

Image quality parameters derived from patient images

an approach using nonparametric statistics

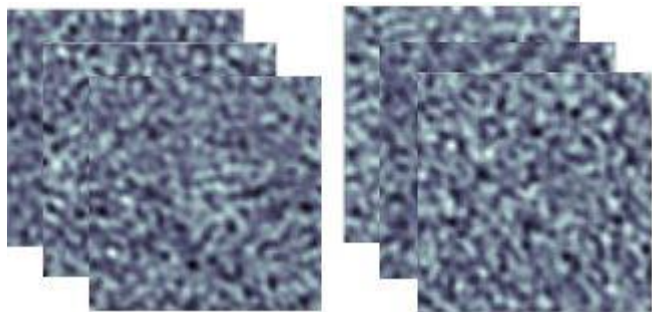
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Physikalisch-Technische Bundesanstalt
The National Metrology Institute



- **why?**
- **how?**
- **example: mammography**

Challenges for the model observer approach



many images needed



huge workload

Challenges for the model observer approach



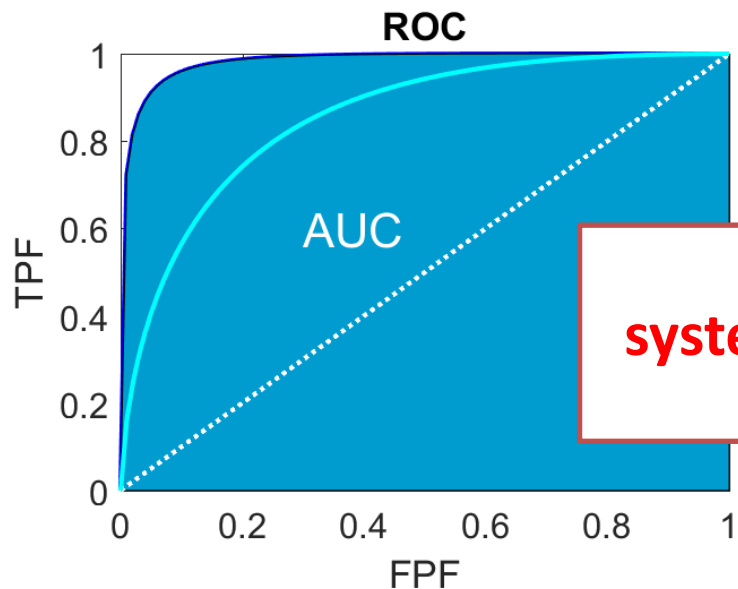
image: BfS, Kunert et al.

AI reconstruction



anthropomorphic phantoms

Challenges for the model observer approach



system-dependent!



MO detection probability



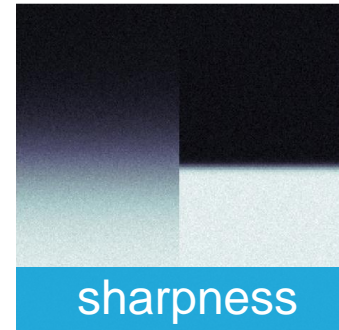
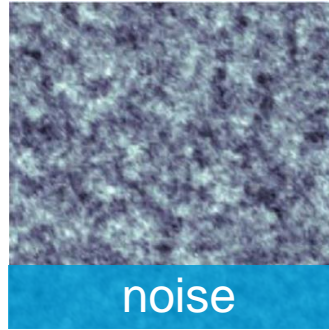
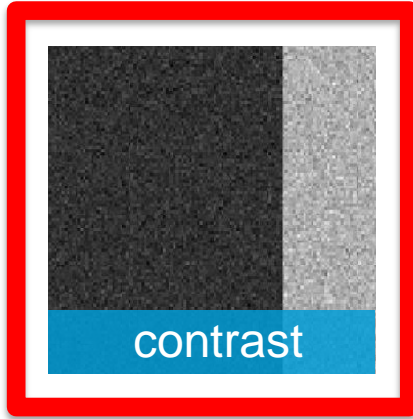
radiologist's assessment

desiderata

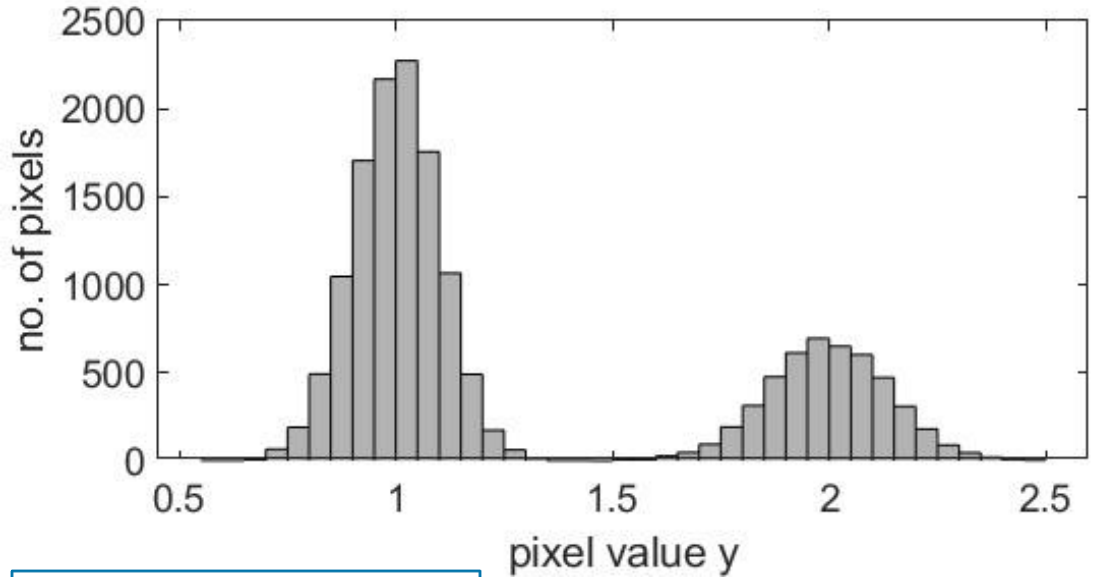
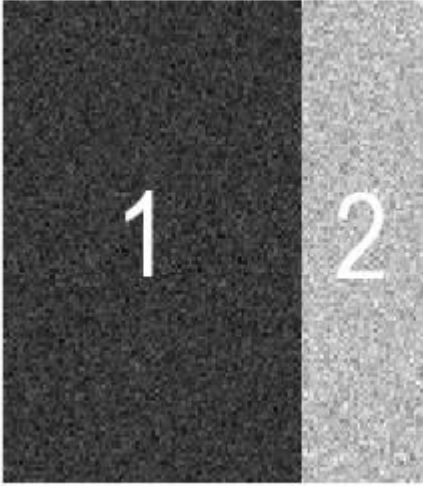


parameters from patient image, objective, task-specific

Which parameters are needed?



