Retrieving 3D MRI Brain Images

Vassili Kovalev and Frithjof Kruggel

Max-Planck Institute of Cognitive Neuroscience
Stephanstrasse 1a, D-04103, Leipzig, Germany
{kovalev,kruggel}@cns.mpg.de

Abstract. The usefulness of 3D image retrieval paradigm is evaluated in the context of neurological research using 265 high resolution MRI-T_1 brain datasets of healthy controls. The method is based on multi-sort co-occurrence descriptors. It is shown that the approach can be used for localization of specific brain regions (mean deviation of 2.4 mm for searching anterior/posterior commissures), retrieval subjects from different age groups (more than 90% correct in top-10 for retrieval of young and aged subjects), and distinguishing very weak differences associated with gender (62% correct in top-10 query results on 210 young healthy subjects).

1 Introduction

Recently, the neurological research involves large amounts of 3D image data of different modalities. It is obvious that the problem of searching "similar" brain images is different from the general image retrieval problems studied in computer vision (e.g., [1]). The purpose of this work is to evaluate the feasibility and usefulness of the brain image retrieval paradigm on 3D MRI-T_1 brain datasets.

The approach presented in this paper is a query-by-example approach and it is based on multi-sort, multi-dimensional co-occurrence matrices proposed in [2]. These 3D image descriptors are sensitive to tenuous differences in brain image patterns and reflection/rotation invariant. In context of brain image analysis with the characteristic "reflected" intensity distribution in the left and right hemispheres and unpredictable sulcal variability, this is a highly desirable property. Being normalized to the sum of elements, they are also insensitive to individual differences in brain volume.

In this study we are evaluating the fitness of the approach on the following non-trivial tasks:

(a) searching for specific brain regions such as anterior and posterior commissures;

(b) retrieval of MRI brain datasets of healthy subjects from different age groups;

(c) testing the ability of the image descriptors to capture almost inconsiderable differences associated with gender.

Query results are represented as top-N images most similar to the given example. The query unit is always a 3D volume of interests (VOI). Depending on specific retrieval task, the VOI may contain the whole brain, certain brain region, or even a single 2D image slice. In most of cases image descriptors can be pre-computed and stored in a database so that searching can be performed in real time. The evaluation procedure used for quantitative analysis of image retrieval quality is similar to the testing technique described in [3].

2   Materials and Methods

2.1   Subjects

The Max-Planck Institute of Cognitive Neuroscience maintains a database of subjects enrolled for functional MRI experiments. Before admission, a high resolution T_1-weighted MRI scan of the head is acquired. Subjects are included in this database if they comply with the informed consent for conducting general fMRI experiments, pass the examination, and do not exhibit pathological or abnormal features (such as ventricular enlargements, subarachnoidal cysts) in their MR tomograms. All scans used in this study stem from this database.

For the first and the third experiments the age- and gender- matched group of 210 young healthy subjects was selected (103 males and 107 females, mean age 24.8, SD 3.97 years). For the second experiment on retrieval of brain images with respect to age we used 55 image datasets that have been conditionally sub-divided into the "young" subgroup, AG-Y (33 subjects aged 16-25 years, 17 males and 16 females) and "aged" subgroup, AG-A (22 subjects, 50-70 years, 11 males and 11 females).

2.2   MRI Data

MR acquisition was performed on a Bruker 3T Medspec 100 system equipped with a bird cage quadrature coil using a T1-weighted 3D MDEFT protocol [4]: FOV 220x220x192 mm, matrix 256x256, 128 sagittal slices, voxel size 0.9 x 0.9 mm, 1.5 mm slice thickness, scanning time 15 min. Scan data were interpolated to an isotropical voxel size of 1.0 mm by a fourth-order b-spline method [5] and aligned with the stereotactical co-ordinate system [6] while removing the outer hulls of the brain. Datasets were finally cropped into a minimum box enclosing the brain of 160x200x160 mm extent.

