NFIQ2 - Features and Concepts

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NFIQ2 Workshop
2021-06-15

Overview Sample Quality

Content

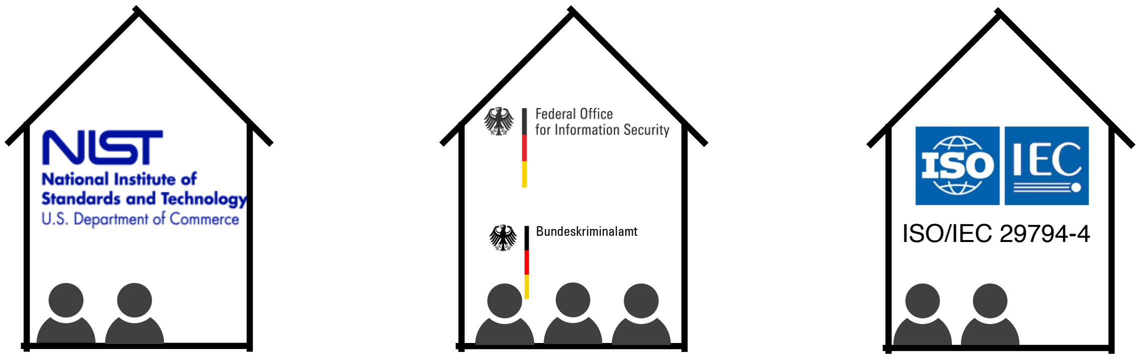
- Evolution of NFIQ2 and ISO/IEC 29794-4:2017
- Application context
- Finger image quality assessment
  - features in NFIQ2
  - normative requirements in 29794-4

Evolution of NFIQ2 and ISO/IEC 29794-4:2017

Quality Metrics for Fingerprint Images

How was NFIQ2.0 developed?

- 2010 - 2021



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Christopher Schiel

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Quality Metrics for Fingerprint Images

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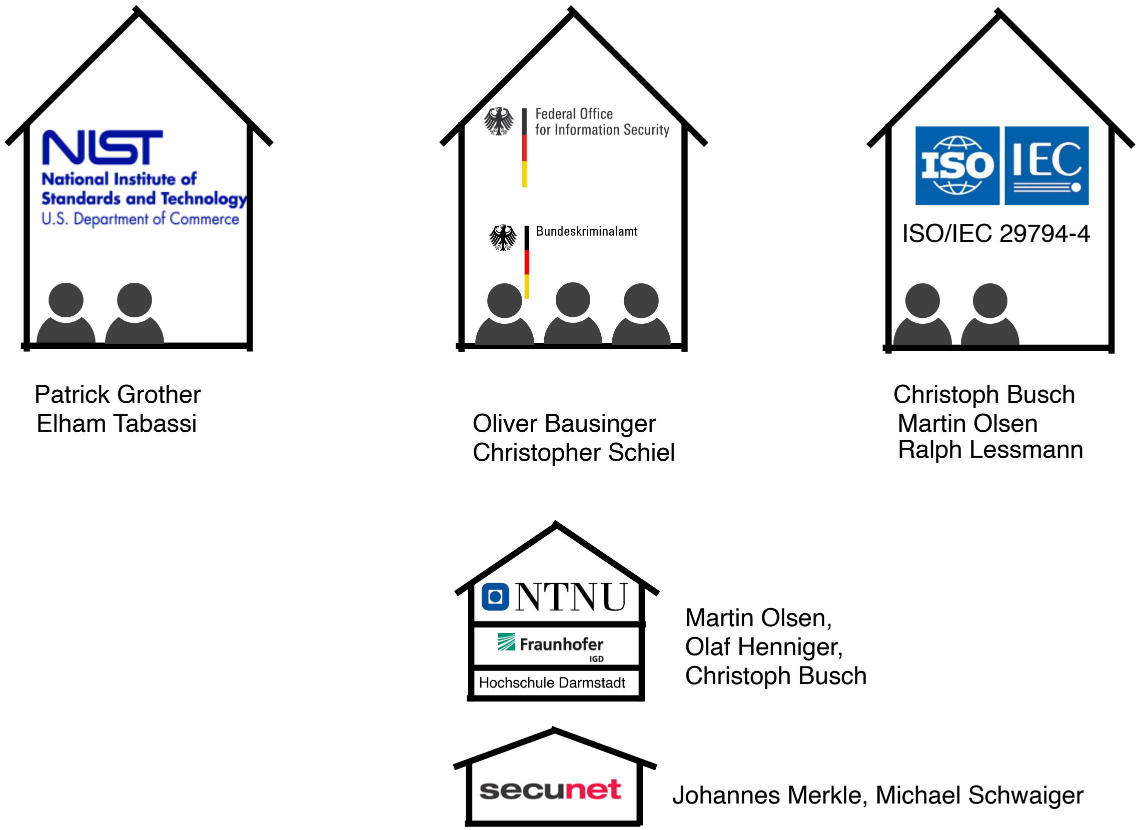

