Visualization of multidimensional histograms using hypervolume techniques

Miroslav Morháč, Vladislav Matoušek and Ivan Turzo

Institute of Physics, Slovak Academy of Sciences, Bratislava, Slovakia

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1. Introduction

Most scalar visualization techniques use a consistent approach across one-, two-, or three-dimensional fields. A scalar variable is a single quantity, in the case of nuclear spectra - counts, which can be represented as a function of independent variables - particle energies.

The goal is to propose a technique that allows one to localize and scan interesting parts (peaks) in multidimensional spectra.

2. Volume rendering techniques

a) Three-dimensional spectra

Three-parameter coincidence spectrum is three-dimensional scalar field with three independent parameters x, y, z (particle energies) and one dependent variable - counts c = f(x, y, z).

One can idealize the display of three-parameter scalar field using discrete symbols at specific locations in the space – glyphs. Glyphs are graphical entities which convey one or more data values via attributes such as shape, size, color, and position.

We have employed a model where the channel – glyph is shown as a sphere (other marks as square, triangle, star etc. also can be used) with the color or size proportional to the event counts it contains.

Particle gradient display technique

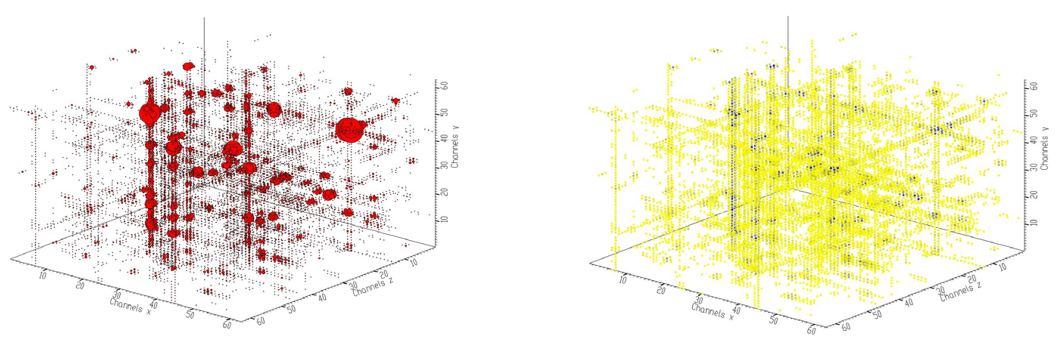

Fig. 1 Three–dimensional γ-γ-γ-coincidence spectrum with channels shown as spheres with size proportional to counts (left) and color proportional to counts with 64 x 64 x 64 nodes (right).

Isosurface display technique

Another technique to display three-dimensional arrays is creation of an isosurface in three dimensional space using marching cube algorithm [1].

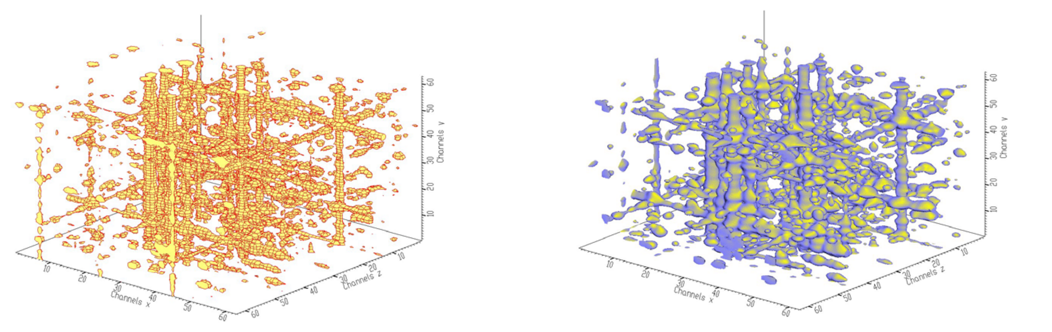

Fig. 2 Three-dimensional spectrum shown in isosurface display mode (left) and isosurface mode interpolated with 3-rd order B-splines with 64 nodes (right).

b) Four-dimensional spectra

The counts is a function of four parameters (particle energies), i.e., c=f(x,y,z,v). Now the glyph represents a slice in the fourth parameter. We depict each slice as a closed polygon with the center positioned in analogy with three-dimensional data at the location.

