Analyzing 3D images of the brain

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OVERVIEW

During the past 5 years, there has been a considerable effort of research in automating the analysis and fusion of multidimensional images, yielding important theoretical and practical new results. These results could now be useful to brain research.

Along these lines, and focusing on 3D images of the brain obtained with CT, MRI, SPECT, and PET techniques, I will present a number of methods useful to produce *quantitative measurements* necessary for an objective analysis of 3D images of the brain.

Such methods include segmentation, shape analysis, rigid and elastic registration, fusion of multimodal images, analysis of temporal sequences (4D data), modeling, and matching of digital atlases. A large number of references on these topics can be found in Ayache (1995a,b), and specific examples from our research group in Malandain *et al.* (1994), Subsol *et al.* (1995), and Thirion (1995).

The following text describes the research tracks to be followed in order to optimize the future exploitation of 3D images of the brain in neuroscience.

NEW VOLUMETRIC IMAGES

It is possible to acquire a variety of 3D images of the brain. They come from different modalities like magnetic resonance imaging, computed tomography imagery, or nuclear medicine imagery. New 3D imagery devices are emerging, like angiographic MRI, magnetoencephalography equipment, or functional MRI.

Volumetric images share the particularity of describing the physical or chemical properties at each point of a studied *volume.* This information is stored in a discrete 3D matrix $I(i, j, k)$ of voxels (volume elements), called a 3D image. A high resolution MR image of the brain may contain more than 16 million voxels, and this makes its manipulation, visualization, interpretation, and/or comparison with other images or atlases quite difficult by hand.

NEW POTENTIALITIES

In fact, there is a new list of potential tasks which could be performed automatically by some dedicated software, and which could help brain research significantly:

- producing a *realistic 3D visualization* of the major brain structures in anatomical images;
- producing *quantitative measurements* of shapes and textures in anatomical or functional images;
- studying *temporal evolution* of anatomical or functional images;
- *fusing* of anatomical and functional images;
- providing *intersubject comparisons* of anatomical or functional images;
- building geometric models of *standard anatomy* from anatomical images;
- building geometric models of *standard activation* from functional images;
- evaluating *deviations* from standard anatomy and/or activation; and
- *planify* and *accurately position* in space a number of physical measuring devices like microelectrodes, for instance.

NEW MEDICAL IMAGE ANALYSIS, GRAPHICS, AND ROBOTICS ISSUES

To complete these new tasks automatically, it is necessary to solve a number of advanced 3D image analysis research problems (and possibly a number of graphics and/or robotics ones):

3D segmentation of images: the goal is to partition the raw 3D image into regions corresponding to meaningful anatomic structures. It is a prerequisite to most of the tasks listed above. Efficient segmentation requires the modeling and extraction of 3D static or dynamic edges and of 3D texture, as well as the generalization in 3D of digital topology and mathematical morphology.

3D shape representation/characterization: this is mainly a prerequisite to solve the registration and identification needs, but also for efficient visualization. It is necessary to describe nonpolyhedral 3D shapes with a reduced number of intrinsic features. This involves mainly computational and differential geometry.

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3D rigid and nonrigid registration and fusion of 3D shapes: once segmented and modeled, new algorithms must be designed to reliably and accurately match such representations together, both in rigid and in nonrigid cases. This is necessary to solve the registration and identification needs. This requires the development and comparison of a number of matching algorithms (tree-search, accumulation, correlation, maximum entropy, etc.), as well as the choice of a class of nonrigid transformations (affine, quadratic, splines, etc.).

3D standard geometric models must be constructed, based on the automatic registration of a number of intersubject anatomic structures or activations. This requires the previous nonrigid matching tools, but also advanced statistical models of random shapes and spatial activations. Once such models are built, it is necessary to build specific registration tools, to adapt these models to the images of an arbitrary subject, allowing the automatic interpretation of the anatomic structures, but also the detection (and quantification) of important deviations from the standards.

Virtual reality, physical models, and image-guided robotics should be developed to provide realistic interactive visualization and to help in planning and simulation, in particular to help in positioning measuring devices within the brain with an extreme accuracy.

CONCLUSION

To exploit fully the potentialities offered by the new 3D images of the brain, there is a strong need for research mainly in the field of 3D image processing and analysis, but also in the fields of 3D graphics and medical robotics.

I believe it is very important that we help, in Europe and in the United States, the best research in these fields, and encourage a strong collaboration between these experts and the experts in neurosciences, to ensure significant progress in the understanding of the brain in the coming decade.

In this spirit, the morphometric analysis of the brain (i.e., the production of quantitative shape measurements on the brain) is the central topic of a European research consortium called *Biomorph,* including our research group, starting in 1996, and to be funded by the European Community within the *Biomed-2* framework.

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