Quality Metrics for Fingerprint Images

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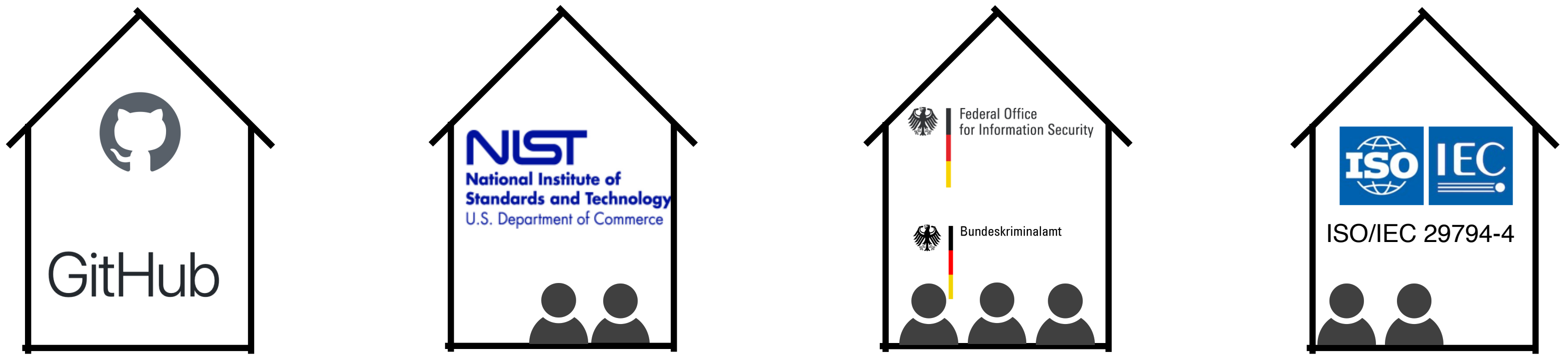

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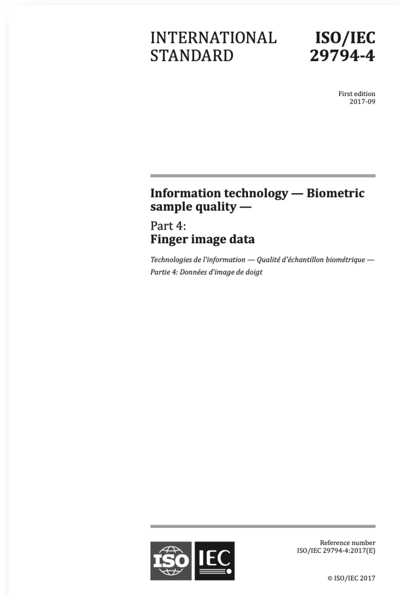
Martin Olsen
Ralph Lessmann

- NFIQ2.0 constitutes the content of ISO/IEC 29794-4
  https://www.iso.org/standard/62791.html



INTERNATIONAL STANDARD

ISO/IEC 29794-4

First edition
2017-09

Information technology — Biometric sample quality —

Part 4:
Finger image data

Technologies de l'information — Qualité d'échantillon biométrique — Partie 4: Données d'image de doigt

Reference number
ISO/IEC 29794-4:2017(E)

