A Battle for Accuracy

Comparing Analysis Methods of Mathematical Morphology and Spherical Harmonics for Tomography

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Introduction

Computer tomography (CT) is an important method for creating imaging data about the insides of three-dimensional objects. In the case of materials science, it can be used to examine parts for defects or to create microscopy quality images for three-dimensional study. CT is also used within the medical imaging community to visualize patients for diagnostic purposes.
In this dataset, image intensity corresponds to flame retardant (FR) concentration.

Data Acquisition

Rods of polystyrene (PS) and a brominated aromatic flame retardant (FR) were prepared at LSU in a condition far from equilibrium, i.e., poorly blended. The further dissolution of FR in PS was monitored by X-ray tomography at the Advanced Photon Source (APS) with repeated cycles of (image-heat). Slight deformation of the sample was noted, especially at a machined notch used for sample alignment. Some 3D data sets are degraded by sample motion during tomography; four data sets show highly resolved structures of FR lumps in a PS matrix. The digital resolution is 1.85 microns/pixel.

Conclusions

The methods produced similar results, but differ in that method A (mathematical morphology) is relatively fast and very robust, while method B (spherical harmonics) requires lengthier calculations for particle identification and tracking across datasets. However, these calculations yield particle motion with respect to time. Furthermore, because the particles have been reconstructed from an analytical model, particles fitting certain parameters can be excluded (too large, too small, too oblong, etc.); analysis can be performed on a particular particle class. Method A, meanwhile, analyzes the entire dataset. The erosion step of method A only provides a crude method of excluding small particles and noise. Method A can be used on any sort of data that can be effectively binarized (including advanced segmentation techniques) while method B requires spherical harmonic fits to near-convex objects.

Future Work

Analysis is ongoing to compare the two methods detailed herein. The methods are broadly applicable to any application with shifts in the sizes of particles, either large or small. Potential applications include tracking similar problems of dissolution of objects into a surrounding matrix, crystal growth, or cell proliferation.

