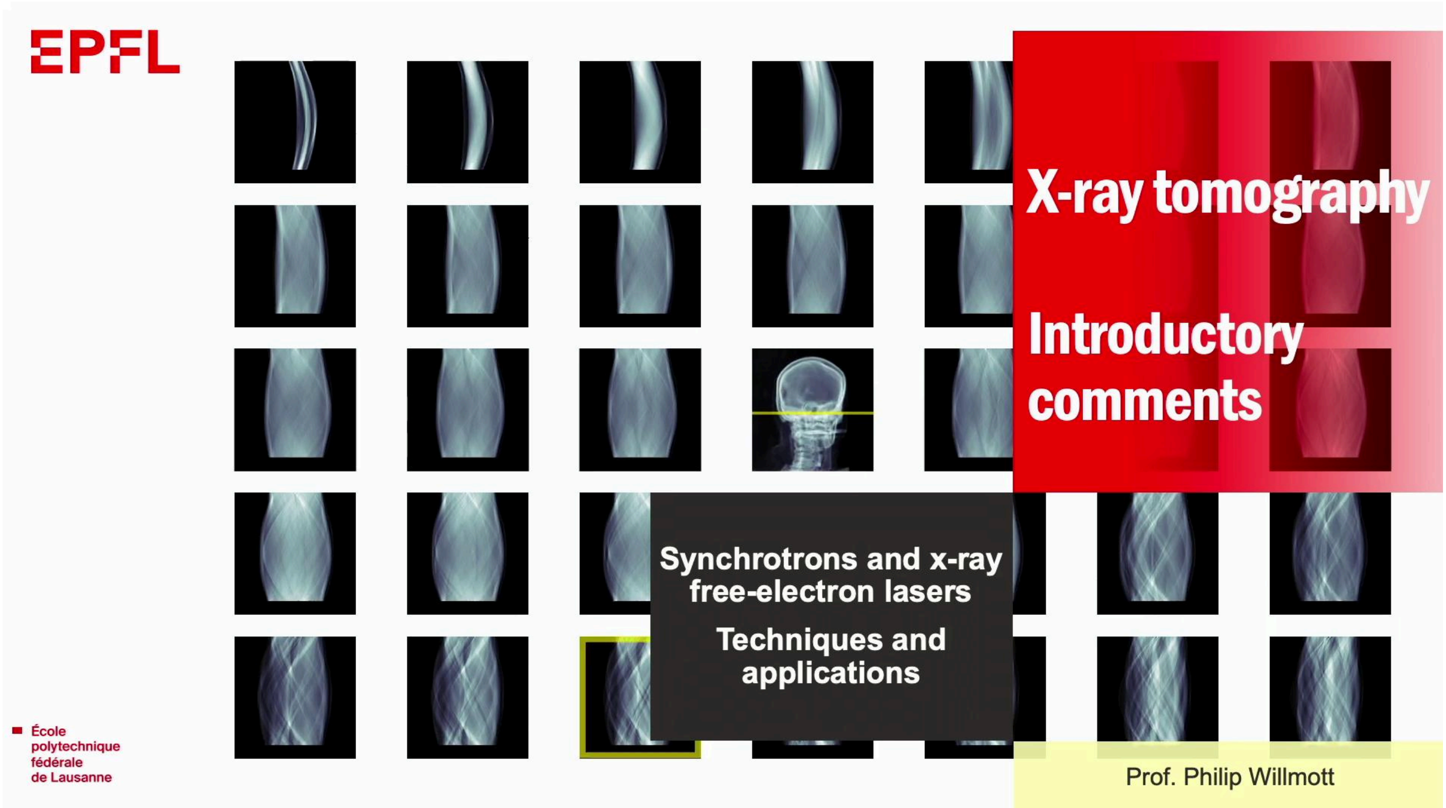

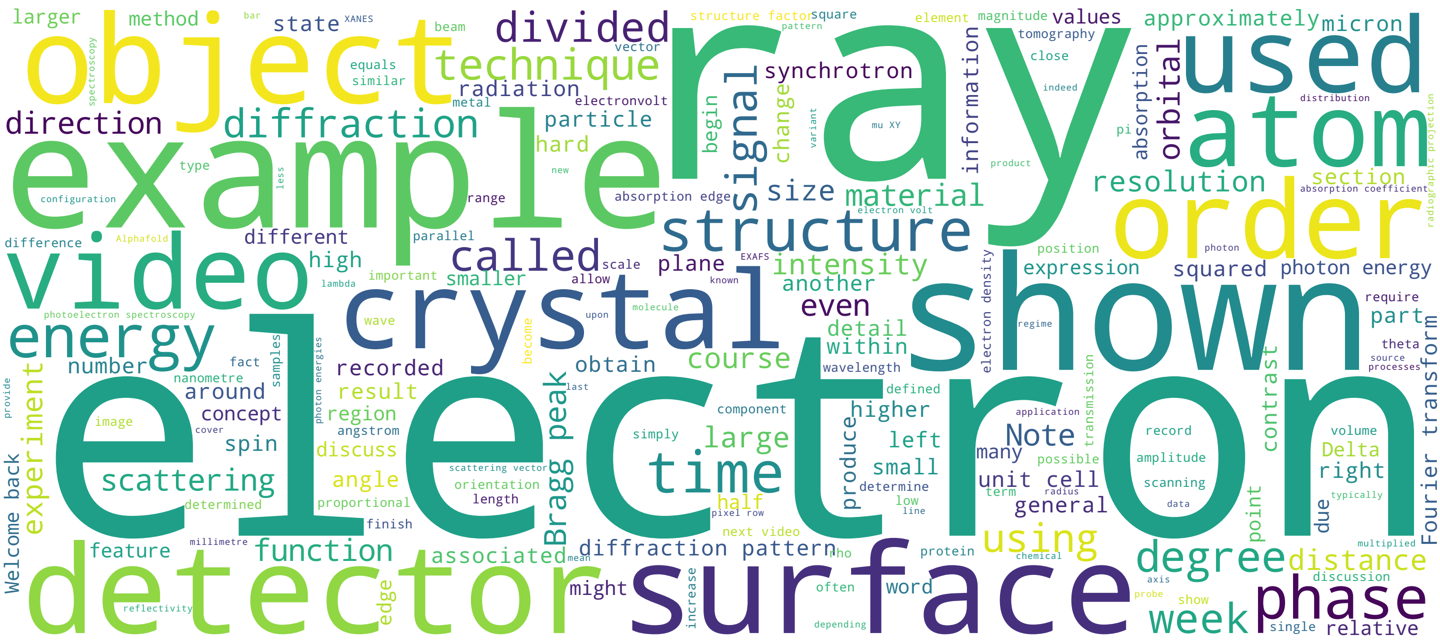

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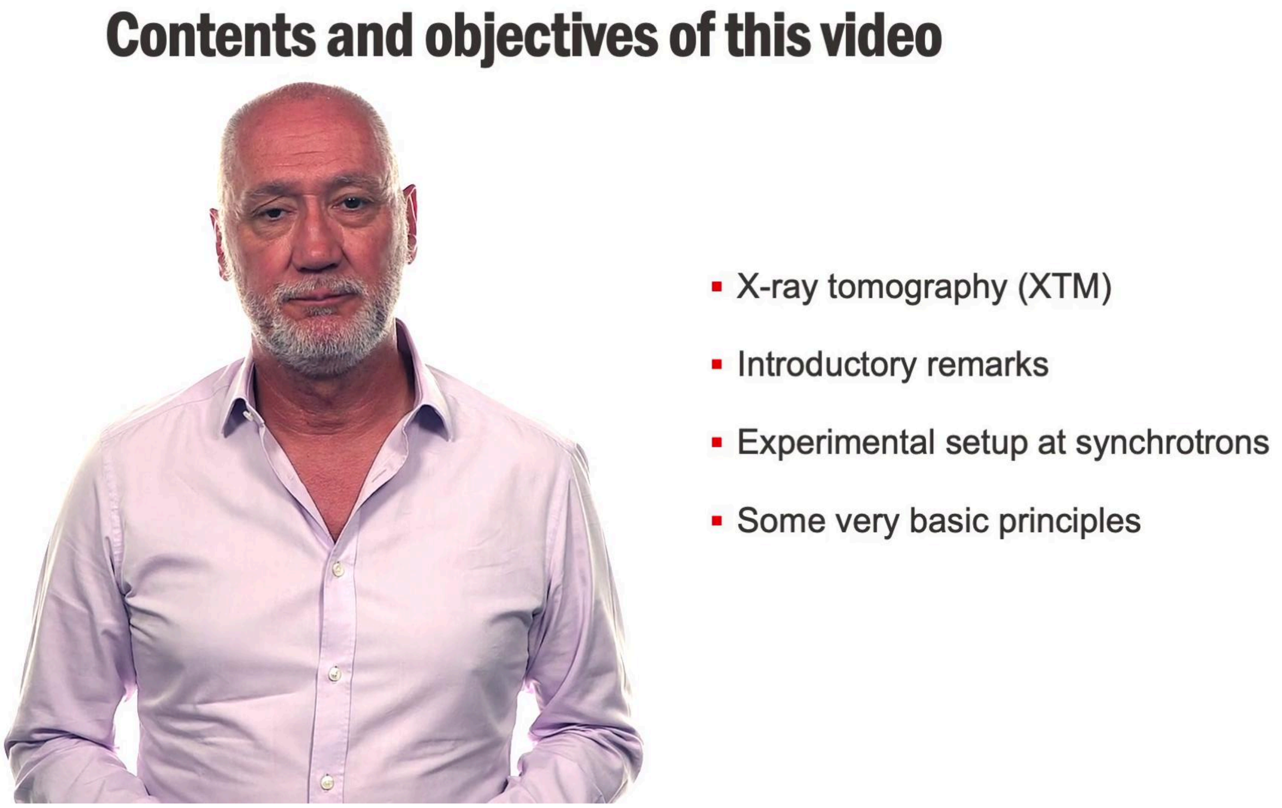


Welcome back to the fifth week of this introductory course on synchotron radiation. In this video, we'll make some introductory considerations relevant to tomography and imaging in general. We will see how an XTM setup typically looks like and consider some very basic principles from '10 kilometres up' before diving deeply into this aspect in the subsequent videos of this week.

