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A study on textures and their perceptual visual dimensions as application for flexible and effective scientific visualization

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Abstract

The use of textures is fundamental in several areas of Computer Graphics, Computer Vision and Image Processing. In this work, we focus on their main relevant attributes, in order to define and design textures as effective visual representations for use in scientific visualization. We concentrate on the problem of visualizing complex multivariate and multi-dimensional datasets as well as in synthesizing multi-fields and temporal evolution of vectorial datasets visualization. Textures features, such as directionality, color and shape are particularly suited for use in a synthesis algorithm, and they serve as effective seed primitives, which can incorporate many visual dimensions for intuitive and flexible data mapping and encoding. As special application, we propose a level-based visualization approach, with a special focus on systematic layering of information for scientific datasets.

Categories and Subject Descriptors (according to ACM CCS): I.3.3 [Computer Graphics]: Picture/Image Generation

1. Introduction and motivation

Texture synthesis and analysis play a crucial role in CG and many further disciplines. They are fundamental in image processing and scientific visualization, and their study draws increasing attention in the scientific community. In this paper, we propose the use of textures as expressive instrument for visualization. We particularly focus on the various features that characterize textures, as they can confer adaptability, flexibility and generality to image-based visualization techniques. A very significant point, which has not yet been deeply investigated, is the interdisciplinary of this research field and, consequently, the correlation between computer science and perceptual theories. In this work, we are also interested in defining and designing effective visual representations, being several textures attributes relevant to convey information. Effectively visualizing the given information is a fundamental issue, as data need to be analyzed and interpreted, and information has to be extracted and understood. One of the main problems in visualization is that our ability to collect data is increasing at a faster rate than our ability to analyze it. Also, tools at our disposal may allow the storing of a huge amount of data, but effective ways of analyzing them still need to be investigated, especially understanding how and why some visual representation are easier and faster to perceive than others. Human vision, cognitive sciences and perception provide the needed feedback to achieve this target. Considering different tasks and audiences, it is necessary to find a compromise between the need for visualizing a lot of variables at the same time and the need for abstracting and simplifying the information. For this purpose, we propose a methodical layering of information that can contribute to effective and expressive visualization.

2. Previous work

Recently, many researchers concentrate in combining scientific and information visualization. Especially art has a deep impact in communicating information: designers have a long tradition in providing visual representations. Recently, pilot studies have been conducted to evaluate the effectiveness of 2d visualization methods, using a set of design factors, rated by visual designers. Kirby *et al.* [KML99] recognized the importance that artistic design has in scientific visualization. This is due to the visual richness provided by the art and the several painterly visual representations. They investigate pictorial styles for visualization applications. Urness *et al.* [UIM*03] also make use of layering and focus on the differencies and synergy between art and visualization.

Similarly, also our work is driven by the target of bringing together information and scientific visualization or, better, to

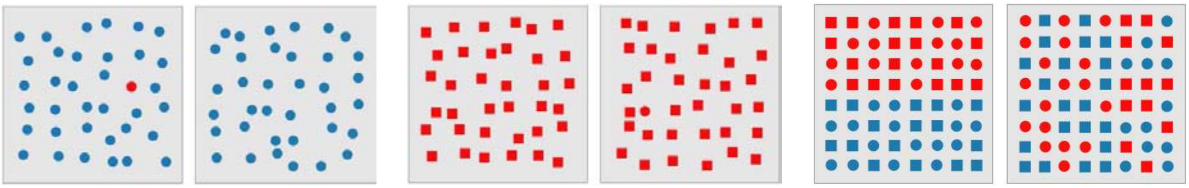

Figure 1: *Treisman's preattentive experiments: target searching based on a difference of hue (left) and shape (center). On the right, horizontal boundary detection is detected, while vertical boundary defined by conjunction of features is not intuitive*

investigate and apply various effective visualization principles to scientific visualization. We are especially motivated by the deal of offering a simple visualization framework for different users and tasks. Further, we particularly focus on combining together many different visualization techniques, attempting to take advantage of their features.

3. Perception for visualization

The main reason for incorporating perceptual issues in the design of visualization methodologies is given by the variety of different tasks and users. When visualizing a scientific dataset, it is important to consider that such representation can be perceived in different ways: an effective visualization is not always and not for everybody an effective visualization. Especially in the case of multi-valued multivariate datasets, users may want to observe the carried information under different perspectives: they may want to display so much information as possible at the same place, in order to investigate possible correlations and interactions between the several variables of the scalar, vectorial or tensorial dataset, or they may want to just isolate some of them to highlight their behavior. Users also may have different levels of expertise and hence, using a too complicated or specialistic visualization may just results in confusion. A very simple example is given by the rainbow color scala used to map temperature scalar data to a range of colors ranging from red to blue. Although the rainbow scala is no perceptual optimal scala, for this task it results very intuitive to understand: every user can interprete the information at a glance without the need of reading labels or further encoding explanations.

