Quantitative Analysis for Computed Tomography

MA 390: Research Projects in Industrial Mathematics
MA 490: Research Capstone

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PNNL Background

- US Department of Energy Research Lab
- Located in Richland, WA
- Research in fields of Computational, Physical, Earth, and Environmental Sciences
- Focus on interests of National Security

Image provided by PNNL.

What is Computed Tomography?

- Computed Tomography (CT) is a non-destructive testing method that uses X-ray radiography to analyze internal structure.
- Images are taken from hundreds of angles around the object; data is transformed into a “voxel” format.
- Less precise than Coordinate Measuring Machines (CMM) for external measurement but *significantly* faster

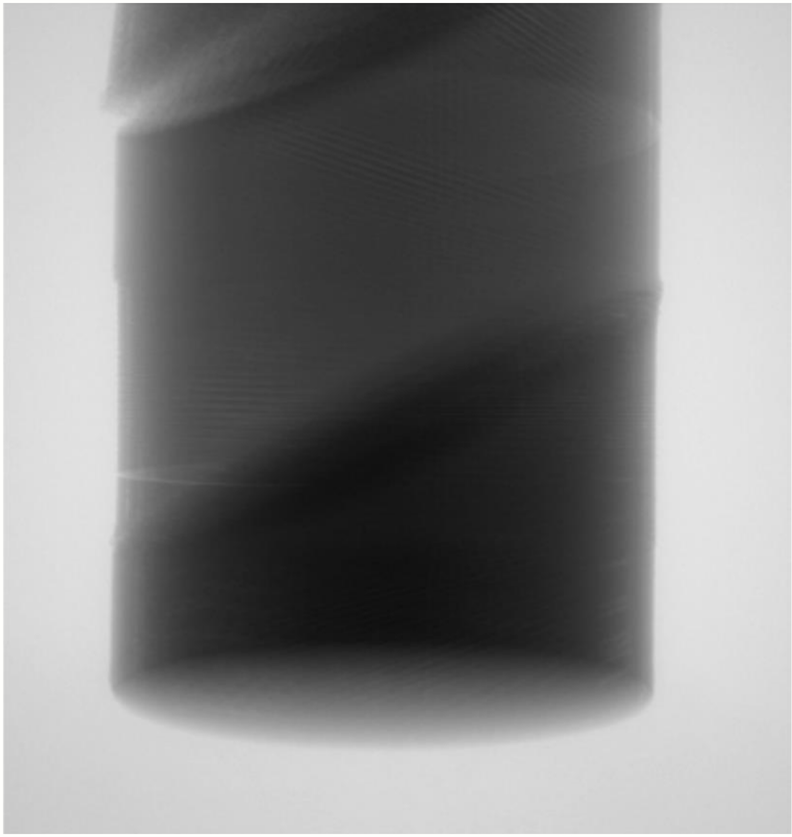


Image provided by PNNL.

Fig.1

Why it matters:

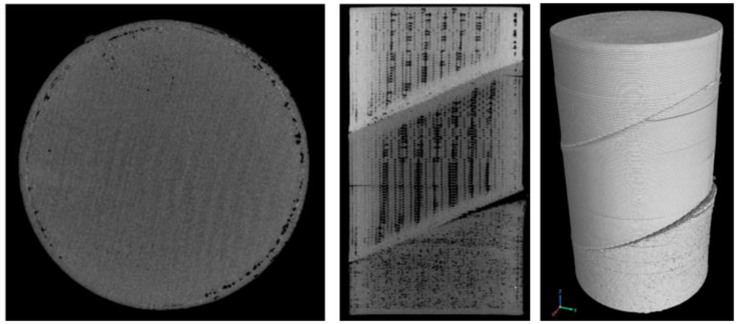
- Helps us to save material and time for the printing process that leaves it with 95% material and 5% air after printing. It also help us to differentiate between the voxels and each of the 3 materials, which is part of the analysis quantities.
- Precise analysis of structure is key for evaluating, calibrating, and improving the technology and its outputs.
- CT scans provide a quick, low-contact, non-destructive method.
- Benefits over CMM (Coordinate Measuring Machine)
  - Less time to complete scans of a given object compared to CMM
  - CT scans are more cost-effective (less expensive per use)
  - Ability to non-invasively probe internal structure (CMMs can only probe outer surfaces)
  - X-ray imaging ensures no damage is done to object during scan

Goals:

