Accelerated Spiral Gridding Reconstruction using Vectorization

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Target Audience: MRI physicists and engineers.

Purpose: Gridding reconstruction of MRI data acquired with non-Cartesian trajectories such as spiral is time-consuming because interpolating the data to a Cartesian grid is required. The long computing time can be prohibitive for applications such functional MRI or high-resolution 3D imaging where large amounts of data are acquired often using multiple receivers. This abstract presents a vectorized parallel computing method that significantly accelerates gridding reconstruction on common desktop CPUs that have multiple (2-8) cores. Modern processors also have SSE (Streaming Single-instruction-multiple-data Extensions) and AVX (Advanced Vector Extensions), which allow each core to simultaneously perform the same instruction on vectors of data. These two features are often neglected in image reconstruction algorithms. However, with a little programming effort and no extra monetary cost, they can be used to accelerate the computation on data that can be arranged in a vector format such as multi-slice 2D spiral or 3D stack-of-spirals. In a proof of concept demonstration we find an approximate five times increase in gridding reconstruction speed compared to multi-threaded gridding methods.

Fig. 1

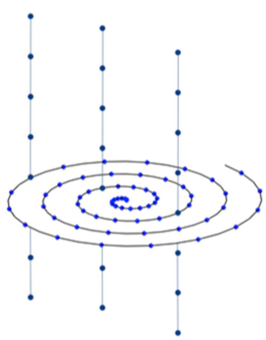


Fig. 2

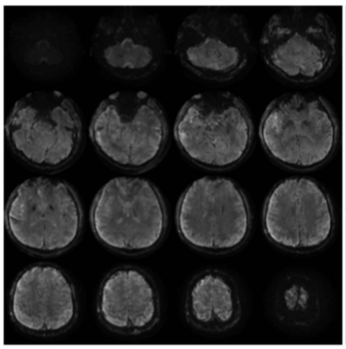


Fig. 3

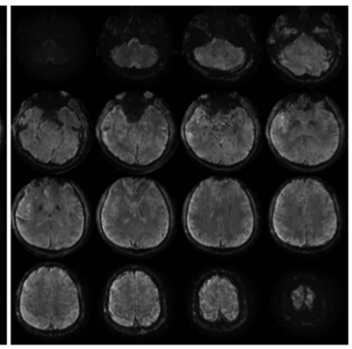
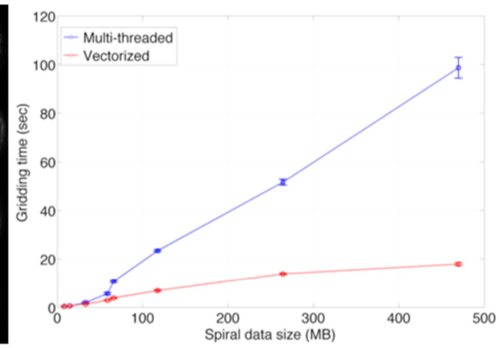


Fig. 4



Methods: Fig. 1 shows that points along the through-plane direction form vectors that have the same in-plane location. Using SSE and AVX gridding can be done only once and applied to all these points concurrently. This vectorized computing concept can be further extended to data acquired with multiple coils, echoes, and measurements by rearranging data at the same in-plane spiral location as a vector. As a proof of concept, spiral data were acquired on a Siemens (Erlangen, Germany) 3T TimTrio Scanner using a 32-channel head coil. The entire brain volume was acquired using a stack-of-spirals trajectory. The reconstruction ran on an Apple (Cupertino, CA) iMac with an Intel (Santa Clara, CA) Core i5 CPU (2.66 GHz, four cores, SSE) and 16 GB (1067 MHz) RAM. The SSE4.2 built in Core i5 CPU can concurrently operate on eight single-precision floating points. The gridding programs were written in C and compiled as external libraries to run in Mathworks (Natick, MA) MATLAB. OpenCL (Open Computing Language) libraries were used to implement SSE and AVX. The OpenCL implementation has a light overhead that runs just-in-time compilation of the vectorized code. Comparison of computing times were made between multi-threaded (four threads) and a vectorized versions of the same gridding program. Both reconstructions were run ten times on data sets with different sizes.

Results: Because SSE and AVX use a special set of registers and instructions, there might be differences between the results from the multi-threaded and vectorized approaches. Figure 2 shows sixteen brains reconstructed using the multi-threaded and vectorized gridding. Comparing to the images shown in Fig. 3 reconstructed using the multi-thread approach, no difference was noticed on the Intel Core i5 CPUs used in this work. Figure 4 shows the gridding time of the multi-threaded (blue) and vectorized (red) methods. The vectorized computing in general was four to five times faster than the multi-threaded gridding. Implementing vectorization using OpenCL has a small overhead of just-in-time compilation of the gridding function. This explains a smaller improvement for smaller data size.

Discussion & Conclusions: The gridding operation is often essential in reconstructing images acquired using non-Cartesian trajectories such as spiral. This is true for even for NUFFT-based iterative methods where the speed of the forward and backward gridding can also be accelerated using the vectorization method described here. Future CPUs that have the new AVX-512 feature are capable of concurrently operating on a vector with 64 single-precision float points, which suggests an even higher gridding speeds can be reached. This study shows no difference in images reconstructed from the vectorization and the multi-thread method. However, different CPU vendors have different SSE/AVX designs, which might produce different results when vectorization is used. Although Graphics Processing Units (GPUs) that can have hundreds to thousands of cores are an alternative approach for accelerating MRI applications (1,2,3), a powerful dedicated GPU is needed, and the data need to be transferred to the GPU memory while the transfer speed of PCI-e remains a bottleneck. Meanwhile, the trend in CPU design seems to be shifted from increasing the clock rate to squeezing more cores into a single die. Therefore taking advantage of the inherent parallel processing power in modern CPUs could be a competitive solution for accelerating MRI reconstructions.

References: (1). Hansen et al, MRM 2008, 59:453-468. (2). Sorensen et al, IEEE Trans Med Imag 2008, 27:538-547. (3) Deng et al, MRM 2011, 65:363.

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