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Considerations for high quality 2D images

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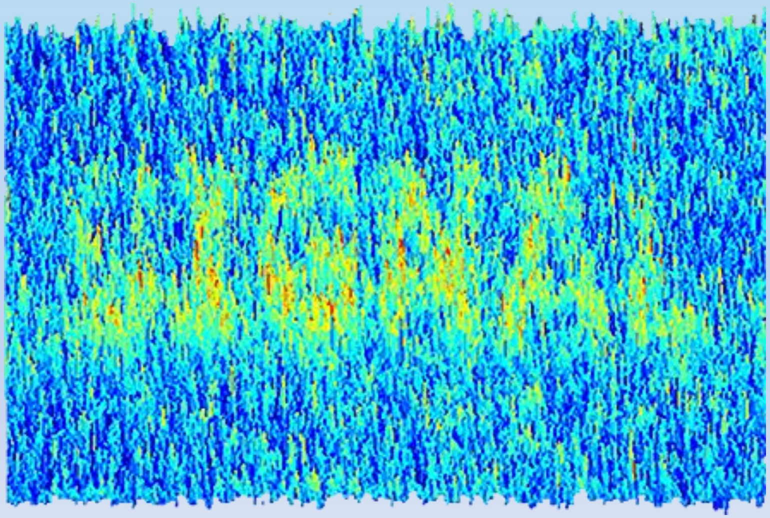
Imperfections

- The x-ray beam is not perfect
- The detector is far from perfect
- Digitisation brings its own problems too

Noise

- ‘Noise’ is any feature of the image that is not useful
- Systematic noise – fixed or slowly varying
- Stochastic noise – random (uncorrelated)



Quality of an image

- CNR – Contrast to Noise ratio, between the signal(contrast) and the noise
- DQE – Detective Quantum Efficiency. A more general metric.
- PSNR – Peak signal to noise ratio, a comparative metric

Detective Quantum Efficiency

- At the limit, the imaging system counts photons (let’s assume a monochromatic beam)
- The errors when counting photons is simple to calculate (Poisson statistics). Sigma=$\sqrt{N}$
- So the standard error on a count of N=10,000 photons is 1%
- DQE measures how well your imaging system performs, compared to this ideal.

More on DQE

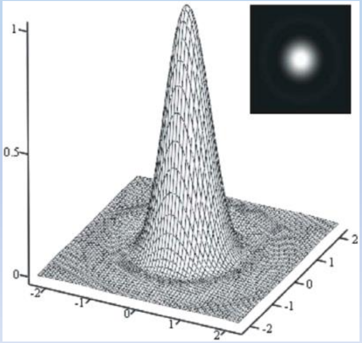
- The Noise Equivalent Quanta (NEQ) is the number of photons which in a *perfect imaging system*, would give rise to the noise you see in your image.
- DQE=NEQ/N (where N is the *actual* number of photons used)
- So when NEQ=N, DQE=1 and you have the perfect detector!
- Typically the DQE on Ruby will be ~0.01
  - For a direct coupled detector like the Hamamatsu it will be more like ~0.1. For a photon counter (Widepix or Xcounter) it can get close to 1 under certain circumstances.

…Yet more on DQE

- The DQE is a function of the spatial frequency in the image.
- It is intimately connected to the spatial resolution

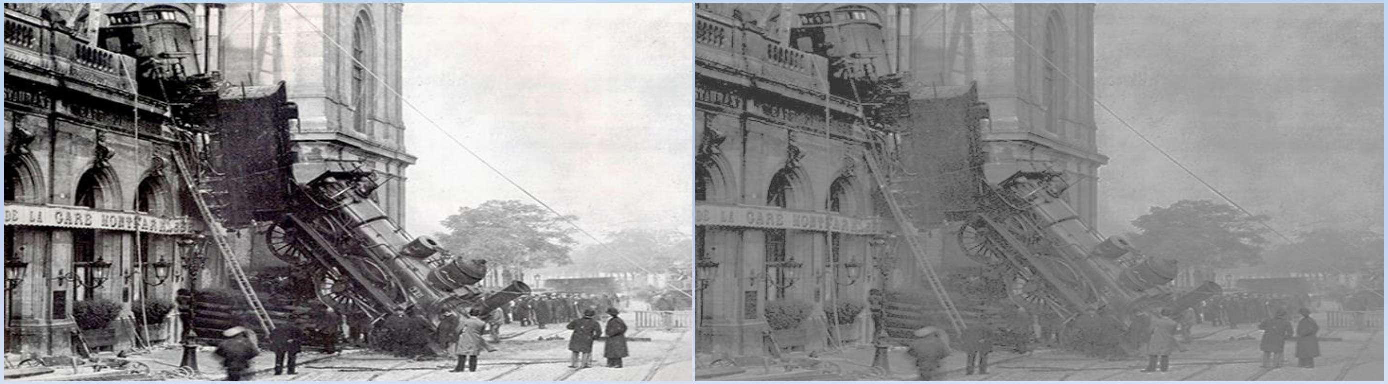
Spatial resolution

- Spatial resolution in the image is limited by the system point spread function (SPSF) of the *imaging system*
- That is not only the detector but the 'system' including the beam and sample.
- Rays are not parallel, coming straight from an infinitesimal source.



