A Design Toolbox
to Generate Complex Phantoms
for the Evaluation
of Medical Image Processing Algorithms

Omar Hamo, Georg Nelles, Gudrun Wagenknecht

Central Institute for Electronics, Research Center Juelich, D-52425 Juelich, Germany
g.wagenknecht@fz-juelich.de

Abstract. In the field of medical image processing, the evaluation of new algorithms is often a difficult task since real data sets do not allow a quantitative evaluation of the algorithms' properties and the correctness of results. Thus, a phantom design toolbox was developed to enable the generation of complex geometries appropriate to simulate anatomical structures as well as realistic image intensity properties and artifacts, such as noise and inhomogeneities. This paper describes the most important features of the new toolbox and shows sample phantoms generated so far.

1 Introduction

Generating appropriate simulated image data for the evaluation of medical image processing algorithms, such as segmentation [1] or registration, is often a challenging and time-consuming task, particularly in case of complex geometries of anatomical regions like the brain. So far, some evaluation databases [2, 3] exist which are based on one or more real image data set for which the expert segmentation result is provided and can be used as a gold standard. In addition, the BrainWeb [4] data set can be modified in image intensity values and image artifacts to build realistic brain phantoms whereas the geometry is fixed. To evaluate or test the behaviour of algorithms under different conditions, phantoms are needed which can be adapted in geometry as well as image intensities and artifacts to be suitable to given evaluation tasks. The phantom design toolbox was developed to simplify the creation of such custom-made and complex mathematical phantoms [5].

2 System description

The toolbox is provided with a graphical user interface based on Qt 4.5 [6] to easily choose, transform and combine geometrical primitives based on constructive solid geometry (CSG) [7]. Three orthogonal 2D views and one 3D view enable the user to monitor the phantom building process step-by-step.

2.1   Available primitives

So far, various rotationally symmetric and polygonal 2D and 3D primitives, as shown in Fig. 1, are available. In addition to these simple geometric primitives, a primitive called three dimensional supershape is made available. This primitive is based on the "Superformula" introduced by Gielis [8] designed "to study natural forms and phenomena". Besides known approaches to create 3D supershapes by extrusion and the spherical product [9], a new approach is made available (1), (Fig. 2).

$$r(\phi, \theta) = \left[\left| \frac{\cos(m\phi/4)}{a} \right|^{n2} + \left| \frac{\sin(m\phi/4)}{b} \right|^{n3} + \left| \frac{\cos(m\phi/4)}{c} \right|^{n4} \right]^{\frac{-1}{n1}} \tag{1}$$
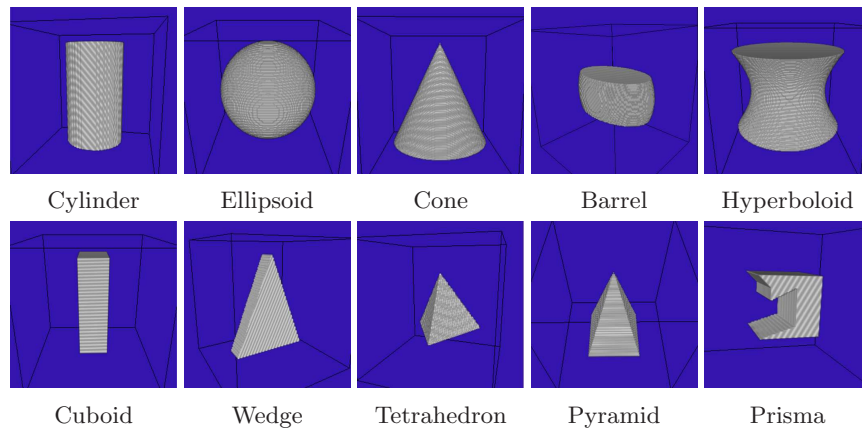

| Cylinder | Ellipsoid | Cone | Barrel | Hyperboloid |
| Cuboid | Wedge | Tetrahedron | Pyramid | Prisma |

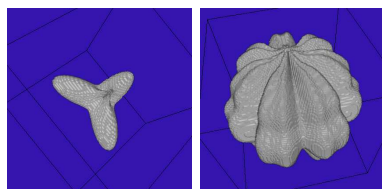**Fig. 1.** 3D primitives.

