PIRT- Parallel Iterative Reconstruction Tomography, with correction for center of rotation errors

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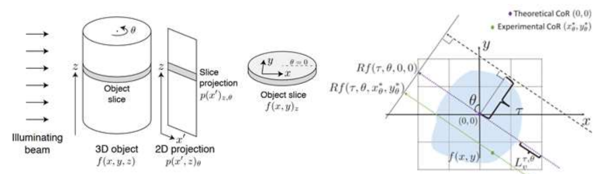
Tomography Overview



(Left) Tomography schematic[1] (Right) Center of rotation errors degrade reconstructions[2]

Statement of need

Existing tomography toolkits specialize in being suited for HPC (ex: memXCT, Trace) or being flexible (ex: TomoPy). PIRT uses a new algorithm for correcting the center of rotation errors while being implemented in PETSc/TAO thereby combining both algorithmic flexibility and distributed memory parallelism for HPC performance. PIRT can reliably reconstruct a sinogram which has 10% center of rotation drifts and 10% added noise. Each slice is reconstructed with MPI parallelism, with MPI sub communicators allowing for concurrent reconstruction of multiple slices. This hierarchical parallelism allows for good throughput.

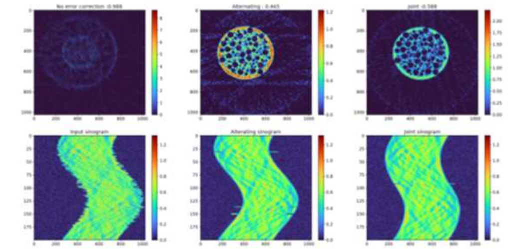
Algorithm & Implementation

PIRT uses a new model for the center of rotation drifts, representing each drift as a scalar parameter and applies the correction as convolution with a gaussian kernel (with the gaussian's properties being determined by the scalar parameter). Two modes reconstruction are available :

- Joint : combine shifts and sample vectors into one vector and optimize for both together
- Alternating : alternate between optimizing with respect to samples and with respect to shifts

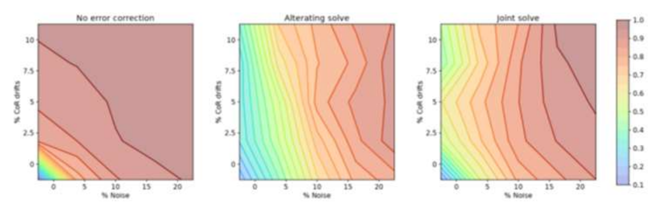
PIRT is implemented in the PETSc/TAO[3] framework in C++ as a scientific software with reusability and clarity being prioritized. HDF5 is used for parallel IO (different sub communicators read different slices) and FFTW is used for convolutions.

Demonstration



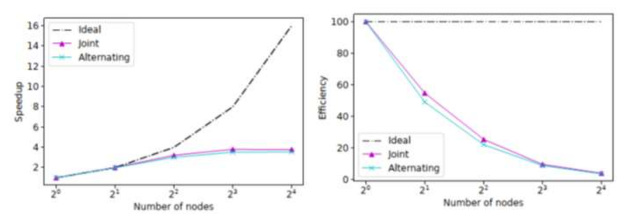
Results with and without error correction, clearly indicating the improvement in quality

Robustness to drifts and added noise



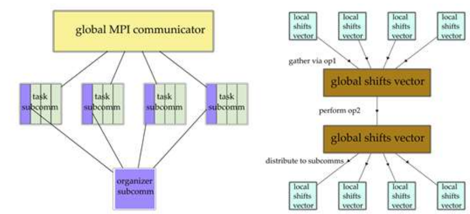
Robustness to added noise and center of rotation drifts

Scalability



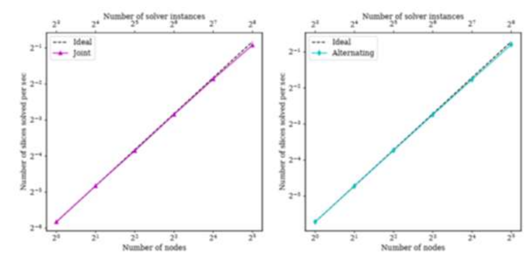
Poor scalability caused by naïve data distribution, however real world datasets are 3D.

3D architecture



Implementation of solver for 3D datasets, using MPI sub-communicators

Throughput



Near-ideal throughput achieved by solving for entire 3D dataset

References

1. Jacobsen, Chris: X-Ray Microscopy. Cambridge University Press, 2019 (Advances in Microscopy and Microanalysis)
2. Austin, Anthony P. ; Di, Zichao ; Leyffer, Sven ; Wild, Stefan M.: Simultaneous Sensing Error Recovery and Tomographic Inversion Using an Optimization-Based Approach. In: SIAM Journal on Scientific Computing 41 (2019), Nr. 3, S. B497–B521
3. Satish Balay et.al. PETSc Web page. https://www.mcs.anl.gov/petsc. 2021
4. We note that PIRT is available at : https://gitlab.com/pirt/pirt