Notes

Summary

0m 05s

Appearances can be deceptive

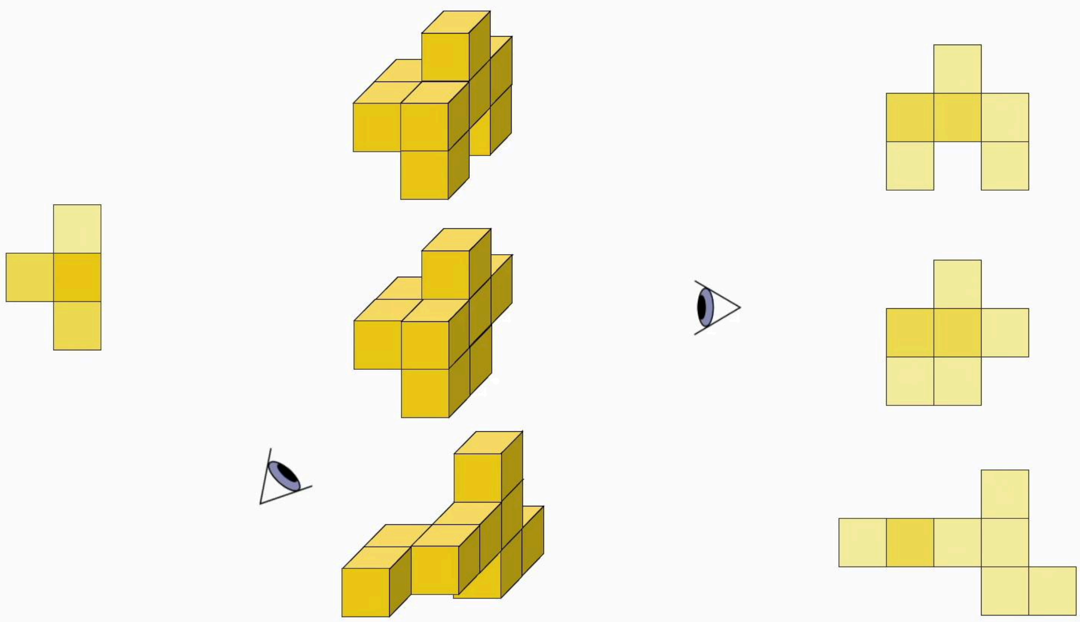
Now, it's often said that the interpretation and the meaning of art depends on your perspective. This has never been truer than in the works of Patrick Hughes, a British artist who created the concept of reverspective. Watch this video of a reverspective of an art gallery. I show this twice as the realisation of what is really going on can be quite arresting, justifying a second look. Note that in what I interpret as a nod to the hierarchical nature of scientific imaging, even the gallery images within the artwork display the same reverspective phenomenon. If you get a chance to see these in real life, you really should take it. So on a more prosaic level, it's patently clear that the X-ray image on the left is of a human hand. Nonetheless, an unanswered question remains. Is this a left or right hand? From this single projection X-ray image, it is impossible to say.