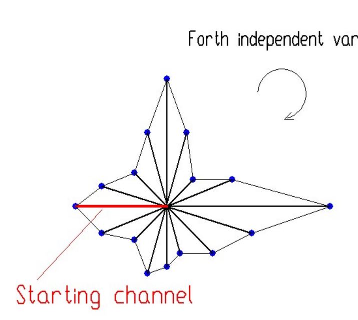

Fig. 3 Principle of four-dimensional display.

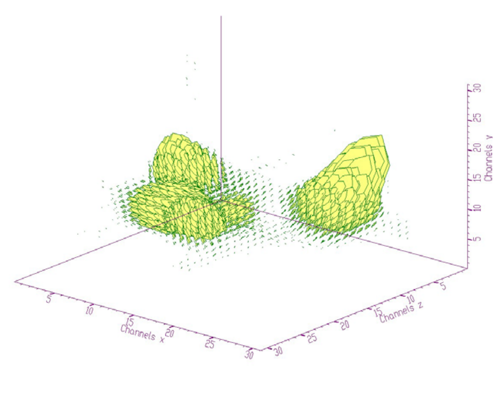

Fig. 4 Display of four-dimensional synthetic spectrum (5 Gaussians).

One can change also the color (level of shading) while keeping the radius of circle constant and according to the resolution in the fourth independent variable. The circle can be divided to the pies and the size of the circle is proportional to the sum of counts in the fourth dimension (Fig. 5).

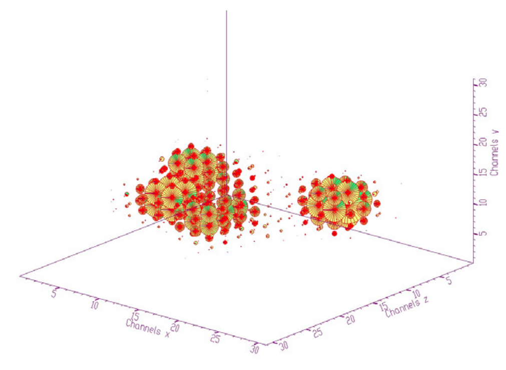

Fig. 5 Display of four-fold synthetic spectrum in rainbow mode.

3. Embedded subspaces [2]

a) Three-dimensional spectra

Let us divide three-dimensional space to two-dimensional space and one-dimensional subspaces. To every point of the two-dimensional space there belongs one one-dimensional subspace.

Let us consider a glyph in the form of rectangle with the size proportional to the integral or to the maximum value of the belonging one-dimensional subspace.

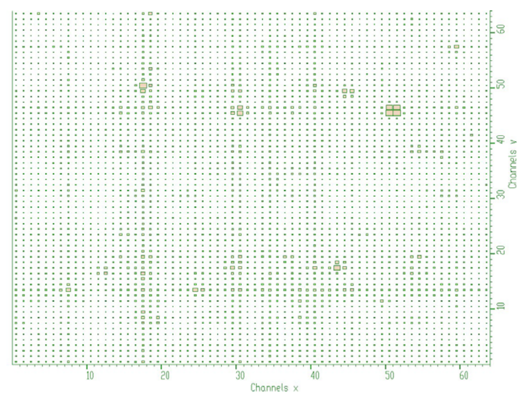

Fig. 6 Projection of three-dimensional experimental spectrum to two-dimensional outer subspace.

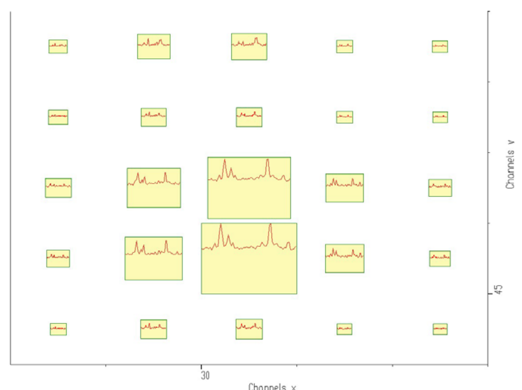

Fig. 7 Displayed one-dimensional inner subspaces of the chosen ROI.

b) Four-dimensional spectra

Let us divide four-dimensional space to two-dimensional outer space and two-dimensional inner subspaces. To every point of the two-dimensional outer space there belongs one two-dimensional inner subspace.

