Contribution ID: **51** Type: **not specified**

Intensity Contrast Transfer Phase Retrieval

At KIT, the IPS and LAS institutes develop cutting-edge in situ, in vivo, operando, and high-throughput synchrotron imaging techniques to characterize materials, biological systems, and the processes occurring within them. Among these techniques, propagation-based phase-contrast X-ray imaging is particularly valuable due to its simplicity and suitability for data-intensive 3D and even time-resolved 4D studies.

Under the assumptions of phase–attenuation duality, monochromatic radiation, and a sufficiently large Fresnel number, the measured intensity contrast can be converted into the object's phase shift using the transport of intensity equation (TIE) approach [Paganin 2002]. However, to enhance image contrast or to address experimental constraints, increasing the propagation distance may be necessary. This leads to smaller Fresnel numbers, potentially violating the assumptions underlying TIE and resulting in blurred phase-retrieved 2D images.

In such cases, the contrast transfer function (CTF) model [Guigay 1977]—which linearizes the object's attenuation and phase shift—can be employed for phase reconstruction. This approach, however, assumes weak attenuation, slowly varying phase shifts, and typically requires regularization [Huhn 2022]. Iterative techniques [Hagemann 2018] offer another alternative and have shown success, but their computational demands make them less suitable for real-time 3D reconstruction pipelines. More recently, deep learning methods [Zhang 2021] have been explored, although they depend on the availability of suitable training data, which may not always exist.

In our contribution, we will describe the Intensity Contrast Transfer (ICT) approach [Faragó 2024], a non-iterative method for phase retrieval that is applicable to both small and large Fresnel numbers, as well as to objects with higher attenuation. ICT can be used with both single- and multi-distance data. Its underlying approximation generalizes those of the TIE and CTF models, converging to them when their respective assumptions hold. When those assumptions are violated, ICT demonstrably outperforms both models, as we will show through theoretical analysis and results on synthetic and experimental data.

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Session Classification: Image Reconstruction Part 2