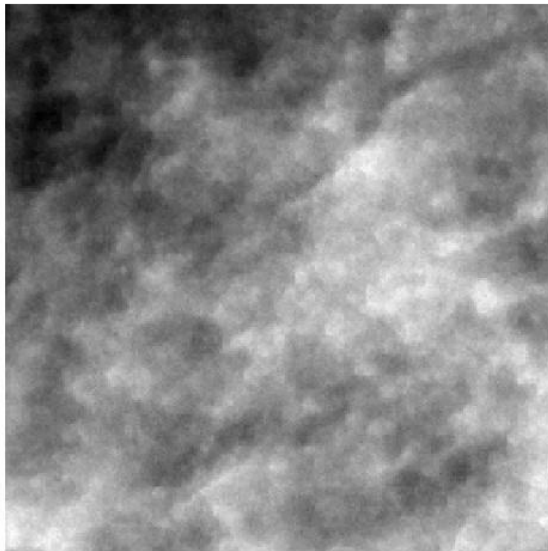
Contrast – as we know it



Michelson-contrast:

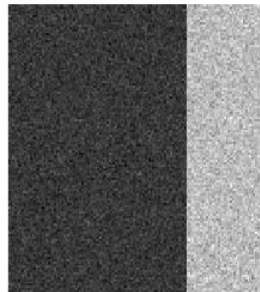
$$C_M = \frac{\mu_2 - \mu_1}{\mu_2 + \mu_1}$$

but what to do with an image like this one?



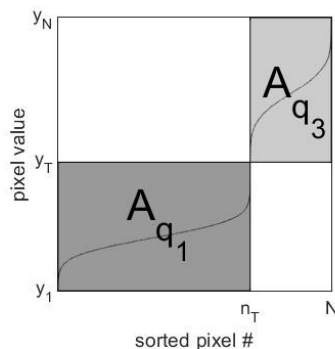
ROI from a mammogram of an anthropomorphic phantom

First, look at the step in a different way...

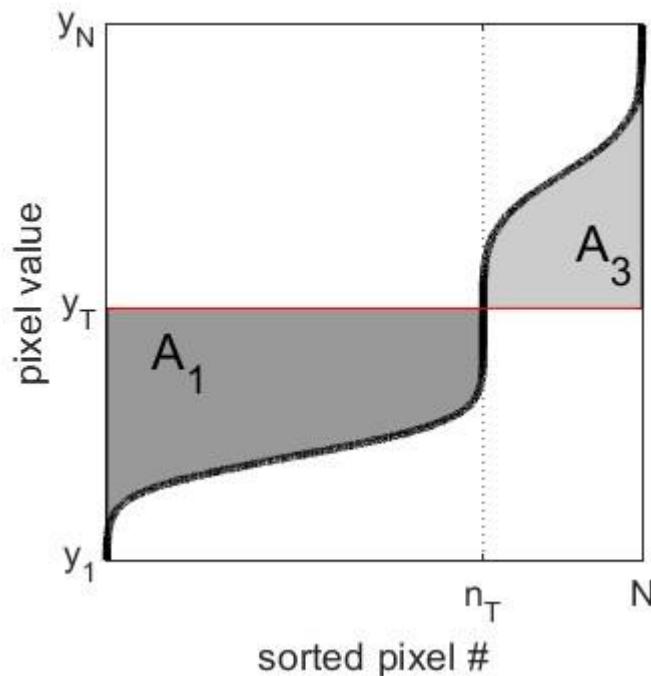


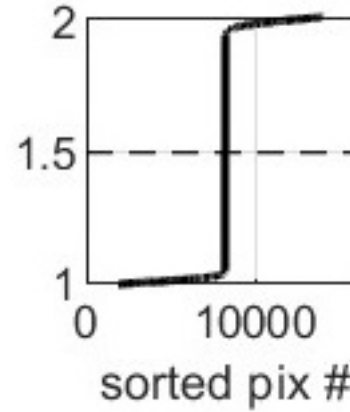
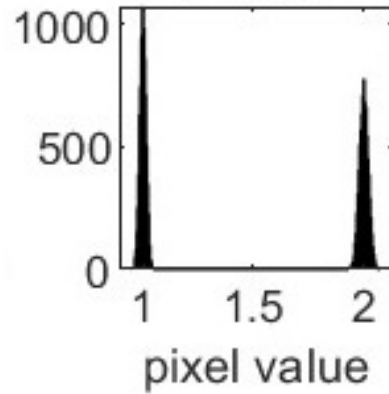
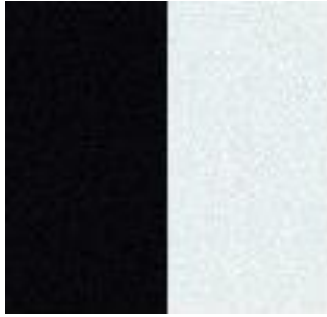
$$\delta = \frac{A_1 + A_3}{A_{q_1} + A_{q_3}}$$

$$\text{CED} = \frac{\delta \cdot (y_N - y_1)}{\mu_H + \mu_L}$$

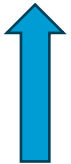


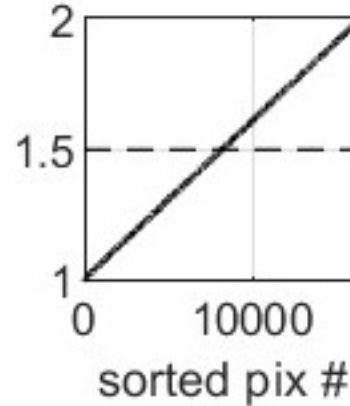
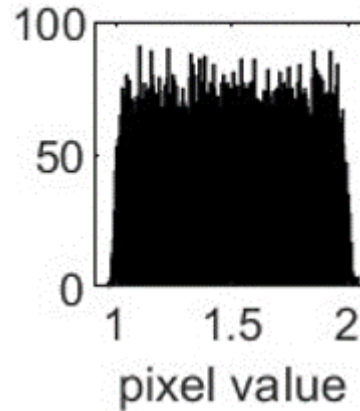
order statistic