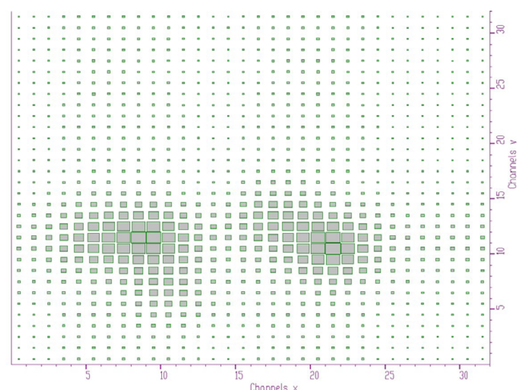

Fig. 8 Four-dimensional synthetic spectrum – outer space.

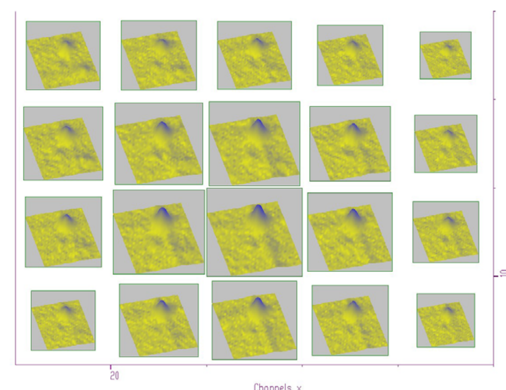

Fig. 9 Four-dimensional spectrum with inner subspaces shown as surfaces – outer subspace is XY.

c) Five-dimensional spectra

To every point of the two-dimensional outer space there belongs one three-dimensional inner subspace. Every three-dimensional inner subspace can be further divided to two-dimensional subspaces and one-dimensional subspaces.

The operation of embedding of subspaces is recursive and can be applied also to higher dimensions.

