Multidimensional scalar fields data analysis by means of multisensory visualization *

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A well-known definition of visualization is the mapping of initial data to a visual representation, which can be perceived and interpreted by humans. Human senses include not only vision, but also hearing, sense of touch, smell and others including their combinations. We discuss in this article multisensory scientific visualization, in other words scientific visualization extended with sound, haptic and other sensory stimuli, related fields and concepts such as visualization, sonification and perceptualization, and geometric modeling using real functions. The formalization of the multisensory analysis process and particularly of establishing correspondences between the initial data and multiple sensory stimuli is an open research question. In this article, some generalizations based on using real-valued vector functions for solving data analysis problems by means of perceptualization are proposed. A more particular case study of a scalar field analysis using scientific visualization extended with such sensory stimuli like sound is considered.

Keywords: *scientific visualization, multisensory analysis, FRep sonification.*

Introduction

Visualization informally can be understood as making invisible visible, but more formally it can be defined as the process of transforming data into a visual form enabling viewers to observe and analyse the data [1]. A more general definition of visualization is “a binding (or mapping) of data to a representation that can be perceived” [3] is used more often nowadays and thus visual analysis is extended to become multisensory analysis. Visualization process is the one that is the most well studied and formalized. The above mentioned paper [2] introduces its formal description as a process of interconnected mappings from initial data to some insight, which can be either directly obtained from generated visual representations or in a combination with automated analysis methods. We have provided a similar formal description for multidimensional data analysis problem solving by scientific visualization method on base of FRep that will be discussed later. While [2] mentions a single-step mapping from a data set to its visual representation within the visual analytics process, [4] goes further and states that to obtain such a visual representation (or a graphical image), one needs to put some geometric model (multidimensional in the general case) into correspondence with the initial data that means a spatial scene, an assembly of spatial objects with their geometric and optical descriptions, has to be constructed, rendered and analyzed. Among the sensory stimuli other than visual, the usage of sound has been widely investigated since early 80-s [5, 6]. The human auditory perception is considered most quantitative because of its sensitivity to subtle changes in the sound characteristics. The technique of data representation using variable sound characteristics such as pitch, volume, note duration, rythm and others is called data sonification [7]. Let us look at sonification method characteristics more closely. In [8] a small survey was made on the situations when using audio analysis may be even more effective than visual perception. The main classes of data that fall in this category are time-varying data and multidimensional data. Currently, it is considered that any person may be trained to develop an ear for music. In the paper [9], there are examples of the presentation of scientific data in the form of musical fragments. This is largely a matter of sensory capabilities of a specific researcher, but we can say that combining auditory and visual perception allows one to significantly enhance the ability to conduct analysis more efficiently, taking advantages of two sensory organs that work differently, and to perceive the same information in different ways complementing each other.

An extension of visualization through creating additional perceptual human inputs or more general a combination of several sensory stimuli for data representation is called data perceptualization [10, 11] (or data sensualization [12]). The typical combinations are between visual and auditory stimuli, visual and tactile/haptic stimuli [13], or three of these stimuli applied together [12].

Multimedia coordinates and FRep

Although some efforts have been made on the development of data perceptualization, a formal framework for establishing correspondences between data and multiple sensory stimuli has not been yet proposed. We believe that the concept of

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multimedia coordinates introduced previously in [14] and applied in multidimensional shape modeling can be a good framework for formalization of mapping from a multidimensional geometric model to a multimedia object that can be treated as a multidimensional object with Cartesian, visual, audio, haptic and etc. A space mapping between geometric coordinates and multimedia coordinates establishes correspondence between the multidimensional shape and the multimedia object. In this way, a correspondence can be also established between the given scientific data and a multimedia object, because introducing a multidimensional geometric model is one of the steps in the visualization pipeline presented previously.

Generally methods and approaches that aim at visual analysis of geometrical objects representing multidimensional data are called multidimensional visualization methods [18] and these techniques usually suppose not only reducing dimensionality through application of specific geometric operations, but mapping data to different photometric characteristics (color, transparency), and includes interactive techniques as well. Most well known of these techniques are covered by different types of multimedia coordinates, introduces in [14], among them are dynamic coordinates (represent continuous coordinates that can be mapped onto physical time), spreadsheet coordinates (take discrete values in the given bounding box) and photometric coordinates (include color, transparency, texture and other visual appearance parameters).