References

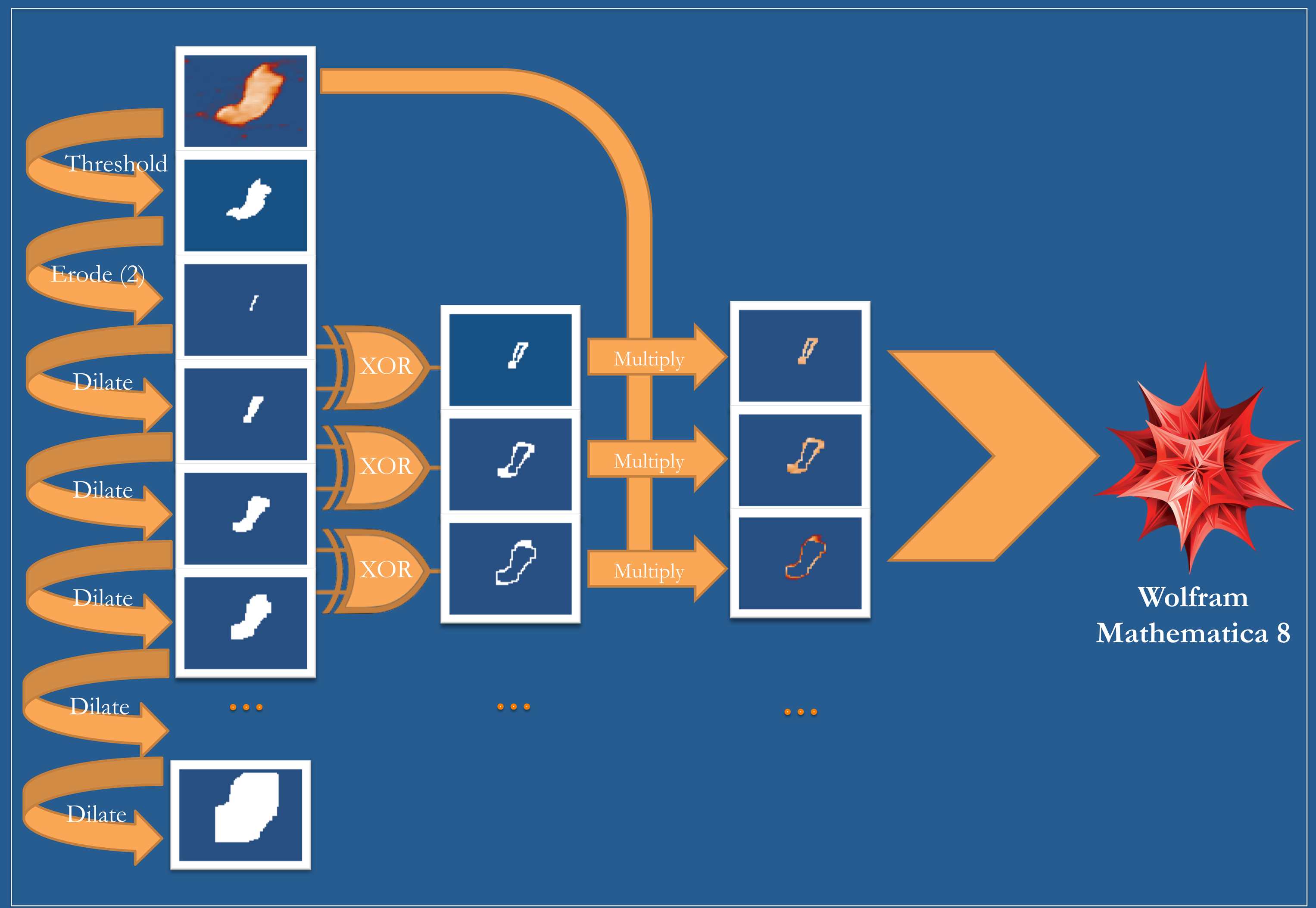
"Synchrotron X-ray Tomography for 3D Chemical Distribution Measurement of a Flame Retardant and Synergist in a Fiberglass-Reinforced Polymer Blend", Barnett, H. A.; Ham, K.; Scorsone, J. T.; Butler, L. G. *Journal of Physical Chemistry B, 114*, (**2010**), 2-9.
"Three-dimensional mathematical analysis of particle shape using X-ray tomography and spherical harmonics: Applications to aggregates used in concrete", E.J. Garboczi, *Cement and Concrete Research, 32*, (**2002**), 1621-1638.

Acknowledgements

Funding graciously provided by the National Science Foundation under award EPS-1003897 to the Louisiana Alliance for Simulation Guided Materials Applications and by CHE-0910937 (Butler, Hall, Simeral).

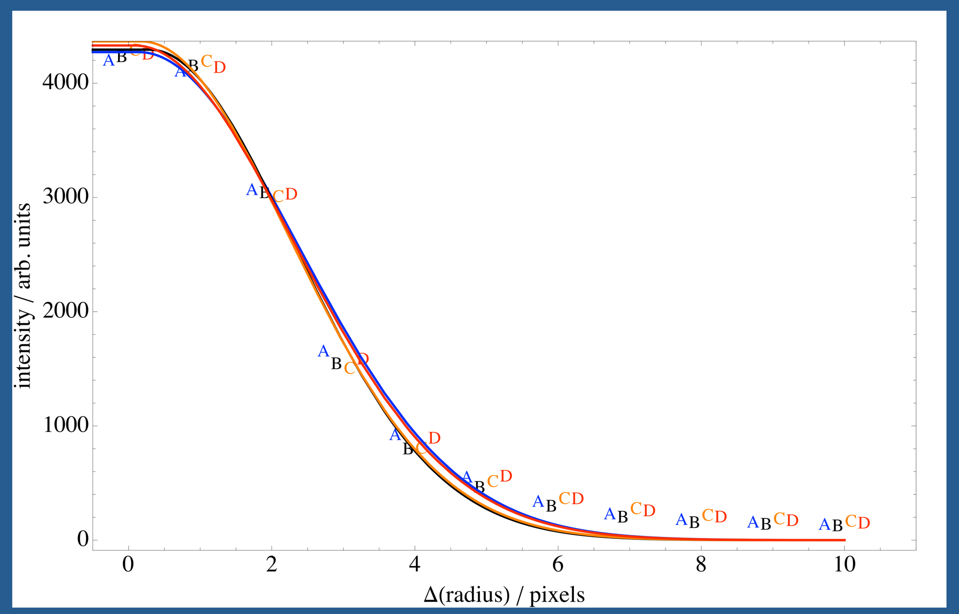
We also thank Drs. Larry Simeral (Albemarle), Kyungmin Ham (CAMD), Francesco De Carlo (APS), and Ed Garboczi (NIST).