In our adaptive visualization system, it is possible to differently set the mapping of the data information onto different visual representation; such *ad hoc* visualization can be also used to match or confirm user expectations and to help them in the data analysis, it puts the basis for a task- and user-oriented approach. In vision research it is important to consider the role of cognitive influence in perception, as perceptual judgment is done in context of our prior experience and expectation, and our state of situational awareness. Theory from cognition proves that what is familiar results to be intuitive to understand: *"That which we know, we have first seen"* (Goethe).

4. Textures: visual dimensions and attributes

According to psychophysical theories, color, orientation, contrast, size, luminance are powerful instruments for visualization: [Jul81a], [Jul81b]. Studies conducted on visual perception prove that some features result for the human eye of better and faster perception. Such features are said *preattentive*, which means that the human low-level visual system rapidly identifies them. Regarding color, certain models were designed to provide additional functionalities for visualization. Some color models specifications [HE99] provide perceptual uniformity; the distance between a pair of colors roughly corresponds to perceived color difference. Ware addressed the issue of constructing continuous color scales that control color surround effects [War88]. Bertin [Ber83] classifies size, value, texture, color, orientation, shape, as "retinal properties". Recent evaluation studies [ALJD05] also use the following design factors to map data: data resolution, feature resolution, linearity, visual bandwidth, dominance, time to read and intuitive association. Although no standard definition actually exists to define in an univocal way the visual dimensions that characterize textures, most scientists agree in recognizing particular importance to the features of orientation, scale and contrast, as well as periodicity, directionality and randomness. Thus, textures are well suited to incorporate many factors and use them for the data mapping. While encoding information, it is crucial to consider potential interference, as this could strengthen or confuse the information in the visualized image. Furthermore, understanding how distinguishable are different features is of particular importance to better design the visualization.

We are interested in the use of patterns to characterize scientific visualization in an image-based way; the use of textures has been successfully applied to scientific visualization, see for example [Int00], [TA03]. Texture features together with their pre-attentive attributes are a valid representation. For this reasons, we encode and map relevant information extracted from the field onto such features using textures as visual primitives. Textures play a fundamental role, as their essential can incorporate all the significant features described above and an adaptive information encoding can extend their potentiality further.

An effective method of displaying more features simultaneously (more detail in §7) can increase the number of at-

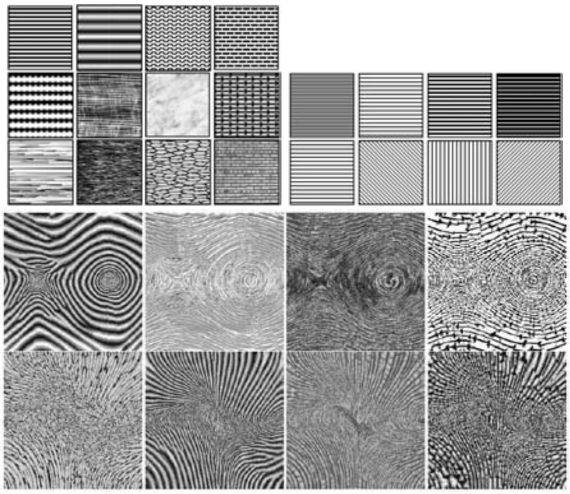

Figure 2: *Directional input samples and rotation and scaling operation over one of them (top); examples of vector fields generated with different appearances (bottom)*

tributes we can represent at one time, and thus, the information to display. Nevertheless, when integrating these features together for early vision, it is necessary to determine the amount of visual interference that occurs during visualization. The experiments of [Tre85] show (Fig. 1) how color or change of curvature are instantaneously recognizable in simple cases, while it is not the case in presence of distractors. Taking into account these theories provides insights for a more effective visualization. A deep understanding of how humans perceive color, shape, and images in general, can help in *ad hoc* designing the tool that serves as instrument for such visualization, telling what is visually compelling. For this reason, methods based on human perception more successfully achieve the goal of visualization and preattentive features are of particular interest for our visualization approach, allowing a visual pop-up of relevant features.

5. Textures as visual paradigm

For such reasons we choose to use these representations; due to the strong flexibility they offer, textures are a valid tool to depict information, and, thus, a good solution for scientific visualization. Textures can be hand-designed, allowing stylistic and illustration-based visualization, which is of particular interest, *e.g.* for educational purposes. Again, cognitive issues are implicitly taken into account, being each illustration an attempt to mimic something we have knowledge about. Textures comprise of many different and significant visual dimensions, which contribute to effective expressive visualization. Fig. 2 shows (for simplicity in grey scala) some directional anisotropic texture patters that can be used for scientific visualization, and Fig. 3 shows how it is possible to combine such visualization with color filtering.

