Grundlagen der Signalverarbeitung

1. Einführung
2. Signalstatistik
3. Prinzip der kleinsten Fehlerquadrate
4. Orthogonalität und orthogonale Funktionen
5. Reihenentwicklungen mit orthogonalen Funktionen
6. Kontinuierliche Orthogonaltransformationen
7. Diskrete Orthogonaltransformationen
8. Schnelle Algorithmen
9. Korrelation
10. Faltung
11. Hauptachsentransformation

- orthogonale Transformation und damit orthogonale Funktionssysteme in der SV wichtig
- orthogonale Funktionssysteme besonders vorteilhaft zur Approximation von Funktionen nutzbar
- Maß für Qualität der Annäherung erforderlich
- eine Möglichkeit: Prinzip der kleinsten Fehlerquadrate

Orthogonale Transformationen sind Anwendungen des Prinzips der kleinsten Fehlerquadrate

$$E^2(c) = \int_{-\infty}^{\infty} [f(t) - f_a(c,t)]^2 \; dt$$

oder diskret $E^2(c) = \sum_{n=0}^{N-1} [f_n - f_a(c,t_n)]^2$ mit f_n Abtastwertesatz

$f_a(c,t)$ angepasste Funktion

$$f_a(c,t) = \sum_{m=0}^{M-1} c_m \, \phi_m(t)$$

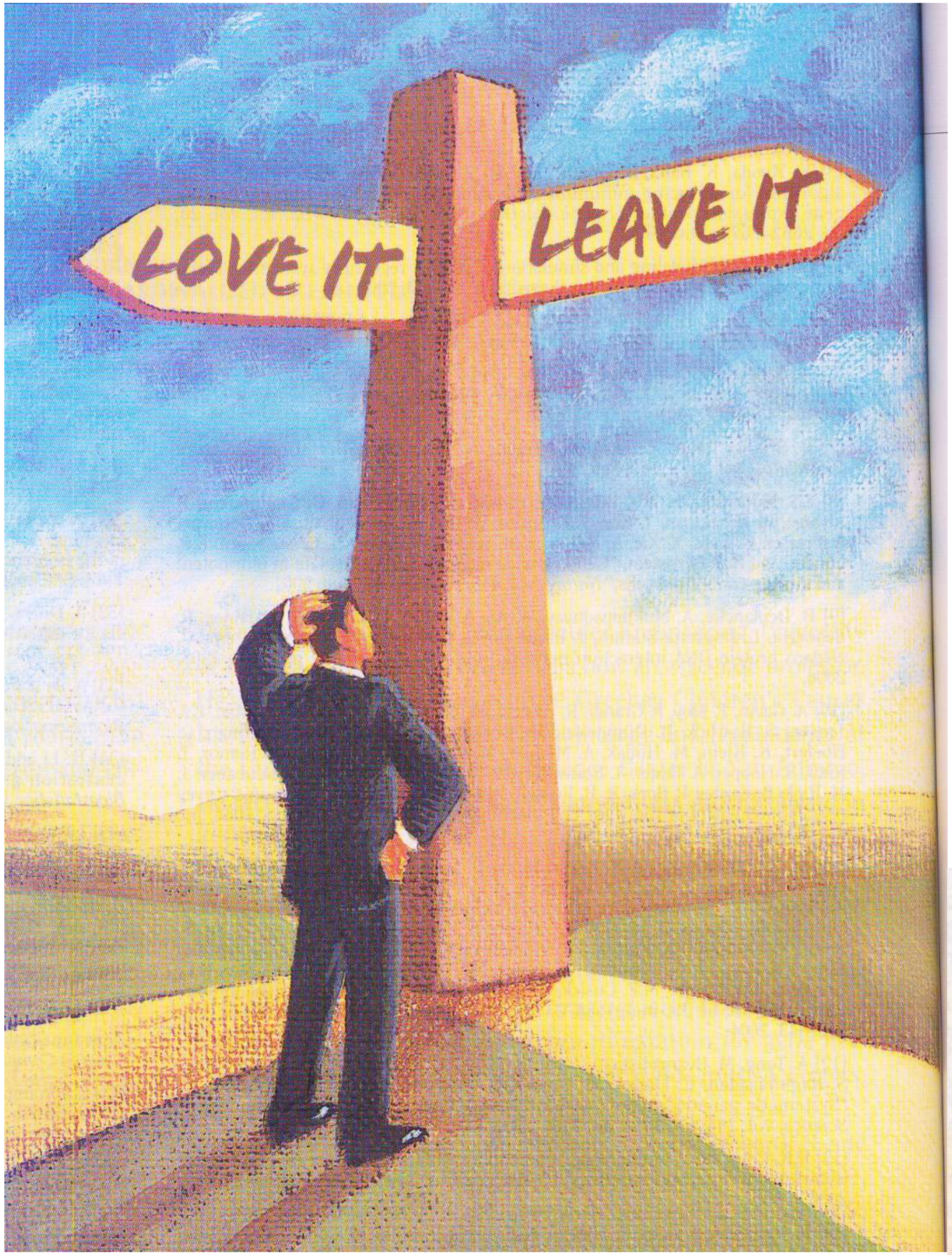
$$
\begin{bmatrix}
\sum^{N} \phi_{0,n}\,\phi_{0,n} & \sum^{N} \phi_{0,n}\,\phi_{1,n} & \cdots & \sum^{N} \phi_{0,n}\,\phi_{M-1,n} \\
\sum^{N} \phi_{1,n}\,\phi_{0,n} & \sum^{N} \phi_{1,n}\,\phi_{1,n} & \cdots & \sum^{N} \phi_{1,n}\,\phi_{M-1,n} \\
\vdots & \vdots & \ddots & \vdots \\
\sum^{N} \phi_{M-1,n}\,\phi_{0,n} & \sum^{N} \phi_{M-1,n}\,\phi_{1,n} & \cdots & \sum^{N} \phi_{M-1,n}\,\phi_{M-1,n}
\end{bmatrix}
\cdot
\begin{bmatrix}
c_0 \\ c_1 \\ \vdots \\ c_{M-1}
\end{bmatrix}
=
\begin{bmatrix}
\sum^{N} \phi_{0,n}\, f_n \\
\sum^{N} \phi_{1,n}\, f_n \\
\vdots \\
\sum^{N} \phi_{M-1,n}\, f_n
\end{bmatrix}
$$