© ISO/IEC 2017

Quality Metrics for Fingerprint Images

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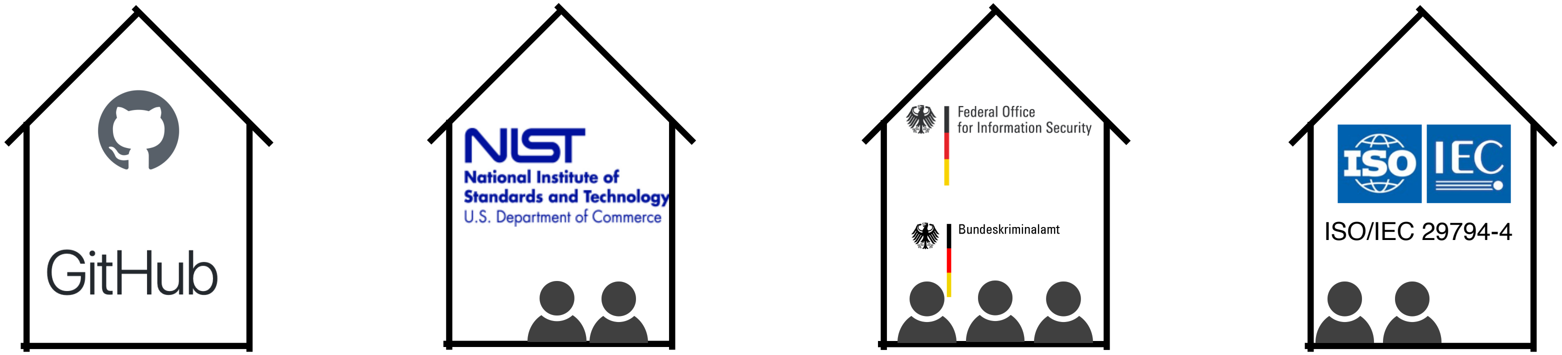

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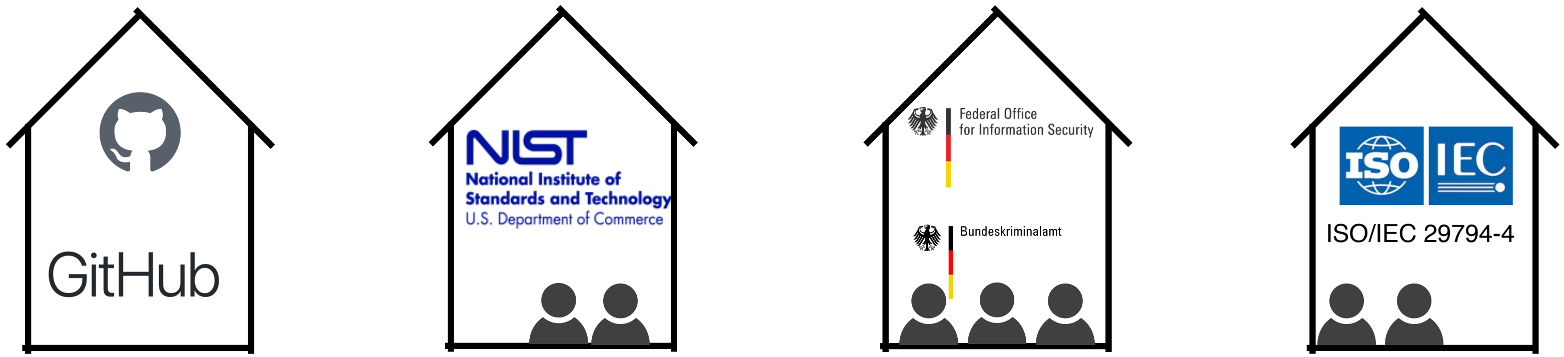
- NFIQ2.1 in 2021
  - Verified quality feature stability
  - Adopted to latest OpenCV
  - Pre-compiled binaries
- Continuation of the maintenance can be expected

Quality Metrics for Fingerprint Images

How was NFIQ2.0 developed?

- 2010 - 2021



Maintenance	Testing	Development	Standardisation
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Application Context MRTD Application

Factors impacting Quality

Face sample quality

- Image capture system out of focus
- No frontal perspective

Fingerprint sample quality

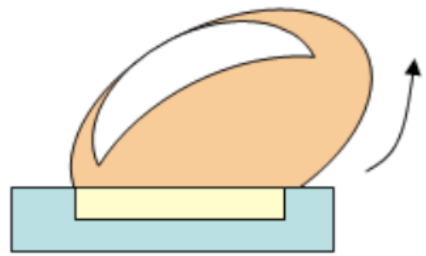
- Defect caused by the source
  - Skin condition such as moist, oily, dry and so on
  - Scars, wrinkles, blisters, eczema, dirt
- Defect caused by the capture device
  - Sampling error, low contrast
- Defect caused by the capture subject‘s behaviour
  - Elastic deformation
  - Improper finger placement (too low, rotated, etc)

If poor quality is known,
constructive feedback should be provided (actionable quality)

