Parameter-Free Reconstruction of Highly Undersampled MR Angiography Images using Gradient Descent with Sparsification

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Introduction: Recently, a new method for generating sparse images from highly undersampled data, Gradient Descent with Sparsification (GraDes), has been introduced [1,2]. This method iteratively determines x, the sparse image to be reconstructed using the following formulation:

$$x \leftarrow H(x + \frac{1}{\gamma} \cdot \Phi^{T}(y - \Phi x))$$

where y is the k-space data, Φ is the resampling/degridding operation (NUFFT from the Fessler toolbox [3] was used for this work), H is a sparsifying transform operation such as thresholding, and γ is a step size which is fixed in the proposed algorithm (set to 1/3 as suggested in the original GraDes work [1]). The advantage of this method over other reconstruction techniques for highly undersampled images, such as compressed sensing [4] or HYPR [5], is that the reconstruction parameters remain constant regardless of the acquisition, making the method easy to implement and robust across different patients. This simple algorithm was tested for the reconstruction of images from highly undersampled MR Angiography data.

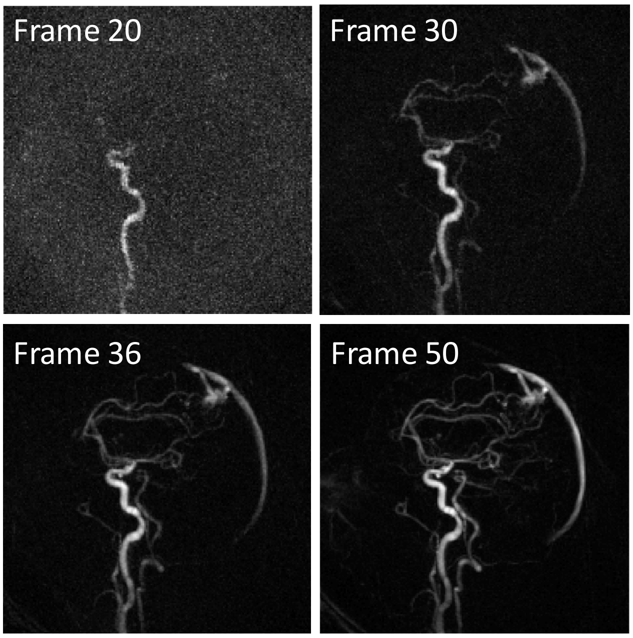

Figure 1: MIP Images generated using 4 projections/frame/partition using the GraDes method without thresholding, resulting in a temporal resolution of 180 ms/frame.

Methods: Contrast-enhanced MRA data were acquired with informed consent from both normal volunteers (N=3) and patients with arterio-venous malformations (AVM) (N=3). For the images shown in Fig. 1, the following acquisition parameters were employed: radial GRE acquisition, TR=3ms, TE=1.5ms, total projections=1344, 75% asymmetric echo, Matrix=192x192, FOV=220x220 FA=20°, Partitions=15, slice thickness=4mm. One-half of the head was covered by these acquisitions. Images were reconstructed with 4 projections per frame and partition and a fixed value of γ, which was used for normalization and to control the speed of convergence of the gradient descent method. In order to start with a reasonable estimate of the current frame x, the result of the previous frame was used to initialize the GraDes routine, as described in [6]. Images were reconstructed using a pixel-number threshold value determined from the signal at the center of k-space as the H parameter in the GraDes formulation, as well as without thresholding.

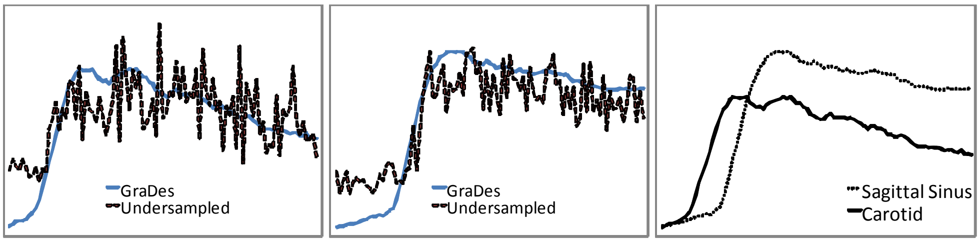

Figure 2: Time curves for representative pixels in the carotid artery (left) and sagittal sinus (center) for the undersampled (dotted) and GraDes reconstruction (solid). The GraDes reconstruction follows the temporal dynamics shown by the undersampled data closely. Additionally, the enhancement of the carotid artery occurs significantly before that of the sagittal sinus in the GraDes reconstruction (shown on right), as expected.

Results: Several representative images reconstructed using 4 projections per partition and frame with no thresholding are shown in Fig 1. In comparison with the results shown in [2], images generated with thresholding had a somewhat pixelated appearance, while the images created using no masking had a more realistic dynamic signal evolution, which can be seen in Fig 1. Additionally, a higher acceleration factor (R~75 compared with Nyquist) was possible using the non-threshold formulation. When using 4 projections per partition per frame, corresponding to a frame rate of 180ms, the arrival of contrast into the AVM can clearly be visualized. The streaking commonly evident in such highly undersampled images has been removed, and the vessels feeding the AVM are clearly depicted. Fig 2 shows that the GraDes reconstruction is temporally faithful to the undersampled data, depicting both the inflow and outflow of the contrast agent.

Discussion: Gradient Descent with Sparsification (GraDes) is a simple method for the reconstruction of undersampled MR Angiography data where high temporal resolution is often required for the characterization of, for instance, AVMs. The method shown here was able to reconstruct highly undersampled images (R~75, temporal resolution = 180ms/frame) which closely follow the temporal dynamics of the undersampled data. This high temporal resolution is possible because only the differences from frame to frame must be reconstructed, as the previous frame can be used as the basis for the next frame. However, residual streaking may remain if the changes from image to image are large; the possibility of resolving these residual artifacts using parallel imaging or a HYPR-like composite image is currently being explored. Despite these slight artifacts, the GraDes method offers images with a high frame rate and excellent temporal fidelity without the need for parameter optimization for different patients.

References: [1] Garg R and Khandekar R. Proc. 26th Int. Conf. on Machine Learning, Montreal, Canada, 2009. [2] Seiberlich N and Griswold M. Proc. 21st Int. Conf. on MRA, East Lansing, MI, 2009. [3] http://www.eecs.umich.edu/~fessler/code/ [4] Lustig M, et al. Magn Reson Med. 2007 Dec;58(6):1182-95. [5] Mistretta CA, et al. Magn Reson Med. 2006 Jan;55(1):30-40. [6] Lu W and Vaswani N, IEEE Intl. Conf. Image Proc (ICIP), 2009.