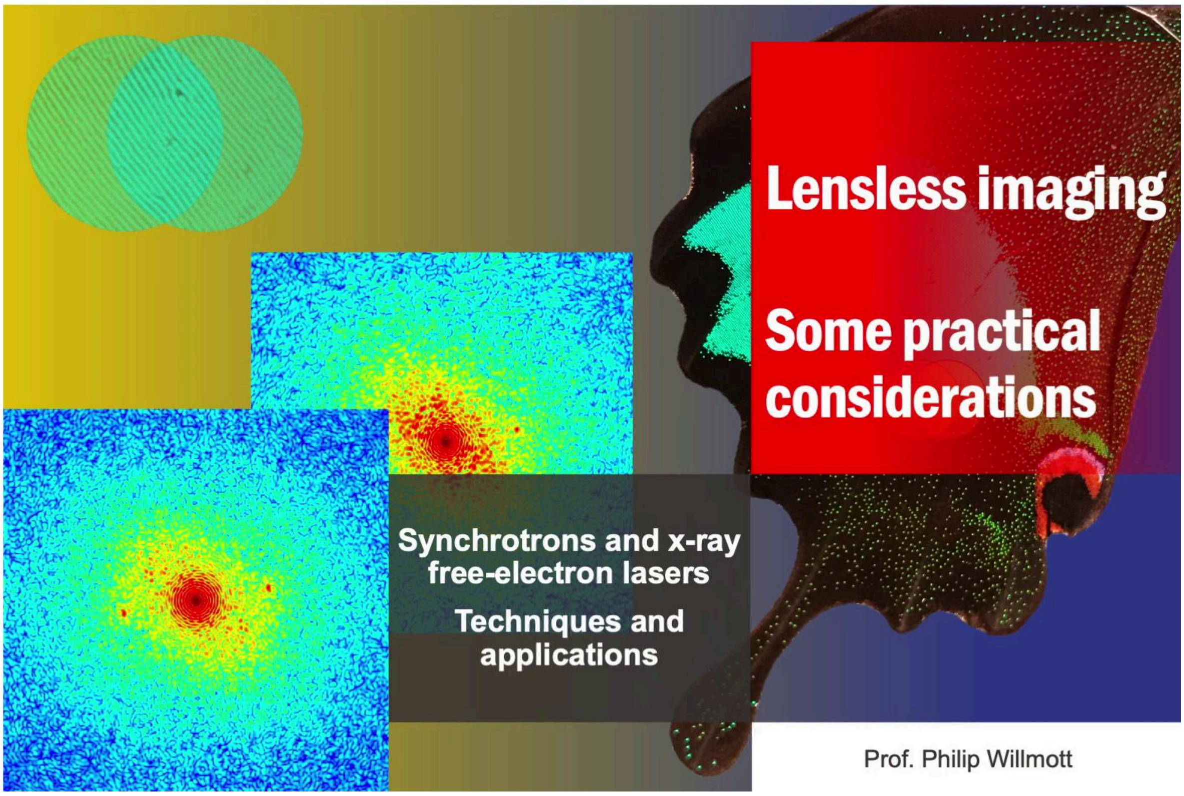
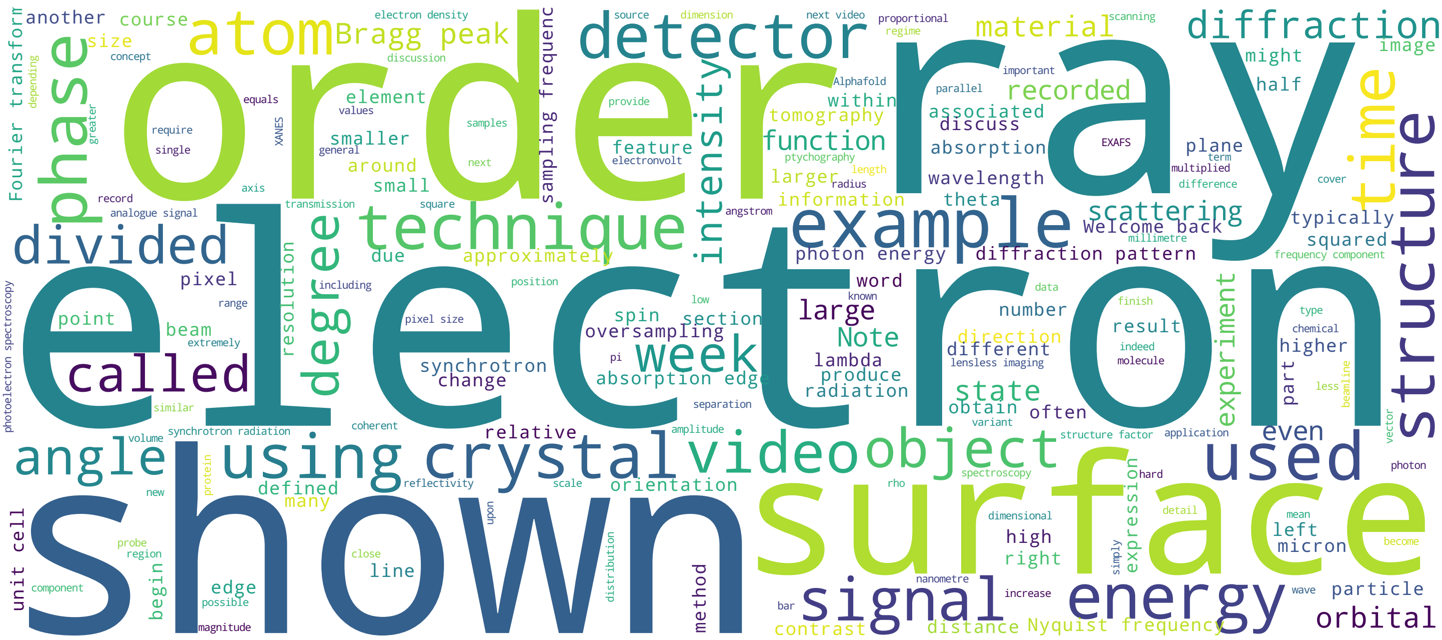
EPFL