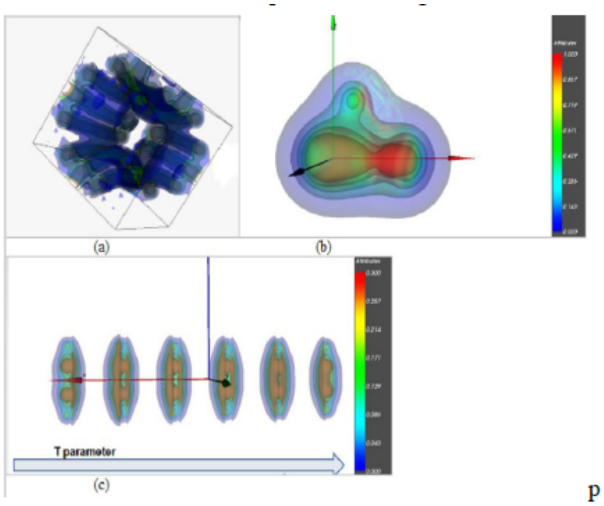

Рис. 1: Examples of static and dynamic scalar fields visualization

In our previous work we've experimented with mutidimentional visualization methods, taking Function Representation (FRep) [17] approach as base for geometrical modelling and presented in [19] constructive hypervolume model as a part of model of spacial scene. Examples of scalar field computer simulation visualization are presented on Fig 1, (a)Visualization of scalar order-parameter field distribution (b)Visualization of electron dencity and electrostatic potential field of NCH molecule (c) Visualization of dynamic electron dencity field of C2H2 molecule with use of spreadsheet technique.

In this work we introduce another type of multimedia coordinates – audio coordinates and as some generalizations on base multimedia coordinates approaches for scalar fields analysis.

Multisensory data analysis

A following interpretation of the basic multisensory analysis process was presented in [20].

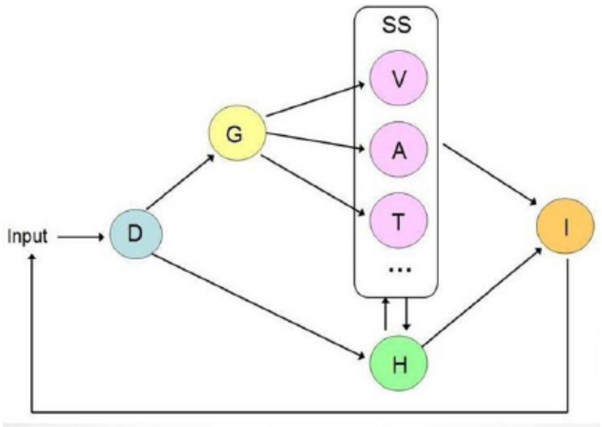

Рис. 2: Multisensory analysis process

In the diagram (Fig. 2), perceptualization process is presented as a transformation (mapping) $M : D \rightarrow I$ from initial data D to insight I, which is the goal of the entire process. The mapping M is a superposition of mappings from one set to another in the diagram. Thus, the initial data undergo geometric interpretation and are mapped to the set G of multidimensional geometric models. The next step is to generate several sensory stimuli SS for human perception through according multimedia objects creation (part of spacial scene). Then various sensory stimuli can be generated using corresponding rendering procedures: visual stimuli V (graphical images), auditory stimuli A (sounds), tactile and haptic stimuli T, and others. Te final insight I can be either directly obtained from the generated sensory stimuli through human perception and analysis, or it is obtained in a combination with generating a hypothesis H and its analysis including automated methods.

The process of data analysis involving both human vision and hearing, we need to obtain a mapping of the given data onto its representation in the form of images and sound and then to analyze the rendered images and sound and to interpret the results of this analysis in terms of the initial data.

