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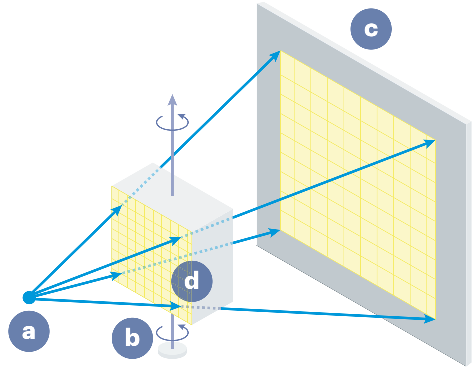
PrimeView
X-ray computed tomography

X-ray computed tomography (CT) non-destructively provides a 3D image of the internal structure of an object. CT uses the penetrating power of X-rays to obtain a series of 2D radiographs of an object viewed from many angles and computationally creates a stack of cross-sectional images showing the object's internal structure.

Experimentation

CT scanners comprise an X-ray source (**a**), a sample stage (**b**) and an X-ray detector (**c**). When imaging cm-sized or mm-sized specimens (**d**), the X-ray source and detector are kept stationary while the specimen on the sample stage rotates.



X-rays are produced by the acceleration of electrons – in most cases, the source (**a**) is either an X-ray tube (laboratory source emitting a spectrum of X-ray energies in a cone shape) or a synchrotron storage ring (large-scale user facility producing parallel X-rays with very high flux and often a single selected X-ray energy). Contrast between features is critical for detection. Because the contrast recorded by each projection depends on the interaction and absorption of X-rays with matter, materials with large differences in electron density are best distinguished by attenuation contrast, while materials with similar atomic number are better imaged with phase contrast. Mechanical stability of both the instrument and the sample is essential during a CT scan otherwise features within the computed 3D reconstruction will be blurred.

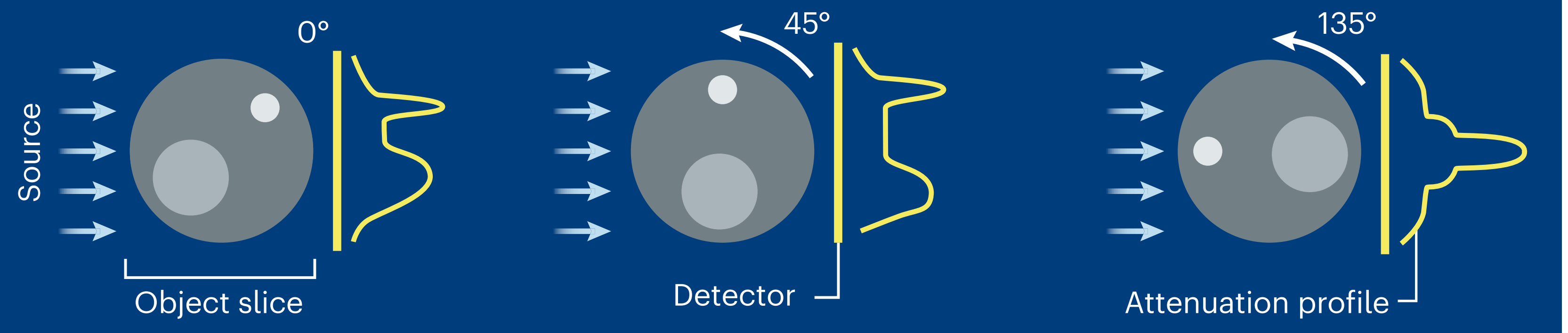
- Projection: a 2D radiograph formed by X-rays transmitted through an object and acquired by the detector at a given angle of illumination. When combined with many others, projections provide the data for numerically reconstructing the object.
- Tomogram: reconstructed 3D image composed of voxels (analogous to 2D pixels).

Results

Reconstruction algorithms (such as filtered backprojection) produce a greyscale tomogram of the object from 2D projections.

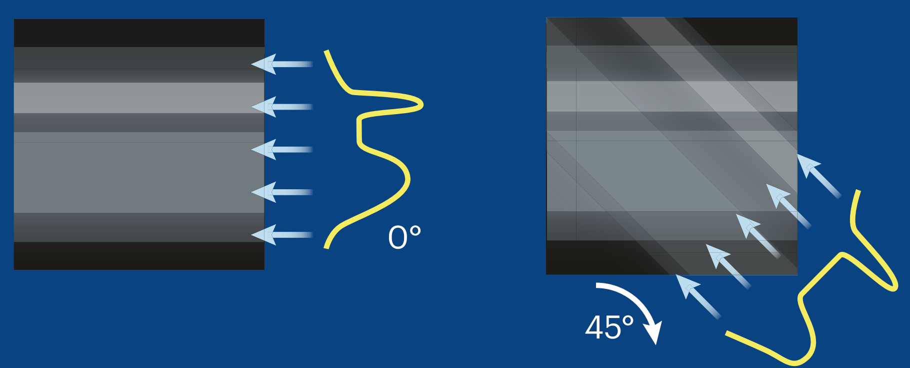
Acquistion

Illuminating the sample from different angles yields projections with different attenuation profiles.

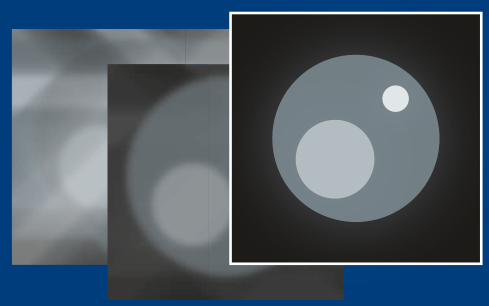


Reconstruction

Backprojecting or 'smearing' each attenuation profile back along the angle at which it was recorded builds up an image of the internal features of the object.

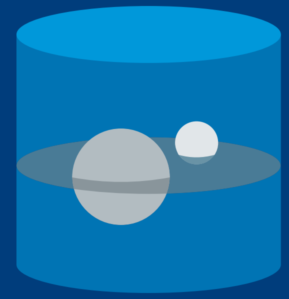


Filtering



Filtering the reconstructed slice removes blurring introduced by the backprojection algorithm. The more projections the better the image.

Reconstructed 3D volume



This reconstruction process builds up a tomogram slice by slice.

Quantifying internal morphology (e.g. particle size) requires segmenting the tomogram into regions representing the constituent materials.

Applications

Non-destructive CT has been used to image delicate samples that cannot easily be sectioned (such as frozen ice cream) or that should not be damaged (such as cultural artefacts), or to assess the integrity of engineering components (such as turbine blades). CT is also used for interrupted or continuous time-dependent studies monitoring 3D structure evolution such as the growth of a malignant tumour, the metamorphosis of a chrysalis, the progress of a fluid through rock or the catastrophic thermal runaway failure of a lithium battery.

Limitations and optimizations

To successfully resolve internal features, the voxel size must be significantly smaller than the feature size. High X-ray doses and high flux can lead to radiation damage even for radiation-insensitive materials. Imaging artefacts such as beam hardening can seriously affect the interpretation of X-ray tomograms and should be corrected for where possible. Finally, large 3D image datasets (>100s Gb) present challenges for storage, analysis and visualization.

Reproducibility and data deposition

Protocols are emerging to make measurement accuracy less hardware-, operator-, and sample-dependent. A number of field-specific repositories are starting to publicly archive 3D image data.

Outlook

Faster image acquisition and improved reconstruction algorithms will enable real-time imaging across a wide range of processes. Machine learning should lower the expertise required to segment and label complex tomograms. Approaches adding elemental selectivity could complement current morphological information.

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