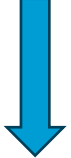


$$\delta = 0.89$$

$$\text{CED} = 0.33$$


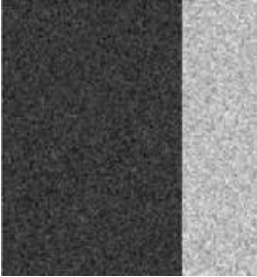
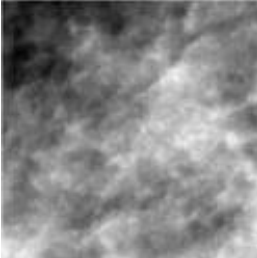


$$\delta = 0.46$$

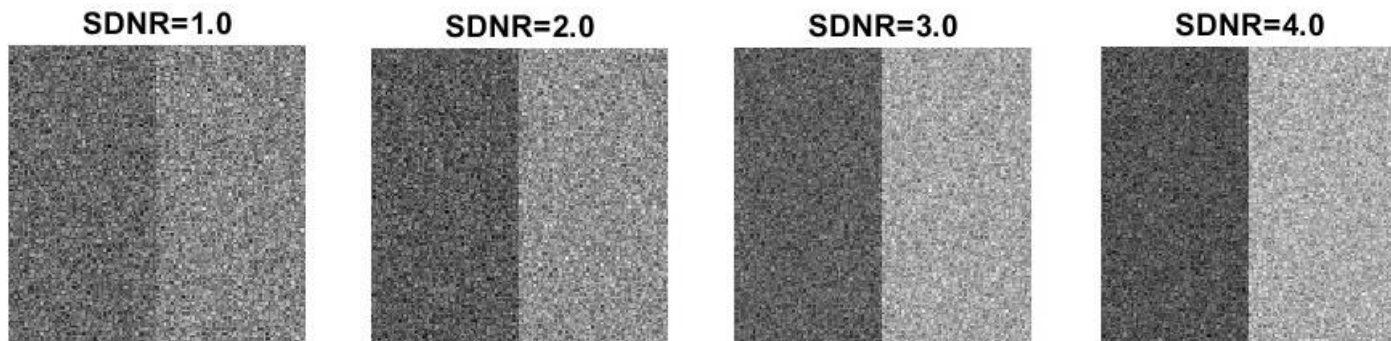
$$\text{CED} = 0.17$$


M. Anton *et al.* **A nonparametric measure of contrast in x-ray images.** PMB, 69(15):155013, 07 (2024)

Michelson contrast vs contrast equivalent distance

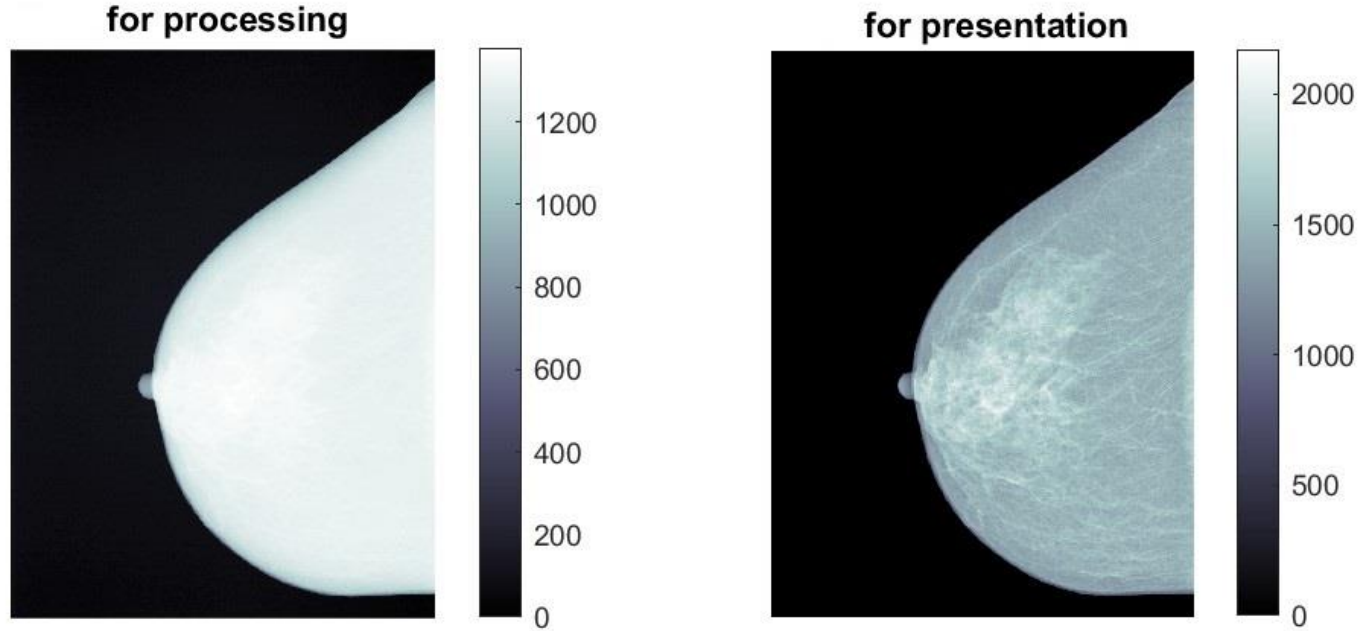
	C_M	CED
	0.333	0.347
	X	0.058

For low noise: $CED \rightarrow C_M$