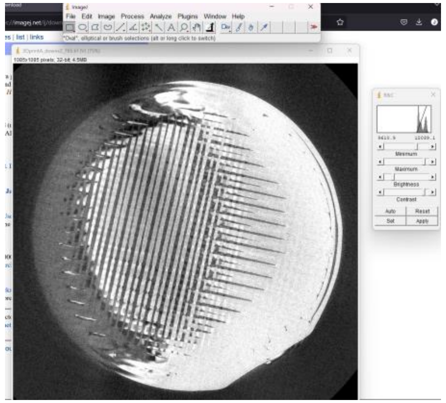
- ~~Establish a knowledge base for the project.~~ (Weeks 1-2) (Week 1!)
- ~~Find FOSS libraries for data visualization.~~ (Weeks 1-2) (Week 1!)
- Measure from a single slice as a proof of concept. (Weeks 2-3)
- Measure a property across various slices and report value with error bars. (Weeks 3-4)
- Analyze material separation between layers. (TBD)
- Determine the voxel intensities between layers with error bars; segment and label the volume by material. (TBD)

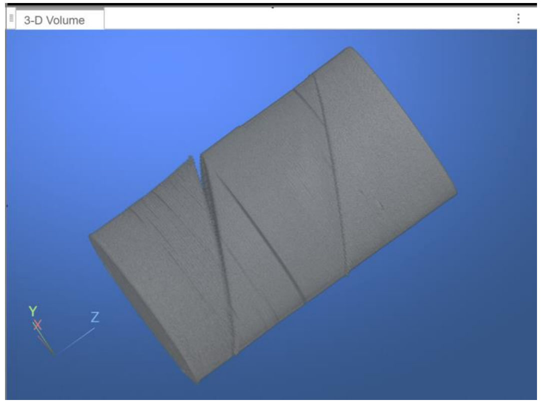
Data Description

- 3D reconstructed object data
- 1789 TIFF files
  - 1085 pixels by 1085 pixels each
  - Can be stacked together to make a 1085 x 1085 x 1789 voxel matrix
- Test Object
  - 3D-printed part
  - Comprised of 3 materials in “top,” “middle,” and “bottom” regions with flat angled boundaries between materials



Images provided by PNNL. Fig.2





Images generated by the ERAU team. Fig.3

Initial Strategy

- Early stages:
  - Slice-by-slice 2D analysis to develop a general understanding and methods.
  - Determine relevant features for our tasks.
  - Delegate tasks and create initial methods.
- Middle stages:
  - Refine initial methods and explore new approaches,
  - Demonstrate basic functionality for each task.
  - Revisit scope, group interests, and challenges.
- Late stages:
  - Evaluate and select the best-performing methods for each task.
  - Demonstrate thorough and complete functionality for proposed tasks.

Data Normalization

Raw Data

- High precision (32-bit floating point).
- High granularity.
- Low performance.
- Low support.
- Preserves outliers and errors.

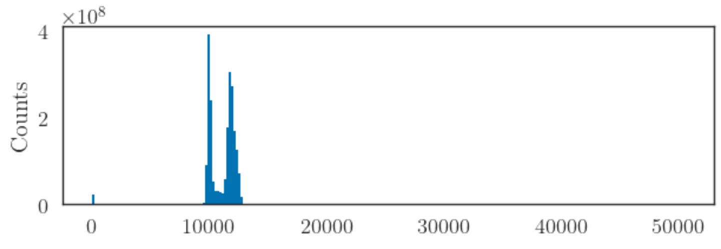


Fig.4

Normalized Data

- High performance.
- High support.
- Focuses on important data and removes outliers.
- Visually intuitive.

