Scientific Visualization – Example exam questions with commented answers

The theoretical part of this course is evaluated by means of a multiple-choice exam. The questions cover the material mentioned during the course as being mandatory for the exam. The study material is given by the slides and the course textbook.

Each question has only one correct answer. Below are given several examples of such questions, with a short explanation of the reasoning behind the (correct) answer. References to equations, chapters, and page numbers relate to the course's textbook "Data Visualizations – Principles and Practice" (A. C. Telea, AK Peters / CRC Press)

Note that these example questions cover only a *part* of the material required for the exam.

1. The questions targeted by visualization can be grouped into two types ("confirming the known" (CK) and "discovering the unknown" (DU)). Which of the following is true?

   a. CK targets only quantitative questions, while DU targets quantitative and qualitative questions;
   b. CK targets qualitative and quantitative questions, while DU targets only qualitative questions;
   c. Both CK and DU can target both quantitative and qualitative questions.

The correct answer is (c). Both CK and DU (and actually, any type of visualization) can in principle target both quantitative and qualitative questions. The difference CK/DU is based on the actual use-case for visualization (see pages 4-6).

2. Which statement concerning data sampling and data reconstruction is true:

   a. Data sampling can be only performed on infinitely-continuous data;
   b. Data reconstruction can never generate infinitely-continuous data;
   c. The continuity of a reconstructed signal is always of a lower order than the continuity of the data from which the signal was sampled;
   d. The continuity of a reconstructed signal is determined by the interpolation method used during the reconstruction.

The correct answer is (d). (a) is not true, we can resample piecewise-linear data (see Sec. 3.9.1). (b) is not true, we can reconstruct data using infinitely-continuous interpolation functions (see Sec. 3.9.2). (c) is not true, since we can e.g. sample a piecewise-linear signal and then use radial basis functions to reconstruct from the samples (combine Sec. 3.9.1 and Sec. 3.9.2). (d) is true: the continuity of the reconstructed signal is determined by the interpolation (basis) function used – if we use a weighted sum of basis functions, the continuity of the reconstruction is exactly equal to that of the basis functions (see Eqn. 3.2)

3. The most frequent interpolation (basis) functions in data visualization are piecewise-constant and piecewise-linear. Which of the following assertions is true:

a. Piecewise-constant basis functions can only be used if we have samples defined at grid (cell) vertices, and piecewise-linear basis functions can be used with samples defined both at grid vertices and cell centers;
b. Piecewise-linear basis functions can only be used if we have samples defined at grid vertices and piecewise-constant basis functions can be only used for samples defined at grid cells;
c. Both types of basis functions can be used with samples defined both at grid vertices or at grid cells.

The correct answer is (b). Piecewise-constant basis functions assume we have one value (sample) we interpolate over an entire cell (Eqn. 3.6). Piecewise-linear basis functions linearly interpolate over a cell between all values defined at the cell vertices (see e.g. Eqn. 3.7). We can of course convert the data beweeen cell-based and vertex-based samples (resampling), but this is outside the scope of interpolation.

4. Shading, as used in the computer graphics step of the visualization pipeline, uses various forms of interpolation. Given a polygonal mesh, which of the following assertions is true:
   a. Gouraud shading can render sharp, C^{-1} shading discontinuities along the edges of a mesh cell;
   b. Flat shading requires vertex normals to be available or precomputed prior to shading;
   c. Both Gouraud and flat shading can in general achieve the same results given appropriate interpolation functions and finely-sampled meshes;
   d. As a function of the mesh size (number of polygons and/or vertices), Gouraud shading has the same computational complexity (big O notation) as flat shading.