Here we suggest that researcher in common case should be trained to interpret some not quite evident sound mappings as in modern practice musicians are training their ear. In our work we take advantage of musicians approach, well-known concepts of music analysis and writing used by musicians from simple properties of sound analysis (pitch, volume, duration, etc.) to "music" properties analysis (tone, interval between tone sand etc.). These concepts are taken as the base of sound mapping and accordingly of sound analysis. In this article, only simple cases of sound analysis (not cases requiring some musical training) will be considered.

Multisensory analysis of scalar fields

n the basis of the proposed approach to multisensory analysis, let us describe the process for solving a high dimensional data analysis problem involving a hybrid visual-auditory representations. The data analysis problem can be formulated as follows:

Given – numerical data D describing the object under consideration;

Required – to obtain an insight I of interest to the researcher regarding the initial object.

Lets consider the solution of the above stated problem by reducing this problem to the following two problems solved one after another:

1) the problem of obtaining a multisensory representation (SS in Fig. 2) of considered data in the hybrid visual-auditory form;

2) the problem of human sensory analysis and interpretation of the results of the analysis with respect to the original description.

Note that we will deal here only with the upper path in the diagram (Fig. 2) from the initial data to sensory stimuli, leaving the hypothesis H formulation, visualization and analysis out of the discussion.

From our experience of participating in scientific research in nuclear physics, chemistry and other disciplines, it is very often the case that the initial data can be presented as a set of real functions of several variables $f_1(x_1, x_2, ...x_k)$, $f_2(x_1, x_2, ...x_k)$, ..., $f_n(x_1, x_2, ...x_k)$ or scalar fields in an abstract kdimensional space describing different characteristics of a complex object under investigation. There are two alternative ways to introduce a multidimensional geometric interpretation (set G in Fig. 2) of such a data. One is quite straightforward as each of the above set of real functions can be considered as a definition of a k-dimensional surface in a $k+n$-dimensional space. However, this interpretation can turn too abstract for further multisensory perception and analysis. Alternatively, all the given data functions can be presented in the form of a vector function

$$f = (f_1, \dots, f_n),$$

which then can be interpreted as an FRep constructive hypervolume model [19] mentioned earlier. This means the function f_1 is describing some multidimensional geometric object and all other components of the vector-function represent attributes defined on this multidimensional geometric shape. The attribute functions $f_2, \dots, f_n$ defined on the obtained geometry can represent various object properties such as material, color, emitted sound, rigidity and others that can be directly mapped to sensory stimuli. Rendering of the spatial scene generates several sensory stimuli as outputs. This process will be illustrated in more detail by the case study below.

Case study

Let us illustrate the scientific visualization extended with sound application in a certain class of problems, where given data represent various scalar fields. A simple scalar field case study using graphical and audio presentation was described briefly in [20]. Let us consider a more complex, but similar case of two scalar fields analysis Problem statement The objects under study is electron density field and electrostatic potential fields of CNH molecule. This two scalar fields are used to be analysed together.

Given

The mathematical model consists of the values of the 2 real function of three variables $f_1(x, y, z)$ and $f_2(x, y, z)$, where (x, y, z) are coordinates of points in space and fields given in the tabular form at the nodes of a rectangular regular grid in the function's domain

Required

To analyze variations of the function depending on changes of independent variables x, y, z.

Geometric model

Let us introduce two interpolation function $Y1(x, y, z)$ and $Y2(x, y, z)$ corresponding to the tabulated functions. The geometric interpretation of the function $Y1$ and $Y2$ are the hypersurfaces $G1_4$ and $G2_4$ in the Euclidean subspace E^4 with coordinates (x, y, z). To facilitate further multisensory analysis, like in [20], we introduce additional attribute functions:

1) $A1 = a_1(x, y, z)$ that will correlate with $Y1$ function values and will correspond to some visual attribute values. This function defines a hypersurface $A1_4$ in the attribute subspace (x, y, z, a_1).

2) $A2 = a_2(x, y, z)$ that will correspond to some auditory attribute and will correlate with Y function value.

3) $A3 = a_3(x, y, z)$ that will correspond to some auditory attribute and will correlate with $Y2$ function value and will correspond to some visual attribute values.