Method A: Mathematical Morphology



A method was developed analyze the entire dataset concurrently, without the need to identify individual particles and track them throughout the datasets. The steps are visualized in the dataflow diagram (above). The dataset is initially binarized using a threshold of approximately 85% of the FR values. The binary image was then eroded with a kernel of r = 2 (for smoothing and particle cleanup) and then sequentially dilated in 3D space (ten times) to produce 10 sequential dilations. The difference between two sequential dilations produced a "shell" of voxels of equivalent distances from the surface of the FR particles. The binary intensity maps (containing 1s and 0s) were then multiplied by the original dataset, providing new datasets of the particle shells consisting of the intensities from the original image.

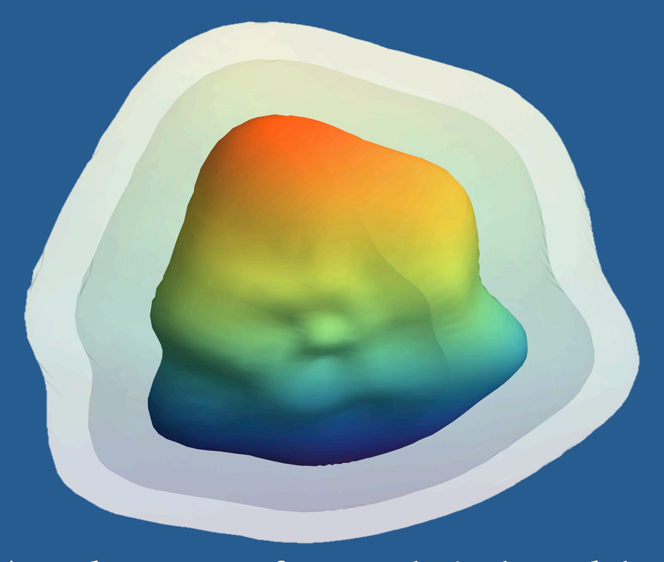
The resulting shell datasets were imported into Mathematica and "sliced" into slabs of 100 pixel width orthogonal to the heat source. A mean, standard deviation, and count were performed on the non-zero intensities within each slab. Mean intensities were then graphed for a particular slab within each dataset (shown below).

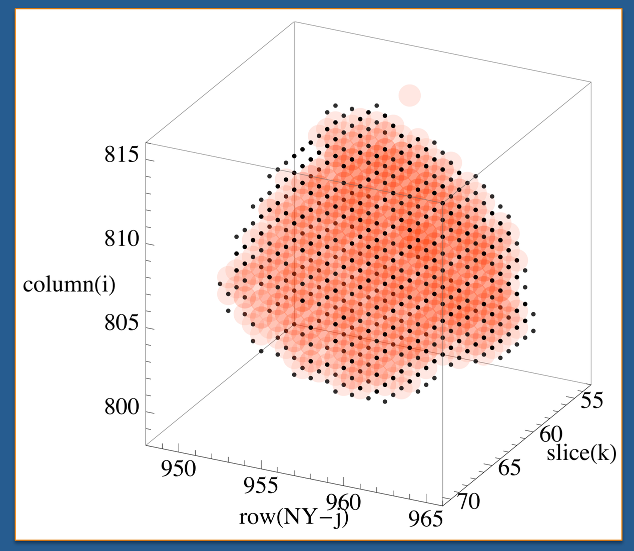


Plot of slab 5 mean intensities. A, B, C, D represent the sequential four datasets with application of heat.

