

Medical Imaging High Performance Computing

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Large-scale Parallel CT Medical Image Reconstruction

■ CT Technology

- Invented by British Engineer G. Hounsfield in 1971
- Principle: utilizes X-ray technology and computers to create images of cross-section “slices” through the body

■ Today's

- CT scanners are fast and patient friendly
- Algorithms required for high performance
- High resolution CT data in both diagnosis and treatment.



Image Reconstruction Basis

- Analytic Algorithms (Filtered Back-Projection, FBP)
 - Efficient computation
 - Predominant in commercial market
 - Sensitive to noise, inaccurate projection data
- Iterative Algorithms (ART, EM)
 - Tremendous computation and easy implementation
 - High-quality reconstructed image from noisy or low-dose and incomplete projection data
 - Weight or penalty functions to redeem the loss of project data

Kasevitch Algorithm

$$f(x) = -\frac{1}{2\pi^2} \int_{I_{PI}(x)} \frac{1}{\|x - y(s)\|} \int_0^{2\pi} \frac{\partial}{\partial q} D_f(y(q), \Theta(s, x, \gamma)) \Big|_{q=s} \frac{d\gamma}{\sin(\lambda)} ds$$

$$D_f(y, \beta) = \int_0^\infty f(y + \beta t) dt, \beta \in S^2$$

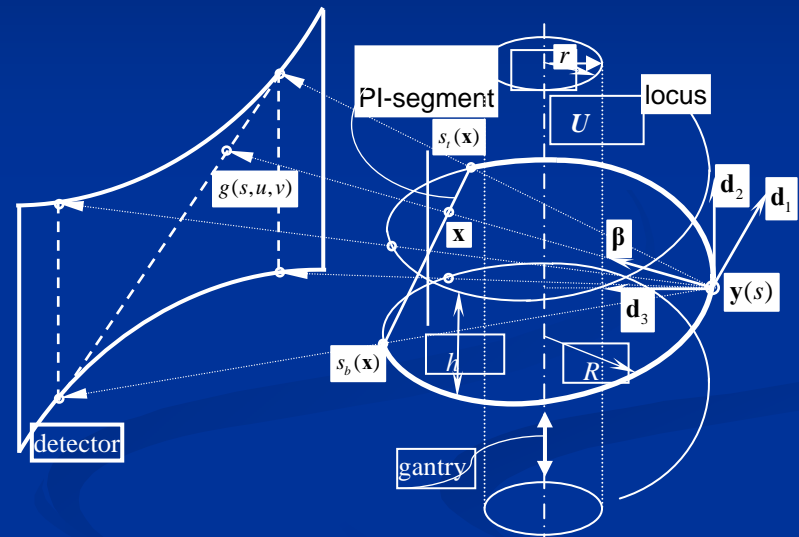
- Hilbert Filtering, intermediate function

$$\psi(s, u, v) = \int_{-\infty}^\infty D_g(s, \tilde{u}, \tilde{v}) \frac{\sqrt{D^2 + u^2 + v^2}}{\sqrt{D^2 + \tilde{u}^2 + \tilde{v}^2} (\tilde{u} - u)} d\tilde{u}$$

$$D_g(s, u, v) = \left(\frac{\partial}{\partial s} + \frac{D^2 + u^2}{D} \frac{\partial}{\partial u} + \frac{uv}{D} \frac{\partial}{\partial v} \right) g(s, u, v)$$