École polytechnique fédérale de Lausanne



Search MOOC

Video

EPFL

Contents and objectives of this video

- Resolving speckle
  - Nyquist frequency
- Oversampling
- Redundancy

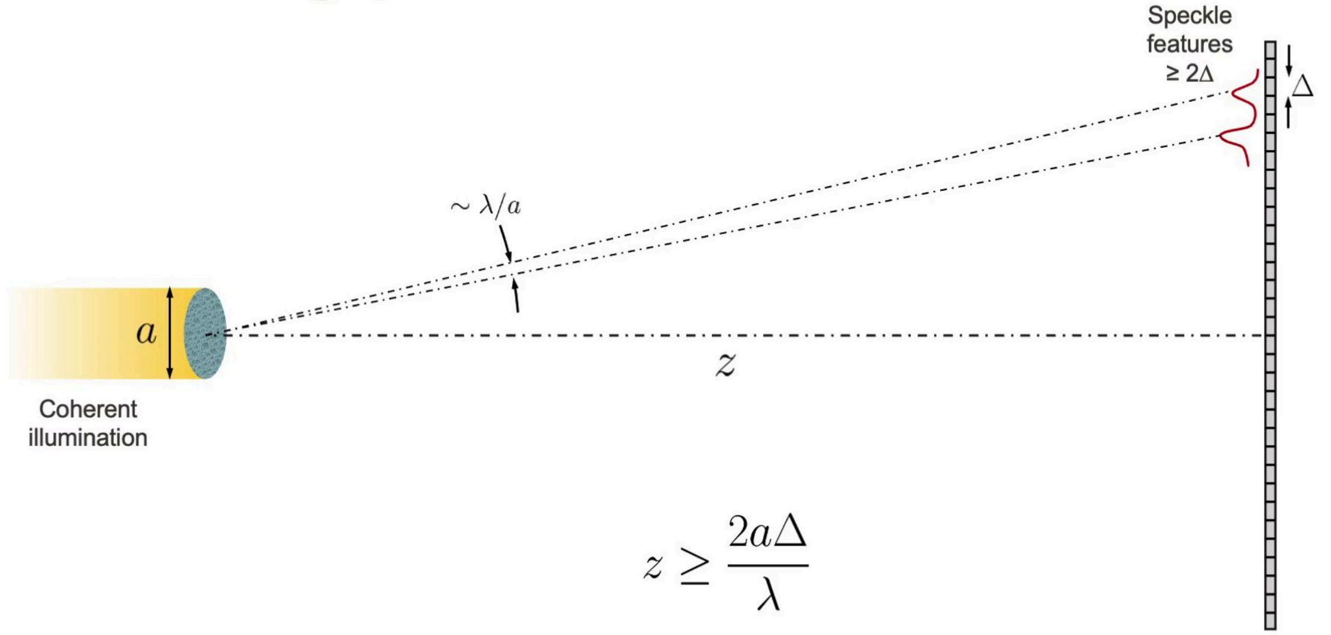
Welcome back to the sixth and final week of this introductory course on synchrotron radiation, in which we discuss lensless imaging techniques. Before moving on to specific experimental methods, it behoves us to understand what limitations we can expect for a given experimental setup and data acquisition strategy. We thus consider spatial sampling and the so-called Nyquist frequency, the related concept of oversampling, and finally, the idea behind the somewhat oddly-named redundancy.