Notes

Summary

0m 31s

Tomography provides insight



So in this manner, tomography provides a deeper insight. Consider this transmission image of an object composed of cubic block elements. The darker the yellow, the thicker is that part of the object in the direction of observation. So for example, all three of these configurations are valid solutions for that single transmission image. Viewed from the right, however, these three different structures have very different shapes. Tomography thus allows one to determine the three-dimensional internal structure of objects by viewing them from many different angles.

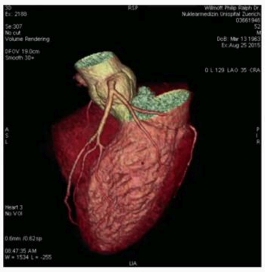
Notes

Summary

1m 38s

X-ray tomography – general comments

- X-ray Computed Tomography (XCT)
  - "Tomo": slice
  - "Graph": image
- Nondestructive imaging
  - Internal architecture
  - Any perspective/slice/isosurface
- Medical CAT scans
  - ~ mm resolution
  - Limited by beam fanning, polychromacity
- X-ray microtomography (XTM)
  - ~ µm resolution or better
  - Requires hard synchrotron radiation 5 – 200 keV



Medical x-ray computed tomogram of a human heart

Fly wing muscles during flight

Morphology of lung alveoli
Haberthür *et al.*, J. Synch. Rad., **17** (2010) 590
Courtesy: M. Stampanoni, Swiss Light Source

Now, it's the relative transparency of condensed matter to hard X-rays that makes the latter such a powerful tool for investigating the internal structures of objects in a non-destructive manner. Indeed, this benefit of X-rays was the first to be recognised, and which caused such a sensation immediately after their discovery more than a century ago. Imagine the frisson of wonder or even horror the public must have experienced at the first display of the radiograms of Roentgen's wife's and his colleague, von Kolliker's hands. Medical radiographic imaging remains the most widespread application of hard X-radiation well over a century later. X-ray computed tomography or XCT or X-ray tomography, XTM, has its orthographical origins in the Greek words tomo, meaning slice, and graph, meaning image or writing down. Tomography is a nondestructive technique capable of determining the internal architecture of an object which can be rendered as slices or isosurfaces, typically of equal absorption strength or refractive index value. Medical CAT scans are extremely common with there being approximately 100 million CT scans per year performed in the United States alone.