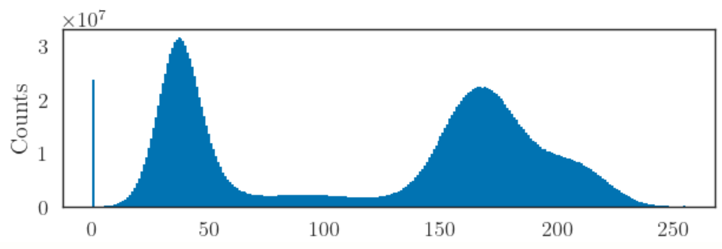


Fig.5

Data Visualization

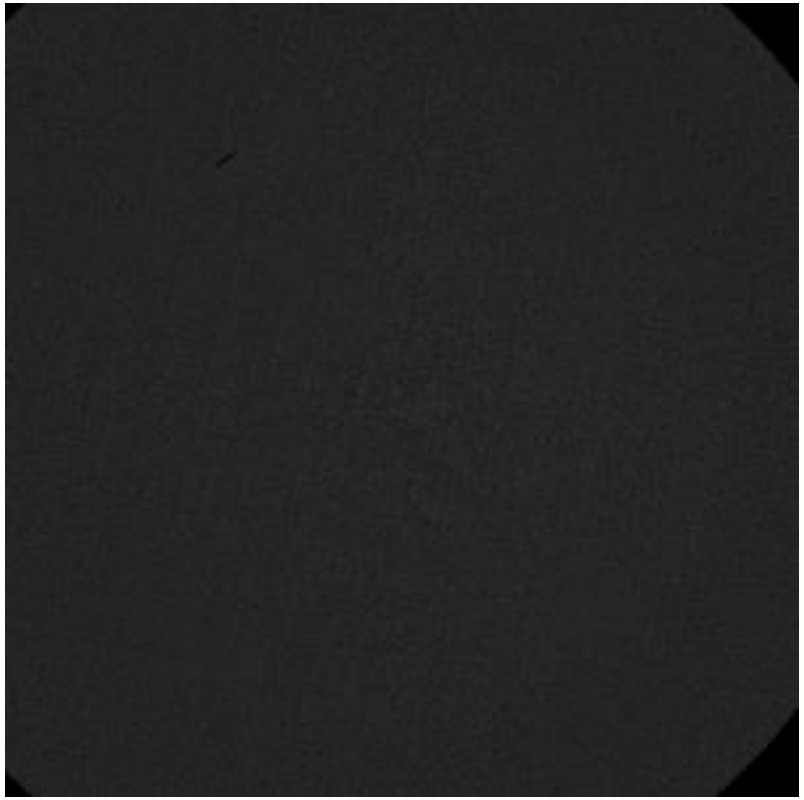


