A general Hierarchical Mapping Framework (HMF) for coil compression

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TARGET AUDIENCE: Neuroimaging scientists and clinicians interested in efficient and accurate reconstruction with high channel-count array coils.

PURPOSE: High channel-count array coils have enabled accurate parallel imaging (PI) reconstruction at very high acceleration factors. However, the computational cost of many PI algorithms scales with the square of the number of channels [1], leading to long reconstruction times. This creates a strong incentive to reduce the effective number of channels used for PI. Methods such as SVD compression [2,3] are applicable to a wide range of k-space sampling patterns, but suffer from low SNR retention at high coil compression rate. The recently proposed Geometric-decomposition Coil Compression (GCC) method [4], tailored for Cartesian k-space sampling, has enabled high coil compression rates with low loss to sensitivity and PI performance. In this work, we introduce a Hierarchical Mapping Framework (HMF) for coil compression that improves upon previously proposed algorithms. We applied HMF to GCC and SVD coil compression to reconstruct highly-accelerated Simultaneous Multi-Slice (SMS) EPI data. We demonstrate that with HMF, the high performance of the GCC method is retained, while the performance of SVD compression can be significantly improved. The application of HMF to SVD compression is likely to extend the benefits seen with GCC for Cartesian acquisitions to non-Cartesian acquisitions (which are incompatible with GCC).

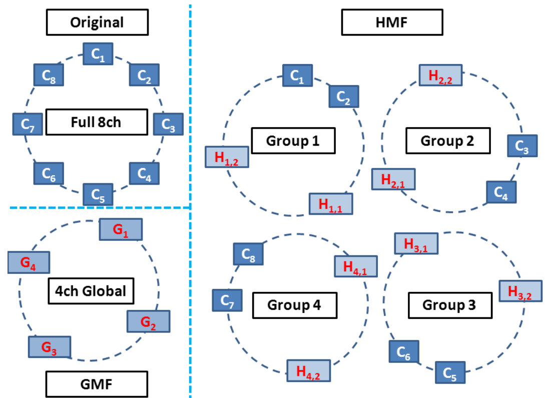

Fig 1. Example of 8ch and 4ch GMF (left). Four PI arrangements are illustrated using HMF (right).

METHOD: PI reconstruction methods such as GRAPPA [5] and Split Slice-GRAPPA (Sp-SG) [6] are formulated to use all available channels as part of the un-aliasing of accelerated data. For example, in the simple 8ch geometry in Fig. 1 (top left) both methods will employ channels C_i $i=1\text{-}8$ to un-alias a given channel C_j. Typically, compression methods rely on a Global Mapping Framework (GMF) that maps the original channels to a subset of channels (to reduce the PI problem size), see the GMF example in Fig. 1 (bottom left). As an alternative, HMF can be used to create a hierarchical grouping of the channels with smaller associated distinct PI systems to solve, see the four HMF arrangements in Fig. 1 (left). With the 8ch geometry, the original channels are partitioned into four subgroups of channels that are strongly correlated to one another. In each subgroup, two virtual coils are generated from the other 6 original channels (e.g. using SVD or GCC). A PI problem is solved for each subgroup in order to estimate un-aliased images for the two original channels assigned to that subgroup. To improve efficiency we can solve for a pseudo-channel whose magnitude is the sum-of-squares combination of the two original channels in the subgroup. The 4 total pseudo-channels are then combined to form the final reconstructed image. With this strategy the HMF and GMF methods have the similar computational requirements for reconstruction. ***Evaluation:*** To evaluate the performance of HMF, the SVD and GCC coil compressions within GMF and HMF frameworks are compared. All methods are imbedded within the Split Slice-GRAPPA (Sp-SG) formulation [6] for SMS-EPI reconstruction. *In vivo* SMS GE-EPI data was acquired from a healthy volunteer using a Siemens 3T Skyra scanner with the following protocol: 72 slices, $2\times2\times2\text{mm}^3$ voxel size, FOV = $196\times196\times144$ mm^3, MB=8, TR=900ms, TE=30ms, Partial Fourier 6/8. Blipped-CAIPI FOV/3 shift was used along with a custom 64-channel head array coil [7] and 5×5 Sp-SG kernel. For all coil compression cases, the 64 channels are reduced to 16 effective channels. Comparisons were made with respect to loss in sensitivity, retained SNR (via pseudo multiple replicas [8]), and reconstruction error (RMSE).

