Fully automatic segmentation of the brain from T1-weighted images using Bridge Burner algorithm

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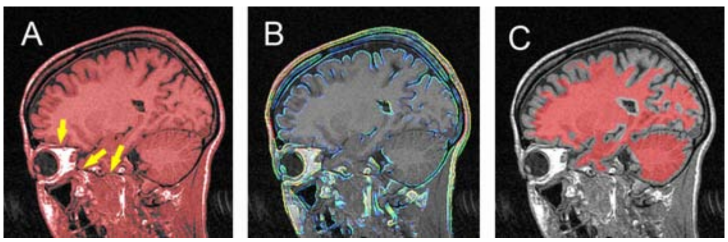
Segmentation of the brain from MR images is a crucial pre-processing step in neuroimaging analyses, including volumetry, morphological studies, coregistration, and nonuniformity correction. We have developed a fully automatic *Bridge Burner* algorithm to isolate the brain from high-resolution T1-weighted MRI. The algorithm exploits the notion that the brain and non-brain structures are either (1) not connected to one another after thresholding the image, (2) separated by a relatively strong edge, or (3) connected by a bridge of voxels which is thin relative to the brain itself. The accuracy of *Bridge Burner* is compared to manual segmentation (consensus of human experts) using images of subjects spanning a wide range of ages, brain disorders, and acquisition protocols.

Methods

The algorithm begins by locating a 1 cm^3 sample of periventricular white matter by maximizes the ratio of the average value of signal intensity, C_w, to its standard deviation in the 1 cm thick coronal slab. The reference value C_w is used as a reference for initial segmentation based on intensity thresholding, yielding V^0 (Fig.1A). The union of boundary facets of V^0 and image edges (Fig. 1B) form the initial set *B* of bridges. "Bridge burning" occurs when immediate neighboring voxels of facets *B*, N(B), are subtracted from V^0. This iterative process continues by subtracting the set of neighboring voxels of the facets of N(B). After P iterations, the largest connected component, V^P_{max} (Fig.1C) excludes non-brain tissue. To offset the morphologic erosion during the bridge burning process, voxels are then added back to V^P_{max} in Q iterations of constrained growing: 1) only those voxels that were removed from V^0 are added back; (2) at each iteration the resulting mask does not cross over the bridges *B*.

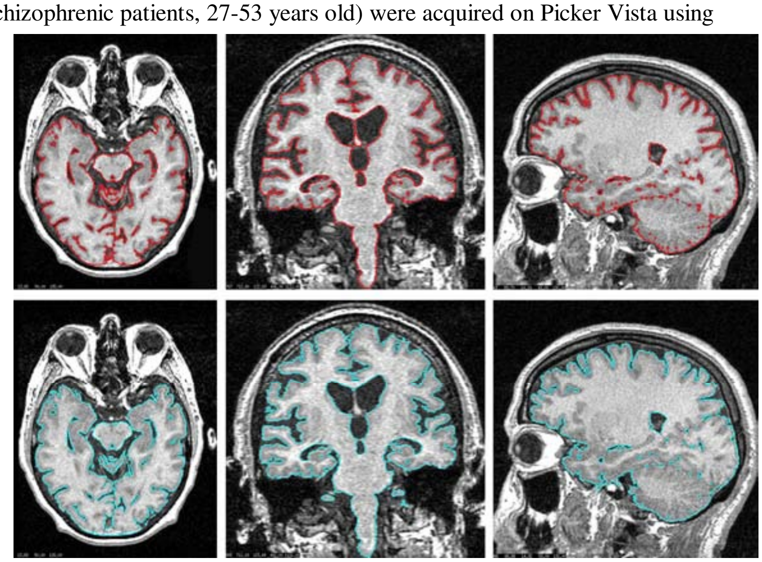


A: initial segmentation (in red) superimposed on a T1-weighted image. The yellow arrows indicate the bridges, or thin connections between the brain and non-brain tissue. B: image edges superimposed on the image using the rainbow color scheme (blue<green<red). C: the largest connected component after bridge burning.

We have assembled 26 T1-weighted images that represent a spectrum of system manufacturers, pulse sequences, and ages, genders, and neurological conditions. Eight data sets (4 healthy volunteers, 4 patients with brain trauma,18-42 years old) were acquired on Siemens Vision using the MPRAGE sequence, TR=9.7 ms, TE=4 ms, TI=1,000 ms, FA=15°, sagittal 1.5mm slices; 256×256×128 matrix. Ten sets (4 volunteers, 6 AD patients, 66-83 years old) were acquired on GE Signa using the SPGRASS sequence, TR=35 ms, TE=9 ms, FA= 60°, coronal and axial orientations, 1.3-1.5 mm thick; 256×192×124 or 256×192×124. Eight data sets (4 volunteers, 4 schizophrenic patients, 27-53 years old) were acquired on Picker Vista using the SPGRE sequence, TR=33 ms, TE=11 ms, FA = 35°, coronal 2.8 mm slices; 256×256×85 matrix. To provide the ground truth, brain masks were generated manually by a team of 7 observers who had 1-14 years of experience in neuroanatomy. Each case was traced by 3 independent experts. The consensus masks M were then generated: a voxel *v* belongs in M if it was marked as brain by a majority (2/3 or 3/3) of human experts. The optimal *Bridge Burner* parameters were determined using three representative training sets; then all sets were segmented using a single common set of parameters.

Results and Discussion

Bridge Burner segmentation errors (the sum of over- and under-segmentation errors) for 26 datasets were 3.4% ± 1.3% (average±st.dev). The corresponding surface errors (Haussdorf measure) were 0.43 ± 0.47 mm. For each case the eyes, facial muscles, scalp and skull were successfully isolated from the brain. The inter-observer agreement was 3.8% ± 2.0% (volume) and 0.48 ± 0.49 mm (Haussdorf surface measure). *Bridge Burner* brain masks are visually similar to the masks generated by the consensus of expert observers (Fig.2). It is interesting to note that the inter-observer discrepancy is larger than the average difference between *Bridge Burner* and the consensus of experts. Meninges and large sinuses were the non-brain structures most often falsely segmented as the brain. While systematic comparison with numerous brain segmentation software packages remains to be made, we noted the advantage of *Bridge Burner* over BET, a computationally efficient and widely used package. On our dataset BET failed to segment four brains, and BET error averaged 5.5% for the remaining 22 cases. *Bridge Burner* requires approximately 5 seconds, including 2 seconds for 3D edge detection task, to process one MRI dataset on a personal computer (AMD-64, 2GHz processor, 1Gb RAM). Overall, the new algorithm shows the desirable combination of high accuracy and fast processing time. Since there is no attempt to model the brain, or to take advantage of a-priori information about its size or shape, we expect the algorithm to be of use to segment other organs from MRI, CT, PET and SPECT data.



Three representative (median segmentation error within three types of data) cases. Top row: the brain outline as segmented by the consensus of human experts. Bottom row: brain masks obtained using *Bridge Burner*.