Method B: Spherical Harmonics

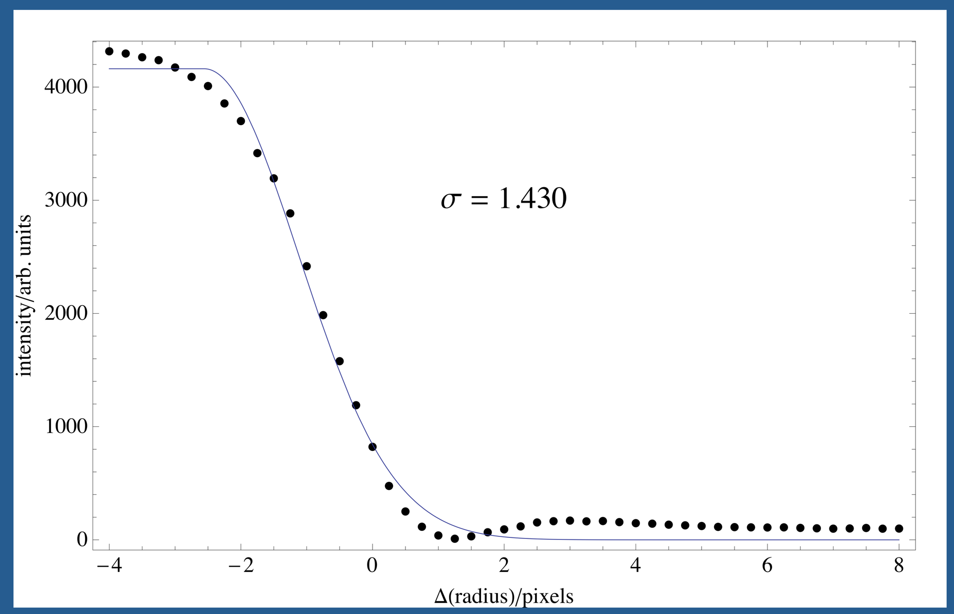
The shapes of undissolved flame retardant particles were modeled with spherical harmonics. First, the 3D tomography data sets were binarized at a threshold value of roughly 25% of particle intensity. Second, FORTRAN code from Dr. Edward J. Garboczi (NIST) was used to detect isolated, approximately convex-shaped objects, determine object center, and model with spherical harmonics up to order 26, though in practice, only up to order 9 were used. For each data set, about 1,500 particles were modeled. Based on center position and the 0-th order spherical harmonic (a rough measure of particle radius), similar particles were tracked in time.





An advantage of an analytical model, such as a spherical harmonic expansion, is the ease with which parameters like the radius can be adjusted. Shown above left is one object with its normal radius and two outer layers at extended radii. The next step is sampling over even spacing in θ, ϕ for these surfaces. Even θ, ϕ spacing is done with the Zaremba, Conroy, Wolfsberg algorithm. In a Cartesian plot, the sampling does not look even, but in a spherical coordinate plot, say like the surface of the Earth, we would see points are evenly spaced at the equator, $\theta = \pi/2$, and at the north and south poles, $\theta = 0$ and π. When we combine this θ, ϕ sampling with the spherical harmonic and the 3D tomography data set, we get a sampling of intensities at points in 3D space corresponding to the surface of the object, as shown above right.

By changing the radius, we can move the sampling points from the interior of the object to well beyond the surface. Collecting the intensity values from the 3D data set, we generate concentration curves, leading to a first estimate of the diffusion gradient (fitted to a gaussian).



Plot of the mean intensities for the collection of sampled points from spherical harmonics reconstruction $\pm\Delta r$.

This poster first presented by Kameron V. Kilchrist (kkilch1@lsu.edu) at the Louisiana State University Summer Undergraduate Research Forum on July 28, 2011