4) $A4 = a_4(x, y, z)$ that will correlate with $Y2$ function values and will correspond to some visual attribute values.

Here the vector-function $(Y, A1, A2, A3, A4)$ can be considered a constructive hypervolume model with each of its components representing a 4D hypersurface in 8-dimensional space with coordinates $(x, y, z, a_1, a_2, a_3, a_4)$.

Spatial scene

The hypersurface G_4 can be put into correspondence with a collection of isosurfaces C_j in the space E^3 by selecting level values c_j for the function $Y1$.

We choose a color scale of selected isosurfaces and thus define the range for the $A4$ function values and map points xi, yi, zi on each isosurface c_j to according values $Y2(xi, yi, zi)$ the corresponding color. We also map each value $Y1 = c_j$ to transparency according to the value of $A1$ function within the selected transparency scale. The sound model includes an introduced point sound source to be used in sound rendering. The location of the sound source (x_s, y_s, z_s) within the spatial scene defines the selected point in space and the sound frequency w of the generated sound is defined by the function $A2$ value at this point. We defined the sound frequency as $w = = k1^* a_2(x_s, y_s, z_s)$, where k is a scalar coefficient. As well we define sound volume as $v = k2^* a_3(x_s, y_s, z_s)$ of the generated sound is defined by the function $A3$ and thus receive complex sound those two characteristics pitch and volume can be analyzed simultaneously.

Thus we form geometrical, optical and sound model. Schematically mapping of 4D hypersurface in 8-dimensional space with coordinates $(x, y, z, a_1, a_2, a_3, a_4)$ into according multimedia coordinates will look like:

{x,y,x} → world coordinates “x”, “y”, “z”

{a1,a4} → photometric coordinate “transparency” and “color”

{a2,a3} → audio coordinate “sound frequency” and “sound volume”.

Rendering

The results of the visual and auditory rendering of the spatial scene are the following (illustrated by Fig. 3):

– a graphical image of projections of semi-transparent colored isosurfaces on a graphical terminal;

– the point sound source represented by the red sphere with the sound source located in its center. It’s location is specified interactively by user;

– sound wave generated by a sound terminal with the frequency corresponding to the location of the point sound source and perceived by the user as a specific sound tone.

If we introduce some basic, well known musical type of sound as input, for example D♯ note sound , by changing it’s tone we will receive it’s transformation to other musical tones (Fig 3). A well trained musical ear can distinguish intervals between these notes, however for help a basic guitar tuner can be used to define note that is played currently . Also sound frequency that is generated at selected source locations can be visualized with the Windows media player Bars and Waves plug-in.

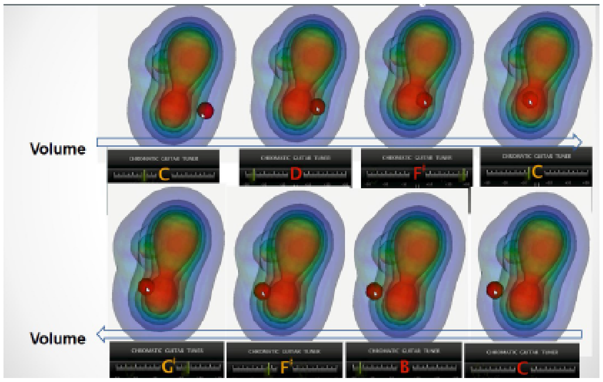

Рис. 3: Exploration of two scalar fields dependency and change with pitch and volume

Here we use an interactive “sphere” widget to define sound frequency w and volume v of the generated sound defined by the functions $A2$ and $A3$ values at fixed values of world coordinates x, y, z.

Conclusion

In conclusion it may be said that the formalization of the mapping between the multidimensional geometric models and the spatial scene available for rendering multiple sensory stimuli is the still research question to address. We have shown a possible solution in the case of the initial data represented by scalar fields (real functions of several variables) and illustrated this by the case study of the scalar field analysis using interactive visual-auditory display. We are planning to involve the concept of multimedia coordinates as a way to establish more complex correspondences between initial data, the introduced multidimensional geometric models and multiple sensory stimuli.

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