6. Adapted texture synthesis for controlled scientific visualization

Although computational expensive, textured image-based visualization can provide effective results in scientific visualization, thanks to a procedure, which is extremely flexible and controllable up to a pixel-based level. The algorithm we propose for this target is straightforward, easily customizable and makes use of image processing filters. Such filters can affect the sample seeds in a variety of ways, both on the fly or in a pre- and post-processing stage of the synthesis process. Fig. 5 illustrates the main steps of the algorithm and more details are given in [TA03] and [TA04]. A visualization system that offers variable settings results to be appealing and interesting for educational issues, since different users may set parameters in different ways while analyzing the data and while trying to derive information or identify particular features of interest. This range of options is designed on the base of perceptual issues, *i.e.* optimally designed (§3, 4, 5) visual representations that better than others can convey information in an easily recognizable way. Human vision theories, cognitive issues and perception, together with psychology, come as useful complementary information to computer science for such definition. In the Computer Graphics community lot of attention is recently given to such research areas. Nevertheless, most existing visualization techniques do not take this into account; with the proposed hybrid algorithm we want to combine the advantages of other visualization techniques, taking advantage of the complementarity of those methods.

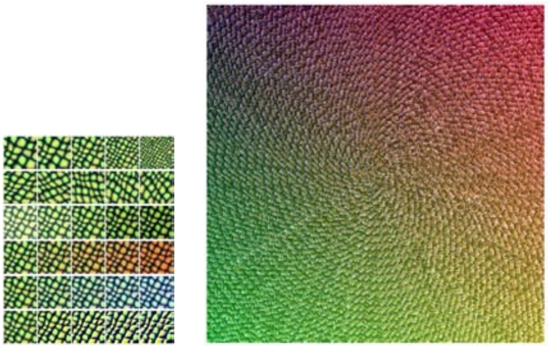

Figure 3: *Simple filtering usage: a lattice of inputs is generated from a single seed and used to produce the output*

Filtering and focusing are implemented and allow simple screen out of unwanted data or highlight points and areas of interest. The interchangeability of visual representations and mapping criteria allow visualizing the data under several different perspectives. Key issues of abstraction are also considered. In §7, we introduce our ideas for layered visualization. The main motivation is that humans use linear thinking, while understanding high-dimensionality is sometime critical. At a panel discussion at ieee vis 2005, Pat Hanharan illustrated the main misconcepts in visualization, and explained why the followings do not have to be assumed *a priori*: *1.)* 3d is better than 2d, *2.)* animation is better than static, *3.)* the more variables the better, *4.)* more views are better than one, *5.)* realistic is better than abstract. The reason of this is that everything has side effects, so the answer to the question: *more is better?* is actually often: *less is more*. Consequently, layering together with user intervention can be a valid solution, providing a custom designed visualization for data exploration under different views. Providing just a static visualization could leave some possibilities unexplored or could ignore potential parameters interactions. In conclusion, interaction in the visualization process contributes to efficiency, controllability and perception.

7. Systematic layered visualization of multi-dimensional multi-variate data

The proposed visualization approach is based on layered information and designed to systematically separate relevant scientific information on different levels. This allows an effective flexible data representation, offering the possibility to visualize multiple datasets simultaneously, or extracting and isolating a part of the information. Considering complex datasets, in general multi-dimensioanl and multi-variate, we can take advantage of texture features for effective layered data encoding. The method is general and customizable: the user-centered visualization offers easy data interpretation, also making the reading of the data more appealing, which is of great relevance, especially in education. An early example that proves this importance is given by the work of [Mei96], which simulates painting animations, showing how painters repetitively use strokes to build up oil paintings.

7.1. Multi dimensional Multi variate Data

A multidimensional multivariate dataset consists of several variables, which need to be intuitively encoded in the data representation. We are developing a simple framework that incorporates all the concepts and features described above and that can be controlled through a set of sliders, buttons, values and threshold settings, letting complex options blending or switching on the base of the level of expertise of the user. We found the best solution for this problem is to use several layers, constrained by a transparency rate.

7.2. Layering information

Layering information for better perception has its origin in the past, may be the most prominent example is the *Vitruvian man* of Leonardo da Vinci. In this drawing, Leonardo exemplifies the canons of human proportions, postulated by the roman architect Vitruvius in the I century a.C. The theory shows that the human proportions are seamlessly inscribable in two perfect geometric figures, the circle and the square. Leonardo illustrates this theory with the innovation of using a single drawing, where he superimposes the same human figure giving the perception of two different simultaneous images (Fig. 4). Numerous visualization techniques are to find in the scientific visualization literature, refer to [LHD*04] for a state of the art. Methods can be classified in *direct, geometric, feature-based and texture-based*. In the following, we explain how several aspects of existing techniques are covered in our approach.