MSE between the signals **x** and **y** is:

$$\mathrm{MSE}(\mathbf{x}, \mathbf{y}) = \frac{1}{N} \sum_{i=1}^{N} (x_i - y_i)^2$$

a more general form is the l_p norm:

$$d_p(\mathbf{x}, \mathbf{y}) = \left(\sum_{i=1}^{N} |e_i|^p \right)^{1/p}$$

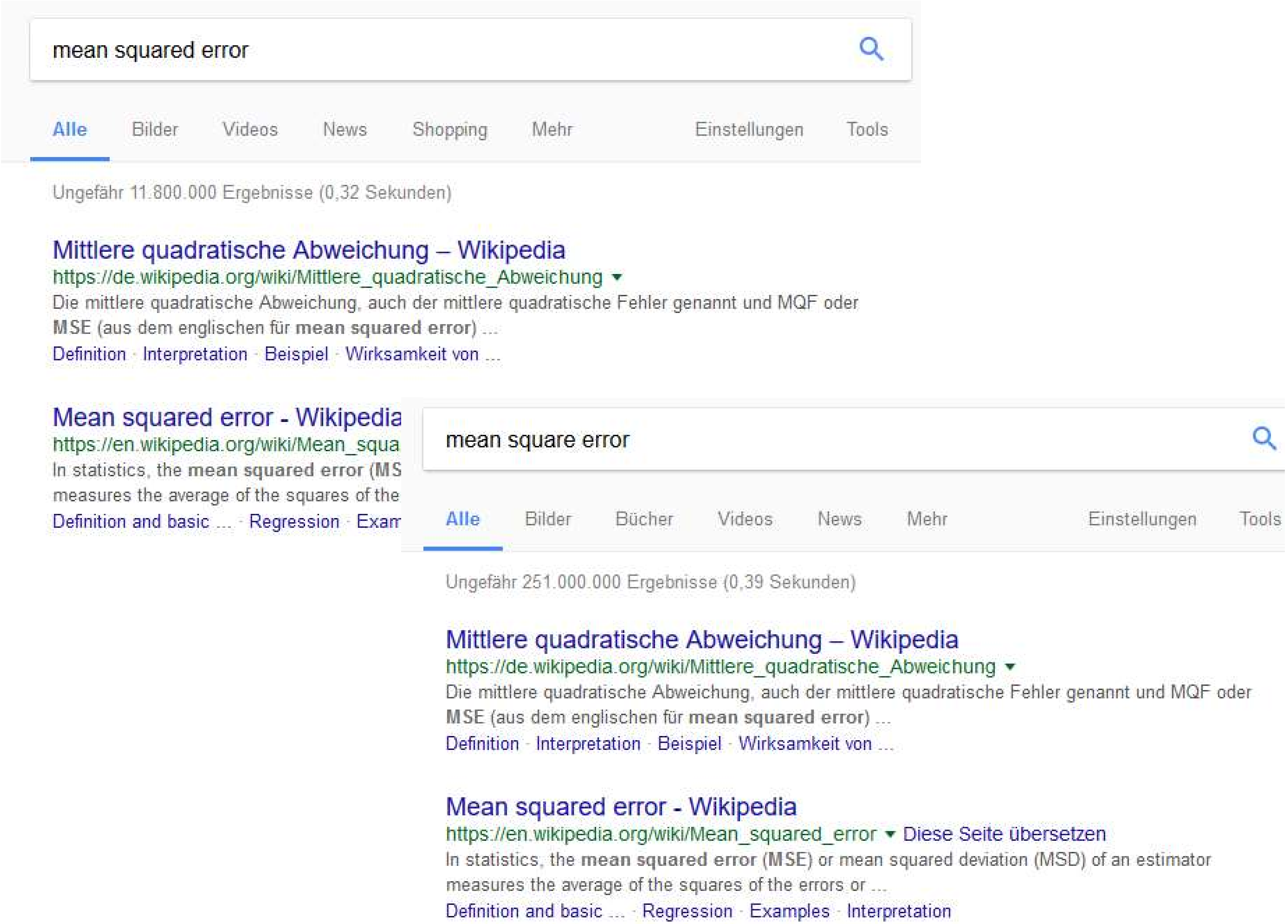


Mean Squared Error: Love It or Leave It?

The conceptual uses of "square" and "squared" are subtly different, although (almost) interchangeable:

- "Squared" refers to the past action of taking or computing the second power (x^2 is usually read as “x-squared”)
- "Square" refers to the result of taking the second power (x^2 can be referred to as the "square of x“)
- mean squared error - thinking in terms of a *computation*: take the errors, square them, average those
- mean square error - a more conceptual feel: average the square errors
- equivalent in function and safely interchangeable in practice

http://stats.stackexchange.com/questions/30816/mean-square-error-or-mean-squared-error


mean squared error
Alle
Bilder
Videos
News
Shopping
Mehr
Einstellungen
Tools
Ungefähr 11.800.000 Ergebnisse (0,32 Sekunden)
Mittlere quadratische Abweichung – Wikipedia
https://de.wikipedia.org/wiki/Mittlere_quadratische_Abweichung
Die mittlere quadratische Abweichung, auch der mittlere quadratische Fehler genannt und MQF oder MSE (aus dem englischen für mean squared error) ...
Definition · Interpretation · Beispiel · Wirksamkeit von ...
Mean squared error - Wikipedia
mean square error
Alle
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Mehr
Einstellungen
Tools
Ungefähr 251.000.000 Ergebnisse (0,39 Sekunden)
Mittlere quadratische Abweichung – Wikipedia
https://de.wikipedia.org/wiki/Mittlere_quadratische_Abweichung
Die mittlere quadratische Abweichung, auch der mittlere quadratische Fehler genannt und MQF oder MSE (aus dem englischen für mean squared error) ...
Definition · Interpretation · Beispiel · Wirksamkeit von ...
Mean squared error - Wikipedia
https://en.wikipedia.org/wiki/Mean_squared_error Diese Seite übersetzen
In statistics, the mean squared error (MSE) or mean squared deviation (MSD) of an estimator measures the average of the squares of the errors or ...
Definition and basic ... · Regression · Examples · Interpretation

Zitate aus Zhou/Bovik (2)

Why do we love the MSE?