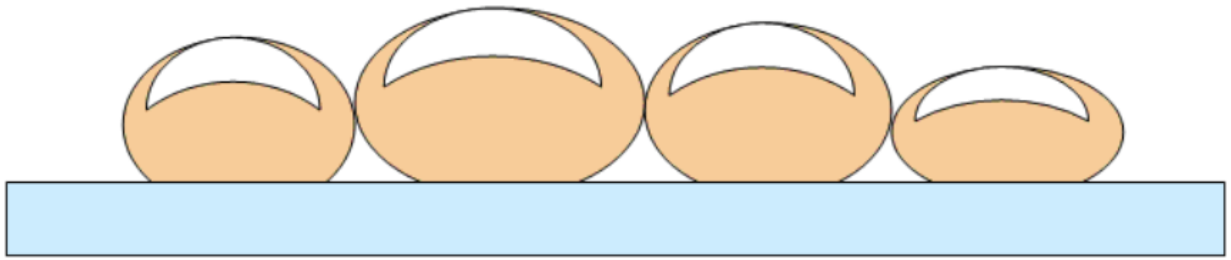
Fingerprint Capture Guidelines

Requirements defined by ISO/IEC 39794-4:2019

- Tilted finger
  - If a finger is placed at an angle to the sensor rather than placed flat on it, the side of the fingerprint will be captured and in general the utility of the sample will be reduced.
  - Decreasing such rolling motion is also necessary to improve the accuracy.