Notes

Summary

0m 05s

Resolving speckle



$$z \geq \frac{2a\Delta}{\lambda}$$

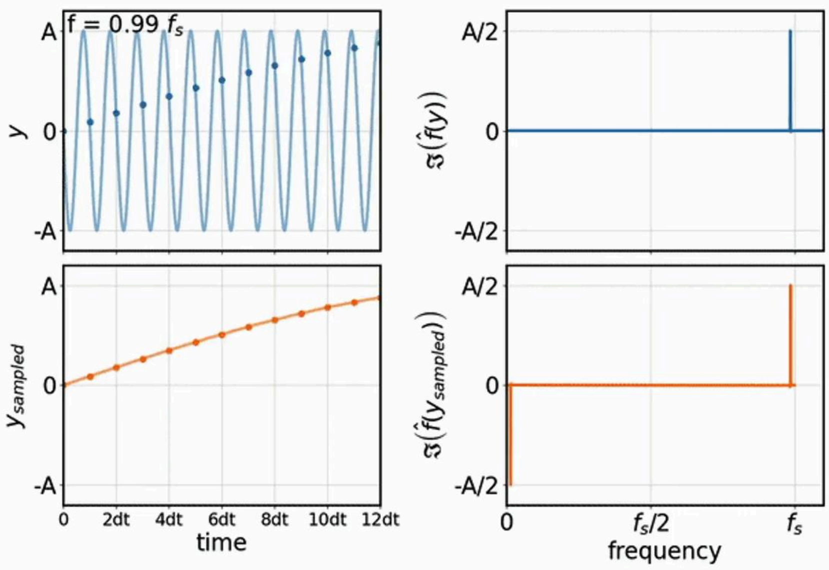
Consider a speckle pattern with characteristic fluctuation angles equal to lambda divided by a recorded on a detector with pixel size Delta. The separation between speckle features is z a divided by lambda, where z is the sample detector distance. In order to resolve these features, the pixel size should be smaller than half of this value, leading to the condition that z should be greater or equal to 2a Delta divided by lambda. For a coherently illuminated area with linear dimensions a equal to 1 micron, and pixel size of 100 microns for a speckle pattern produced by 1 Angstrom radiation, z should therefore be larger than 2 metres.