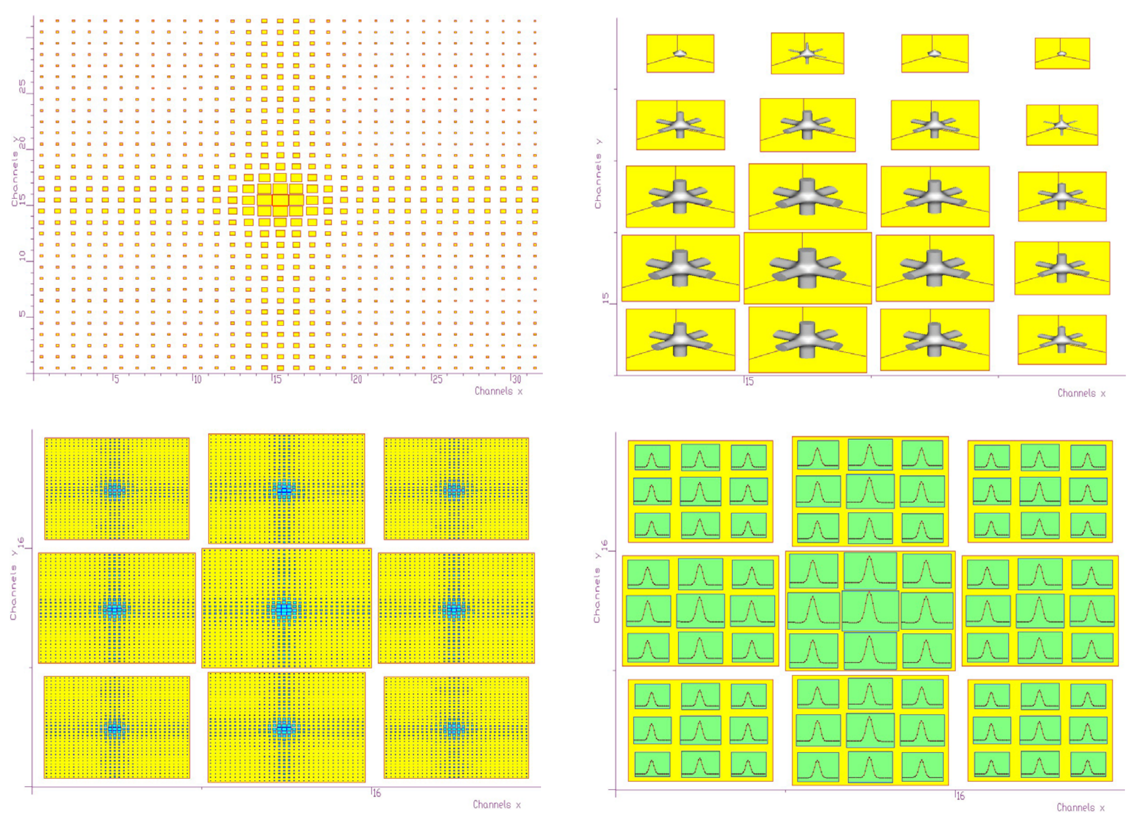

Fig. 10 Outer subspace of five-dimensional spectrum (upper-left), zoomed ROI with displayed three-dimensional inner subspaces in isosurface mode (upper-right), zoomed ROI with shown outer and the first level inner subspaces (left) and zoomed ROI with shown outer, the first level and the second level inner subspaces.

This technique is recursive and can be extended to any dimension. It allows to choose any combination of axes of outer space or higher level subspaces.

4. Hypervolume visualization

It is designed to provide simply and fully explanatory images that give comprehensive insight into the global structure of scalar fields of any dimension [3]. Projection of m-dimensional space to two-dimensional space can be defined as mapping

$$\Pi\left(\Re^m \rightarrow \Re^2\right)$$

Geometrical imagination of multidimensional space – evolution from three-dimensional to five-dimensional

a) Four-dimensional space

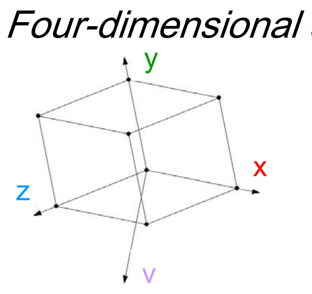

Fig. 11 Addition of v-axis to three-dimensional space.

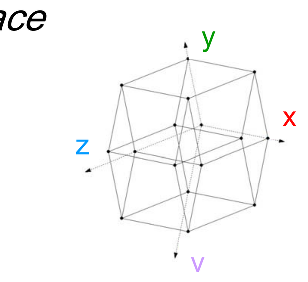

Fig. 12 Supplementation of three-dimensional spaces to four-dimensional by moving the cubes in the fourth dimension.

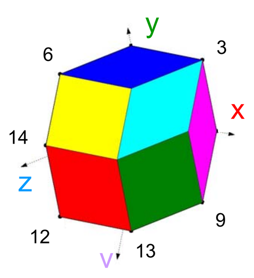

Fig. 13 Four-dimensional space.

b) Five-dimensional space

We can proceed in analogous way by adding w-axis to four-dimensional space.

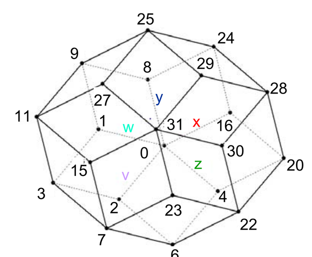

Fig. 14 Five-dimensional space with removed internal vertices and edges.