- clear physical meaning – it is the natural way to define the energy of the error signal
- such an energy measure is preserved after any orthogonal (or unitary) transform
- this property distinguishes d_2 from the other l_p energy measures, which are not energy preserving
- MSE is an excellent metric in the context of optimization

Zitate aus Zhou/Bovik (1)

- method of choice for comparing competing signal processing methods
- it is the nearly ubiquitous preference of design engineers seeking to optimize signal processing algorithms
- it has been widely criticized for serious shortcomings, especially when dealing with perceptually important signals such as speech and images
- “it is easy to use and not so bad”, “everyone else uses it”

Zhou Wang and Alan C. Bovik: Mean Squared Error: Love it or Leave It? IEEE Signal Proc. Magazine (98) Jan. 2009

Zitate aus Zhou/Bovik (2)

Implicit assumptions when using MSE

signal fidelity is

- … independent of temporal or spatial relationships between the samples of the original signal (same MSE in case of re-ordering)
- … independent of any relationship between the original signal and the error signal (error signal can be added to different original signals for the same MSE)
- … independent of the signs of the error signal samples
- all signal samples are equally important to signal fidelity

Problem:

- Funktion f(t) soll durch Funktion f_a (c,t) „möglichst gut“ angenähert werden
- Parametersatz c gewährleistet „beste“ Annäherung

Diplomarbeit von Sebastian Jänisch: Empirische Studie zur Beurteilung von Fehlermaßen für Bildsignale, September 2013

Motivation:

- subjektive Qualitätsbewertung von Bildern verlässlich, aber kostenintensiv
- objektive Bewertung meist einfach zu berechnen, aber „ungenau“
- objektive Bewertung mit perzeptuellem Bezug rechenaufwendig, aber genau

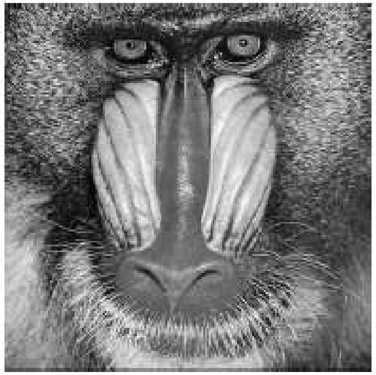
Referenzbildauswahl

kirche.bmp

SFM = 28.23
SAM = 221.47
Entropie = 7.44

krad.bmp

SFM = 47.68
SAM = 44.83
Entropie = 7.51



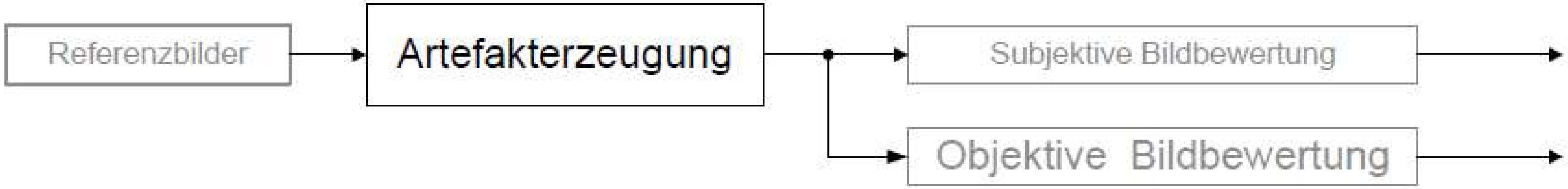
mandrill.bmp

SFM = 50.82
SAM = 48.03
Entropie = 7.33

waschbaer.bmp

SFM = 21.15
SAM = 152.97
Entropie = 6.30

Artefakterzeugung



Parameter verwendeter Bildkompressionen & Bildstörungen

- *JPEG*: Qualität
- *JPEG2000*: Q-Layers, C-Ratio, R-Layers
- *SPIHT*: C-Ratio
- *Salz-und Pfefferrauschen*: Intensität
- *Weißes Rauschen*: arith. Mittelwert, Varianz

Subjektiver Vergleich JPEG - JPEG2000

Originalbild
512x512 Pixel
8 bpp

JPEG - 0,25 bpp
opt. Huffman,
flache Quant.-matrix

JPEG2000 - 0,25 bpp
5/3 Filter, 4 Quality Layer (2,0 | 1,0 | 0,5 | 0,25 bpp)

JPEG2000 - 0,25 bpp
9/7 Filter, 4 Quality Layer (2,0 | 1,0 | 0,5 | 0,25 bpp)

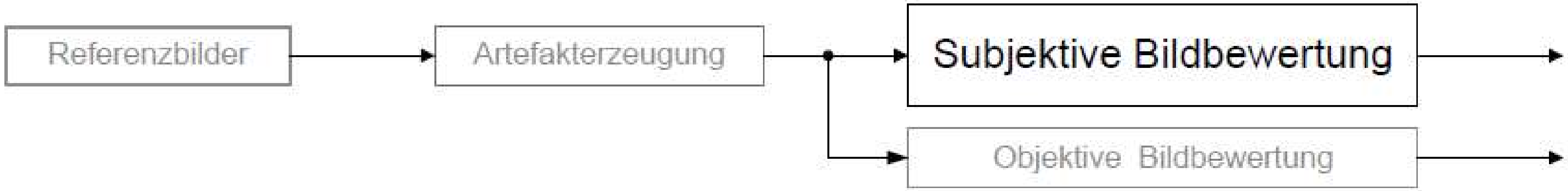
The Tile Parts parameter has three options, as noted below. The appropriate tile parts options are automatically selected by the JPEG 2000 encoding profiles. They can also be set manually.

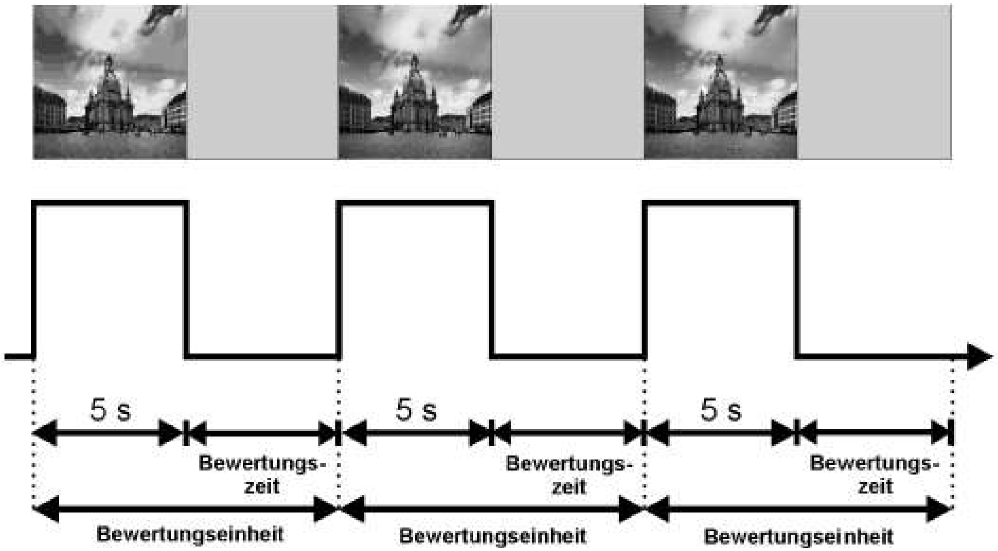
Tile Parts Options:

