Data-driven X-ray tomography
MSc project

Project description

X-ray tomography has revolutionized the field of medical imaging and nano-tomography is currently an active research field for high-resolution imaging applications such as integrated circuit (IC) inspection [1-3]. In such case, both high-resolution and wide field-of-view is necessary, which suffers from extremely long image acquisition times. For example imaging a 1-mm^3 volume with a resolution of 50 nanometers would take several months. Another consequence of such imaging are X-ray radiation induced sample deformations, which not only makes tomographic reconstruction difficult, but can also destroy the underlying circuitry under investigation, especially at the transistor level. To realize large volume IC inspection the student will develop a novel data-driven image acquisition method for faster and more-dose efficient imaging. The method will also be applicable to other sample types that exhibit anisotropic scattering.

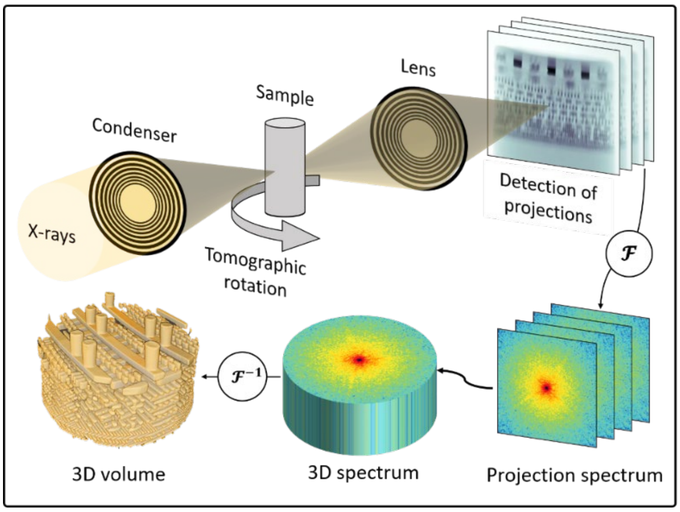
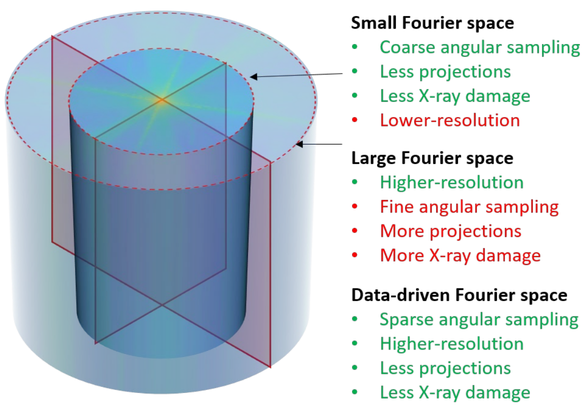


Figure 1. In tomography projections are collected at multiple sample rotation angles between 0 and 180 degrees followed by 3D volume reconstruction.

In tomography, 2D projections of the sample are reconstructed at angles from 0 to 180, Fig. 1, followed by a reconstruction of the 3D volume. Each projection represents a thin plane of the reconstructed volume in Fourier space (Fourier transformation of the tomogram), which must be filled without gaps. The cross-sectional Fourier space area of the tomogram scales with the sample thickness and resolution, hence, imaging larger samples and/or at a higher resolution will necessitate a larger number of projections to fill the 3D spectrum. To reduce radiation dose and imaging time a lesser number of projections must be acquired which comes at a cost of reconstruction artefacts and reduced resolution in 3D. Fortunately, some samples like ICs have very directional features, allowing to optimize the 3D image acquisition process.



Goal

To reduce image acquisition times and to improve overall reconstruction quality due to reduced radiation dose, projections can be acquired using sparse and unevenly sampled angular ranges. We propose a project to use machine learning algorithms to determine at which sample rotation angles most of the data should be collected. The most important rotation angles will be extracted from a low-resolution tomogram, which can be acquired very quickly during an experiment and used to determine optimal high-resolution image collection parameters. In the case of IC imaging up to 90% less data can be collected without loss of image quality.

Deliverables

A functional code that would take a low-resolution 3D volume and determine the best angles necessary for time-consuming high-resolution measurement. Integration of the code with our open-source MATLAB software package [4] would be useful. These results would be of great practical importance for regular operation during X-ray imaging experiments and have potential for a publication. If the project is finished quickly, an extension is possible for even more optimized image collection.

Data

A 3D experimental dataset of an integrated circuit will be provided at multiple resolution levels to mimic a real data-driven experiment. Simulations will also be done to simulate a 3D sample. Data will be processed on the GPU cluster in PSI.

Additional information

- **What will you learn?**
    - Apply machine learning for imaging problems.
    - Reconstruct 3D volume using multiple 2D images.
    - Understand and simulate image formation.
    - Solve real-world problems in the field of X-ray nano-tomography.
- **Requirements:** Python proficiency, machine-learning proficiency, MATLAB knowledge is useful.
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Literature

[1] Holler, M., Odstrcil, M., Guizar-Sicairos, M., Lebugle, M., Müller, E., Finizio, S., … Aeppli, G. (2019). Three-dimensional imaging of integrated circuits with macro- to nanoscale zoom. Nature Electronics, 2, 464-470. https://doi.org/10.1038/s41928-019-0309-z

[2] Holler, M., Guizar-Sicairos, M., & Raabe, J. (2021). State-of-the-art high-resolution 3D x-ray microscopy for imaging of integrated circuits. Electronic Device Failure Analysis, 23(2), 13-19. https://www.dora.lib4ri.ch/psi/islandora/object/psi:38001

[3] Holler, M., Guizar-Sicairos, M., Tsai, E. H. R., Dinapoli, R., Müller, E., Bunk, O., … Aeppli, G. (2017). High-resolution non-destructive three-dimensional imaging of integrated circuits. Nature, 543(7645), 402-406. https://doi.org/10.1038/nature21698

[4] Wakonig, K., Stadler, H. C., Odstrčil, M., Tsai, E., Diaz, A., Holler, M., Usov, I., Raabe, J., Menzel, A., & Guizar-Sicairos, M. (2020). PtychoShelves, a versatile high-level framework for high-performance analysis of ptychographic data. Journal of applied crystallography, 53(Pt 2), 574–586. https://doi.org/10.1107/S1600576720001776