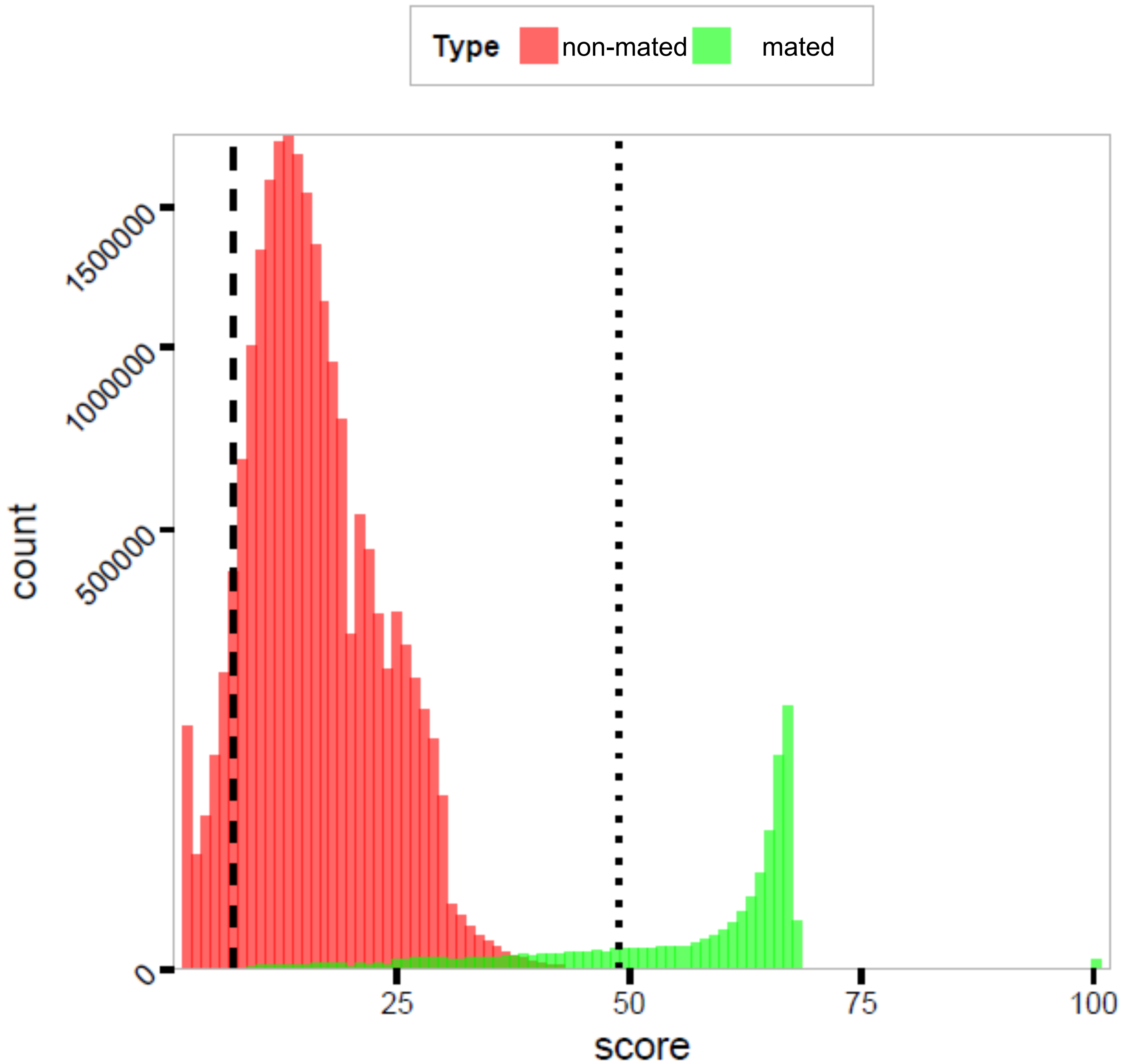


  - Note that simultaneous capturing of multiple fingers has an advantage of reducing the rolling motion.