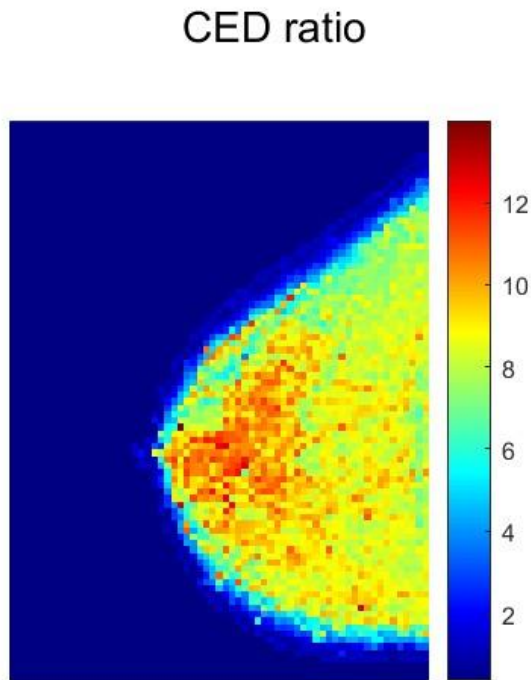


C_M	0.0911	0.0908	0.0910	0.0912
CED	0.1630	0.1060	0.0943	0.0918

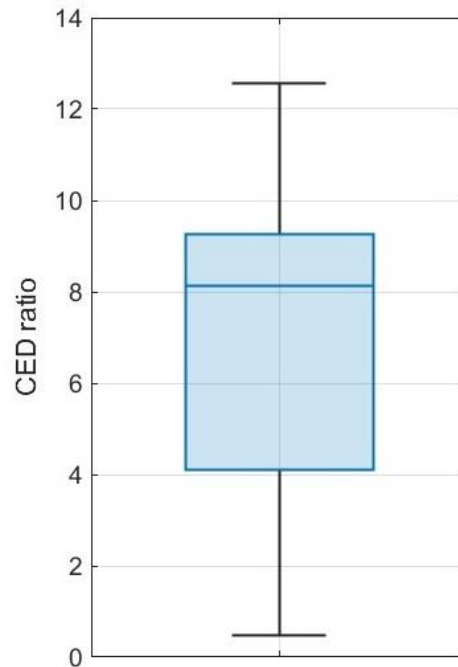
Application example: mammography



Contrast enhancement by processing

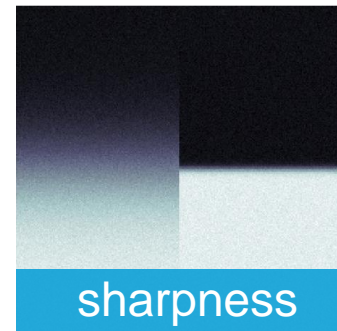
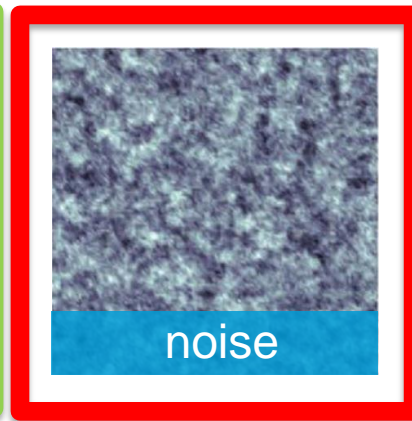
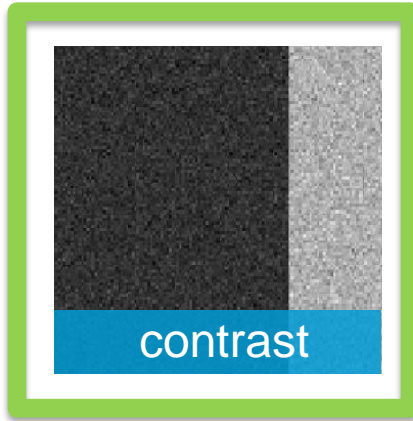


for presentation / for processing



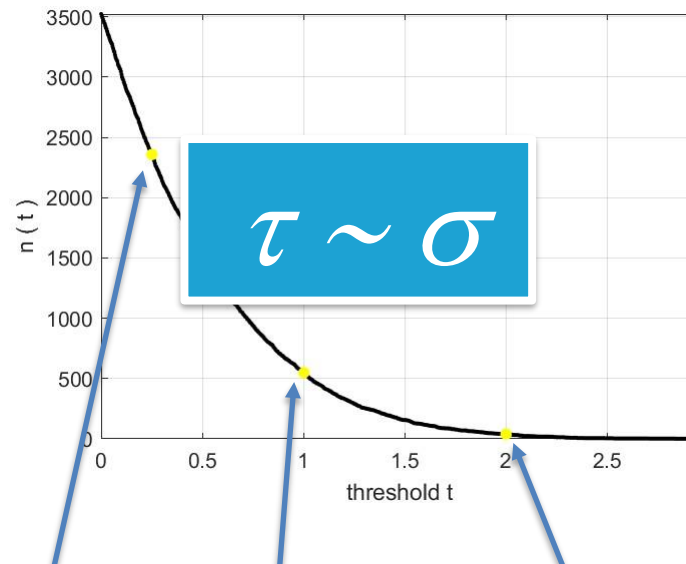
CED: contrast equivalent distance on 32 x 32 px sized ROIs

Which parameters are needed?



CED

Noise parameter τ – it's just counting...