- Weighted Backprojection

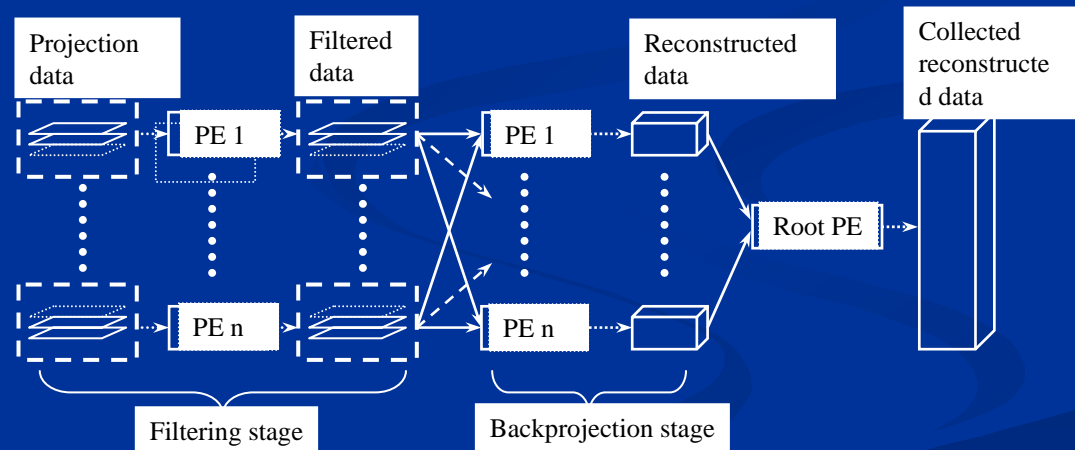
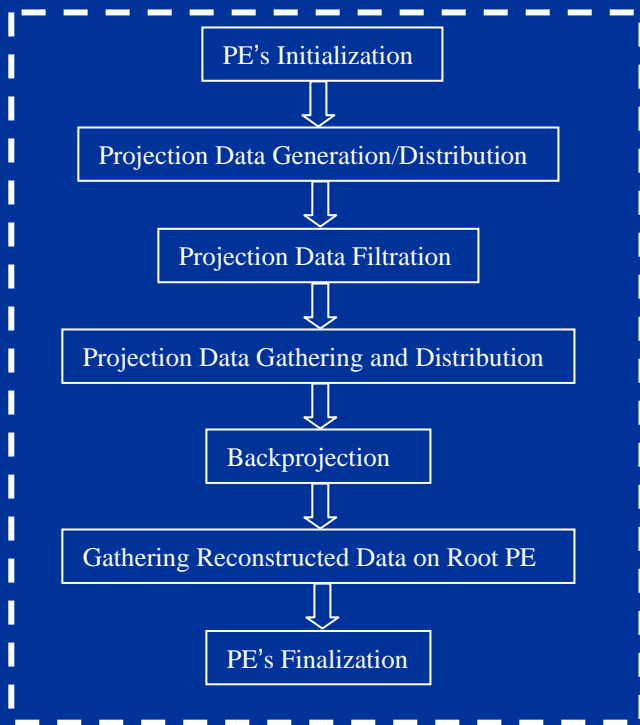
$$f(\mathbf{x}) = -\frac{1}{2\pi^2} \int_{s_b(\mathbf{x})}^{s_r(\mathbf{x})} \frac{1}{\|\mathbf{x} - \mathbf{y}(s)\|} \psi(s, u^*, v^*) ds \Big|_{u^* = \frac{D(\mathbf{x} - \mathbf{y}(s)) \cdot \mathbf{d}_1}{(\mathbf{x} - \mathbf{y}(s)) \cdot \mathbf{d}_3}, v^* = \frac{D(\mathbf{x} - \mathbf{y}(s)) \cdot \mathbf{d}_2}{(\mathbf{x} - \mathbf{y}(s)) \cdot \mathbf{d}_3}}$$