Notes

Summary

2m 20s

X-ray tomography – general comments

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  - Internal architecture
  - Any perspective/slice/isosurface
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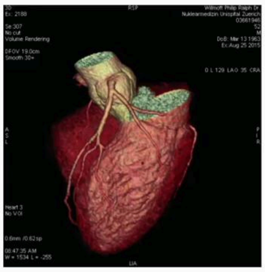
Fly wing muscles during flight



Medical x-ray computed tomogram of a human heart

Morphology of lung alveoli
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Courtesy: M. Stampanoni, Swiss Light Source

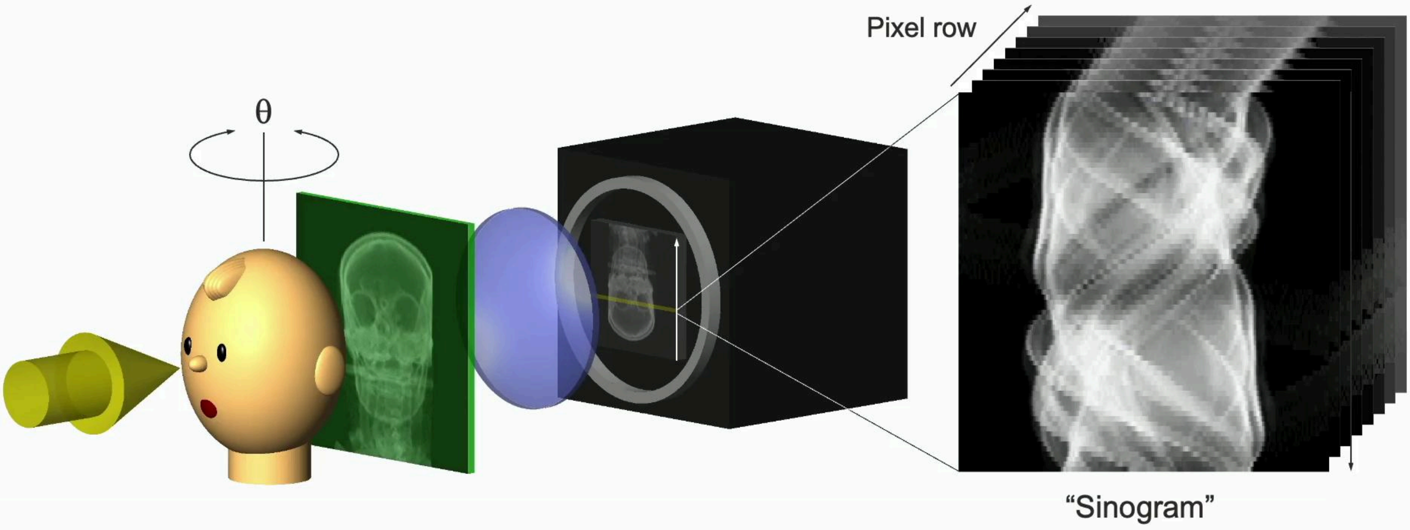
However, their resolution is normally limited to a little less than a millimeter, limited by beam divergence or fanning of the lab-based X-ray source and the source's polychromacity. However, synchrotron-based X-ray microtomography or XTM can offer spatial resolutions of a micron or even better, and typically uses photon energies in the hard X-ray regime between about five and 200 keV. It's useful for a wide range of materials, including inorganic substances such as rock, concrete, ceramic, or metal, but also for objects made from bone and soft tissue. In recent years, optimisation of tomography beamlines using high X-ray fluxes has driven the speed of data acquisition to such an extent that it is now routine to record entire tomography scans in a few seconds or even, in favorable circumstances, in the millisecond timescale. Time-resolved biomedical studies using tomography of processes such as breathing or blood circulation are thus now possible, and processes on timescales well below a 10th of a second and approaching one one-hundredth of a second are beginning to be probed.