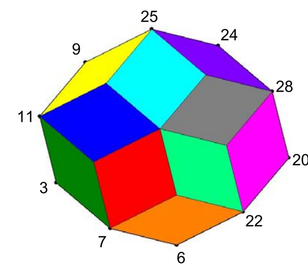

Fig. 15 Five-dimensional space.

c) Examples of four-dimensional spectra

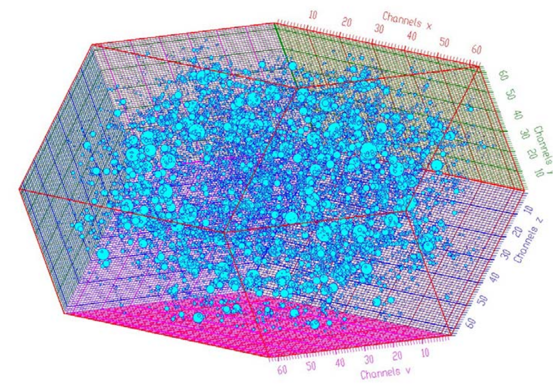

Fig. 16 Four-dimensional experimental spectrum with rasters.

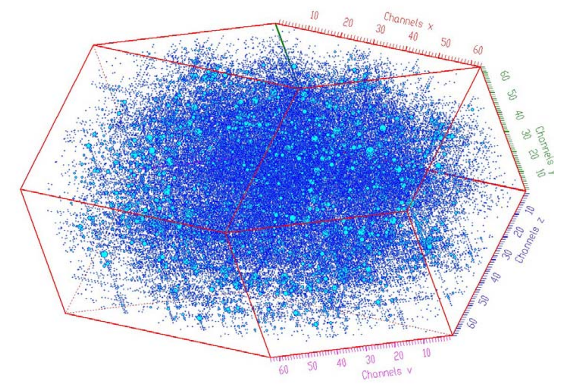

Fig. 17 Four-dimensional experimental spectrum.

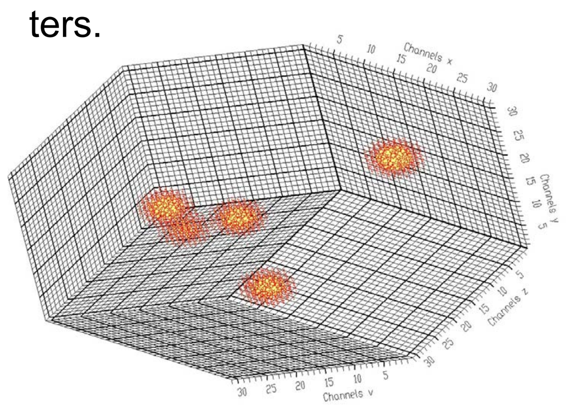

Fig. 18 Five four-dimensional Gaussians (sigma = 1.5).

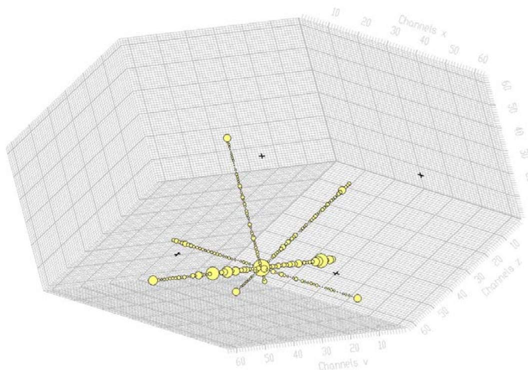

Fig. 19 Four three-fold slices in experimental four-dimensional γ-ray spectrum.

d) Examples of five-dimensional spectra

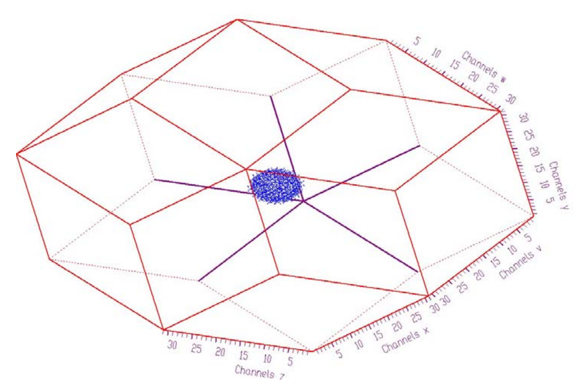

Fig. 20 Five-dimensional Gaussian.