- Resolution (R) = Groups data inside of the tile parts by resolution level. This option results in the fastest decodes at the icon level.
- Quality Layer (L) = Groups data inside of the tile parts by quality layer. This options results in the fastest decodes of images at lower resolution.
- Component (C) = Groups data inside of the tile parts by component. This options decodes only one band at a time.

http://www.lizardtech.com/support/knowledge-base-article/how-do-i-encode-extremely-large-jpeg-2000-images/

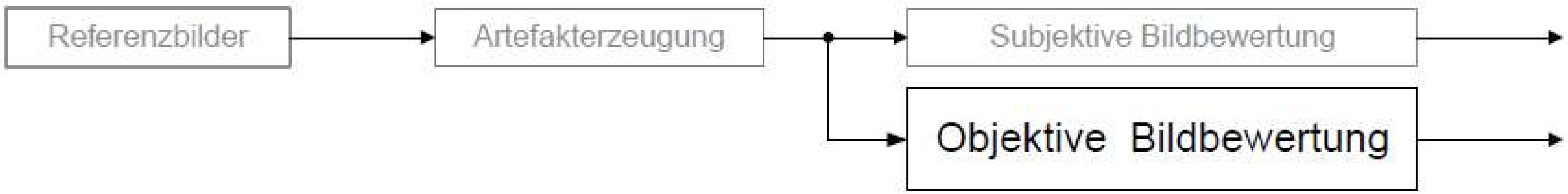
Subjektive Bewertung





- 5 - ausgezeichnet
- 4 - gut
- 3 - ordentlich
- 2 - mäßig
- 1 - schlecht

Objektive Bewertung



Bildgenauigkeit (Image Fidelity)*

- Mittlerer quadratischer Fehler (MSE)
- Spitzen-Signal-Rausch-Verhältnis (PSNR)
- Maximale Differenz (MaxD)
- Struktureller Inhalt (SC)
- Korrelation (CQ)
- MSE nach Laplace (LMSE)
- Normalisierter absoluter Fehler (NAE)

Bildqualität (Image Quality)

- Full Reference Verfahren (FR)
- Reduced Reference Verfahren (RR)
- No Reference Verfahren (NR)

Methoden ohne und mit Bezug zur menschlichen Wahrnehmung

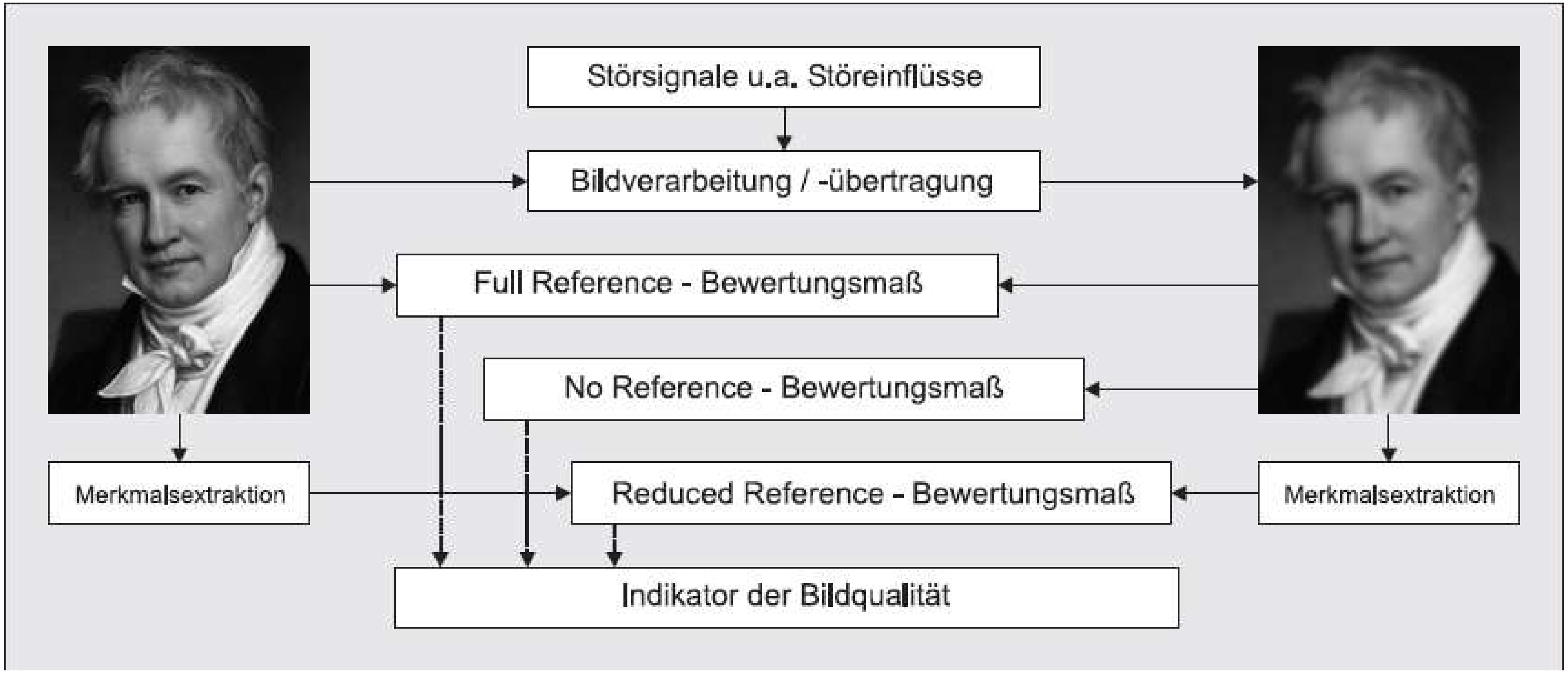
* Wiedergabetreue

Objektive Bewertung ohne Bezug zur menschlichen Wahrnehmung

- „technische“ Unterschiede zwischen zwei Signalen berechnet
- triviale Differenzbildung, mittlerer quadratischer Fehler, l_p-Norm
- Signal-Rausch-Verhältnis, maximale Differenz, ...

Objektive Bewertung mit Bezug zur menschlichen Wahrnehmung

- mit vollem, keinem oder reduziertem Bezug zu einem Referenzbild



Bildqualität III

No Reference Bewertungsmaß nach Bovik et al.

- horizontale und vertikale Hochpassfilterung des 2D-Einangssignals
- Umsortierung der Differenzbilder in jeweils einen 1D-Signalvektor
- 1D-Diskreten Fouriertransformation mit Rechteckfenster
- Summation der Einzelbetragsspektren
- Medianfilterung auf globale Betragsspektren
- Gewichtung $\rightarrow$ NR-Fehlermaß

Reduced Reference Bewertungsmaß nach Martini et al.

