

Tomographic Reconstruction & Resolution Study using Agave Supercomputer

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Introduction

Computerized Tomography (CT) scans utilize X-ray radiation and must be used sparingly. Typical mono-energetic photon beams have an energy between 70keV and 150keV. However, the resolution can become an issue due to statistical noise and insufficient photon energy for penetrating dense tissues and muscle. Our goal is to design tomographic reconstruction code to study resolutions at 150KeV utilizing the ASU Agave supercomputer to simulate events from 1 million to 10 million per angle, whilst studying how a convolution with a ramp filter enhances picture quality.

CT scans are acquired by taking one-dimensional projections of a 3-dimensional system via the detection of x-ray photons. An x-ray image is acquired at differing angles from 0 to 180 degrees. The x-ray images are then manipulated via a computer program and back projected to give a two-dimensional cross section of the original object. This cross section has a specific resolution that is dependent on the number of events, size of detector element, energy and distance between source and object.

Methodology

- GEANT4, the simulation of particles through matter.
- ROOT, data analysis assistant for high-energy physics.
- Custom tomography code, for converting sinograms into 2D reconstructions.

The following methodical process was used:

1. Utilize GEANT4 to create a C++ program that involves the creation of human phantom geometry filled with desired materials, along with an ideal rotatable detector plane for parallel beam geometry with a particle gun.
2. Organs, bones and other soft tissues, filled with appropriate biological materials. Lungs filled with air as well as a cancer tumor in the left lung.
3. Inject 50% iodine blood contrast material into cancer tumor to flare up on tomograph.
4. Program loops, generating 1 million events from 0 to 180 degrees of shooting a mono-energetic photon beam at mid chest level.
5. Turn into a sinogram (position vs angle) using ROOT and Agave.
6. My tomography code uses the sinogram for a 2D reconstruction using the Filtered Back-Projection algorithm (CT scan).
7. Repeat this process for 10 million events.
8. Compare results directly with and without the convolution for sinograms at 1 million events to show convolution importance.
9. Show how spatial resolution is dependent on number of events ran with 2D reconstructions at 1 million and 10 million events.

Filtered Back-Projection Geometry Derivation

The projection of an object is a summation of line integrals from 0 to 180 degrees. The line integrals represent attenuated x-ray beams as it hits the detector plane.

Start with the 1D Fourier Transform of detector array $p(s, \theta)$ which rotates around the object from 0 to 180 degrees.

$$f(x, y) = \int_0^\pi \int_{-\infty}^{\infty} P(\omega, \theta) |\omega| e^{2\pi i \omega (x \cos \theta + y \sin \theta)} d\omega d\theta,$$

The convolution (ramp filter) $h(s)$ is described by the inverse Fourier transform of:

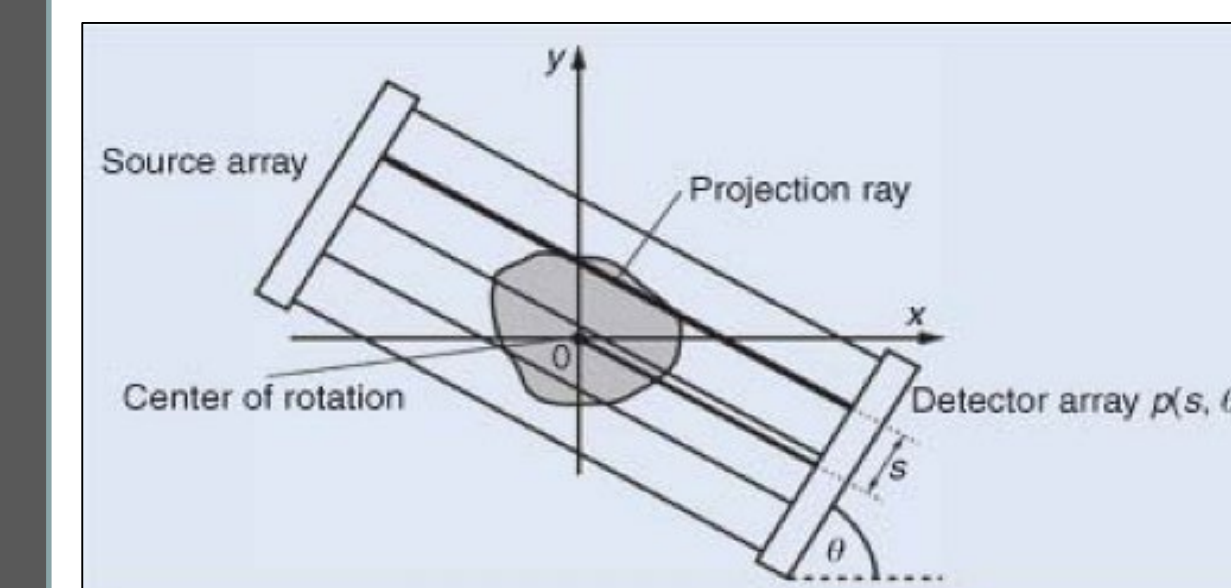
$$f(x, y) = \int_0^\pi \int_{-\infty}^{\infty} P(\omega, \theta) |\omega| e^{2\pi i \omega (x \cos \theta + y \sin \theta)} d\omega d\theta,$$