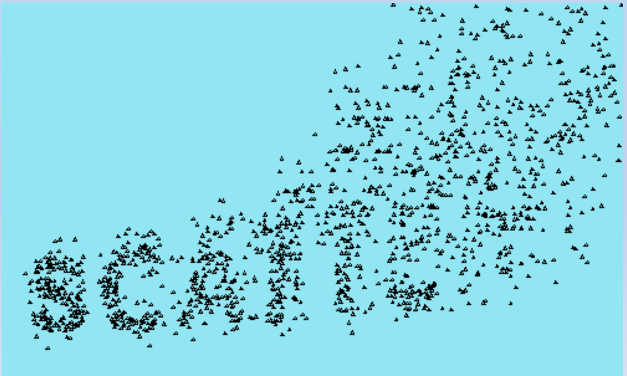
Contrast resolution

- The contrast resolution is also limited by the SPSF. Related to this by the Modulation Transfer Function (MTF)
- In all our systems the contrast gets worse for higher spatial frequencies.
- The MTF depends on the configuration of the beamline, imaging setup, and the detector.



Avoid scatter

- In general when photons scatter they lose the information they carry. They create a ‘fog’ on the image.
- We reduce scatter by using minimal air paths, slits, and low density detector windows.

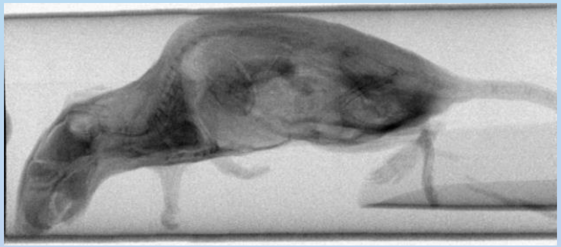


Use the detector dynamic range

- The detector digital output is usually 8 bit or 16 bit
  - 0-255, or 0-65535
- Carefully choosing the image intensity range will enhance the SNR in the image.
- 1 DU in 8 bits = 0.4%
- 1 DU in 16 bits = 0.0015%

Understand the detector

- The detector degrades your pristine image
- It adds dark noise, often in the form of a noisy ‘pedestal’
- It chops flux measurements into discreet quanta, the digital units (DU)
- It misses recording all photons
- All this combines to reduce the DQE



Exposure and Acquisition times

- In our imaging systems we select these two times on the GUI.
- The Exposure time is the time when the detector is ‘live’ and collecting the image data
- Then there is a necessary delay whilst the detector reads out and resets, before we can start collecting the next image.
- The Acquisition Time is the total time between collecting images. You can see it will have a minimum value

Detector output

- Individual images are currently saved as separate files
- We use the popular Tagged Image File Format (TIFF).
- Detector TIFF files contain 16 bit integers with no compression
- We will soon move to a more comprehensive way of saving experiment data called Hierarchical Data Format version 5 (HDF5)

Parameters we can control

- Beam brightness (ph/mm^2/sec)
  - Filters
  - Mono tuning
- Image intensity – Beam brightness and exposure time
- Frame averaging (noise adds in quadrature so SNR increases (slowly))

Energy Dependence of Contrast

- To some extent the beam energy is determined by measurements, at the start of an imaging experiment.
- Broadly: the contrast gets lower as the energy increases.
- Thicker, and higher Z materials require higher energies for a given attenuation.
  - We always want to collect that magic > 50% of the detector dynamic range.
- It is (much) harder to retain DQE and spatial resolution at higher energies.

Data reduction

- For making image calculations it is best to turn the 16 bit integers into *floating point* numbers.
- This is done automatically in XTraCT
- Applied to image set:
  - Standard noise reduction: Flat and Dark
  - Median filter
  - Zinger filter
- Applied to sinogram:
  - Ring artefact filter

Yet more on DQE

- The DQE is a function of the spatial frequency in the image.
- It is intimately connected to the spatial resolution:
  - $SNR^2_{in}=N$, and $SNR^2_{out}=N^2G^2M^2(x)/W(x)$
  - $DQE(x)=NG^2M^2(x)/W(x)$
  - So $DQE(x)=SNR^2_{in}/SNR^2_{out}$