Source: ISO/IEC 39794-4:2019

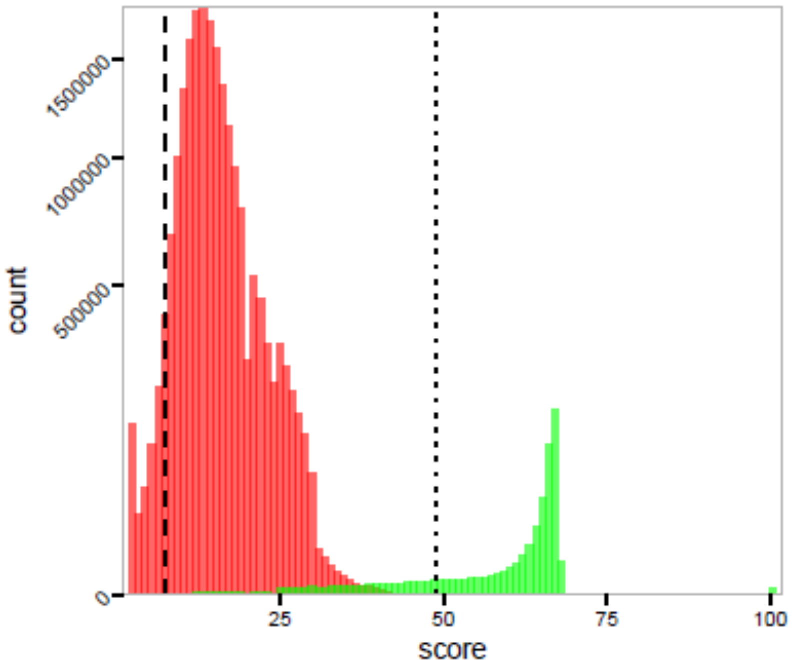
Comparison Score Distributions



Comparison Score Distributions

non-mated score 2.11

non-mated score 48.86



mated score 7.31

mated score 48.86

mated score 67.84

Finger Image Quality Assessment

Factors impacting Quality

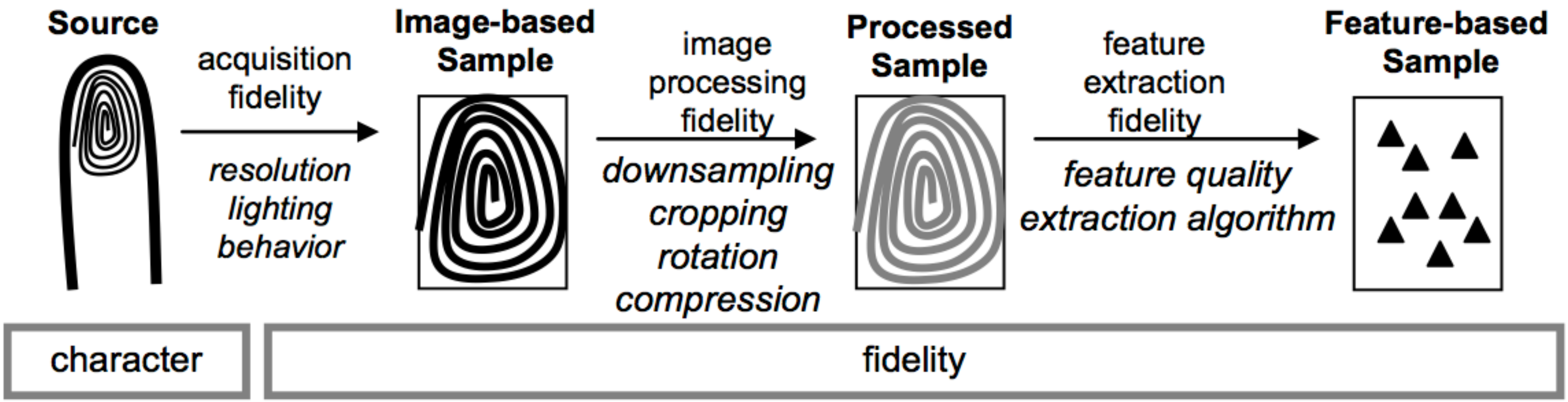
What is reflected by „quality“

- Character of a sample
  - An expression of quality based on the inherent properties of the source from which the biometric sample is derived.
  - For example, a scarred fingerprint has a poor character
- Fidelity of a sample to the source from which it is derived
  - An expression of quality based on fidelity reflects the degree of its similarity to its source.
  - For example sensor quality, noise related to capture process
- Utility of a sample within a biometric system.
  - An expression of quality based on utility reflects the predicted positive or negative contribution of an individual sample to the overall performance of a biometric system.
  - Is there valuable biometric information in the sample?

Character and Fidelity

Quality reference model illustration

- Quality = function (character, fidelity components)
- Utility reflects the impact of the quality of a single sample on system performance