(a) is false – Gouraud shading is linear interpolation, hence it creates a C^0 *signal (the shading, or luminance, is C0 continuous at the edges of a polygon). (b) is false – flat shading only requires face, or polygon, normals. (c) is also false – flat shading is piecewise-constant, while Gouraud shading is piecewise-linear, hence they cannot achieve exactly the same result on any mesh. (d) is true: both Gouraud shading and flat shading are linear in the mesh size, since they work cell-by-cell. See Chapter 2 and pages 51-52.*

5. Dataset spatial domains (regions in space where data is represented discretely) are typically sampled using grids, or meshes. Which of the following statements is true:
   a. A mesh can only contain cells of a single type (e.g. only triangles, or only tetrahedra);
   b. A mesh can contain cells of different dimensionalities (e.g. triangles and tetrahedra);
   c. A mesh can contain only cells of the same dimensionality but various types (e.g. triangles and quads).

(a) Is not true: a mesh can contain e.g. triangles and tetrahedra; the interpolation takes place cell-wise, so as long as the cells share edges consistently, the type of a cell doesn't influence the types of a neighbor cell. (b) is not true: the purpose of meshes (grids) is to capture a spatial domain having a given dimensionality (e.g. 2D or 3D); a mix of 2D and 3D cells will, thus, fail to capture three dimensions in the area where we use only 2D cells. Given the above, (c) is true. See Sec. 3.4.

6. Meshes (or grids) in data visualization are constructed by assembling cells of various types and dimensionalities. Which of the following statements is true:

a. An uniform mesh can only contain cells of a single type;
b. An unstructured mesh can only contain cells of a single type;
c. A structured grid has the same modeling power in terms of topology as an unstructured grid, but requires more memory (storage space);
d. Any mesh has to represent a compact (connected) spatial domain.

(a) is true: an uniform mesh cannot assemble cells of different types, see the definition in Sec. 3.5.1. (b) is false: an unstructured grid is the most general grid type, and can combine cells of different types, as long as they have the same dimensionality. (c) is false: a structured grid cannot, for example, model shapes with holes (in 2D) or tunnels (in 3D), see Fig. 3.10. (d) is false: there is no explicit constraint, or requirement, that the spatial domain covered by a mesh to consist of a single connected component (think e.g. of the isosurfaces, which are meshes which can consist of multiple components).

7. Different color representation systems exist, such as the RGB and HSV systems. Which of the following statements is true:

a. The HSV system is computationally more expensive to use than the RGB system;
b. The HSV system is better than the RGB system as it can represent more colors;
c. The mapping from RGB to HSV has a singularity (RGB values for which we cannot uniquely determine a HSV value);
d. The RGB and HSV representations do not sample a given color space uniformly.

(a) is not true: both HSV and RGB systems are equally computationally complex, as the complexity is given by what an application finally does with the computed colors, and not how the colors are stored. (b) is not true: both RGB and HSV systems can represent the entire color cube (albeit they encode the value of a color differently). (c) is true: for gray values (R=G=B), we cannot determine a hue (these colors are completely desaturated, S=0). (d) is not true: both RGB and HSV systems are coordinate systems, and not sampling schemes of a color space. As such, how we sample the color space depends on how we construct samples in the two (RGB and HSV) spaces, and not the coordinate system (RGB or HSV) itself (this is a trickier question).

8. Tensor fields describe higher-dimensional data attributes present in various visualization applications such as the study of shapes and medical imaging. Which of the following is a correct definition of a tensor field:

a. A tensor is a triplet of three vectors;
b. A tensor is a triplet of three vectors, plus a triplet of three scalars;
c. A tensor indicates the variation of some scalar function at each given point in space and in each given direction around that point;
d. A tensor is a function indicating the variation of a vector in space around a point.

(a) is formally not true – a tensor is a field, thus a function of (at least) space, and thus cannot be a triplet of three vectors. The same is true for (b). Note that actually (a) and (b) are not even the definition of a tensor attribute (data value); they can encode the extremal values of

the tensor variation in all directions around a given point, but don't fully describe this variation. (c) is the right definition (see e.g. slides). (d) is not true – a tensor encodes the variation of a scalar function, not a vector function. See also Sec. 3.6.4.

