient truth* by which the viewer is expected to think about his attitude towards environment, these displays aim to encourage their viewers to change their behaviour or their belief. It was proposed that a display within a shopping environment that showed how many local products were being bought in comparison to foreign products, would encourage clients to buy more local products [20]. The success is debatable. Several ethical issues are raised as well. There is a certain danger of manipulation that should not be neglected, since ambient displays are meant to be perceived almost unconsciously. Also the aforementioned activity monitoring of public spaces is not uncritical, privacy concerns are raised if cameras are used to survey the people [25].

4 Examples

This section presents three examples of visualization projects that were created with an aesthetic concern in mind or involved art practices.

4.1 2D-Fluid Flow, Supernova

Traditional art has been an inspiration for the visualization technique used by Kirby et al. [15] and Tateosian et al. [31].

They use the idea of various layers of paint where underlying layers shine through at certain places on the canvas to construct their visualization that is able to convey multivariate data. The metaphor of brush strokes is used to create the painterly rendering style. Different data dimensions are encoded with different brushes.

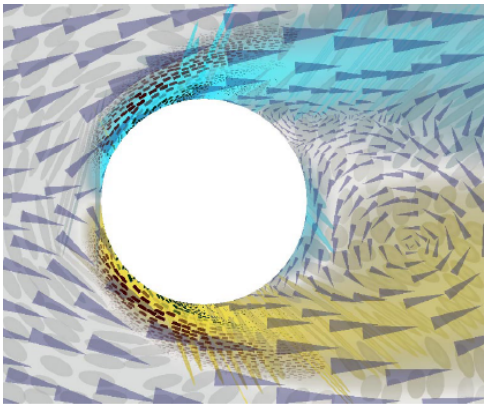

Fig. 9. Visualization of 2D flow hitting a cylinder [15]

Figure 9 shows a scientific visualization of air flow hitting a cylinder in which a total of nine quantities like velocity or vorticity are encoded with different stroke features like shape, color, transparency and orientation. Different layers of brush strokes shine through.

Another idea borrowed from traditional art is the varying degree of abstraction to eliminate unimportant distractions. Higher details are displayed in areas of importance[31]. That aspect is made visible in *Figure 10* in which homogeneous regions receive less detailing than in areas that represent a high data frequency.

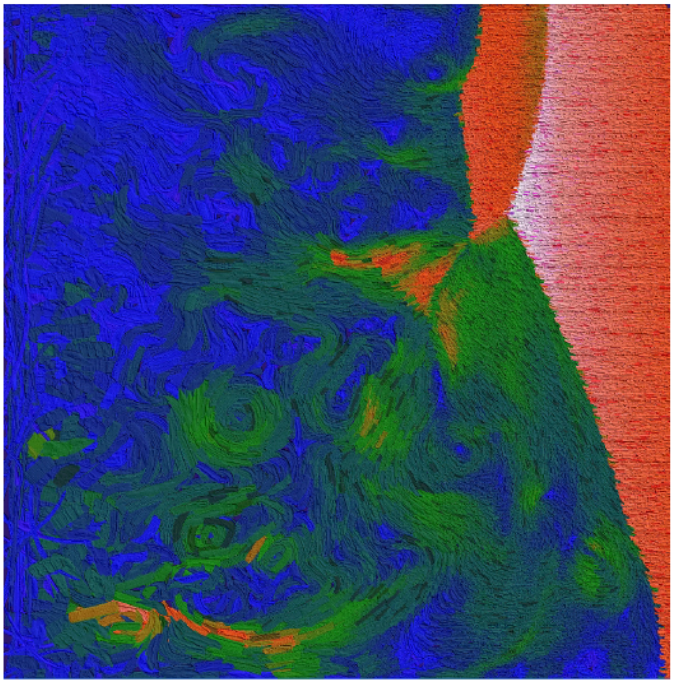

Fig. 10. Visualization of the dataset of a supernova, with Δx and Δy mapped to orientation, magnitude mapped to color, density mapped to size, pressure mapped to aspect ratio. [31]

4.2 Valence

Ben Fry, the author of the popular *Processing* programming environment[2], has created a set of different visualization projects. One of it is called *Valence*, a project to examine huge datasets and the relations embedded within the data. It is described on his website[3] and was used for the visualization of the human genome in the *Genome Valence* project[4], of websites and even ordinary text. The data is presented in 3D and can be interactively turned around and viewed from different angles.

Fig. 11. Valence by Ben Fry, Comparison of Wittgenstein and Goethe at Ars Electronica, 2001 [9]

Figure 11 shows the text version that was exhibited at the Austrian *Ars Electronica*, comparing texts by Wittgenstein and Goethe. The text version reads any input text, and as it reads a new word, it is added to the visualization and connected with the previous through an arc. The words are aligned within the volume of an invisible sphere where the more often a word appears in the text, the further away from the center it is pushed.

The result is a striking visualization of a net of interconnected words, slowly growing in size and complexity; not only beautiful but useful in providing information of relationships and frequency of occurrence, thereby exposing trends in the data.

5 Is it Art?

The mass of new technologies and visualization is viewed sceptically not only by traditional artists [23]. Many fear the dilution of the perception of arts and have criticized that many people make the mistake of the

> "extraction of still images from a moving or interactive screen with the intent of positioning the stills within an art context based on a rather naïve notion about art that sees such a discipline as a marketable exchange of "aesthetic" pictures."[23]

Some researchers do not consider the resulting visualization as art since they have no artistic training themselves and have borrowed the style of finished and established traditional art [11][8]. Others yet do so within the following concept of art:

> "We believe that art needs to engage the users intuition, and that it should allow a person to experience something new. Both of the systems described in this paper achieved this, but in significantly different ways."[1]

[2] http://processing.org
[3] http://benfry.com/valence/index.html
[4] http://benfry.com/genomevalence/

Yet art is more than the final resulting image: Depending on the perspective, one can regard visualization as a technology (therefore a task-oriented "tool"), a science or art itself [34]. In the latter case, the whole process of creating a visualization is considered as art, defined by the thought and ideas that went into it. In traditional art that notion has been termed *concept art*, defined by the fact that the idea is more than the final product [8]. This concept is mirrored in the term *Research Art* coined by Gaviria [23]. Like science, artistic visualization should collaboratively investigate new ideas and strive for an innovative art that is beyond decoration.

Many researchers demand a collaboration between artists, designers and scientists [13]. The aim is to integrate science and art as flawlessly as Leonardo da Vinci did. Therefore artists and scientists have come together in interdisciplinary, so-called "renaissance classes" [17][15] for the exchange of ideas.

Several other research fields have absorbed this idea of integration. *Aesthetic Computing* commits to the appliance of art practice to computing [8], and *Algorithmic Art* discovered the use of computer algorithms and programming languages to create art[13].

It has been argued that visualization can learn several things from art. For a better understanding of visualization it is necessary to establish a profession of aesthetic criticism with academic credit like it is done in arts[23]. A basis, that is language and theory, has to be developed in order to be able to discuss the quality of work that is partly subjective [17]. Kosara has therefore launched a website on which constructive criticism of informative graphics is published[5].

6 Conclusion

This text has given an overview of the many different perspectives on aesthetics in information visualization. It has shown that beauty of a visualization is not equal to its artistic quality, and that aesthetics is more than "pretty pictures". Aesthetics has to be recognized as not just being a by-product of science (for example like all these nice images of mathematic fractals) but an integral part of science.

Further reading and up-to-date results from information visualization research are provided by the blogs by Andrew Moere[6], Christian Schmidt[7] and Manuel Lima[8].

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