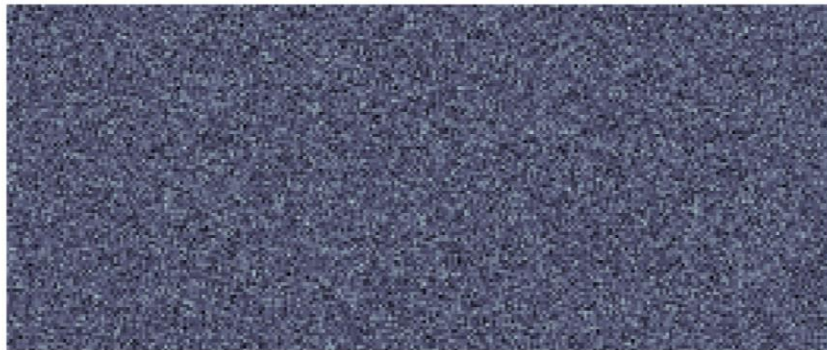


$$|y_0 - y_i| > t \quad \forall i=1..8?$$

$$\tau = (\sum t n(t)) / \sum n(t)$$

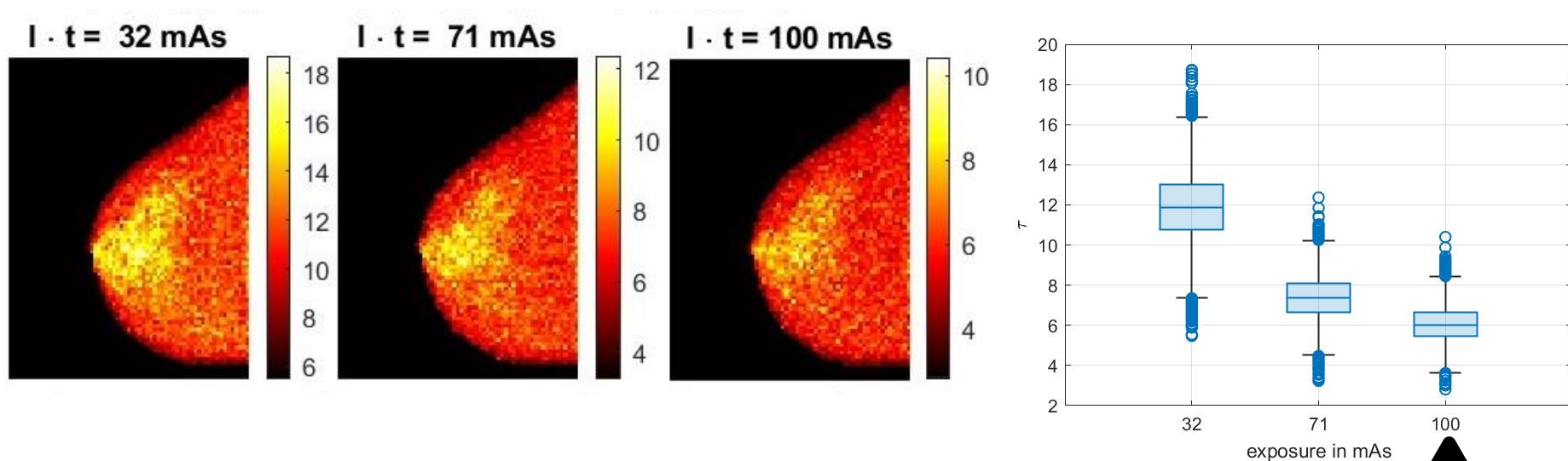
variance: σ^2 , unbiased estimator: $s^2 = \frac{1}{N-1} \sum_{i=1}^N (y_i - \bar{y})^2$

τ is less affected by background structures!



	white noise
τ	70.5
σ	147.3

Noise quantification by τ in mammograms

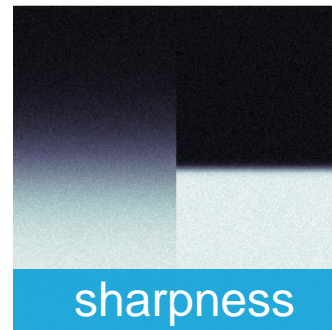
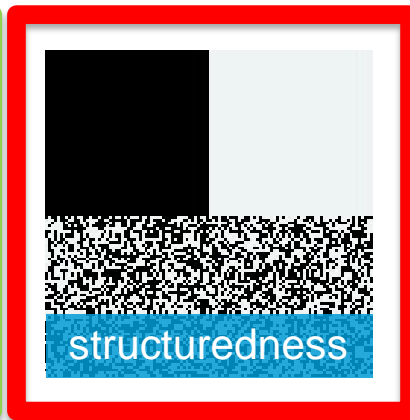
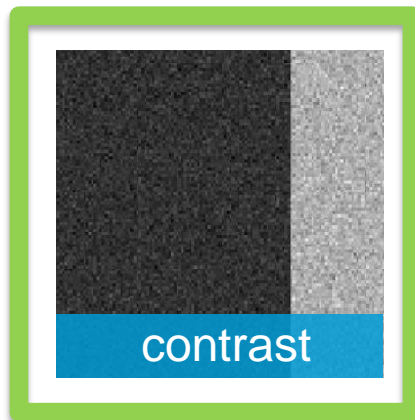


limitation: τ measures „white“ part of noise only!



M. Anton *et al.* A nonparametric measure of noise in x-ray diagnostic images – mammography. PMB, 68(4):045003, 02.2023

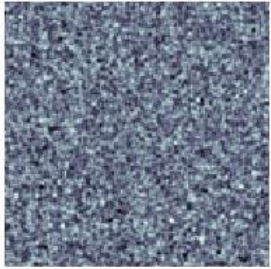
Which parameters are needed?



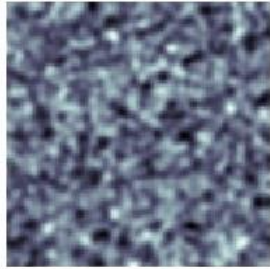
CED

τ

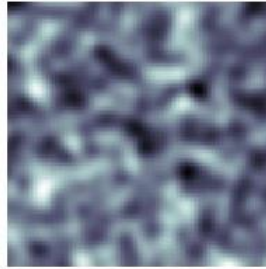
Relative mutual information U of co-occurrence matrices



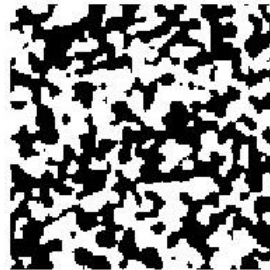
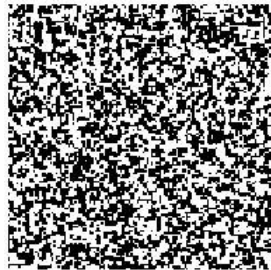
$U=0.04$