2.3   Method

Image comparisons were performed by calculating $L2$ distance between their descriptors. We have employed multidimensional co-occurrence matrices suggested in [2] as VOI descriptors. For the definition of matrices, let us consider an arbitrary voxel pair (i, k) defined on a discrete 3D voxel lattice by voxel indices $i = (x_i, y_i, z_i)$ and $k = (x_k, y_k, z_k)$ and with the Euclidean distance $d(i, k)$. Let us denote their intensities by $I(i)$ and $I(k)$, local gradient magnitudes by $G(i)$, $G(k)$ and the angle between gradient vectors by $a(i, k)$. Then the general, six-dimensional co-occurrence matrix can be defined as:

$$W = ||w(I(i), I(k), G(i), G(k), a(i, k), d(i, k))||,$$
$$a(i, k) = \cos^{-1}(g(i) \bullet g(k)),$$

where $g(i) \bullet g(k)$ is the dot vector product and $g(i)$, $g(k)$ are normalized intensity gradient vectors at voxel positions i and k. Gradient vector components can be derived by any suitable 3D operator. Since we are dealing with high frequency textures, we used filter with a small 3x3x3 window proposed in [7].

In order to define the exact computational procedure for the above matrix, let us denote the integer intensity bins $I(i)$ and $I(k)$ by indices $b_I = 1, ..., B_I$, gradient

magnitude bins $G(i)$, $G(k)$ by $b_G = 1, ..., B_G$, distance bins $d(i,k)$ by $b_d = 1, ..., D$, and relative gradient angle bins $a(i,k)$ by $b_a = 1, ..., B_a$. Then, in terms of integer matrix indices, the matrix element $w(I(i), I(k), G(i), G(k), a(i,k), d(i,k))$ can be defined as:

$$w(b_{Ii}, b_{Ik}, b_{Gi}, b_{Gk}, b_a, b_d) = card \ \{(i,k) \in \mathbf{R}^3 \mid i \neq k, \ b_{Ii} = I(i), \ b_{Ik} = I(k),$$
$$b_{Gi} = G(i), \ b_{Gk} = G(k), \ b_a = a(i,k), \ b_d = round(d(i,k)),$$
$$x_k = (x_i + \Delta x), \ y_k = (y_i + \Delta y), \ z_k = (z_i + \Delta z),$$
$$-D \leq \Delta x \leq D, \ -D \leq \Delta y \leq D, \ 0 \leq \Delta z \leq D,$$
$$\Delta z S^2 + \Delta y S + \Delta x \ > \ 0, \ S = 2D + 1\}$$

where Δx, Δy, and Δz are offsets on X, Y and Z axes measured in image raster units. The last two lines of the definition formalize the requirement of selection of all possible voxel pairs with no repetition. When calculating matrices, we always follow the original image raster and round Euclidean distances $d(i,k)$ to the nearest integer matrix bin in order to avoid incorporation of non-existing intensity values caused by interpolation. Therefore the *round* operator is defined in the common sense, i.e., as rounding to the nearest integer value. These descriptors are rotation/reflection invariant because they take into account the relative orientations only.

The image analysis methods were implemented in the C programming language for recent PC workstations. Key implementation details are given in [2].

3 Results

3.1 Searching for Specific Brain Regions

The anterior/posterior commissure (AC/PC) has been chosen for this experiment because it represents the brain region, which can be defined reliably. Co-occurrence matrices were calculated with 8 bins for both intensity and gradient magnitude and inter-voxel distances ranged from 1 to 4 mm. The angle axis was omitted because in this experiment we are not interested in the anisotropy properties of brain images. The basic step of the experiment is as follow (Fig. 1): we take a 160x200x3 mm image VOI containing AC/PC plane in the middle slice as a query example, scan another dataset, choose the best match, and calculate its deviation from the true AC/PC location. Fig. 2 shows typical query examples and corresponding searching results. In order to avoid the influence of random factors, in each run we used the mean VOI descriptor computed over the 10 different subjects as a query example for the rest 200 subjects. Thus, our statistical results (Fig. 3) are based on 21*200=4200 queries. Investigation of gross errors (about 5% of cases, see the left shoulder of the histogram) has revealed that they are caused either by "atypical" brain anatomy or certain miss-alignments of original datasets.

3.2 Retrieval by Age

This experiment is closely related to the neurological problem of quantification of brain atrophy due to the normal aging. The whole brain is considered as a VOI in the case. Descriptors were calculated with the same parameters except the number of angle bins set to 6. Each image from both AG-Y and AG-A subgroups was subsequently

submitted as a query example. Searching results were considered as correct if they belong to the same age group as given query. Typical searching results are shown in Fig. 4 (all are correct). Statistical data are summarized in Table 1.