Fig. 2. Three dimensional supershape. By variation of only a few parameters, a variety of primitives can be created.
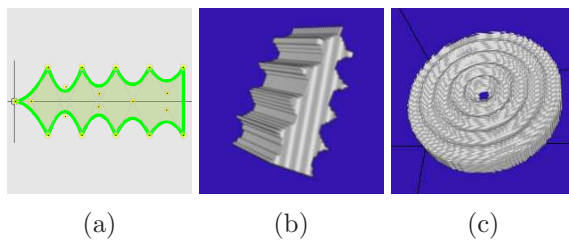

Fig. 3. Extrusion of a shape.

(a)   (b)   (c)

In order to generate even more complex and freely definable primitives, the toolbox provides a tool to draw two-dimensional boundary contours based on linear, quadratic and Bezier curves. The voxelized two-dimensional object (Fig. 3(a)) can then be extruded in one direction (Fig. 3(b)) or around one axis (Fig. 3(c)).

2.2   Composition of phantoms

The primitives chosen can be defined in value, size and position and be transformed by affine transformations. The boundary representation of the primitives is used to transform and position them on the volume grid. Phantoms can be composed of primitives using the Boolean operations union, difference, intersect or distinguish. The intensity value of the resulting combination can be calculated from the input values by operations, such as sum, difference or product. The resulting combination can in turn be used like a single primitive in further steps and be integrated into a user specific library.

In addition, the discrete values of the components can be modified to simulate real images including definable image artifacts, such as additive white Gaussian noise, and different kinds of inhomogeneities, such as nonlinear intensity non-uniformity fields from estimated real MRI scans [4]. In order to seperate a phantom into different tissue types (e.g., white and grey matter for brain phantoms) dependent on the dictance to the phantom's surface, an operation based on a distance transformation is made available.

The phantoms can be saved in all possible big and little endian data formats and different file formats, e.g., RAW and Analyze 7.5. The phantom exports module allows further histogram-based modifications of already assigned values, e.g., clipping or histogram equalization. Furthermore, the whole phantom building process can be saved in an editable XML file, to enable the user to stop and rebuild or modify the phantom at each step of the building procedure.

3   Results

The graphical user interface of the resulting phantom design toolbox is shown in Fig. 4. The phantom shows different brain tissue types and the simplified geometry of a branching cortical sulcus.

In Fig. 5, a phantom representing the corpus callosum is shown. It was created by using a MRI image of the sagittal view as a template to draw the border strip with cubic and Bezier curves. The voxelized and extruded primitive has then been combined with several hyperbolic, cylindrical and elliptical primitives using the CSG operation difference (A/B) to generate the curved surface shape.

Fig. 6 shows a phantom which is generated by drawing the contours of the cerebral cortex within the blue box. The gray matter was simulated by thickening and labeling these contours with a darker gray value. Then the voxelized object has been extruded by rotating it. The liquor is represented by an ellipsoid which was combined with the extruded primitive by the CSG operation union. A lesion