Source: ISO/IEC 29794-1:2016

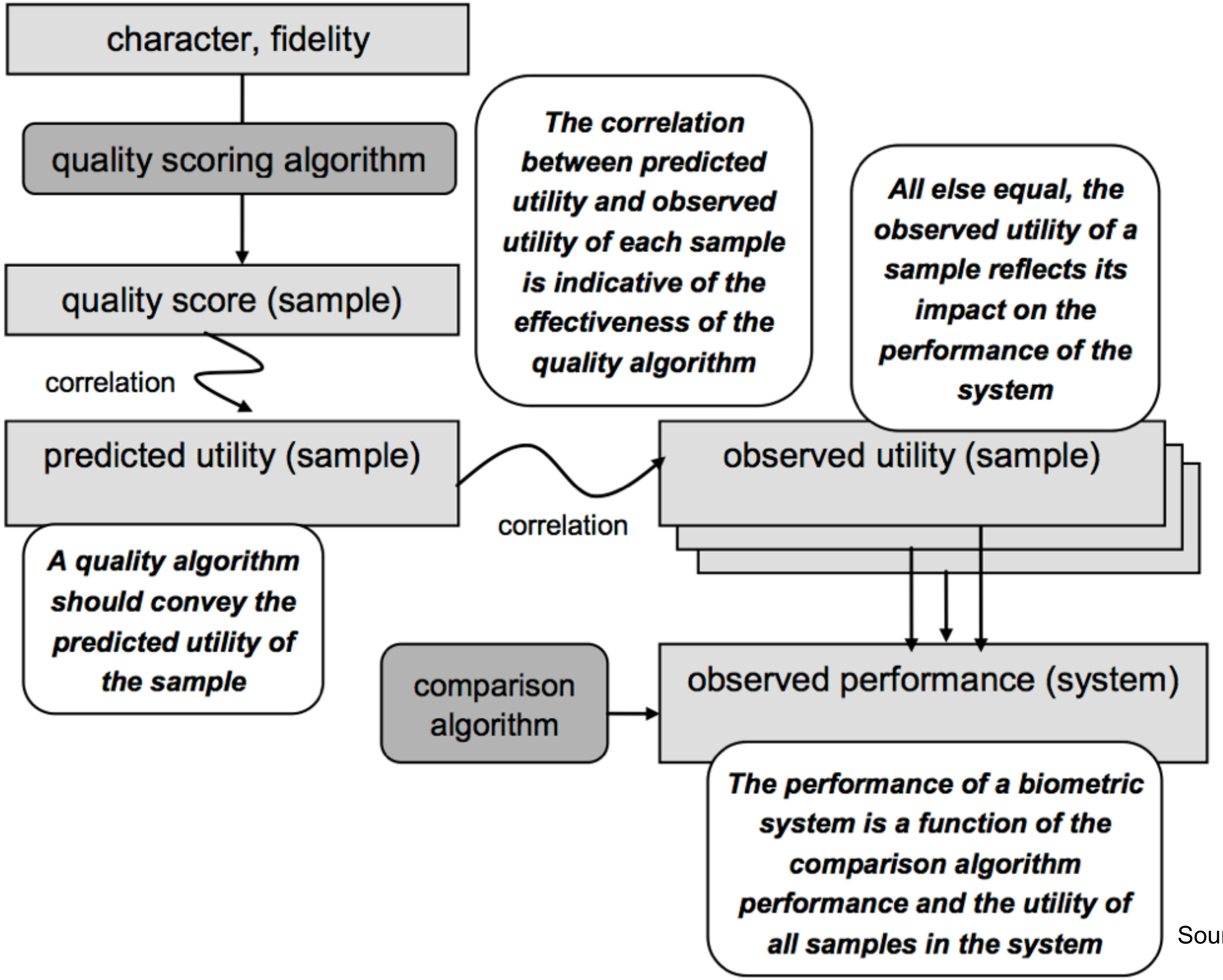
Quality Score

Definition

- of quality scores according ISO/IEC 29794-1
  - **quality score:**
    - *a quantitative expression of the degree to which a biometric sample fulfills specified requirements for a targeted application.*
- As there are (at least for facial image assessment) multiple algorithms in use, we must encode, which algorithm was used to compute the score
  - **quality algorithm identification (QAID):**
    - *The Quality Algorithm ID (QAID) is an identifier of the quality algorithm used to calculate the quality score of the sample.*
    - *As long as there are no common criteria for quality assessment, it is indispensable to enable the recipient of a record to differentiate between quality scores generated by different quality algorithms and adjust for any differences in processing or analysis as necessary.*

Quality and Performance

Relationship between quality and system performance

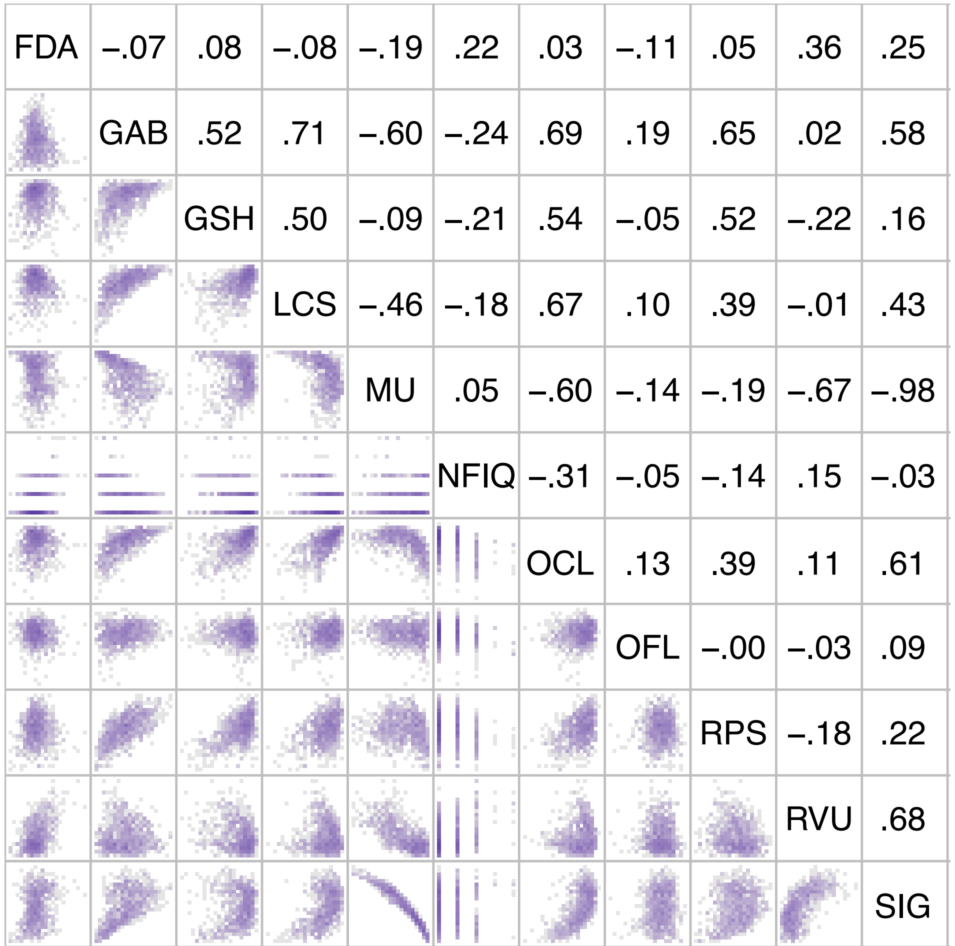


Source: ISO/IEC 29794-1:2016

Objective of the Quality Metric

Predictability of comparison success

- The quality metric should ideally predict the performance for a comparator - on a given sample
- Scatter plots of
  - quality features and utilities (Spearman correlation)
  - FVC2004 DB1 a