3.3 Retrieval by Gender

It is commonly known that the anatomical differences associated with gender are very weak, often on the border of statistical significance. Therefore this experiment was performed to test the sensitivity of the approach rather than the utility of the retrieval task itself. Again, each 3D brain image of 210 subjects was used as a query example. The correctness of retrieval results was judged according to gender (see the second row of Table 1).

4   Conclusions

Results of the first experiment suggest that retrieval of 3D brain sub-regions by their visual similarity may provide certain assistance in pre-processing and the analysis of 3D MRI datasets. However, the usefulness of this technique is limited. This is mostly because of complex spatial structure of anatomical brain images and high inter-subject variability. In contrast, the second experiment on retrieval of subjects from different age groups based on the whole brain images has demonstrated very promising results. The reason for such high rate of correctly retrieved datasets ($> 90\%$ in the top 10) is perhaps the ability of multi-sort co-occurrence descriptors to capture various features of brain atrophy (e.g., change of gray/white matter ratio, ventricle enlargements, decline of white matter anisotropy). Note that these measurements are poorly defined or not available at all on 2D slices. The rate of 60–65% of correct gender retrieval in the third experiment is another evidence of high sensitivity and specificity of 3D image descriptors we used (for n=210 this rate corresponds to the statistical z-scores of 5.0–6.0 with $p < 10^{-5}$).

In conclusion, this feasibility study demonstrated the usefulness of 3D MRI image retrieval paradigm in neurological research. The utility of slice-based approaches remains doubtful.

References

1. Gupta, A., Jain R.: Visual Information Retrieval. Comm. ACM. **40** 5 (1997) 70–79
2. Kovalev, V.A., Kruggel, F., Gertz, H.-J., von Cramon, D.Y.: 3D Texture Analysis of MRI Brain Datasets. IEEE Trans. Med. Imaging. **20** 5 (2001) 424–433
3. Kovalev, V., Volmer, S.: Color Co-Occurrence Descriptors for Querying-by-Example. Int. Conf. on Multimedia Modeling, Oct. 12-15, Lausanne, Switzerland, IEEE Comp. Soc. Press (1998) 32–38
4. Lee, J.H., Garwood, M., Menon, R., Adriany, G., Andersen. P., Truwit, C.L., Ugurbil, K.: High Contrast and Fast Three-Dimensional Magnetic Resonance Imaging at High Fields. Magn Reson Med. **34** (1995) 308–312
5. Thevenaz, P., Blu, T., Unser, M.: Image Interpolation and Resampling. In: Bankman, I.N.(ed.): Handbook of Medical Imaging. Academic Press, San Diego (2000) 393–420
6. Kruggel, F., von Cramon, D.Y.: Alignment of Magnetic-Resonance Brain Datasets with the Stereotactical Coordinate System. Med. Image Analysis. **3** 2 (1999) 175–185
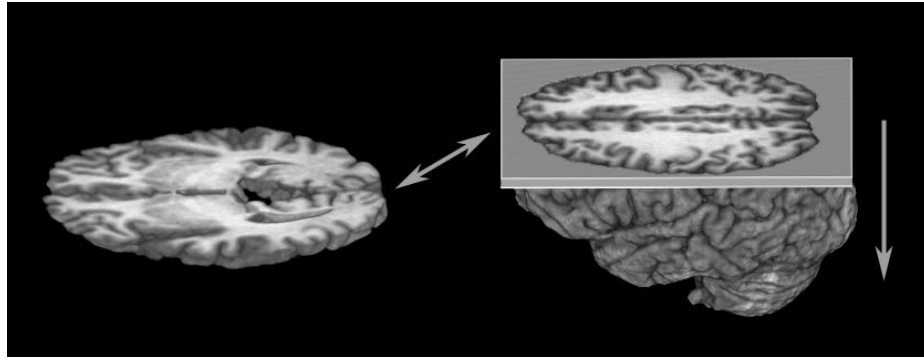7. Zucker, S.W., Hummel, R.A.: A 3D Edge Operator. IEEE PAMI. **3** (1981) 324–331

