Universal shape interpolation using the Radon transform

Peter Adany[1], Phil Lee[2], Douglas R. Denney[3], Sharon G. Lynch[4], and In-Young Choi[4]

[1]Hoglund Brain Imaging Center, University of Kansas Medical Center, Kansas City, KS, United States, [2]Department of Molecular and Integrative Physiology, University of Kansas Medical Center, Kansas City, KS, United States, [3]Department of Clinical Psychology, University of Kansas, Lawrence, KS, United States, [4]Department of Neurology, University of Kansas Medical Center, Kansas City, KS, United States

TARGET AUDIENCE: Developers of image processing pipelines; scientists interested in 3D image processing and quantification of anatomical volumes.

INTRODUCTION: In image analysis, the manual identification and drawing of region of interest (ROI) shapes over reference images is a demanding yet important task. For example, the disease state of Multiple Sclerosis (MS) may be revealed by subtle changes of lesion volumes and brain parenchymal fraction. It often may be preferable to draw ROIs over original scan images rather than resampled images, taking advantage of the clearest images and potentially fewer slices to edit. However, this can incur a compromise of data quality due to the subsequent resampling steps. Axial upsampling of images is most easily done by intensity interpolation. However intensity interpolation does not produce smooth axial contours, rather, it produces severe discontinuities unless low-pass filtering is applied in all directions thereby discarding high frequency details. A more suitable method is shape interpolation which can merge information transversally while preserving fine details. Shape interpolation can be done using vertex-based mesh representations [1], but generation and manipulation of meshes is complicated compared to intensity interpolation. Meanwhile, intensity interpolation is robust, fast and easy so it is used ubiquitously for upsampling despite its limitations.

The Radon transform has inspired interpolation techniques, e.g. seismic data reconstructions [2]. Because the Radon transform samples information viewed at many angles in the image plane and presents this information as one-dimensional projections, it may serve advantageously as a domain for shape interpolation. We define a heuristic for interpolation between two Radon projections that requires no prior knowledge of the inputs and no convergence. We investigate the capability of the algorithm to preserve high frequency details and to connect dissimilar shapes, and we test the algorihm on a human intracranial cavity (ICC) shape image. Finally, we investigate a compensation method for artifacts of the filtered back projection (FBP) using baselines derived at adjacent coordinates.

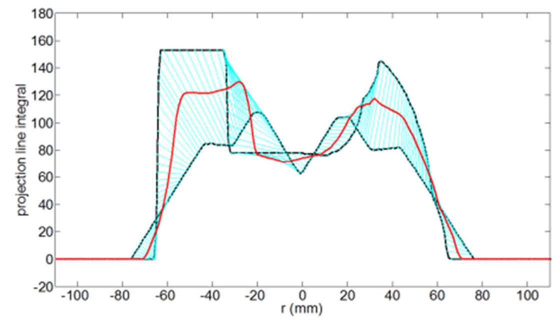

Figure 1. Projections (black) along the y axis of images in Fig. 2, interpolant line segments (blue) and the midway interpolated projection (red). The red line splits each blue line segment by the same fraction.

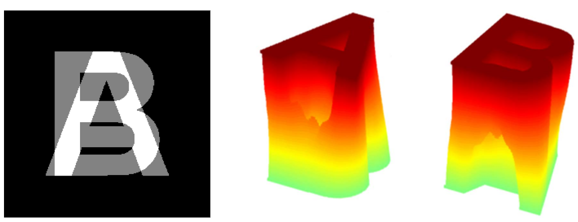

Figure 2. Shape interpolation using the Radon transform, between two dissimilar shapes containing corners, openings and curves.

METHODS: Image pairs were taken from 3D image data with 256 x 256 pixels and 1x1mm transverse resolution. Images were Radon transformed to size 367 x 32, comprising projection profiles at 32 angles distributed from 0 to π. Interpolant line segments (blue in Fig. 1) were positioned such that adjacent end points were equidistant. Interpolated projections (red in Fig. 1) were produced by intersecting the line segments at specific points. Images were produced via FBP of each set of interpolated projections. Artifacts of FBP reconstruction were removed by thersholding and further improvement by subtraction of baselines was investigated. Error attributable to information loss was estimated by interpolating identical shapes and assessing mean squared differences.

RESULTS AND DISCUSSION: A degree of similarity between images leads to a degree of similarity between their Radon transform projection profiles, but their relationship is not well defined, as illustrated by Fig. 1 which shows projections for the images in Fig. 2. In order to restrict the solutions, we state that there exists a set of straight line segments connecting the input projections and intersecting an intermediate projection at equal relative positions along them, noting that the error-free intermediate projection is undefined if the shapes are dissimilar. As a heuristic solution, we place adjacent endpoints so they are equidistant along each projection. The step size-based constraint is favored because it is error-free in the limit that shapes are similar, it yields a predictable and stable morphing characteristic, its resolution is easily scaled, its error approaches zero in the vicinity of each input projection, and it presents few singularities and edge cases compared to more complicated splining criteria. An interpolation between highly dissimilar shapes is shown in Fig. 2. As this shows, an averaging effect takes place through the full rotation of views offered by the Radon transform. Note that the apparent connection among nearby sharp corners did not rely on any adjustment or knowledge about the input. The algorithm was applied to an example mask image of an ICC from automatic segmentation (BET) shown in Fig. 3 (A) and in low resolution (Fig. 3 (B)). Upsampling by intensity interpolation generated a highly discontinous result (Fig. 3 (C)). The proposed algorithm produced results shown in Fig. 3 (D). The sum of absolute error by the new technique was reduced by approximately 50% relative to intensity interpolation. In summary, the proposed shape interpolation algorithm using the Radon transform may outperform intensity interpolation without posing high implementation costs, and thus it may be a useful alternative to intensity interpolation for axial upsampling of shapes.

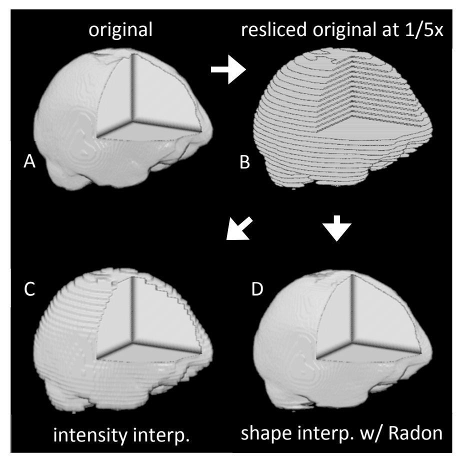

Figure 3. Example human intracranial cavity (ICC) (automatic segmentation (BET)) at 1x1x1mm resolution (A), and re-sliced to 1x1x5mm resolution (B) to test axial upsampling interpolations. Results of nearest-neighbor intensity interpolation to original resolution (C), and results of proposed shape interpolation via Radon transform (D).

REFERENCES: 1. Hong et al. Proc. on Graphics Interface '88: 229-235 (1988). 2. Trad et al. Geophysics 67: 644-656 (2002).