Notes

Summary

3m 51s

XTM experimental setup

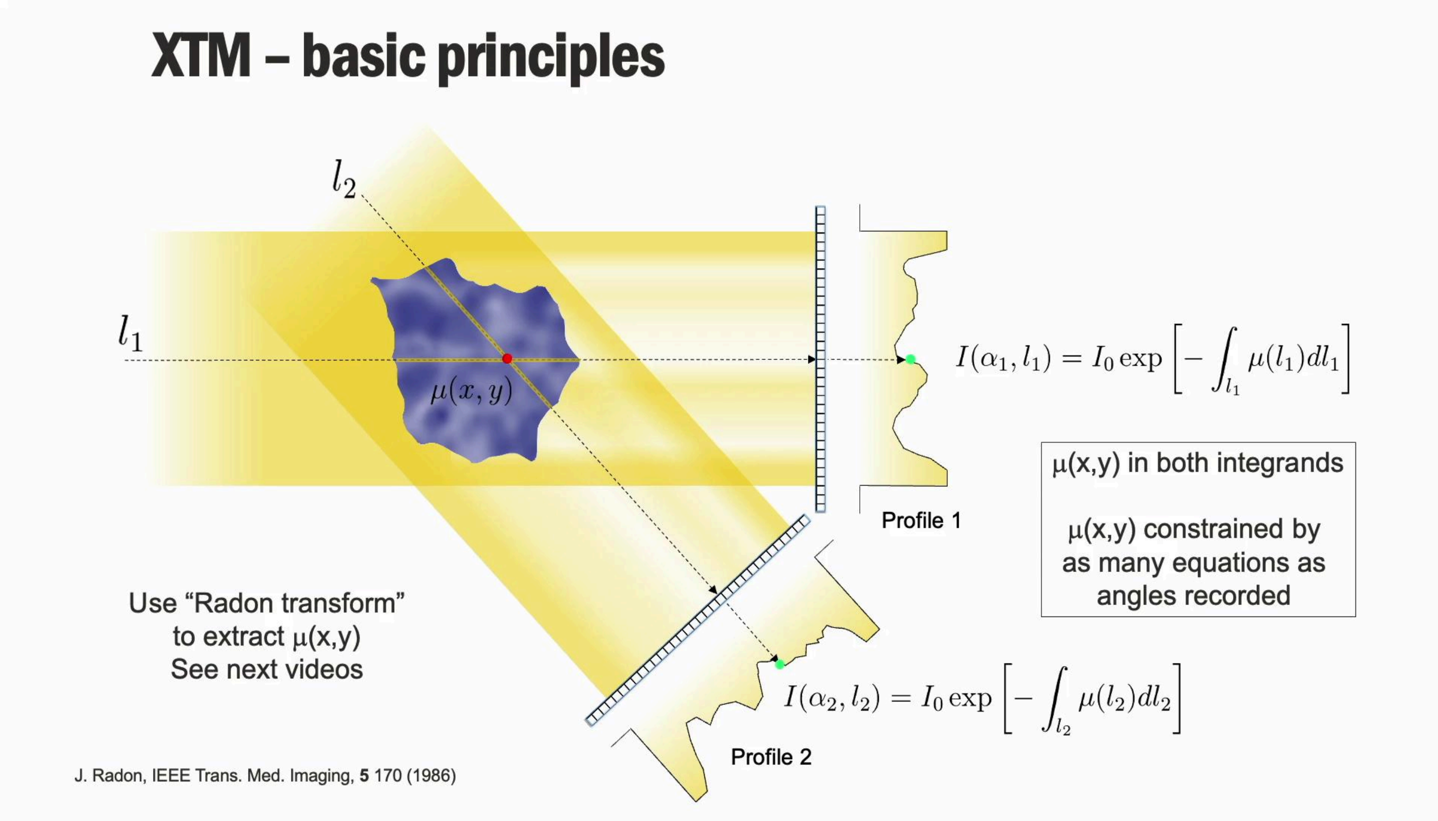


In a classical XTM experiment, the object under investigation is rotated through 360, or more commonly for synchrotrons, 180 degrees, and the transmission radiograph recorded on a pixelated X-ray detector. For a given pixel row perpendicular to the sample orientation axis, the transmission signal will vary as the sample is rotated, assuming, of course, that the sample doesn't have cylindrical symmetry and the rotation axis is the same as the cylindrical axis. Now, this change in transmission for a given pixel row is plotted out as a function of the rotation angle in a so-called sinogram. A stack of all these sinograms corresponding to the different pixel rows thus comprise the entire dataset required to generate the three-dimensional image.