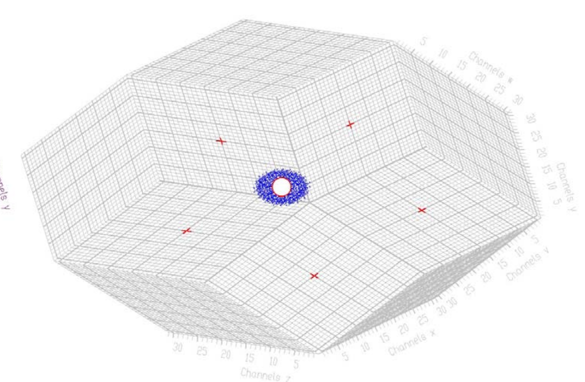

Fig. 21 Five-dimensional Gaussian with marker and rasters.

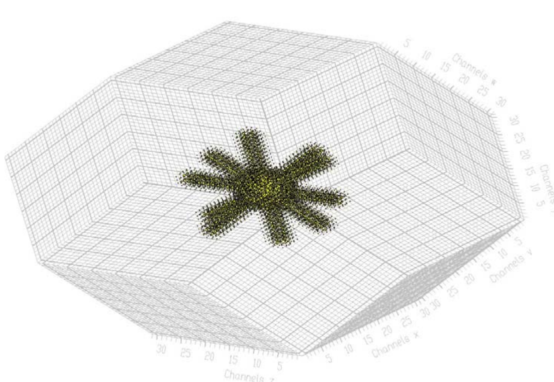

Fig. 22 Five-dimensional Gaussian with ridges.

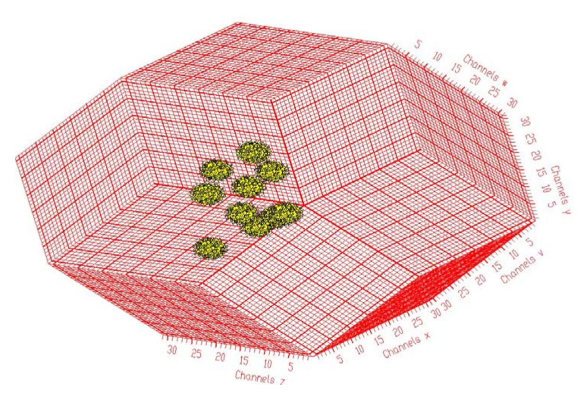

Fig. 23 Five-dimensional Gaussian.

Conclusions

Conventional volume rendering techniques are not extensible to higher dimensions.

We have derived a new technique of visualization of multidimensional spectra based on projections of embedded subspaces. This allows one to localize interesting parts in the data, to find correlations among neighboring points and to discover trends in multidimensional data. This technique is extensible to higher dimensions. However it does not provide user with global view in all dimensions.

The new algorithm of hypervolume visualization is presented in this poster. It is based on particle scattering display mode. This technique is extensible to any dimension and makes it possible to provide user with compact global view of multidimensional data.

The visualization algorithms presented have been implemented in the data acquisition, processing and visualization system DaqProVis which is being developed at Institute of Physics, Slovak Academy of Sciences [4].

References

[1] Morháč M., Kliman J., Matoušek V., Turzo I., Sophisticated visualization algorithms for analysis of multidimensional experimental nuclear data, Acta Physica Slovaca 54 (2004) p. 385.

[2] Morháč M., Matoušek V.: Interactive visualization of multidimensional coincidence spectra. ACAT2007, NIKHEF, Amsterdam, Netherlands, Proc. PoS (ACAT) 064. p. 1-34, http://pos.sissa.it.

[3] C. L. Bajaj, V. Pascucci, G. Rabbiolo, D. Schikorc: Hypervolume visualization: a challenge in simplicity, Symposium on Volume Visualization,Proceedings of IEEE symposium on Volume visualization, Research Triangle Park, North Carolina, United States, pp. 95-102, 1998.

[4] Morháč M., Matoušek V., Turzo I., Kliman J.: DaqProVis, a toolkit for acquisition, interactive analysis, processing and visualization of multidimensional data. NIM A, Vol. 559 (2006), p. 76-80.