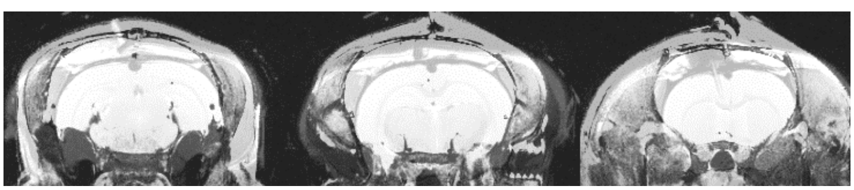
Image Registration by Global Maximization of Mutual Information Based on a Genetic Algorithm

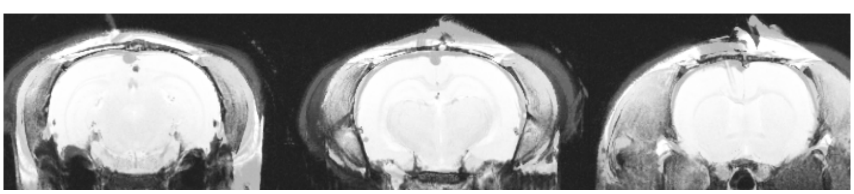
H. Yu[1], J. M. Sullivan, Jr. [1], H. R. Ghadyani[1], J. Q. Zhang[1]
[1]Bioengineering Institute, Worcester Polytechnic Institute, Worcester, MA, United States

Introduction: Image registration of all subjects within a group is a critical step to obtain an accurate composite activation map for functional magnetic resonance image (fMRI) analysis. Mutual information is the most widely adopted similarity metric for automatic image registration [1,2]. Multi-dimensional optimization techniques are applied to search for the maximum mutual information from two volume images. However, because of image distortion, interpolation methods, bin size of histogram and other reasons, the registration process contains many local maxima. Conventional optimization techniques require a good initial start location. Frequently, they fail due to entrapment about localized maxima. In this paper we present a genetic algorithm (GA) approach that avoids the local maxima traps of conventional optimization techniques. Genetic algorithms are based on the principles of Darwinian natural selection (survival of the fittest). The general workflow of a genetic algorithm has two steps: 1. randomly generate an initial population. 2. repeated application of the natural selection operation until the termination measure is satisfied. The natural selection process identifies individuals based on their fitness to participate in the genetic operations; and it creates new individuals using reproduction, crossover, mutation, and architecture-altering operations. Once the termination criteria are satisfied, the best individual is selected from the population. To evaluate the performance of the GA registration, the results are compared with classical non-gradient and gradient optimization techniques (Downhill simplex, Quasi-Newton).

Methods: The transformation model was the affine 4x4 matrix involving translation, rotation, and scaling in all 3 orthogonal coordinate directions, independently. The partial volume interpolation technique was used to construct the joint histogram from two images. This interpolation method has the mutual information vary smoothly as a continuous function of registration parameters. Normalized mutual information (NMI) was the similarity metric used to evaluate the accuracy of image registration. $NMI(A, B) = (H(A) + H(B))/H(A, B)$, where $H(A)$, $H(B)$ are the individual entropies and $H(A, B)$ is the joint entropy. According to information theory, the uncertainty of a random variable with probability mass function $p(x)$ is measured by its entropy $H(x)$: $H(x) = -\Sigma p(x) \log[p(x)]$. We incorporated the genetic algorithm into the registration framework as the optimization technique. To improve the computational efficiency and robustness of our genetic algorithm, we implemented the algorithm with PCX (parent-centric recombination operator) and G3 model (Generalized Generation Gap) features. There are 9 parameters for transformation model. For each parameter, the search space is user-specified. The maximum normalized mutual information is the objective function for this registration process. When the objective function change was less than 2% within 100 iterations the GA terminated.

Results: Experiments were conducted with images of different dimensions and voxel resolutions. Each image set had (256x256) in-plane pixel resolution. However, the pixel spacing and slice counts were different. No pre-processing (smoothing, threshold setting) was required. The parameter constraints used were: [-30, 30] pixels for translation, [-20, 20] degrees for rotation and [0.25, 2] for scaling ratio. Fig 1 displays the initial misalignment at 3 distinct regions of the brain prior to registration. Fig 2 shows the registered subjects. The alignment differences within the brain are graphically indistinguishable. The registration results were compared with the Downhill simplex and Quasi-Newton optimization techniques using the same image sets: Although Downhill simplex and Quasi-Newton methods had a slightly faster registration speeds (10-12%), our GA approach always produced significantly better final alignments. Numerous trials of the conventional strategies failed for grossly misaligned image sets. However, the GA approach aligned the images successfully each time. These results demonstrate the robustness and precise alignment attainable with the GA registration while preserving computational efficiency within 10% of other strategies.





Conclusion: An image registration strategy using global maximization of normalized mutual information was developed. Coupling this mutual information with a GA strategy was shown to be a robust and accurate registration strategy. The registration quality was superior to the conventional alignment techniques. Significantly, the GA was not strongly sensitive to the initial start point nor was it susceptible to local maxima.

Reference: [1] Wells, W., et. al., "Multi-modal volume registration by maximization of mutual information", Med. Image Anal, V1, (1996). [2] Maes, F., et. al., "Multimodality Image Registration by Maximization of Mutual Information", IEEE Trans. Med. Imag., V16, (1997).