Notes

Summary

5m 10s



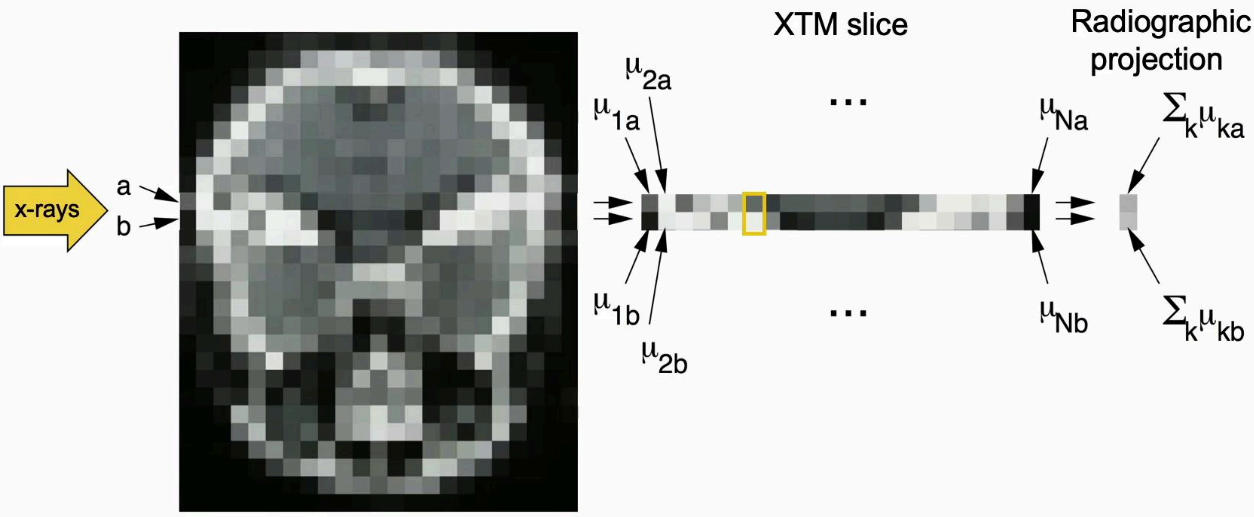
Let's take a first glance at the mathematics of the analysis of tomographic data. We let a homogeneous, monochromatic, and parallel X-ray beam pass through a sample onto a detector. We consider now a single line within this beam, L_1, and the point within the sample along that line with an absorption coefficient mu XY. The transmitted intensity on the detector given by the green spot is equal to the incident intensity at L1, which is I0, multiplied by the degree of transmission, which itself is equal to the integral of the negative exponent of the absorption coefficients by the sample along L1, multiplied by the length element, dL. Now, at another angle, Alpha 2, here we show this by the detector being at a new orientation, but in synchrotron-based experiments, it is in fact the sample that rotates. But let's not concern ourselves with this detail now. So at another angle, the transmitted intensity at the pixel located downstream of the point mu XY along the new line L2 will be determined by the absorption profile along L2. The value of mu XY has thus been constrained by two equations. Its degree of constraint is thus given by how many different angles one records. In order to determine the value of all values of mu for all possible positions in the sample, one uses the so-called Radon transform, discussed in more detail in the following videos.

Notes

Summary

6m 06s

Sinograms



So what advantages does tomography confer over traditional radiographic projections? Let's consider two adjacent rows of voxels within a tomographic slice. Voxels are the three-dimensional equivalent of pixels within the 3D tomographic reconstruction. The size of the voxel is given by the pixel dimensions and the angular step size. In the radiographic projection, the two intensities correspond to the product of the absorption contributions of all the voxels in their respective lines. This results here in very similar transmissions at the end, although the individual voxels in the two rows are actually substantially different from one another. So, for example, the two absorption strengths of the voxels highlighted here are very different from each other. So in other words, the contrast between individual voxels in the tomographic reconstruction is in general, much higher than that in a simple radiographic projection. And of course, one also gets to see the detailed three-dimensional internal architecture.

Notes

Summary

7m 57s

In the next video, we will look at the concept of back projections and how they relate to forward projections or simply projections. This will introduce us to the halo problem, which we will address in the video thereafter.

Notes

Summary

9m 09s