The object's position in Cartesian coordinates as a function of $f(x, y)$ can then be derived:

$$f(x, y) = \int_0^\pi p(s, \theta) * h(s) |_{s=x\cos\theta+y\sin\theta} d\theta,$$

After filtering the back-projection of the projection data convoluted with $h(s)$ we get a tomographic reconstruction relating the detector array position s as a function of x and y from 0 to 180 degrees. i.e., Assigns a point (x, y) for the x-ray attenuation coefficient of the object for the integral above.

Hornegger, J., Maier, A., & Kowarschik, M. (2018, October 7). *CT Image Reconstruction Basics*. Radiology Key. Retrieved April 13, 2023, from <https://radiologykey.com/ct-image-reconstruction-basics/>

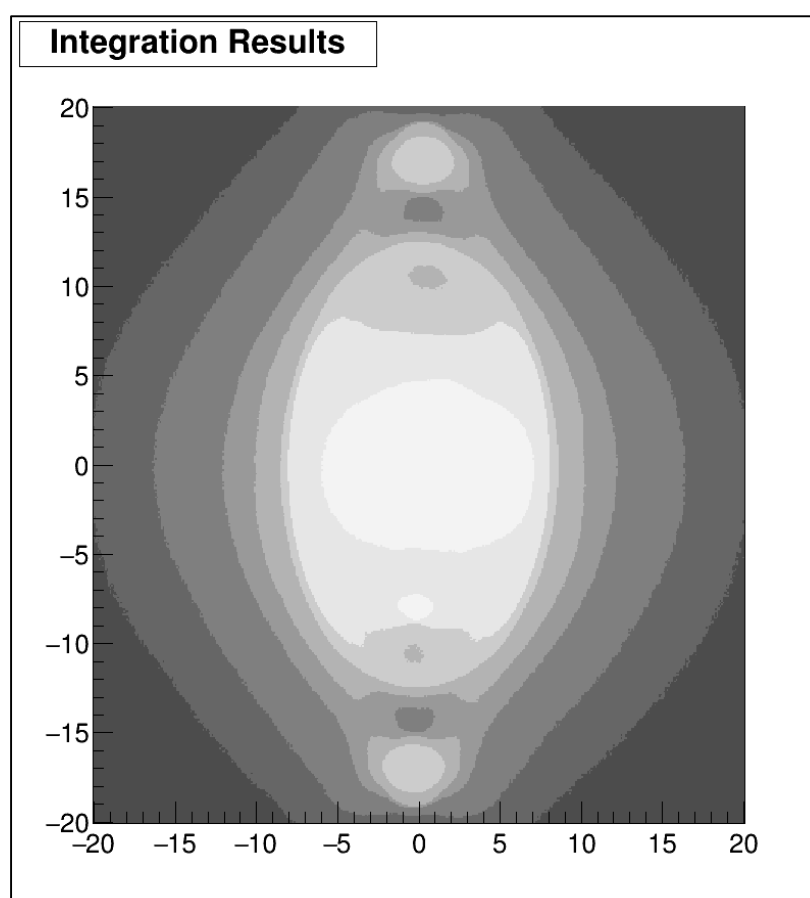


Conclusion

There is a clear dependence on number of events for resolution. The simulation was performed at the maximum allowed energy for safe CT

scans. It could be possible to reduce this energy and increase the number of events to overall make an efficient CT scan that can be close to realistic expectations. In the future I will create a quantitative measure of the resolution based on a comparison of a signal to surrounding statistical noise in the background.