$U=0.40$



$U=0.61$



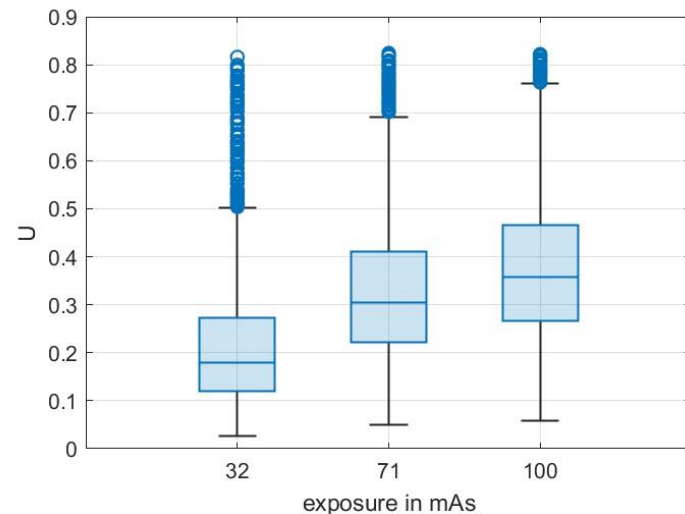
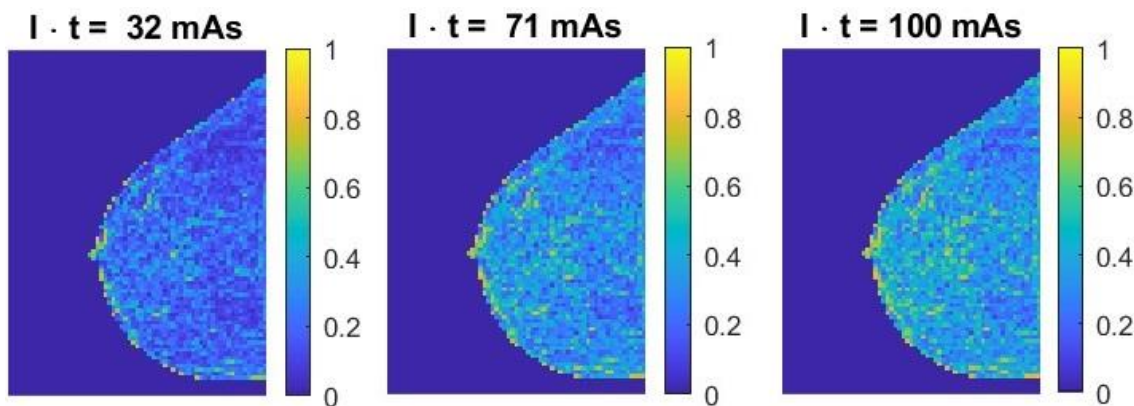
From entropies of 2D-adjacency probabilities

segmented, using y_T

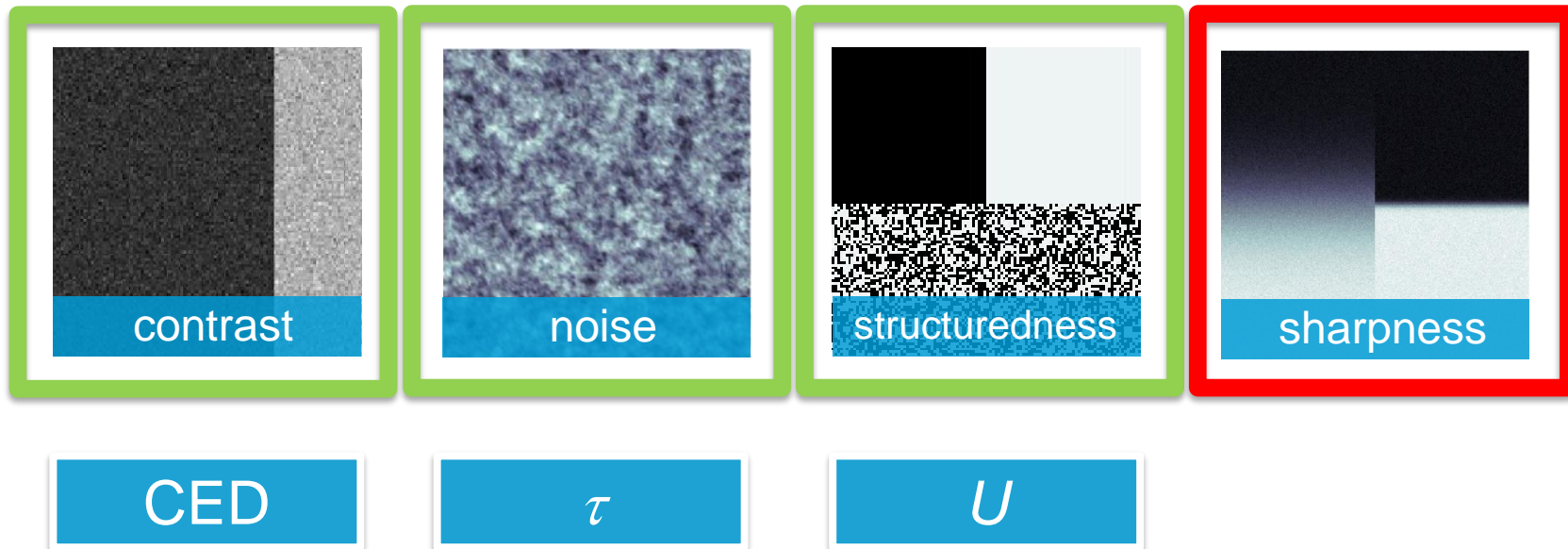
?

Nowosad and Stepinski: **Information theory as a consistent framework for the quantification and classification of landscape patterns**, Landscape Ecology 34(9):2091-2101 (2019)