Fig.6

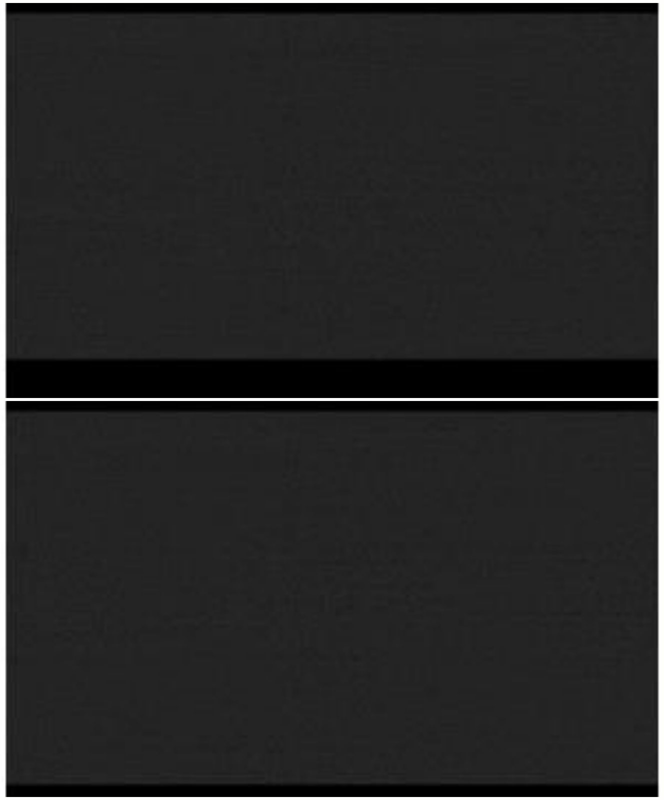
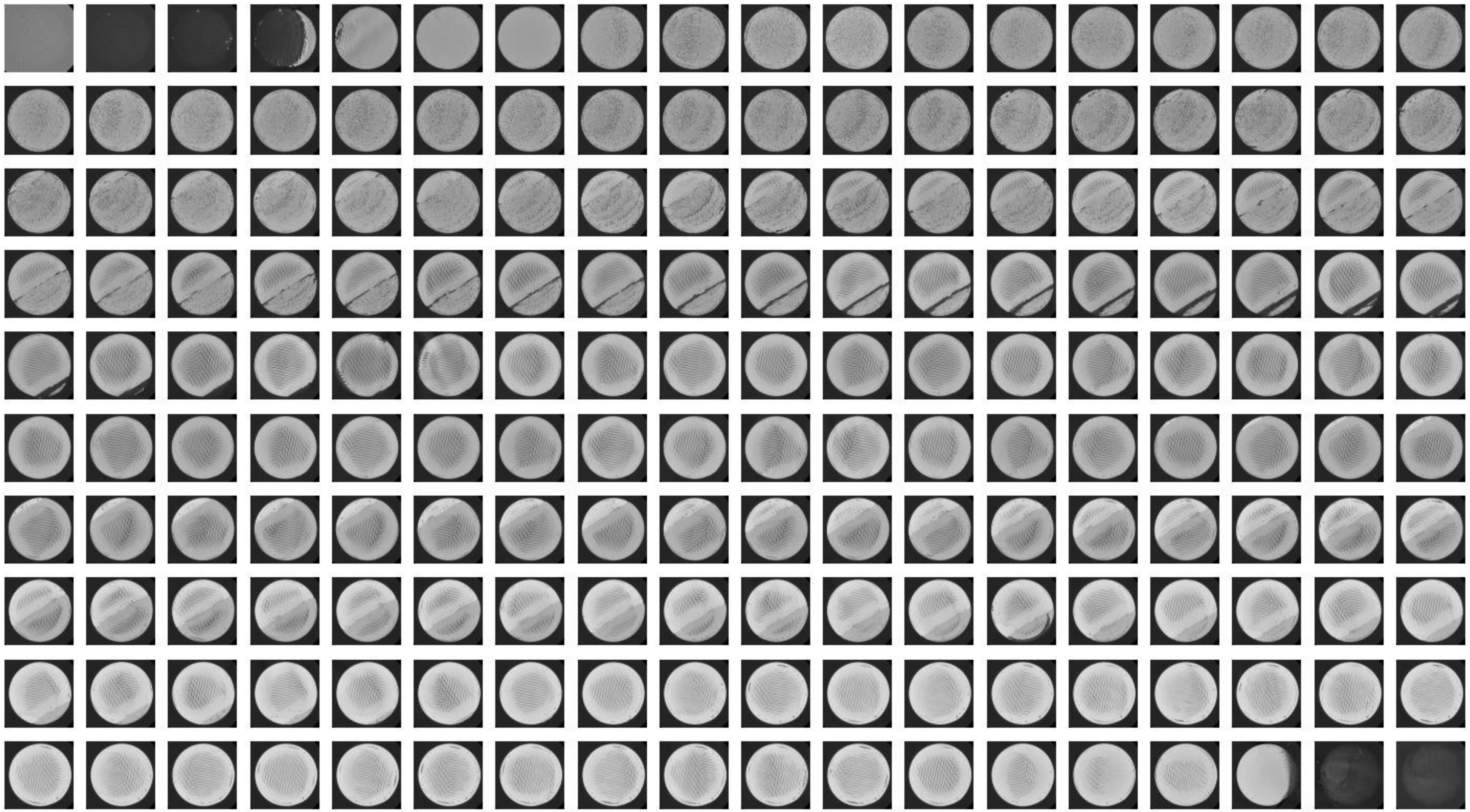