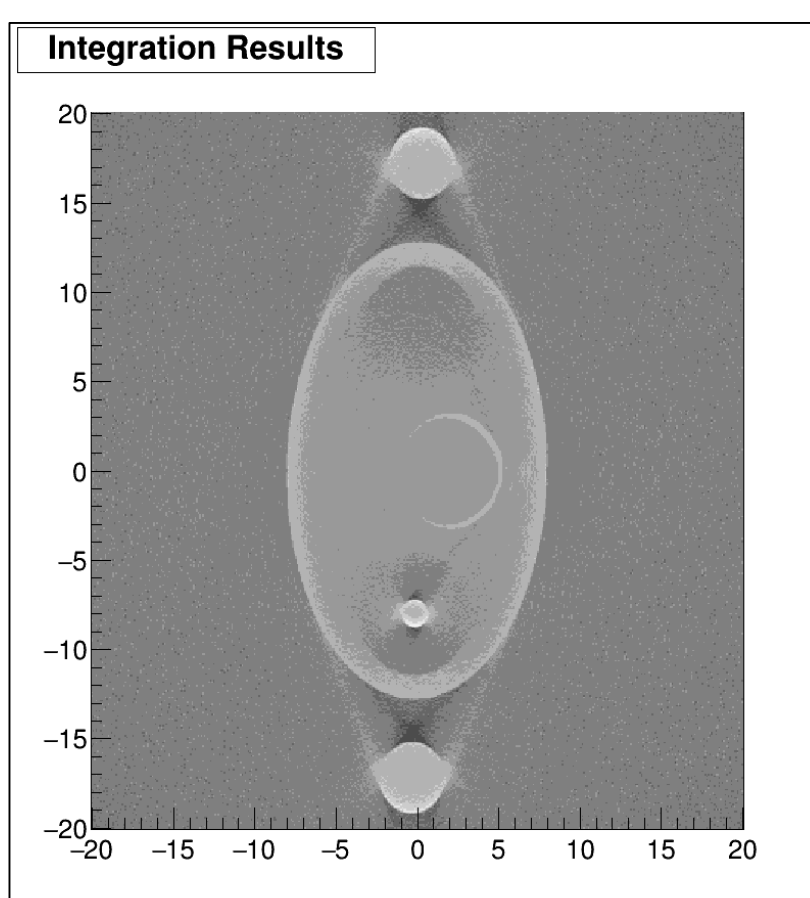
Convolution Study



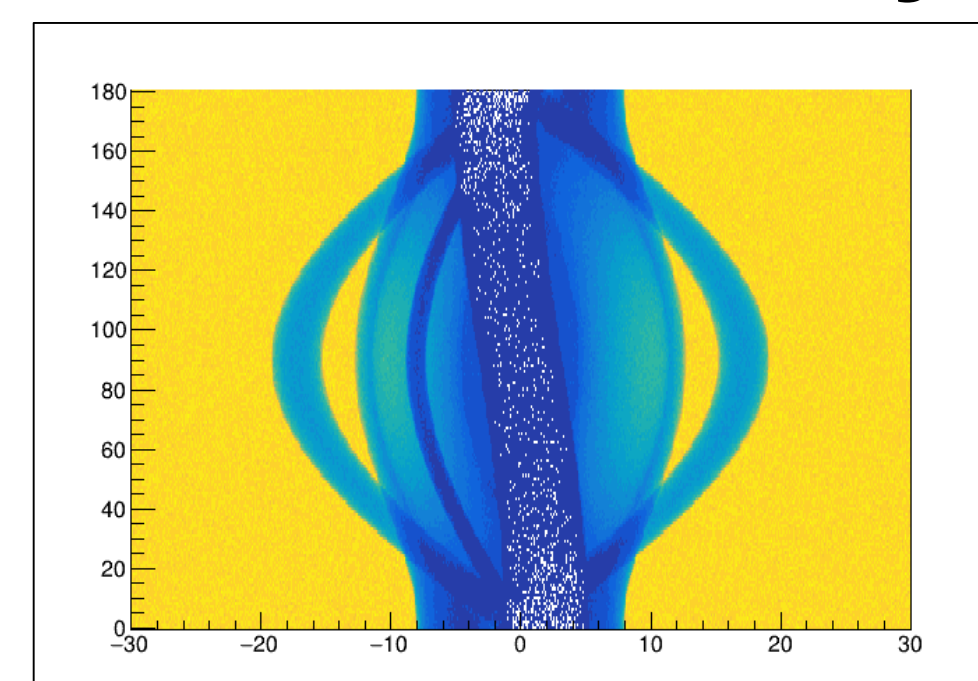
The first figure shows a tomograph for 1 million events per angle at 150KeV without the added convolution. The tomograph is extremely blurry and has visual artifacts. Without the filter there is little to make out from the sinogram and the results are lacking clarity. It is an unfinished result.

The second figure shows a tomograph for 1 million events per angle at 150KeV with the added convolution. The tomograph is much easier to observe and collect data from. You can see the cancer flare up in the left lung (glowing orb-like shape). This is because of the 50% iodine/blood contrast. You can also see the lungs, heart, and arm bones take shape due to differing attenuation coefficients. The bone flares up due to large amounts of calcium which absorb the photons.

The convolution $h(s)$ is a critical step in CT scanning because it smooths out the high and low intensity peaks (blurry and shiny parts) and creates a readable result.



Resolution Study



The sinogram shows us the density of hits for each angle versus the hit location on the detector. The first figure is for 1 million events, and we have a decent resolution, but we are missing parts of the heart (white speckles).

The second figure is for 10 million events, and we have a better resolution and can easily see the heart more clearly