- Unterabtastung des ungestörten X und gestörten Y Bildsignals
- Bildzerlegung in einzelne Blöcke
- Bildblockauswahl (aus Ergebnissen von Eyetrackingverfahren)
- Kantendetektion nach Sobel mit Schwellwertberücksichtigung
- Berechnung einer Gesamtähnlichkeit

SSIM - structural similarity

In spatial domain, the SSIM index between two image patches $\mathbf{x} = \{x_i | i = 1, ...M\}$ and $\mathbf{y} = \{y_i | i = 1, ..., M\}$ is defined as [1]

$$S(\mathbf{x}, \mathbf{y}) = \frac{(2\,\mu_x\,\mu_y + C_1)\,(2\,\sigma_{xy} + C_2)}{(\mu_x^2 + \mu_y^2 + C_1)\,(\sigma_x^2 + \sigma_y^2 + C_2)}\,, \tag{3}$$

where C_1 and C_2 are two small positive constants (see [1] for details), and $\mu_x = \frac{1}{M}\sum_{i=1}^{M} x_i$, $\sigma_x^2 = \frac{1}{M}\sum_{i=1}^{M}(x_i - \mu_x)^2$ and

$\sigma_{xy} = \frac{1}{M}\sum_{i=1}^{M}(x_i - \mu_x)(y_i - \mu_y)$, respectively. It can be shown that the maximum SSIM index value 1 is achieved if and only if $\mathbf{x}$ and $\mathbf{y}$ are identical.

Objective Bewertung mit vollem Bezug zur menschlichen Wahrnehmung

- berücksichtigen fundamentale Eigenschaften des visuellen Systems
- wichtig: Helligkeits-, Kontrast- und Strukturunterschiede

$$SSIM(X,Y) = [l(X,Y)]^{\alpha} \cdot [c(X,Y)]^{\beta} \cdot [s(X,Y)]^{\gamma}$$

structural similarity

$$= \left(\frac{2\mu_x\mu_y + C_1}{\mu_x^2 + \mu_y^2 + C_1} \right)^{\alpha} \cdot \left(\frac{2\sigma_x\sigma_y + C_2}{\sigma_x^2 + \sigma_y^2 + C_2} \right)^{\beta} \cdot \left(\frac{\sigma_{xy} + C_3}{\sigma_x\sigma_y + C_3} \right)^{\gamma}$$

μ,σ	Mittelwerte, Standardabweichungen, Kovarianz
C, α,β,γ:	Konstanten

SSIM-Index

- geht bei Vereinfachung (Exponenten und Konstanten = 1) über in den *Universal Quality Index*:

$$UQI\left(X,Y\right)=\frac{4\mu_{\mathrm{x}}\mu_{\mathrm{y}}\sigma_{\mathrm{xy}}}{\left(\mu_{\mathrm{x}}^{2}+\mu_{\mathrm{y}}^{2}\right)\left(\sigma_{\mathrm{x}}^{2}+\sigma_{\mathrm{y}}^{2}\right)}$$

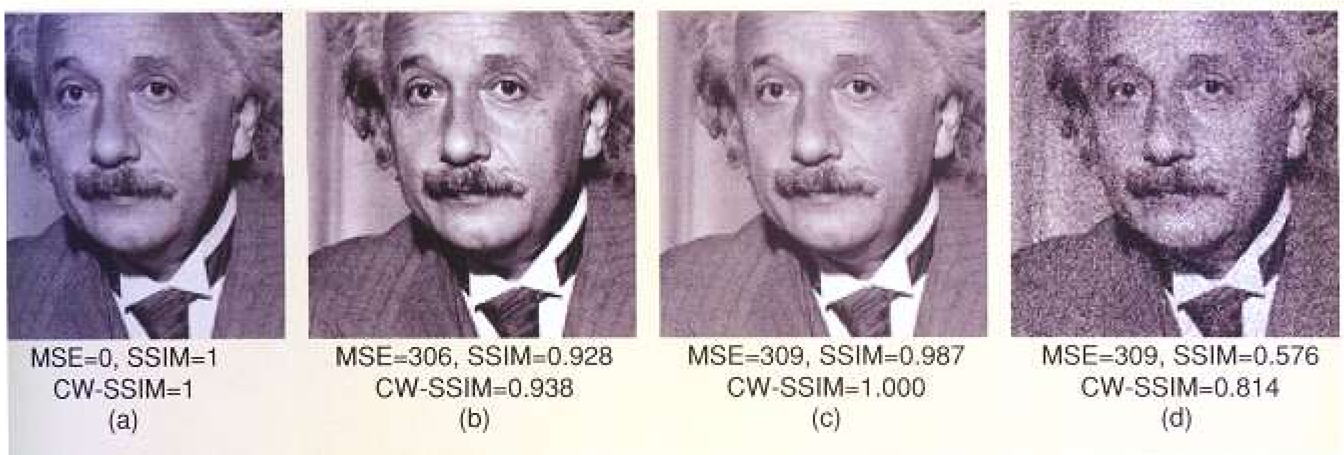
- oft auch lokal angewendet

CW SSIM – complex wavelet structural similarity index

In the complex wavelet transform domain, suppose $\mathbf{c}_x = \{c_{x,i} | i = 1, ..., N\}$ and $\mathbf{c}_y = \{c_{y,i} | i = 1, ..., N\}$ are two sets of coefficients extracted at the same spatial location in the same wavelet subbands of the two images being compared, respectively. We extend the spatial domain SSIM algorithm into a complex wavelet SSIM (CW-SSIM) index (note that the coefficients are zero mean, due to the bandpass nature of the wavelet filters):

$$\tilde{S}(\mathbf{c}_x, \mathbf{c}_y) = \frac{2 \left| \sum_{i=1}^{N} c_{x,i} \, c_{y,i}^{*} \right| + K}{\sum_{i=1}^{N} |c_{x,i}|^2 + \sum_{i=1}^{N} |c_{y,i}|^2 + K} . \qquad (4)$$

Comparison of image fidelity measures for „Einstein“ image altered with different types of distortions.



