Photon detection and noise

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System’s view

\[ f(x) \rightarrow h(x) \rightarrow \sum_k \delta(x - k) \rightarrow \text{noise} \rightarrow \text{digitization} \]
Photon detection and noise

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Detectors
CCD
PMT

Noise
Poisson
Thermal
Digitization

Dealing with noise
Averaging

Pixels (sampling)
Two types of detectors

- Charge-coupled devices (CCD)
- Photo multiplier tubes
CCD

Photon detection and noise

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Figure: Courtesy Bart Vermolen
Photon detection and noise

Biomedical Imaging and Image Analysis

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Figure: Courtesy Bart Vermolen
Photo multiplier tube

Figure: From Microscopic Image Analysis for Life Science Applications
Noise in detectors

Physical limitation

The process of photon counting is statistically described by a poisson distribution

\[ P(s = f; \lambda) = \frac{\lambda^f e^{-\lambda}}{f!} \]
Thermal noise

Physical limitation
Thermal energy in the silicon lattice causes Gaussian distributed noise:

\[ P(s = f; \lambda) = \frac{1}{\sqrt{2\pi\sigma}} e^{-\frac{(f-u)^2}{2\sigma^2}} \]
Digitization "noise": pixel depth

8 bits = 256 levels

6 bits = 64 levels

4 bits = 16 levels

3 bits = 8 levels

2 bits = 4 levels

1 bit = 2 levels
Digitization "noise": pixel depth

Model as additive noise

\[ \text{RMS} = \frac{Q}{\sqrt{12}} \]
Dealing with noise: averaging

random variable $f$ \quad $\text{Var}\{f\} = \sigma^2$

$$Z = \frac{1}{N} \sum_{k=1}^{N} f_k \leftarrow \text{uncorrelated}$$

$$\text{Var}\{Z\} = \frac{\sigma^2}{N}$$

Averaging multiple images, or by

Digital convolution: $g[k] = f \ast h[k]$

$$= \sum_{p \in \mathbb{Z}} f[p] h[k - p] \quad h = \frac{1}{N}[1, 1, \cdots, 1]$$
Averaging: be careful

Image

Fourier Transform