Fig.7

Data Visualization

Fig.8



Data Visualization

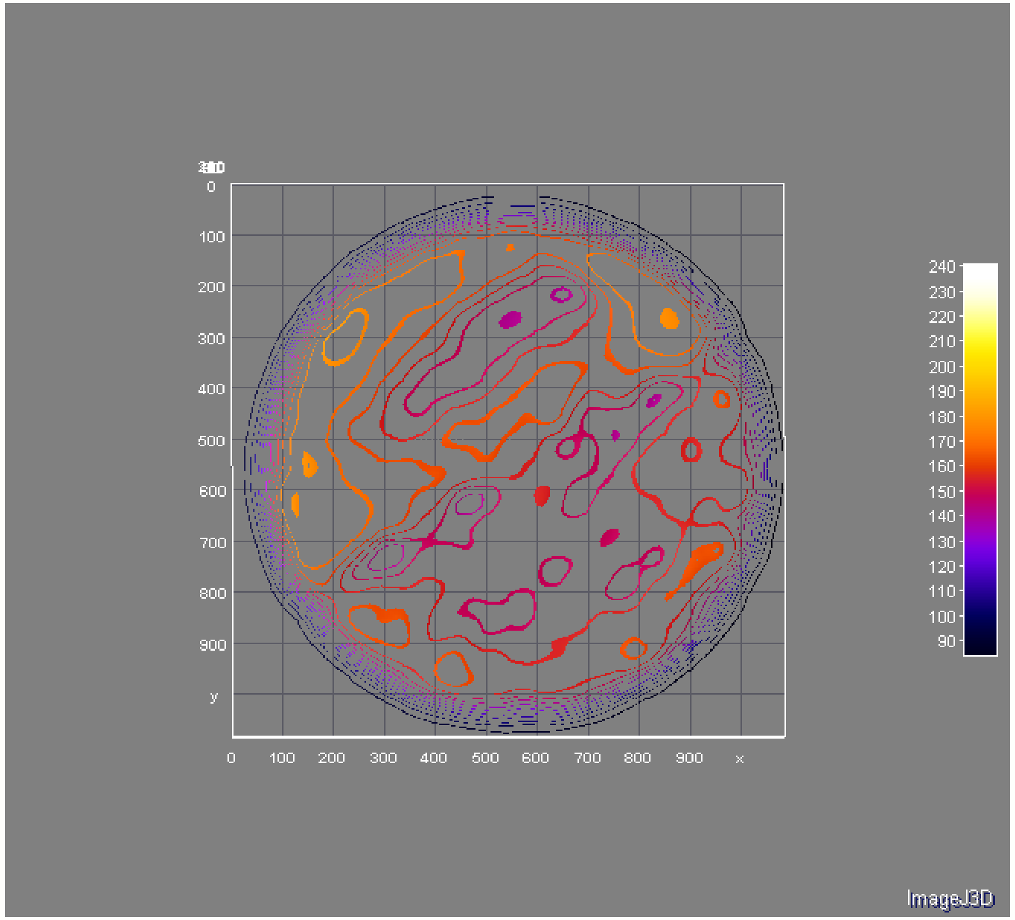


Fig.9

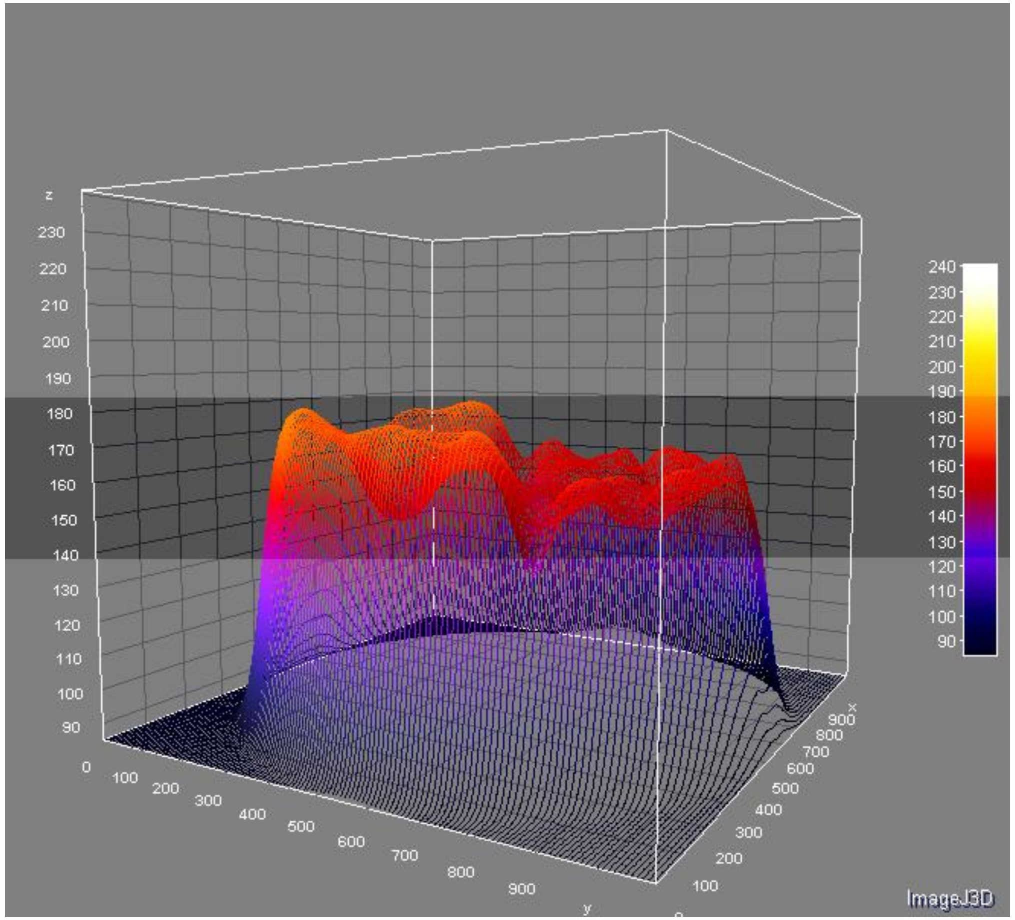


Fig.10

Early Dimensioning Approaches

- Diameter is in all directions around the z-axis. Only measuring along the x and y axes is not suitable.
- Must find the diameter using the whole cross-section.
- Why not just draw a circle of known diameter and see how well it matches?
- It works well! Unless the diameter is an odd number, or not aligned to a whole voxel, or.. many other little things.
- Good start, but better methods exist.