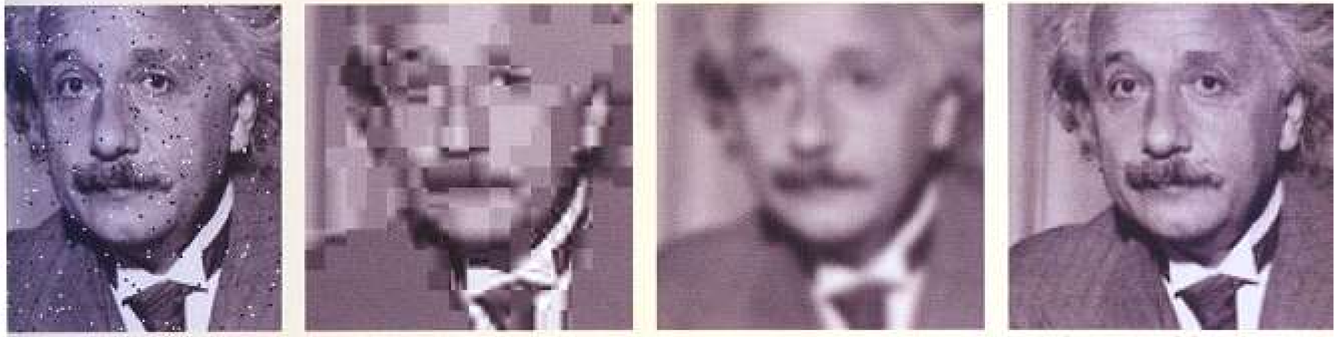
a) Reference image

b) mean contrast stretch

c) Luminance shift

d) Gaussian noise contamination

Comparison of image fidelity measures for „Einstein“ image altered with different types of distortions.



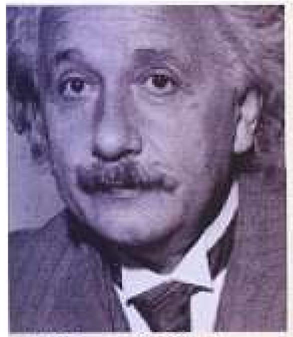
SE=313, SSIM=0.730 CW-SSIM=0.811 (e) | MSE=309, SSIM=0.580 CW-SSIM=0.633 (f) | MSE=308, SSIM=0.641 CW-SSIM=0.603 (g) | MSE=694, SSIM=0.505 CW-SSIM=0.925 (h)

e) Impulsive noise contamination

f) JPEG compression

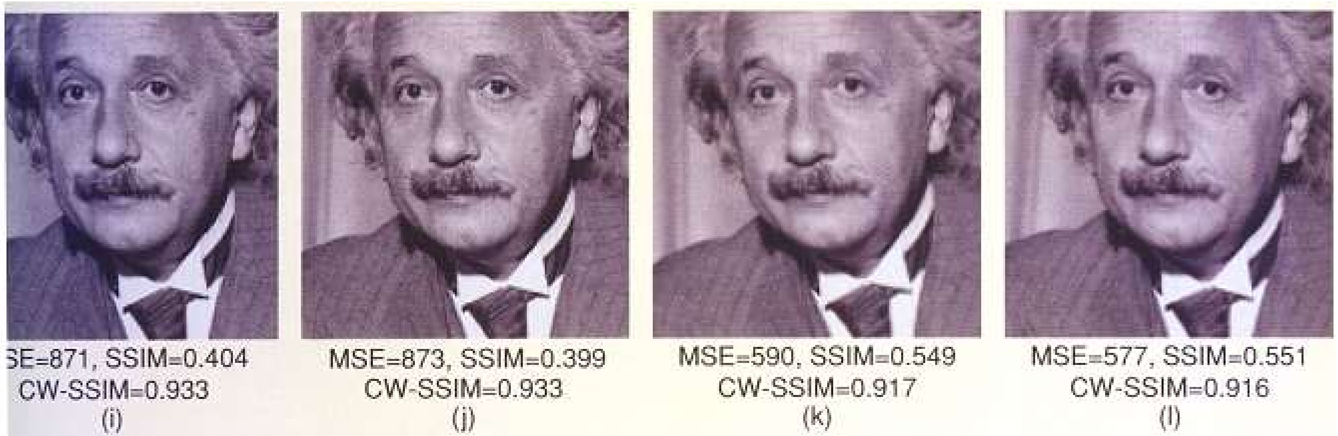
g) Blurring

h) Spatial scaling (zooming out)



MSE=0, SSIM=1
CW-SSIM=1
(a)

Comparison of image fidelity measures for „Einstein“ image altered with different types of distortions.