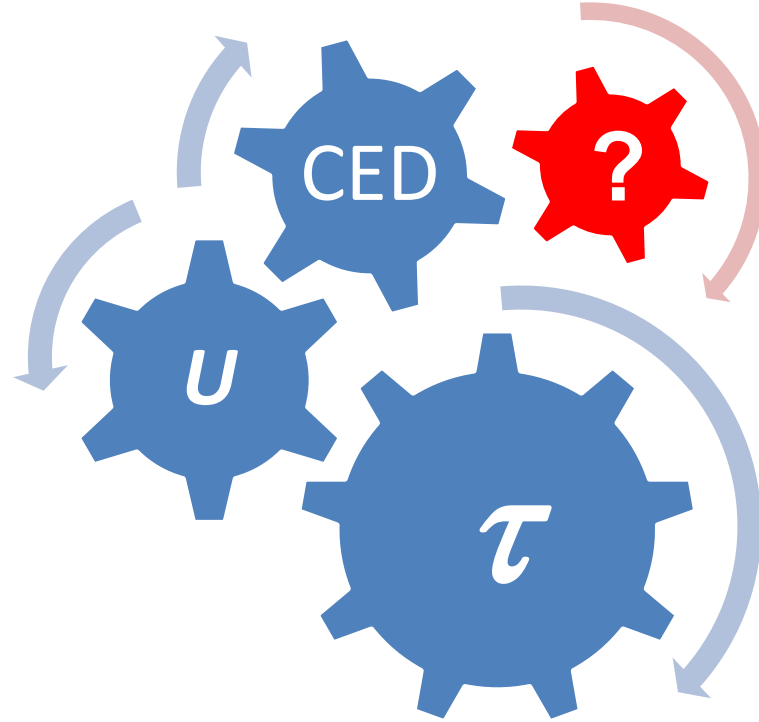
Relative mutual information U , mammograms



Which parameters are needed?



The parameters are closely interrelated!

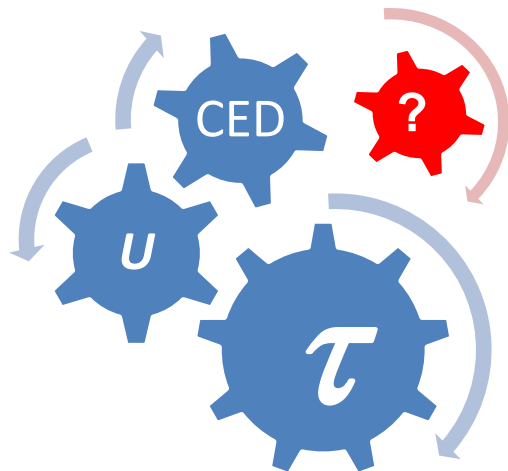


To do

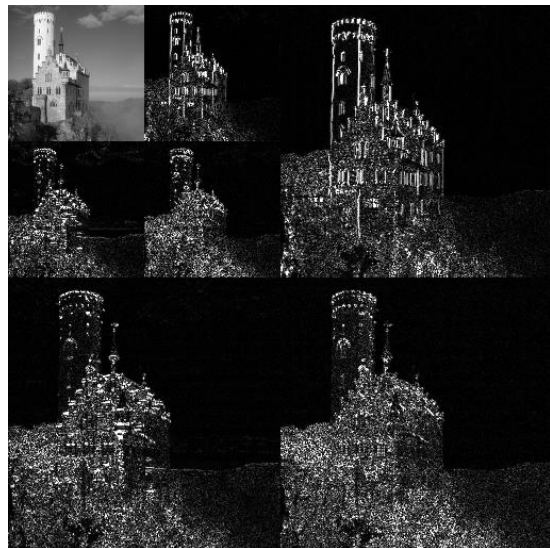
sharpness



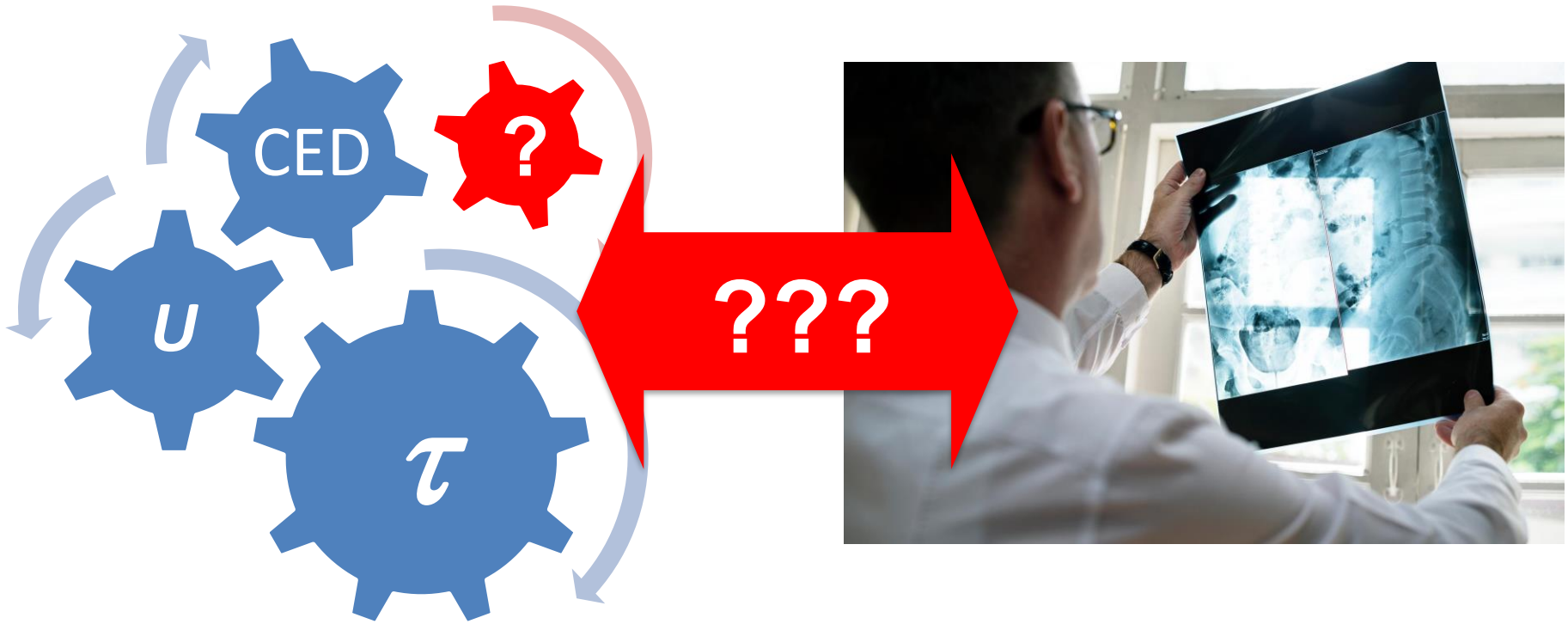
interrelations



multiscaling



To do



Questions?

noise:

<https://doi.org/10.1088/1361-6560/acb485>

<https://www.mathworks.com/matlabcentral/fileexchange/125855-non-parametric-noise-measure-tau>.

