Searching for New Proton CT Image Reconstruction Techniques

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The Bergen pCT Collaboration

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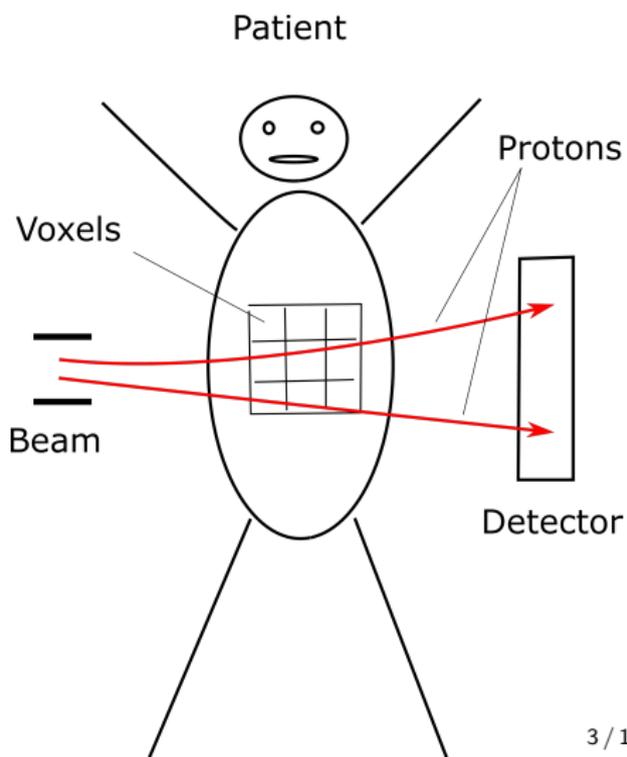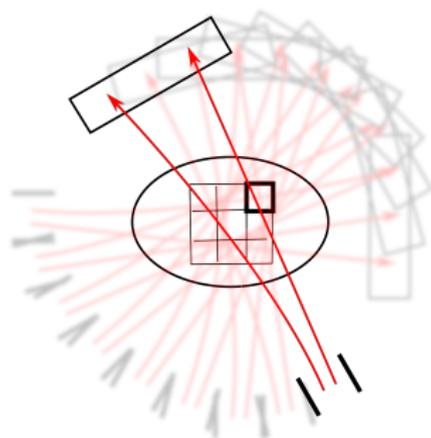
Proton Therapy & Proton Imaging

Therapy:
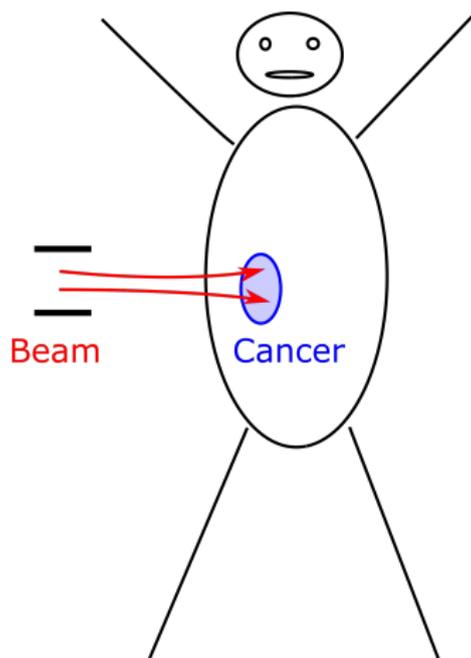
Imaging:

Image Reconstruction – a Huge Linear Problem

Huge linear problem:

$$\mathbf{y} \,=\, \mathbf{A}\,\mathbf{x}\,,$$

where:

- $\mathbf{y}$ is the energy loss of protons $\Leftrightarrow$ track integral of RSP
- $\mathbf{x}$ RSP value of voxels
- $\mathbf{A}$ proton – voxel interaction coefficients

Goal: Solve the linear problem

$$\mathbf{x} \,=\, \mathbf{f}\,(\,\mathbf{y},\,\mathbf{A}\,)\,.$$

New techniques

Image Reconstruction – the Richardson–Lucy algorithm

- First application in the field of proton CT imaging
- Originally developed for astrophysics image reconstruction
- It is a fixed point iteration for sparse systems
- Initialization: arbitrary positive vector
  Usually unit vector or approximate solution

Approximation of the ith voxel of the next iteration:

$$x_i^{k+1} = x_i^k \frac{1}{\sum\limits_j A_{i,j}} \sum_j \frac{y_j}{\sum\limits_l A_{l,j} x_l^k} A_{i,j} \ ,$$

where k is the iteration number. Typically takes 20-300 iterations.