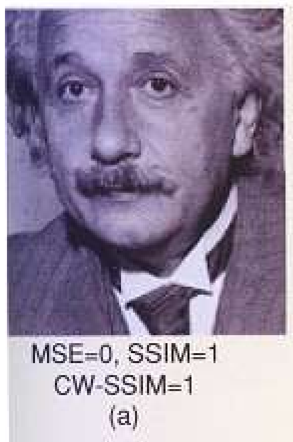


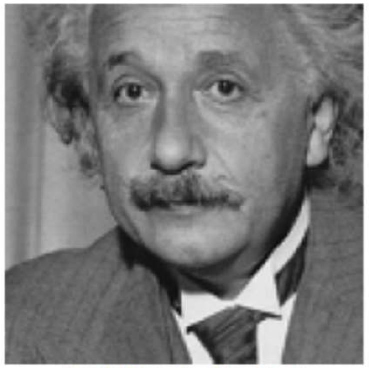
i) Spatial shift to the right

j) Spatial shift to the left

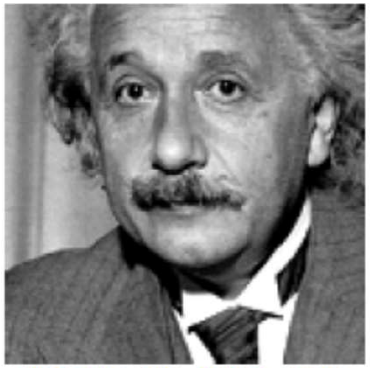
k) Rotation counter-clockwise

l) Rotation clockwise

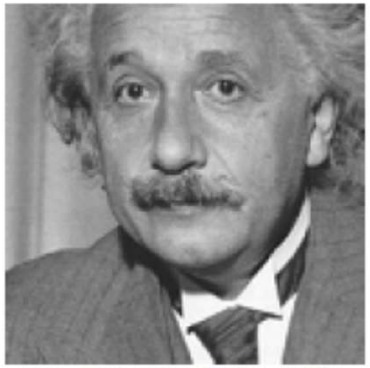




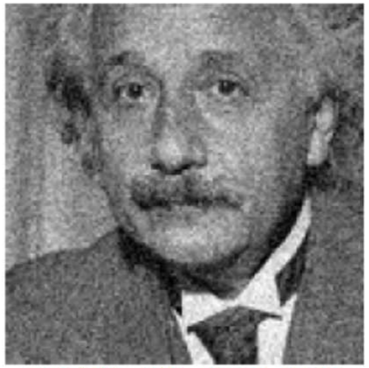
(a) MSE=0, SSIM=1
CW-SSIM=1



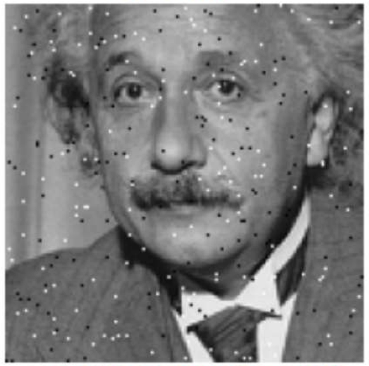
(b) MSE=306, SSIM=0.928
CW-SSIM=0.938



(c) MSE=309, SSIM=0.987
CW-SSIM=1.000



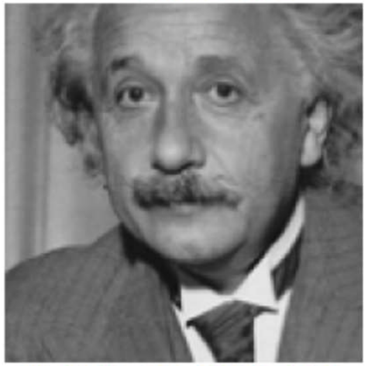
(d) MSE=309, SSIM=0.576
CW-SSIM=0.814



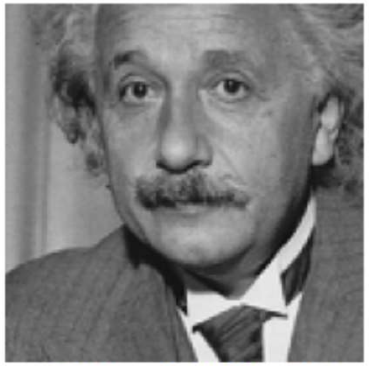
(e) MSE=313, SSIM=0.730
CW-SSIM=0.811

(f) MSE=309, SSIM=0.580
CW-SSIM=0.633

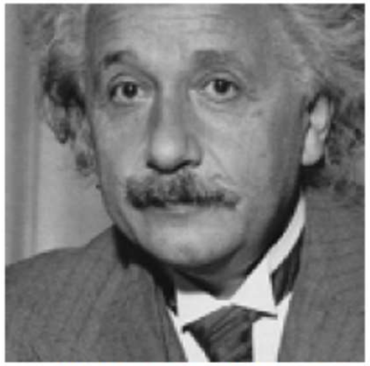
(g) MSE=308, SSIM=0.641
CW-SSIM=0.603



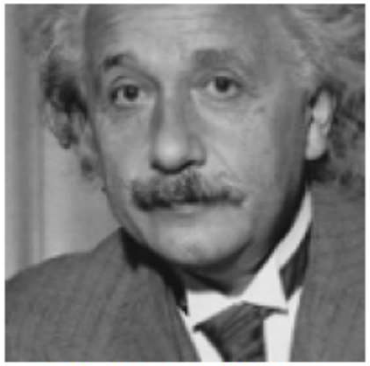
(h) MSE=694, SSIM=0.505
CW-SSIM=0.925



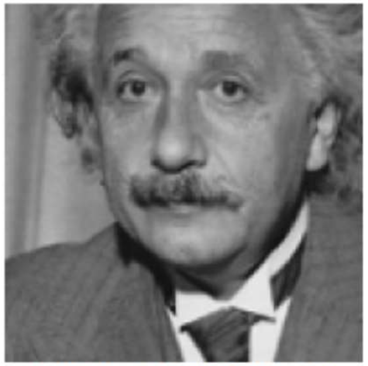
(i) MSE=871, SSIM=0.404
CW-SSIM=0.933



(j) MSE=873, SSIM=0.399
CW-SSIM=0.933



(k) MSE=590, SSIM=0.549
CW-SSIM=0.917



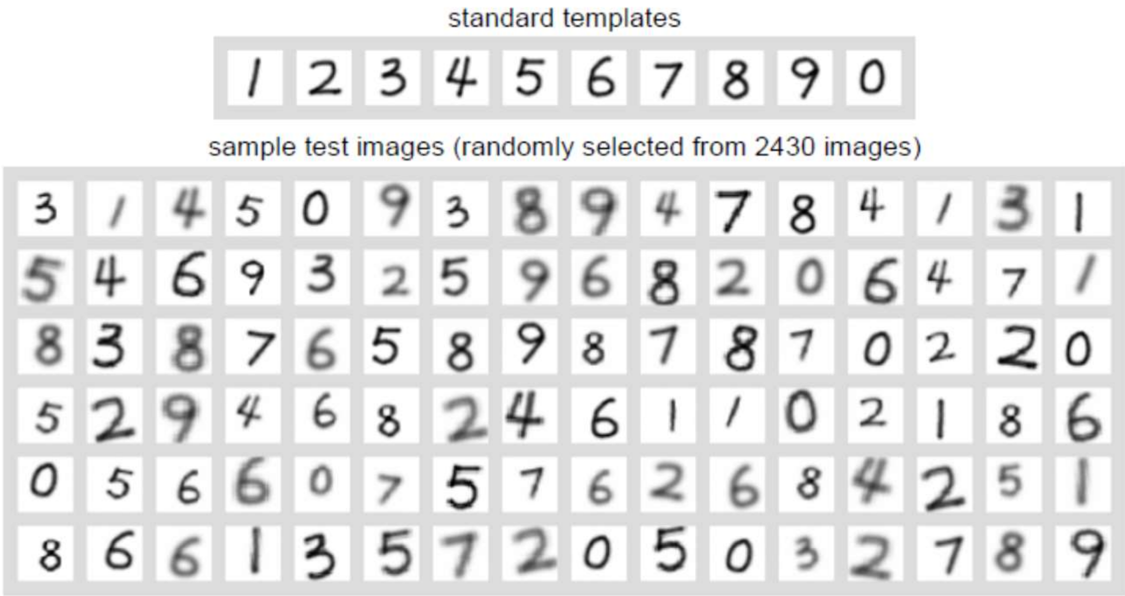
(l) MSE=577, SSIM=0.551
CW-SSIM=0.916

Aus Tabelle 5.13 können die Ergebnisse, nach Anwendung von Gleichung (66), über einen möglichen linearen Zusammenhang von MOS und objektiver Bewertung entnommen werden.