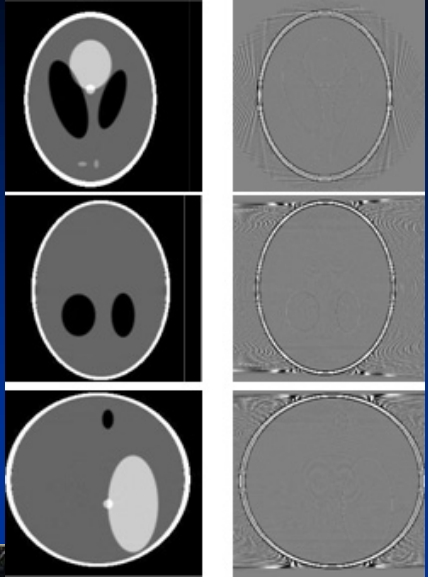
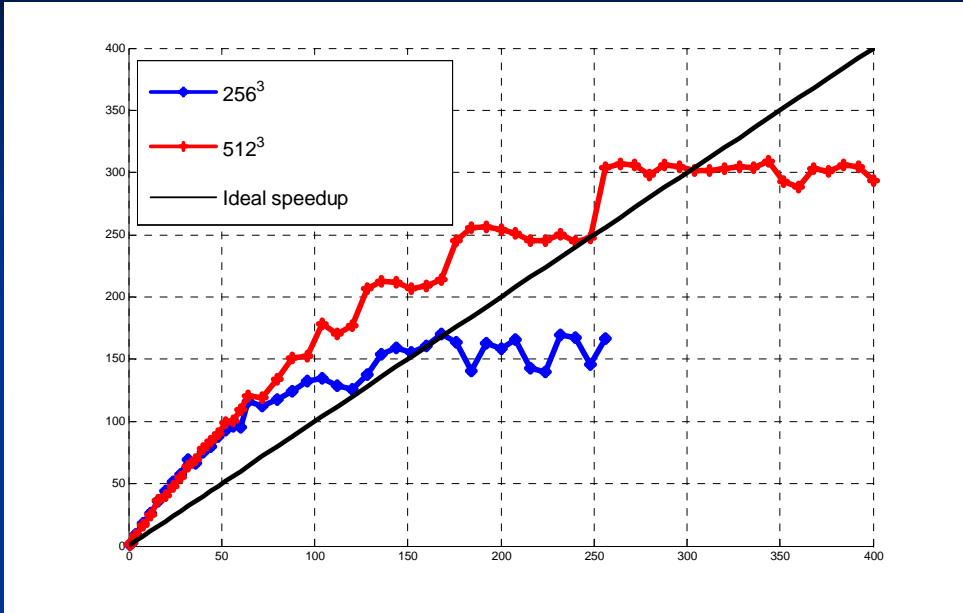
Geometrical illustration of the helical cone-beam CT system

Parallel Katsevich Algorithm

■ Parallel implementations



parallel reconstruction process



TeraGrid-NCSA

Parallel Katsevich Algorithm

- Scalability study (Ni et al., 2006)

$$S_n = \frac{T_{\text{sequential}}}{T_{\text{parallel}}} = \frac{T_{\text{init}} + (nm)[t_{\text{filter}} + kt_{\text{bp}}] + T_{\text{output}}}{\sum_{i=1,2,3} T_{\text{comm},i} + \sum_{j=1,2} T_{\text{comp},j} + T_{\text{output}}}$$

$$= \frac{T_{\text{init}} + (nm)[t_{\text{filter}} + kt_{\text{bp}}] + T_{\text{output}}}{T_{\text{init}} + T_{\text{latency}} + \left[\frac{(nm)}{N} + 2m\right]t_{\text{transfer}} + \frac{(nm)}{N}t_{\text{filter}} + T_{\text{latency}} + \frac{(nm)}{N}t_{\text{transfer}} + \frac{k(nm)}{N}t_{\text{np}} + T_{\text{latency}} + k(nm)t_{\text{transfer}} + T_{\text{output}}}$$

$$S_n = \frac{(t_{\text{filter}} + kt_{\text{bp}})}{(2 + kN)t_{\text{transfer}} + (t_{\text{filter}} + kt_{\text{bp}})} N = \frac{N}{1 + (2 + kN)\frac{t_{\text{transfer}}}{t_{\text{filter}} + kt_{\text{bp}}}} = \frac{N}{1 + \lambda}$$

$k = V/P$ (in unit of voxel/pixel)

Parallel Iterative Algorithms

- Iterative methods (suitable for clinic use)
 - Algebraic Reconstruction Technique (ART-like algorithms)
 - Simultaneous Iterative Reconstruction Technique (SIRT)
 - Simultaneous ART (SART)
 - Statistical Reconstruction (Expectation Maximization, EM-Like algorithms)
 - Maximum Likelihood – EM (MLEM)
 - Ordered Subset –EM (OSEM)

Parallel Implantations

- Deployed the parallel iterative algorithms on
 - Linux cluster
 - Windows compute cluster
 - P2P

Windows-XP



MCMS



TeraGrid



Linux



Linux

Grid-based Medical Imaging

- Using Grid technologies to develop Medical Imaging Grid
 - Web Services
 - Data Grid
 - Heterogeneous Computation resources
 - Medical Imaging Informatics



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Q&A