Notes

Summary

0m 40s

Nyquist frequency



- Sampling frequency ≥ 2 x highest frequency contained in the signal

$$f_s \geq 2f_c$$

- For a given f_s, the maximum frequency you can accurately represent without aliasing is the Nyquist frequency. The Nyquist frequency equals one-half the sampling frequency

$$f_N = fs/2$$

- "Aliasing": when

$$f_s < 2f_c$$

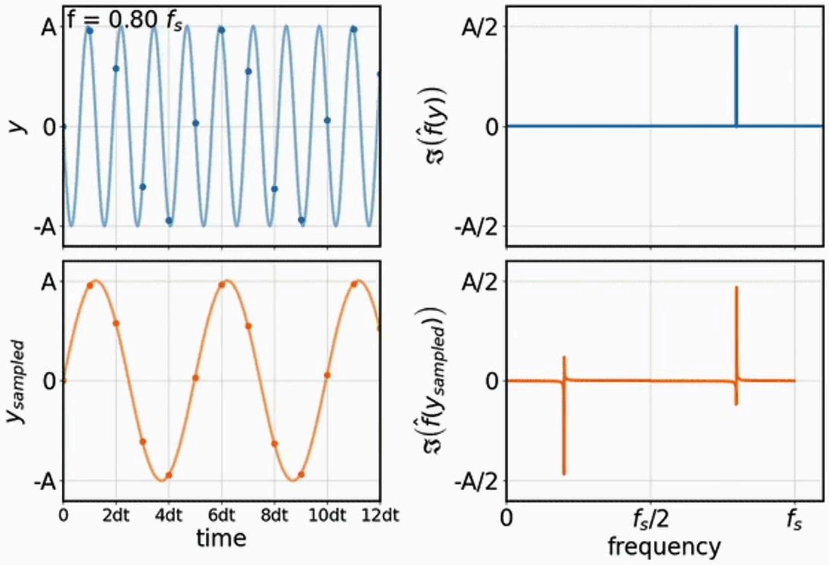
The above has assumed that if we set a sample detector distance equal to 2a Delta divided by lambda, then the speckled peaks are located exactly above pixels, and these pixels are interleaved with other pixels, which register minima in the speckle intensity. If the speckled peaks sit across two pixels, then it will not be properly resolved either spatially or regarding its intensity. The Nyquist frequency defines the maximum frequency that can be accurately represented or captured when performing analogue to digital conversion or sampling of a signal, in this case, speckle.

Notes

Summary

1m 36s

Nyquist frequency



- Sampling frequency ≥ 2 x highest frequency contained in the signal

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- "Aliasing": when

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Creative Commons: https://en.wikipedia.org/wiki/Aliasing#/media/File:FFT_aliasing_600.gif

In order to convert an analogue signal into a digital format, the signal is sampled by the detector pixels at discrete spatial intervals. According to the Nyquist-Shannon sampling theorem, a signal should be sampled with a resolution that is at most half the size of the finest features present in the analogue signal. In other words, the sampling frequency should be greater than twice the highest spatial frequency component of the original signal. This requirement ensures that there is enough information to accurately reconstruct the original analogue signal from its digital representation. Now, the Nyquist frequency is defined as being exactly half of the minimum sampling frequency. If the analogue signal contains frequency components beyond the Nyquist frequency, a phenomenon called aliasing will occur. Aliasing causes these high frequency components to be incorrectly represented as lower frequency components in the digital signal, leading to distortion and loss of information, as we can see on the left-hand side here. To avoid aliasing, the sampling frequency must be chosen carefully. In practical applications, it's common to use a sampling frequency that is significantly higher than the Nyquist frequency in order to ensure a safety margin and avoid potential issues caused by filtering imperfections or noise.

Notes

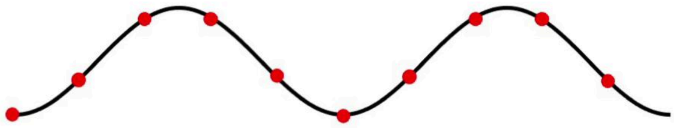
Summary

2m 25s

Oversampling

- Measuring spatial frequency

$$f_s > f_N$$



$$f_s = 2.5 f_N$$

$$O = \frac{f_s}{f_N}$$

This leads us to the concept of oversampling. The degree of oversampling, O, is the ratio of the sampling frequency to the Nyquist frequency. In the example here, the oversampling is 2.5.