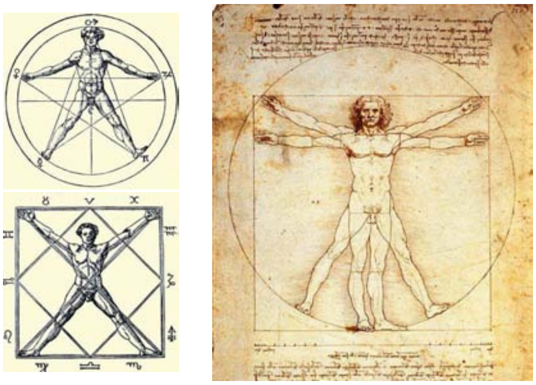

Figure 4: *Medieval illustrations of Vitruvius's theory (left) and Leonardo's drawing with both the "homo ad circulum" and the "homo ad quadratum" (right)*

7.3. Multi-dimensional multi-variate Data

We adopt layers for our visualization approach; superimposition of information is useful for visualizing datasets via different levels of abstraction. The possibility of separating the information and presenting it with different complexity allows to combine or blend together slices of information. Thus, it is possible to show a great amount of information, but it is also possible to leave a portion by side, in case too many overlapping layers result to be complicated and avoid intuitive visualization. The way each layer contributes to the final data representation can be stressed by the user by setting a transparency rate. The visualization framework builds up of all information slices and for this reason it methodically includes the peculiarities of valid existing visualization techniques. We are testing different cases and we found that a good compromise is to use up to four layers, allowing several combinations by changing the relationship among layers. It is important to select a good tradeoff between the need for concentrating the amount of data in a single visualization, and the need for highlighting just a relevant part of it. Further, intervention is possible to customize in part the layer representation; depending on the particular application or user, not only the amount and complexity of information can vary, but also the visualization style, focusing for instance on scientific, theoretical, informative or artistic glyphs. The possibility of abstracting information allows to simplify the data representation in a straightforward way, similarly as done in *geometric visualization*.

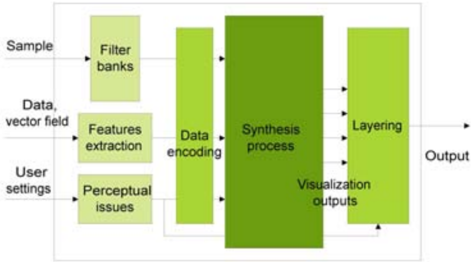

Figure 5: *Block scheme of the visualization process*

Vector, Tensor and Flow Fields: Texture-based methods are well suited for the visualization of vectorial data. A dense visualization better represents a complex field avoiding the risk of missing peculiar information, as it could occur in sparsely sampled visualization. Considering the numerous features of textures (§ 4), we choose the approach of [TA03] to visualize the basic structure of the vector field. The technique is particularly intuitive in conveying the principal characteristics (e.g. magnitude, curvature). The method is image-based and adapts a directional texture to the field, accordingly changing its orientation, resolution and attributes.

Scalar fields: Once the planar components of the dataset are visualized, further dimensions and attributes need to be encoded in visual representations. A simple solution for scalar distributions is to use color mapping. We want to meaningfully specify links among color scala and data, as special color ranges and tones are accepted by the audience to carry given information. Part of our current work is to consider perceptual vision studies for a proper intuitive data mapping.

Singularities: Singularities of different order significantly characterize vector fields. Using topological analysis in our approach, we can isolate and adequately represent them, as in the case of *feature-based visualization* methods.

Filtering: We use progressive filters and image processing operators to vary the visualization appearance. In this way, attributes of the field can be encoded. Brightening and blurring filters enhance information depending on the level of interest; embossing provides effect of depth or elevation, etc.

Visual cues and artistic styles: Either to highlight singularities or to stress points or regions of interest, we can use glyphs, icons and special visual representations as in *direct visualization*. In this way it is easier to recognize the features of the vectorial dataset. Part of our future work consists in integrating artistic effects for particular field attributes.

8. Conclusions

We present a study on textures and their perceptual properties, and motivate their use in scientific visualization. We describe their visual features and explain the reasons why they are specially suited to effectively convey information. We introduce an approach based on layered information to visualize complex multi-dimensional and multi-variate datasets in an intuitive, effective and flexible way. Our methodology combines different techniques and links them together through perceptually-based principles. The system is customizable and provides user- and task-driven visualization. Such study facilitates data exploration and analysis. Concepts and considerations from fields such as Computer Graphics and Computer Vision from one side, and Human Vision, Psychology, Perception and Cognition from the other side have been taken into account and interdisciplinary research can be further conducted. Such interesting field needs to be deeper investigated, as promising relevant contributions, from specialistic visualization to educational tasks, are to find in several research disciplines.

9. Aknowledgement

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