Fig. 1. Searching for anterior/posterior commissural plane. Every image (*right*) is scanned by the 160x200x3 mm VOI for the best match with the descriptor of given query example (depicted on the *left*)
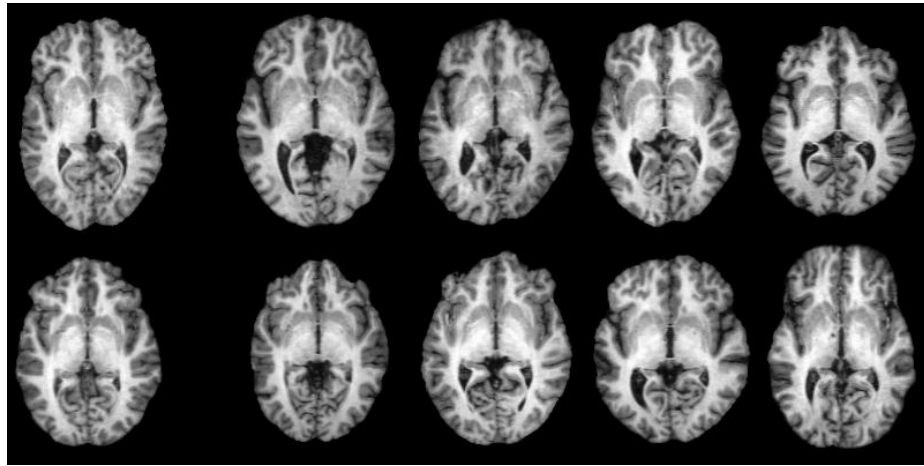

Fig. 2. Typical results of commissural plane localization. Query examples (*leftmost images*) and searching results for 4 different subjects are presented. Only central slices of 160x200x3 mm VOIs are shown

Table 1. Statistical results of brain image retrieval

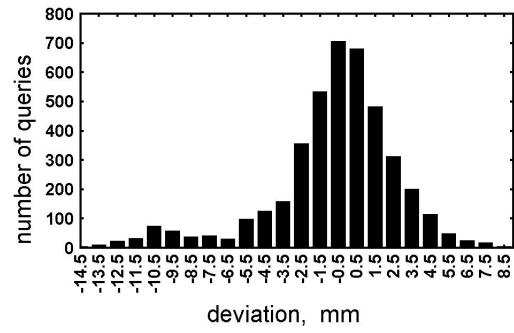| % of correct in top-N	N=20	N=15	N=10	N=5	N=1
young/aged	96.4	93.8	90.6	86.3	82.2
male/female	67.6	65.1	61.9	61.1	60.5

Fig. 3. Deviation of detected commissural plane from its real position (mean deviation m=2.4, SD=2.5 mm). Statistical results are based on 4200 queries
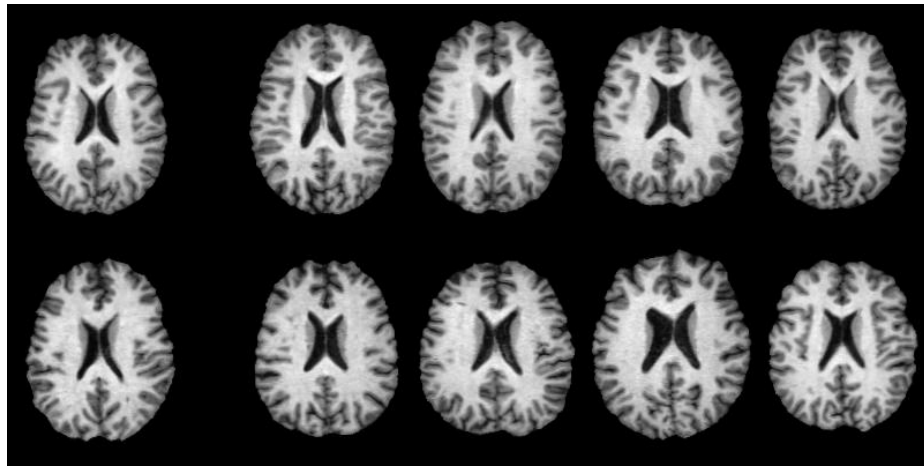

Fig. 4. Typical results of retrieving young (16-25 years, *top row*) and aged (50-70 years, *bottom row*) subjects. Characteristic slices of query examples (*leftmost*) and their 4 best matches are shown