

Considerations for 2D image quality

Chris Hall

IMBL

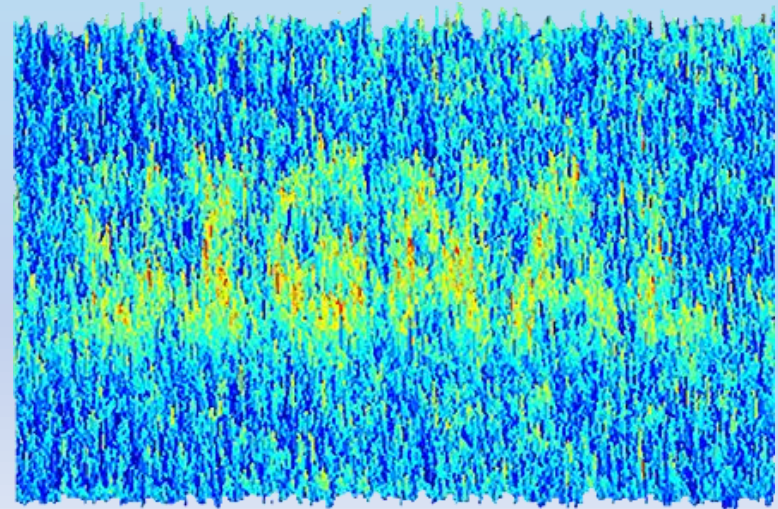
Imperfections

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



Noise

- ‘Noise’ is anything 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

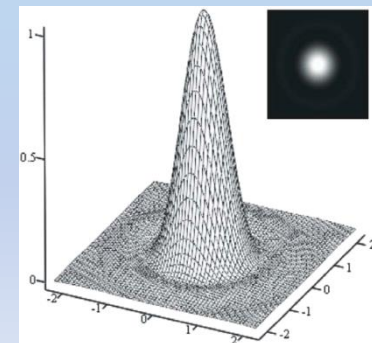
- The Noise Equivalent Quanta (NEQ) is the number of photons which in a *perfect imaging system*, would give rise to the noise you see in your image.
- $DQE = NEQ/N$ (where N is the *actual* number of photons used)
- So when $NEQ=N$, $DQE=1$ and you have the perfect detector!
- Typically the DQE on Ruby 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

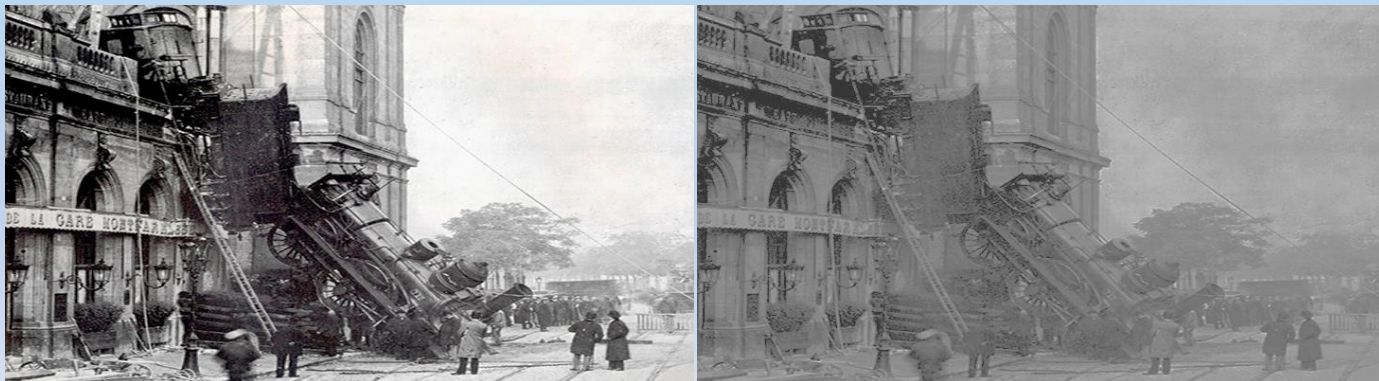
Spatial resolution

- 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.



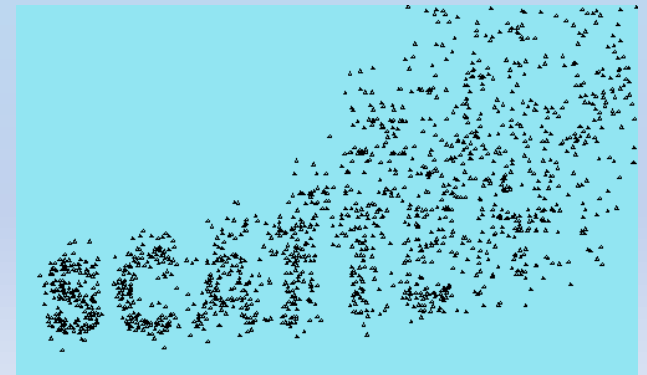
Contrast resolution

- 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.



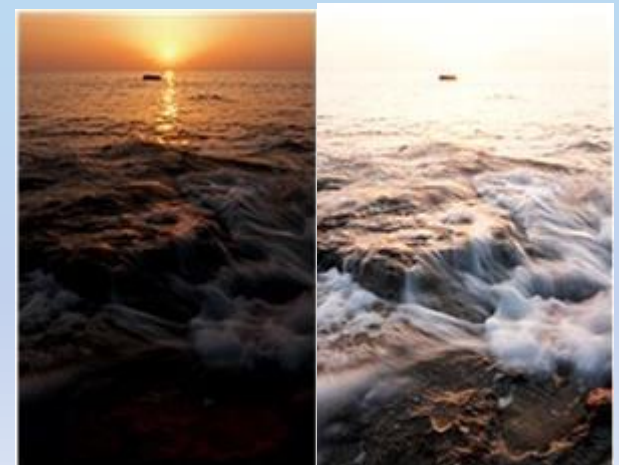
Avoid scatter

- 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.



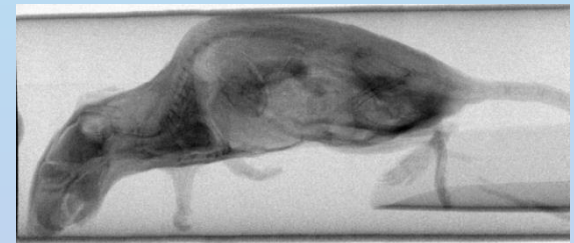
Use the detector dynamic range

- 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 discrete 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 ($\text{ph/mm}^2/\text{sec}$)
 - 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:
 - $\text{SNR}_{\text{in}}^2 = N$, and $\text{SNR}_{\text{out}}^2 = N^2 G^2 M^2(x) / W(x)$
 - $\text{DQE}(x) = N G^2 M^2(x) / W(x)$
 - So $\text{DQE}(x) = \text{SNR}_{\text{in}}^2 / \text{SNR}_{\text{out}}^2$