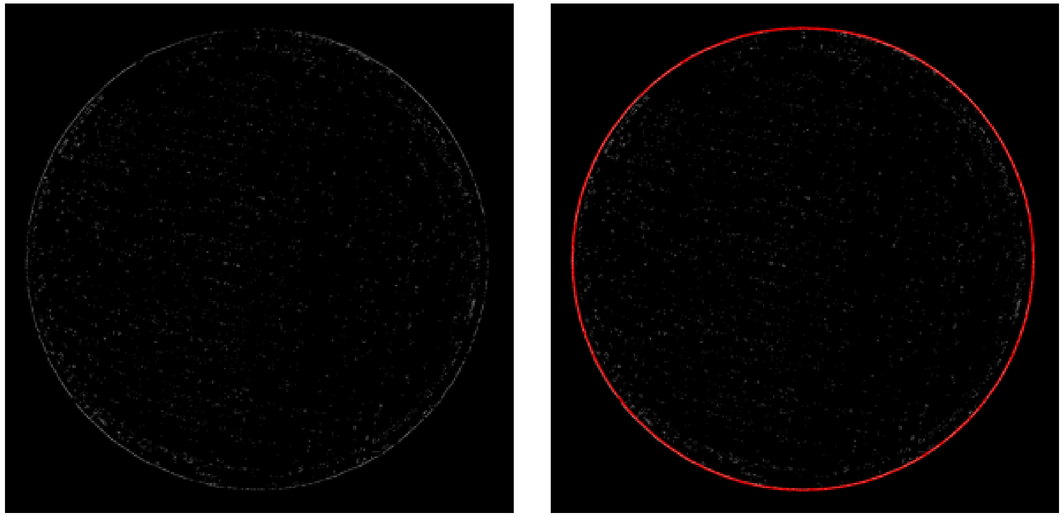


Fig.11

Height Dimensioning

- Simpler method than the diameter.
- Start at the edge of the image and choose the edge of the object when intensity passes a given threshold.
- Not the greatest but it's an easy start.

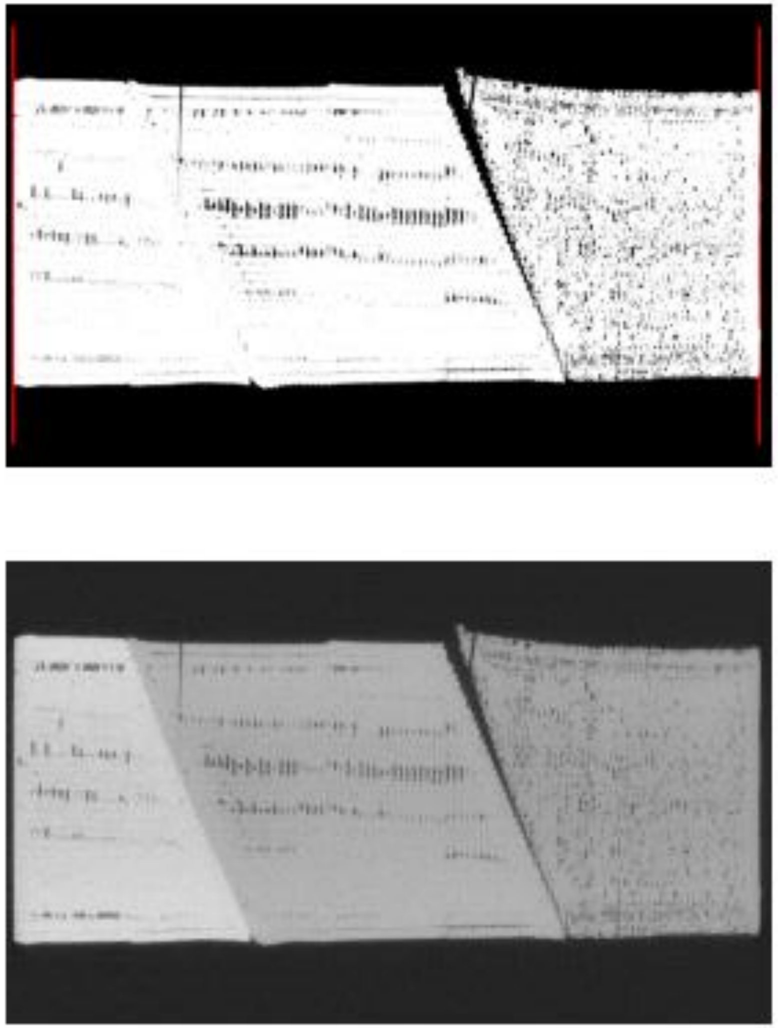


Fig.12

Next Steps: Segmentation

- Histograms show a clear Gaussian mixture. Each material has a clear mean.
- Fitting Gaussian distributions, use them to predict material.
- Not going smoothly, selection needs context?
- ITK has native segmentation methods, these will be explored.