9. The effectiveness of a visualization is often described by the so-called 'inverse mapping' which connects its output (rendered image) to its input (datasets). Which of the following is true:

  a. The inverse mapping has to be implemented in a visualization tool in the same time that we implement the direct mapping;
  b. The inverse mapping requires that the visualization pipeline (dataset-to-image) is an injective function;
  c. For a given visualization pipeline, the dataset-to-images mapping is always invertible, or always not invertible, as this depends of the actual visualization algorithms being used;
  d. The inverse mapping does not have to be an exact mathematical inverse of the direcrt mapping, as this inverse mapping is performed by the user mentally to answer dataset-related questions.

(a) is not true – the inverse mapping is a mental process, not an algorithm implemented in software. (b) is also not true – as long as we can answer our questions about the data mentally using only the final image, the dataset-to-image mapping may be (and typically is) not strictly speaking an injective function. (c) is also not true: the inverse mapping is performed by the user mentally, and not the software. (d) is true: see Ch. 4, and in particular 4.1.3.

10. Color mapping and contouring are two related visualization techniques which share some similarities. Which of the following statements is true:

  a. We can obtain exactly the same results as isolines (2D contours produced e.g. by marching squares) with a pixel-based rendering (2D image) if we use a 'delta' (Dirac) colormap which maps all data values to a color, except the contoured value which is mapped to a different color;
  b. 2D contouring has a higher computational complexity (big O notation), as a function of the size of the dataset (number of cells) than 2D color mapping applied to the same grid;
  c. Dirac color mapping (see (a)) is inferior to contouring, since it can only show a single contour for a single contoured value;
  d. Isolines (produced e.g. by marching squares) have a higher accuracy than Dirac color mapping, but cannot be applied to piecewise-constant interpolated data.

(a) is false: in many cases, using a Dirac color map will create 'gaps' or breaks in the displayed contours, if color mapping is applied per-cell (constant interpolation); or will create fuzzy thick bands, if color mapping is applied per-vertex (linear interpolation. (b) is false: both contouring and color mapping are O(C) where C is the number of cells in the dataset. (c) is false: Dirac color mapping may be inferior to contouring for the reasons sketched above at (a), but it definitely can show more contours (e.g. if we use two 'color pulses' in the colormap, see also Fig. 5.2). (d) is true: we cannot apply marching squares or alternatives to piecewise-constant interpolated data, since at the core of marching squares we assume that the data is linearly interpolated between the vertices of a cell. See also Sec. 5.2.

11. The isolines of a scalar dataset and the gradient field of the same dataset are related quantities. Which of the following is true:

   a. The isolines are always tangent to the gradient field;
   b. The isolines are always orthogonal to the gradient field;
   c. The isolines meet at the non-zero divergence points (sources and sinks) of the gradient field;
   d. The isolines can only be computed when the gradient field is divergence free.

(a) is not true, see the relation of the isolines with a gradient field (Fig. 5.9 and related text). (b) is true, see the same text as above. (c) is not true, consider Fig. 9 where we see that the gradient field has two sinks (and moreover, the isolines of a field never meet). (d) is not true, see the counterexample again from Fig. 5.9.

12. Contouring and slicing are related data visualization operations that link 2D and 3D visualization algorithms. Which of the following is true:

   a. Slicing is required to extract 2D dimensional datasets prior to contouring;
   b. Slicing and contouring are not commutative: if we slice a 3D dataset, and next contour it, the result is not the same as contouring a 3D dataset and next slicing the contours;
   c. Slicing and contouring are commutative operations, but only if we use the same color map;
   d. Slicing and contouring are commutative operations regardless of the kind of the slice surface (planar, non-planar, and oriented at any desired angle).

(a) is not true, since we can of course perform contouring in 3D (marching cubes). (b) is not true, see Fig. 5.17 and related text. (c) is not true – color mapping has nothing to do with slicing and contouring, which are geometric operations. (d) is true – although the example in Fig. 5.17 uses a planar slice, we could very well use a curved surface or a slice plane oriented with another angle than the one in that figure and obtain the same result.