Probability Density Based Proton – Voxel Interaction

- The distribution of the real proton path is Gaussian around the Most Likely Path (MLP)
- The standard deviation (σ) is changing along the path $\Rightarrow$ average σ is considered in this work
- The MLP is approximated as a third order spline
- The proton – voxel interaction coefficient calculation is based on the distance between the center of the voxel and the third order spline MLP
- Every voxel and proton pair evaluated $\Rightarrow$ slow even on GPUs

Probability Density Based Proton – Voxel Interaction
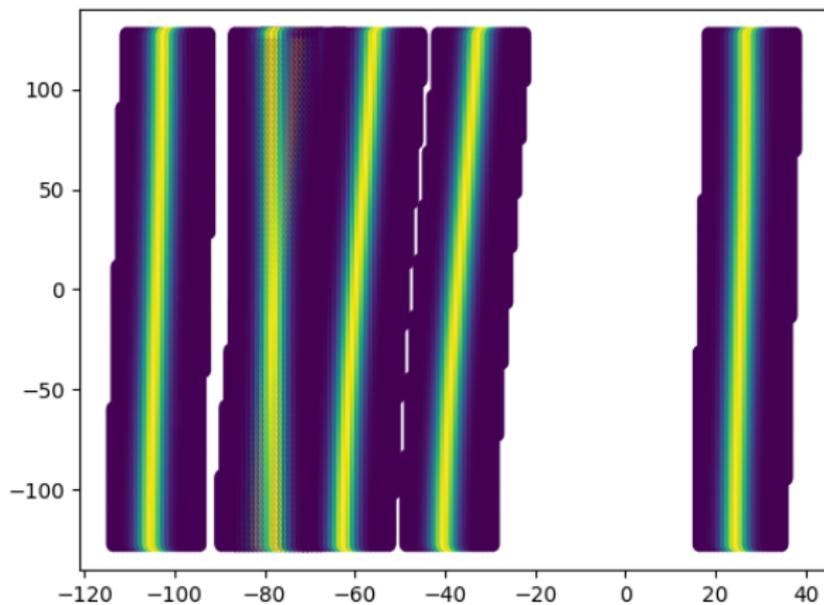
Results

Ideal Imaging – Shepp – Logan Phantom

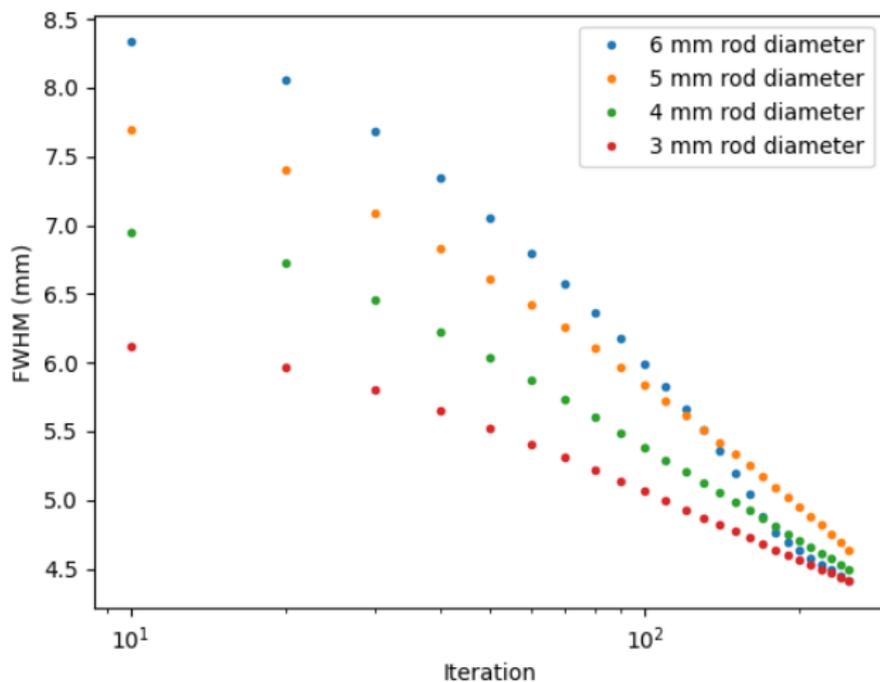- Reconstructed RSP distribution and convergence
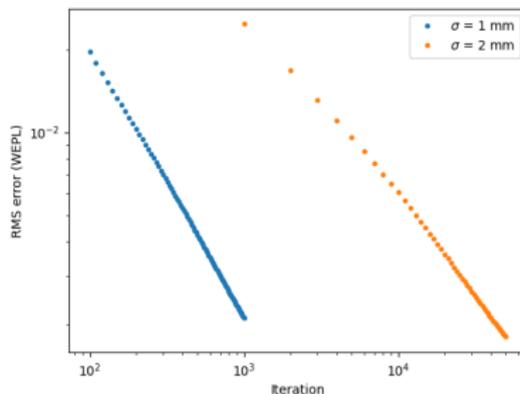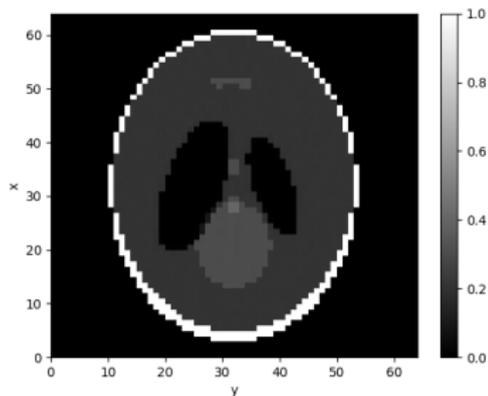
Derenzo Phantom – Spatial Resolution