(green arrow) was simulated by a local spherical gradient field. Finally, noise and a nonlinear inhomogeneity field were applied.
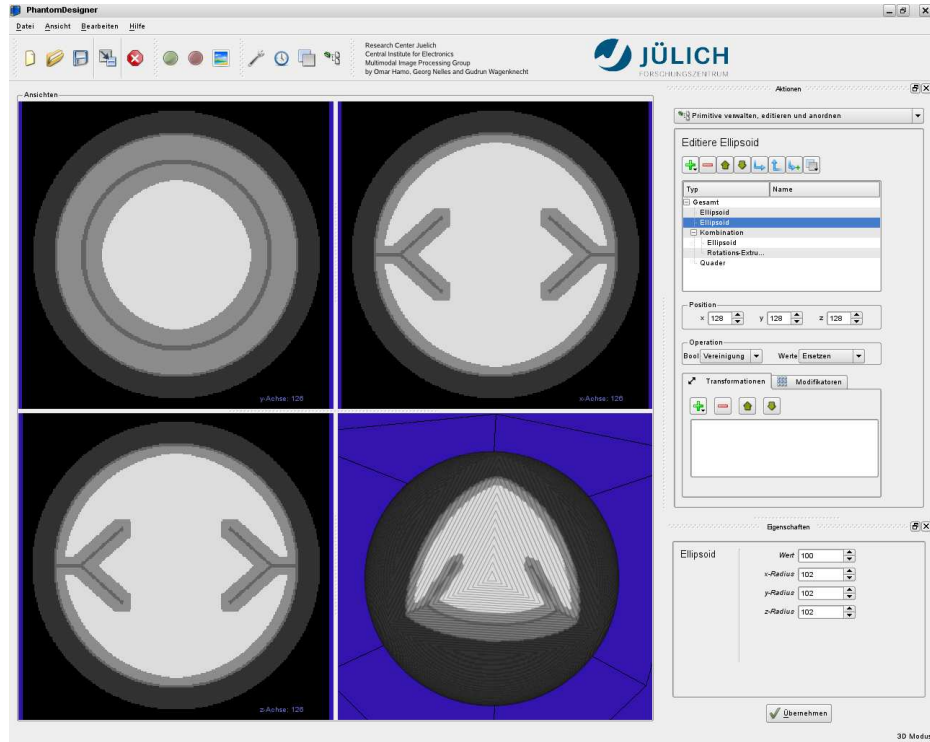

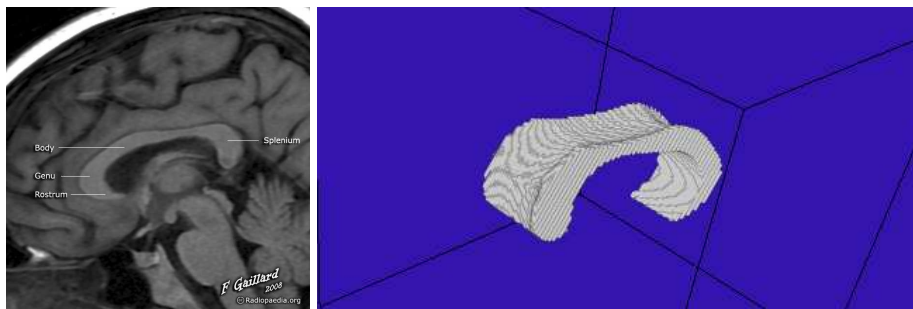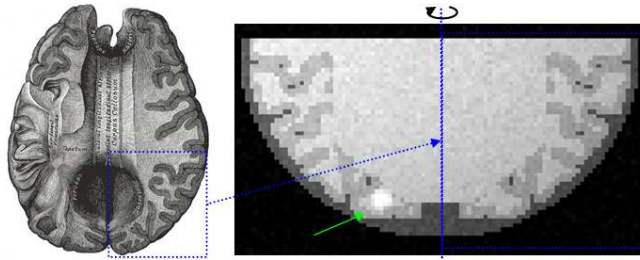**Fig. 4.** Graphical user interface .

Fig. 5. Phantom (right) derived from a sample slice of the corpus callosum [10] (left).

Fig. 6. The phantom (right) is derived from a sample slice of the brain [11] (left).

4   Conclusion

Simulating complex geometries of anatomical regions is a difficult and time-consuming task. The phantom design toolbox allows building such complex phantoms in a fast, intuitive and easy way. Pairs of realistic-looking phantoms, one representing the anatomical structures and one representing the corresponding gray value image (e.g., of a simulated MR dataset), can be created to evaluate medical image processing algorithms. A second toolbox is already implemented to enable those quantitative evaluations.

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