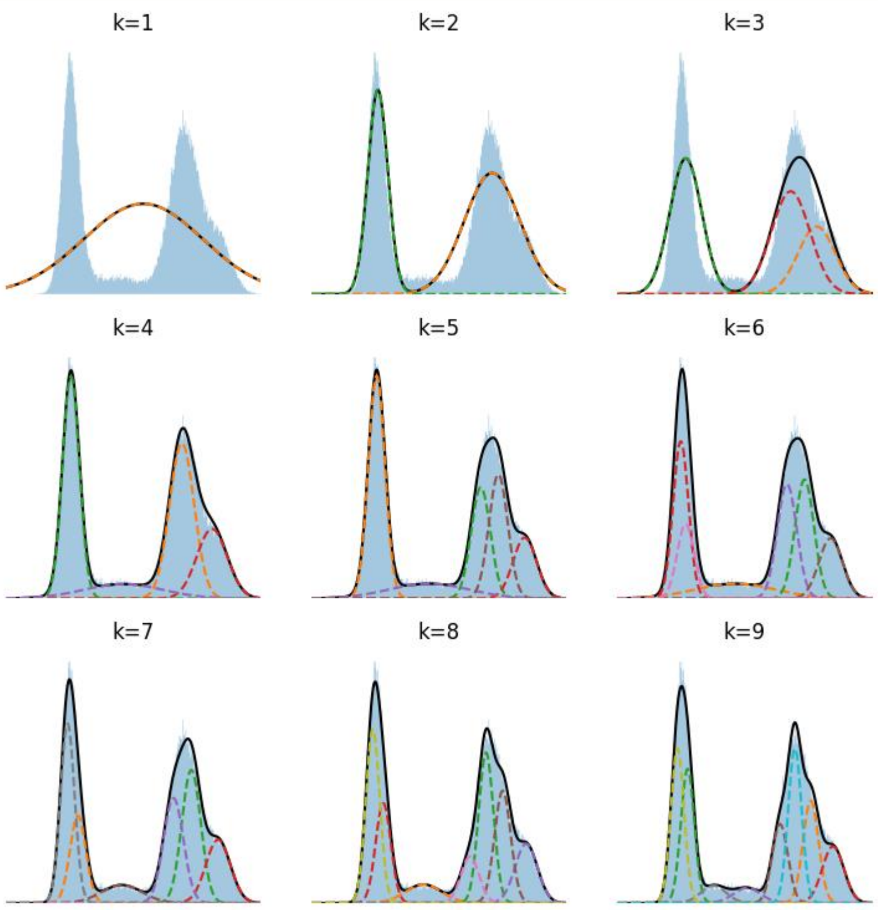


Fig.13

Next Steps: Dimensioning

- Instead of a custom circle fit, OpenCV supplies the Hough Circle Transform.
- Automatic circle detection and fitting.

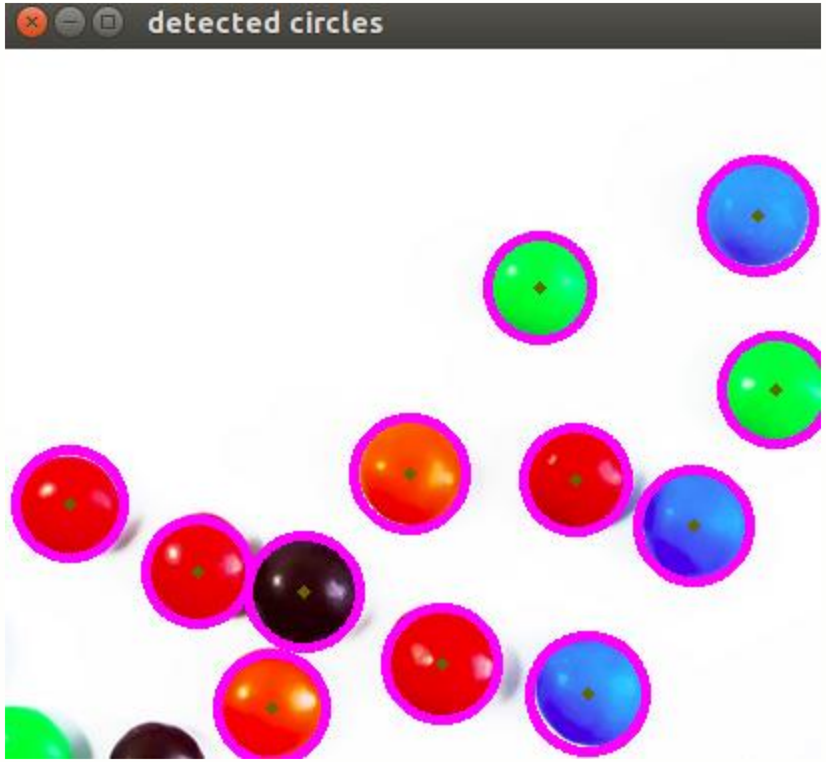


Image provided by OpenCV.