contrast:

<https://doi.org/10.1088/1361-6560/ad6119>

<https://www.mathworks.com/matlabcentral/fileexchange/173950-deltaetal>

relative mutual information (Nowosad & Stepinski 2019):

<https://doi.org/10.1007/s10980-019-00830-x>

<https://www.mathworks.com/matlabcentral/fileexchange/174040-relative-mutual-information-uxy>

noise



contrast



mutual information



Thanks

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- Clemens Elster



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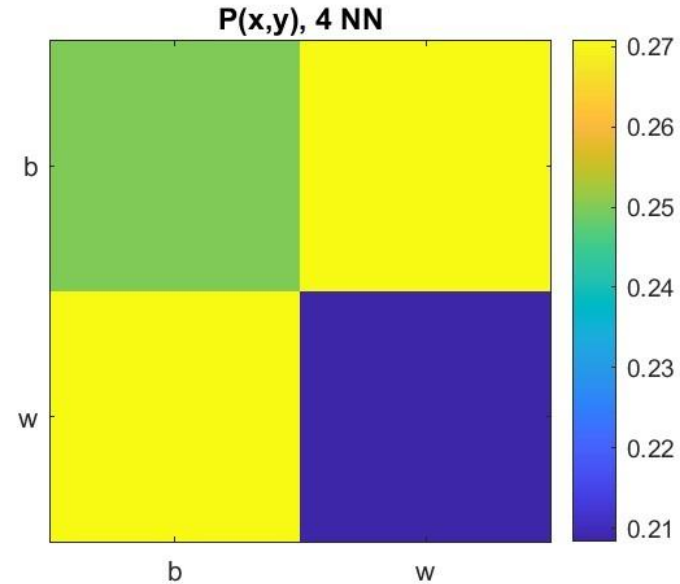
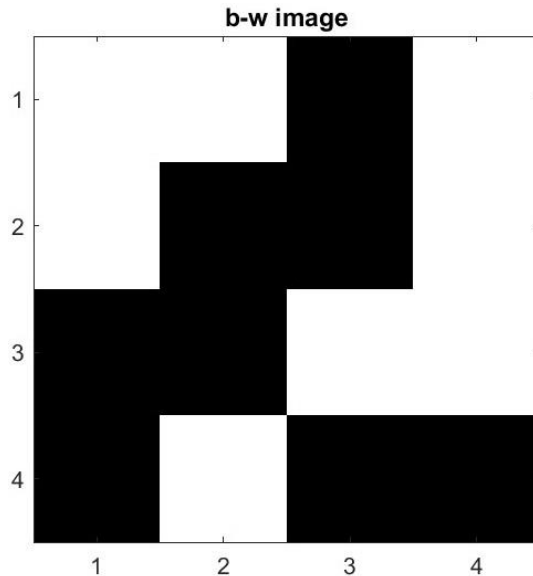
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www.ptb.de



Stand: 11/24

Grey level co-occurrence matrices



$$P(x,y) = P(x=c_i, y=c_j), c_i \in \{b, w\}, i=1,2$$

for n grey levels: $P(x,y) = n \times n$

Joint entropy

$$H(x, y) = - \sum_{i=1}^K \sum_{j=1}^K P(x = c_i, y = c_j) \cdot \log_2 [P(x = c_i, y = c_j)]$$

measures the diversity of the heights of bins in the co-occurrence histogram

Conditional entropy

$$H(y|x = c_i) = - \sum_j P(y = c_j|x = c_i) \cdot \log_2 [P(y = c_j|x = c_i)]$$

averaging over c_i :

$$H(y|x) = - \sum_{i=1}^K \sum_{j=1}^K P(x = c_i, y = c_j) \cdot \log_2 [P(y = c_i|x = c_j)]$$

conditional entropy

measures configurational complexity of a pattern

More entropies. And U , finally:

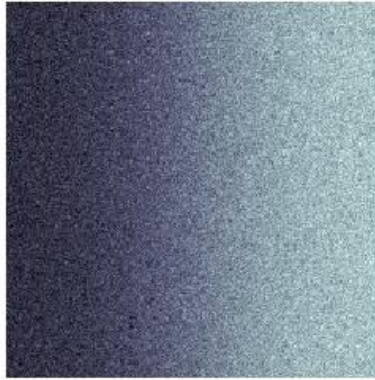
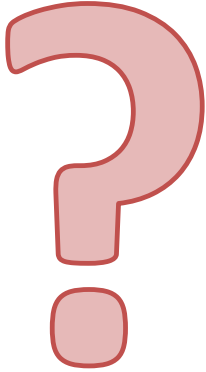
$$H(y) = - \sum_{j=1}^K P(y = c_j) \cdot \log_2 P(y = c_j) \quad (\text{marginalised P})$$

$$H(x, y) = H(x) + H(y|x) \quad \text{chain rule}$$

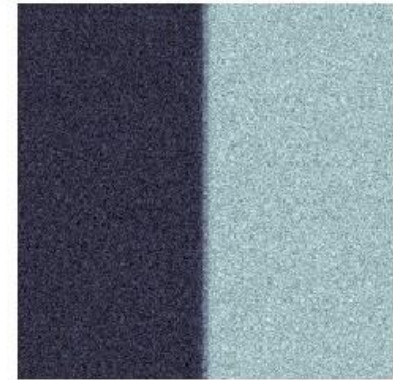
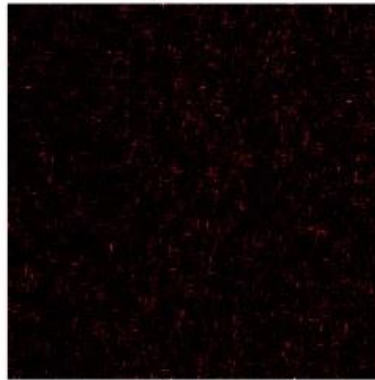
$$I(y, x) = H(y) - H(y|x) \geq 0 \quad \text{mutual information}$$

$$\boxed{U = I(y, x)/H(y)} \quad U \in [0, 1] \quad \text{relative mut. inf.}$$

Sharpness index ζ_i



$\zeta_i=0.13$



$\zeta_i=1.24$