Absoluter Korrelationskoeffizient nach Pearson							
	Image Fidelity-Bewertungsmaße						
	MSE	PSNR	MaxD	SC	CQ	LMSE	NAE
JPEG	0.83	0.50	0.77	0.74	0.85	0.81	0.78
JPEG2000	0.76	0.60	0.75	0.67	0.71	0.76	0.73
SPIHT	0.89	0.88	0.91	0.82	0.85	0.83	0.93
SAP	0.38	0.43	0.26	0.38	0.39	0.38	0.38
WN	0.51	0.61	0.62	0.70	0.59	0.60	0.56
	Image Quality-Bewertungsmaße						
	SSIM	NR	RR				
JPEG	0.83	0.83	0.80				
JPEG2000	0.76	0.66	0.70				
SPIHT	0.90	0.75	0.79				
SAP	0.39	0.15	0.21				
WN	0.54	0.62	0.21				

Tabelle 5.13: Der $|r_s|$ zwischen Image Fidelity- bzw. Image Quality-Maßen und MOS

MOS mean opinion score

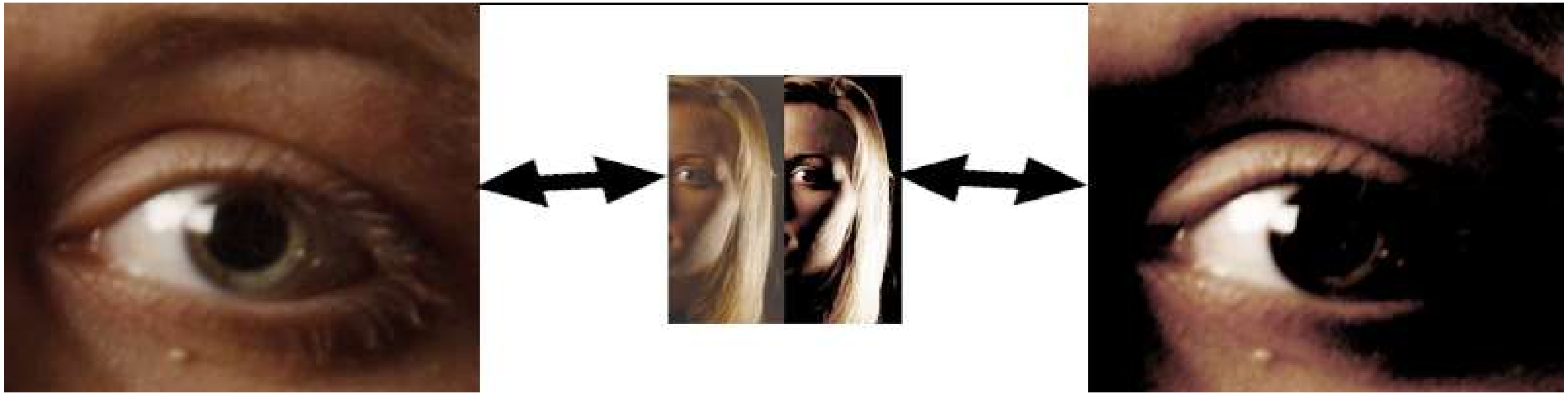


correct recognition rate (%)

digit	MSE	SSIM	CW-SSIM
1	84.0	76.1	100
2	65.4	45.3	98.4
3	49.4	47.7	97.1
4	63.8	41.6	100
5	47.7	18.5	96.3
6	56.4	42.0	97.9
7	68.3	60.9	94.2
8	49.8	39.1	99.6
9	59.3	51.4	100
0	51.4	46.5	93.0
all	59.6	46.9	97.7

Fig. 2. Pattern matching without registration. Each test image (from a database of 2430 images) is matched to the ten standard templates using MSE, SSIM and CW-SSIM as the similarity measures, without any normalization or registration process in the front. The test image is then "recognized" as belonging to the category that corresponds to the best similarity score. The resulting correct recognition rates show that both MSE and SSIM are sensitive to translation, scaling and rotation of images, but CW-SSIM exhibits much stronger robustness.

Beispiel aus Wikipedia



Abhängig vom Bewertungsmaßstab wird das linke Foto (enthält weniger Kontrast) oder das rechte Foto (enthält weniger Details) als unschärfer empfunden.

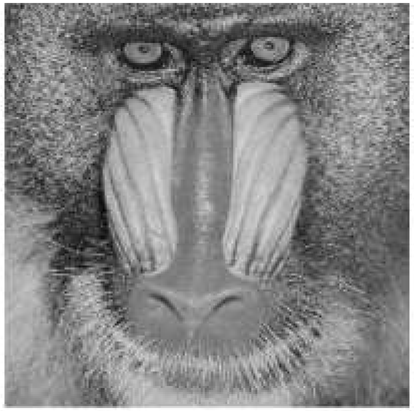
Ursachen:

- Motiv- oder Kamerabewegung (motion blur)
- Kameraobjektiv unfokussiert (defocus blur)
- Atmosphärische Störungen, Linsenfehler (Gaussian blur)
- Schüttelnde Kamerabewegung (shake blur)

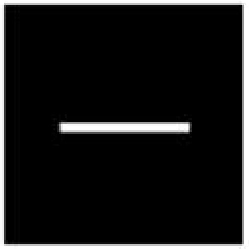
.....u.a.

motion blur | defocus blur | Gaussian blur | natural “shake” blur

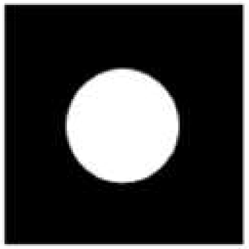
Quelle: Lösch, Depth from Blur, Universität des Saarlandes, Bachelor Thesis



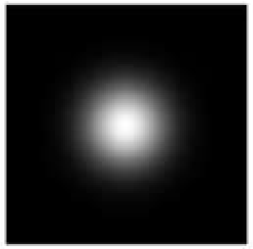
sharp image



motion blur



defocus blur



Gaussian blur

motion blurred image

defocussed image

Gaussian blurred image

JH LABS

Java Image Processing

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Blurring for Beginners

Introduction

This is a short tutorial on blurring techniques for beginners. When I was learning this stuff, there was very little available material which was useful. That's not true of course - there was masses of material, but half of it was way too simple and the other half began "Let T be a vector function evaluated over the half-open interval...." and was full of very scary multi-line equations with those big sigma symbols and things. This article is meant to remedy that. I'll talk about various kinds of blur and the effects you can use them for, with source code in Java.

A Disclaimer

Whenever blurring is mentioned, there's always somebody who says "Hey! That's not a real motion blur!", or writes angry letters in green ink complaining that the mathematics is dubious or that there's a much faster way to do this using the sponglerizer registers on the HAL-9000. Ignore these people. This is a big subject, and this article is just for beginners (of which I can proudly say I am one). What matters is you get the results that you're aiming for, and if the results you're aiming for require dubious mathematics, then so be it. If the results you're aiming for look horrible to me, then that's fine, as long as they look good to you.

Another Disclaimer

There's source code in Java for pretty well everything I talk about here. I make no claims that these are optimised in any way - I've opted for simplicity over speed everywhere and you'll probably be able to make most of these thing