Fig.14

Next Steps: Infill Analysis

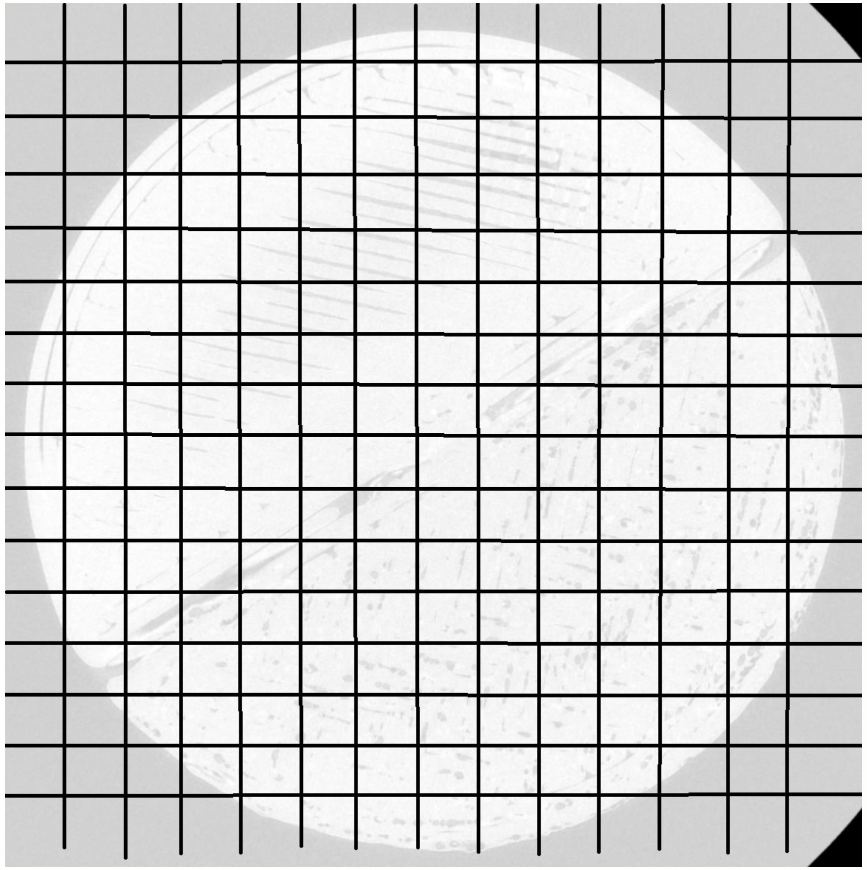


Fig.15

- Analyzing the infill can give insight into material/air ratio and print quality for each material
- Process measures the ratio of light (material) and dark (air) pixels within each square
- Repeated for each 2-D slice to obtain material/air analytics for the entire 3-D object

Next Steps: Tofu

- Try Tofu for CT preprocessing.
  - Extensive denoising/deblurring, isolation.
- Tofu is a free, open-source software package that supports CLI, API, and GUI interfacing with CT data.

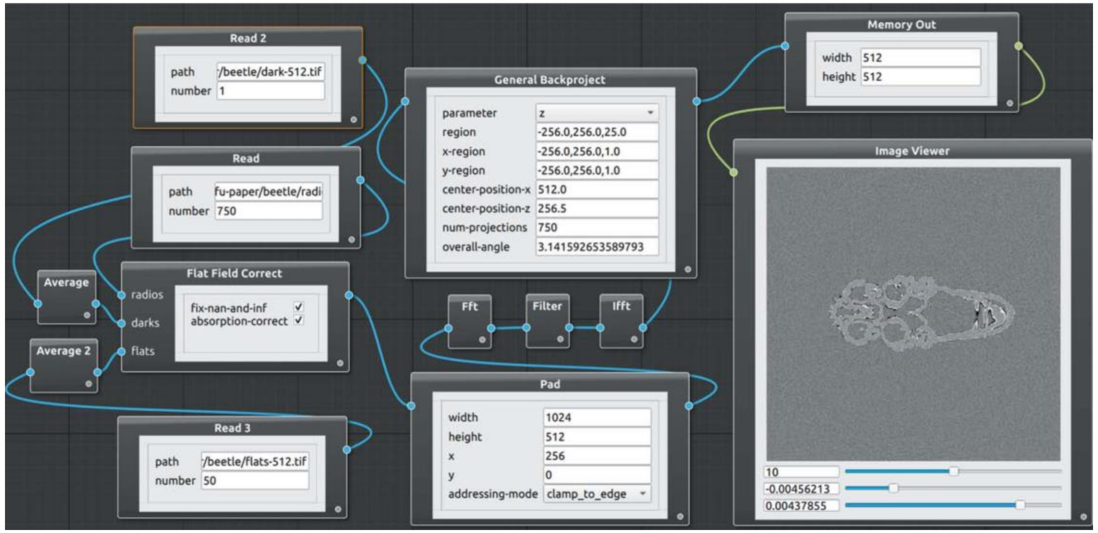


Image provided by Tofu. Fig.16