- Reconstructed RSP distribution and valley-to-peak distribution
- Spatial resolution is the FWHM of the point spread function
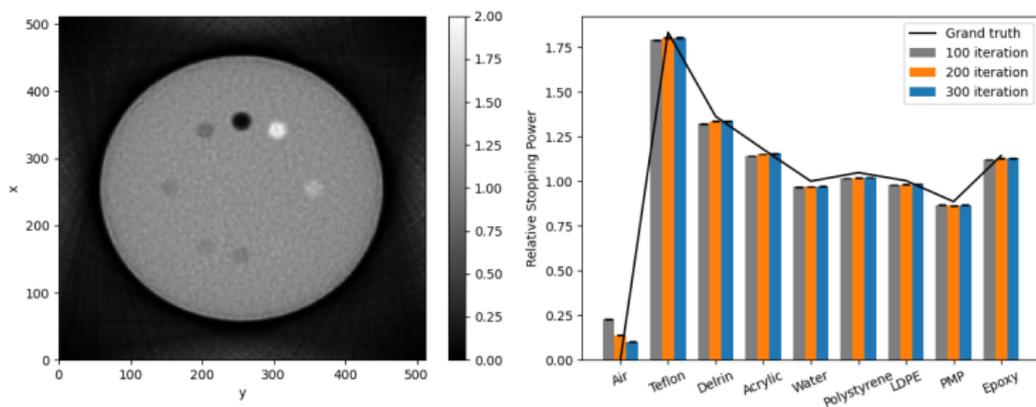- Proton CT literature: 3.1 mm $<$ my algorithm: 4.4 - 4.6 mm
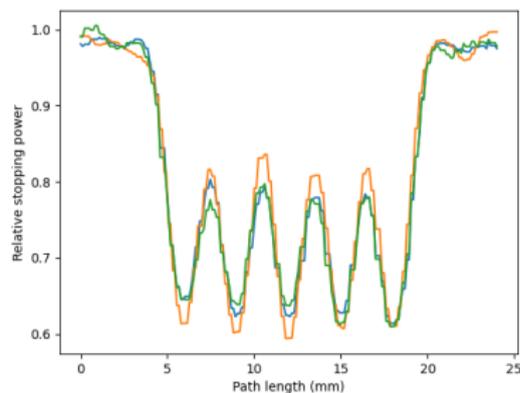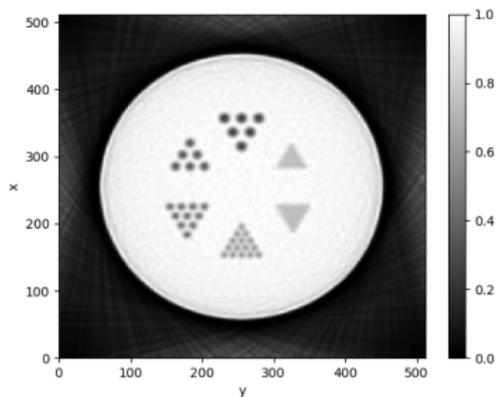
Derenzo Phantom – Spatial Resolution

CTP404 Phantom – RSP Accuracy

- Reconstructed RSP distribution and avg. RSP of the inserts
- RSP accuracy: pCT literature: $0.4\% <$ my algorithm: 3%

Summary

Technique:

- Application of Richardson – Lucy algorithm for pCT

Results:
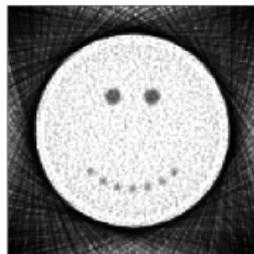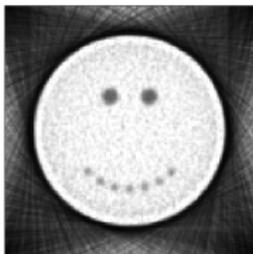
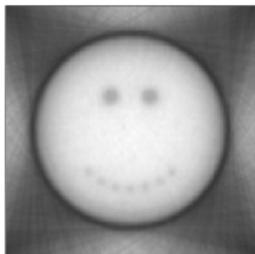- Promising results
- Further investigations is required

Technique:

- Gaussian probability density based proton – voxel interaction

Results:

- Works
- The advantage of this approach is unclear

Thank you for your attention!