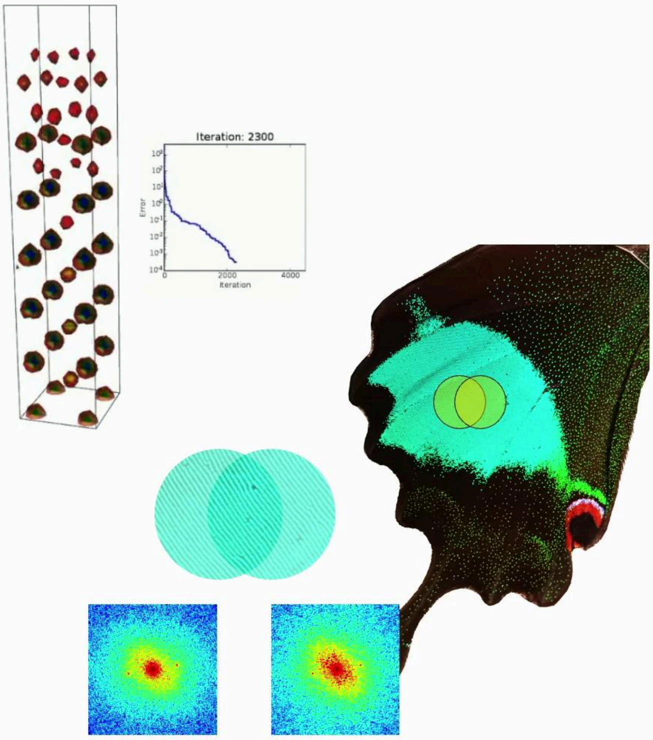
Notes

Summary

4m 08s

Redundancy

- Additional information/constraints beyond raw scattering data
  - Sparsity of real-space object such as atomicity
  - Physical extent of object
    - "Shrink-wrap"
  - Positivity of scattering (electron) density
  - Symmetry considerations
  - Consistency in overlapping illuminated regions (e.g., in ptychography)
  - …
- Narrows down possible solutions



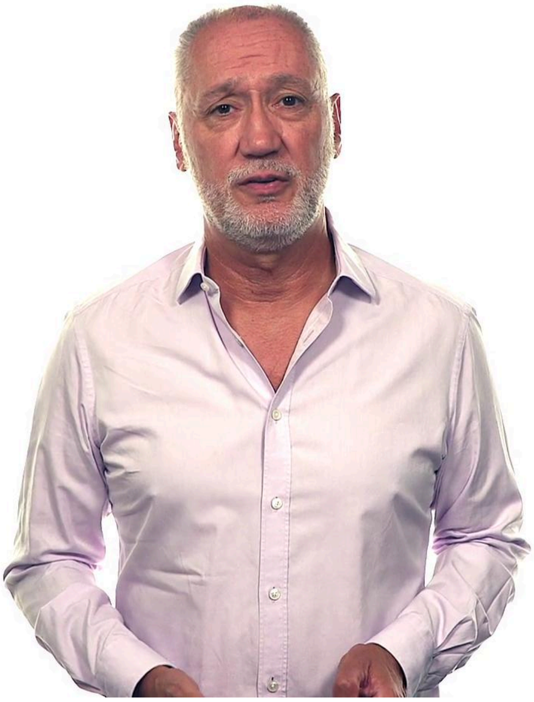
Now, redundancy is the term used for additional information one can reasonably use about the system under study outside the raw data, in this case, the scattering data. This might be the reasonable assumption of atomicity in the case of Angstrom resolution studies of crystal structures. The electrons tend to pile up in concentrated regions around the nuclear cores, as we all know. Now, other constraints might be a pre-knowledge of the physical extent of an object, the need to have positive electron densities, sometimes symmetry considerations, and in the case of ptychography, as we shall see later in this week, the requirement that the overlap region of two adjacently illuminated parts of a sample must yield the same real-space solution. Redundancy, thus, is essential in narrowing down solutions to the phase problem.

Notes

Summary

4m 23s

In the next video...



In the next and final video of this penultimate section of the course, we will look at lensless imaging as carried out in coherent X-ray diffractive imaging, both in the forward scattering direction and also Bragg CXDI, which is used for nanocrystalline single-crystal samples.

Notes

Summary

5m 25s