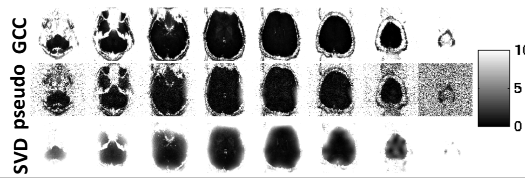

Fig 2. 16/64ch sensitivity loss for GCC, SVD, and pseudo.

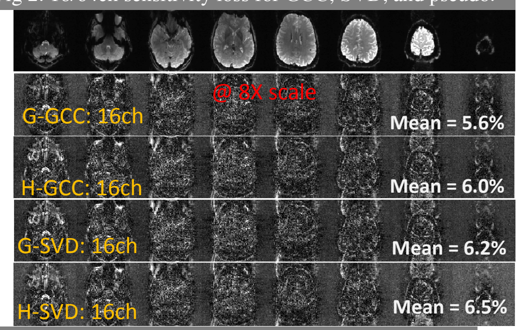

Fig 3. Mean Sp-SG artifacts for MB=8, using HMF and GMF.

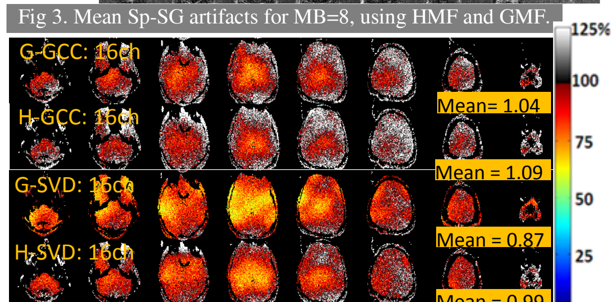

Fig 4. Retained SNR for MB=8, using HMF and GMF.

RESULTS: For the results in Fig. 2-4, G- and H- designate the use of a specific compression method within the GMF or HMF respectively. Fig 2 shows the percentage loss in sensitivity using SVD, GCC, or pseudo channels (used for HMF). The sensitivity loss is significant for SVD (~5x larger than GCC) but the pseudo-channels are within 1% of GCC. Figs. 3 and 4 show differences in the sum-of-square image RMSE and retained SNR when compared to the full 64ch data. It is important to note that Fig. 3 only shows the parallel imaging error, i.e. it does not include the loss in sensitivity due to compression (see Fig. 2). The use of HMF significantly increased the mean SNR (12%) for the SVD based compression. This is over 70% of the difference between the G-GCC and G-SVD methods. The HMF method did however slightly reduce the quality of the G-GCC result. The Sp-SG artifact level did not substantially change for HMF (~0.3-0.4%).

DISCUSSION and CONCLUSION: The additional flexibility provided by HMF enables alternative coil compression techniques to be used for many acquisition types. In the case of Cartesian sampling, HMF was used to bring the level of performance for SVD compression sustainably closer to that observed with the Cartesian optimized GCC compression. As HMF exploits the coil array topology (through correlation) the benefits should extend to irregular sampling patterns and coil geometries. **REFERENCES:** [1] Brau et al. MRM 2008; [2] Huang et al., MRM 2008; [3] Heberlein et al. ISMRM 2009; [4] Zhang et al, MRM 2013; [5] Griswold et al. MRM 2002; [6] Cauley et al., MRM 2013; [7] Keil et al., MRM 2012; [8] Robson et al., MRM 2008;
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