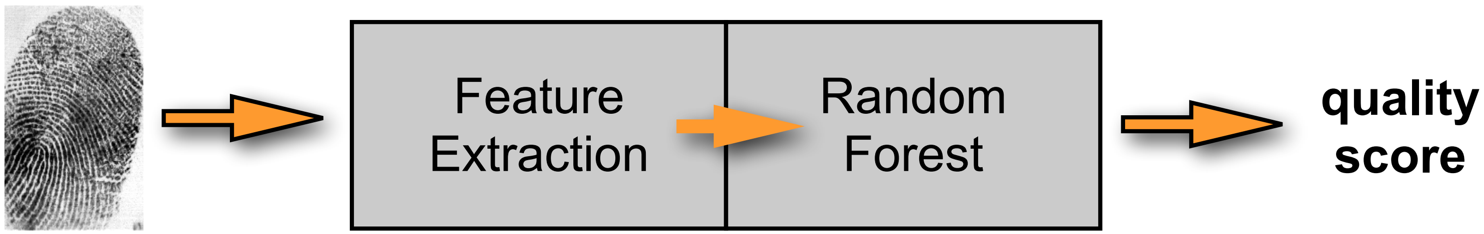
Source: Martin Olsen, PhD-thesis, 2016

Fingerprint Quality Scoring Algorithm

Quality Score - Finger Images

Quality scoring algorithm

- NIST Fingerprint Image Quality (NFIQ2)
  - open source developed from 2010 to 2016 (NFIQ2.0)
  - handcrafted features - explainable algorithms
  - machine learning algorithm (RandomForest)
- Metrics defined in ISO/IEC 29794-4:2017
  - NFIQ2 is the reference implementation of ISO/IEC 29794-4:2017



ISO/IEC-29794-4: Finger Image Quality

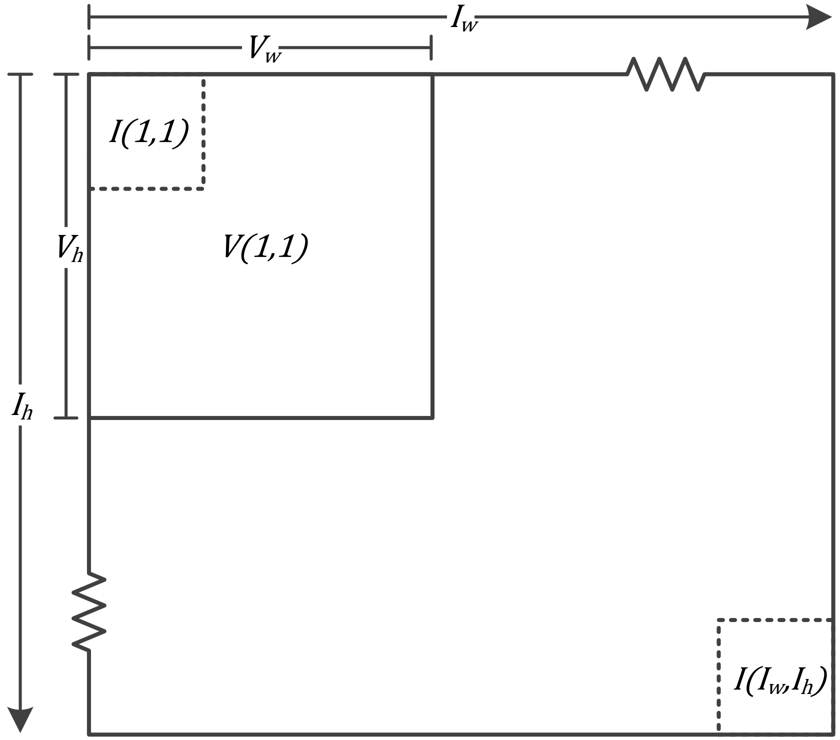
General normative requirements

- A complete finger image quality analysis shall examine both the local and global structures
- The finger image shall have a spatial sampling rate of 196,85 pixels per centimetre (500 pixels per inch)
- Prior to computing features, fingerprint images are cropped to remove white pixels on the margins.
  - pixel intensities take values [0, 255] for an 8-bit gray scale image
  - image columns and rows which are near constant white background are removed

ISO/IEC-29794-4: Finger Image Quality

Image analysis

- Quality scoring algorithms operate
  - on local feature
  - on global features

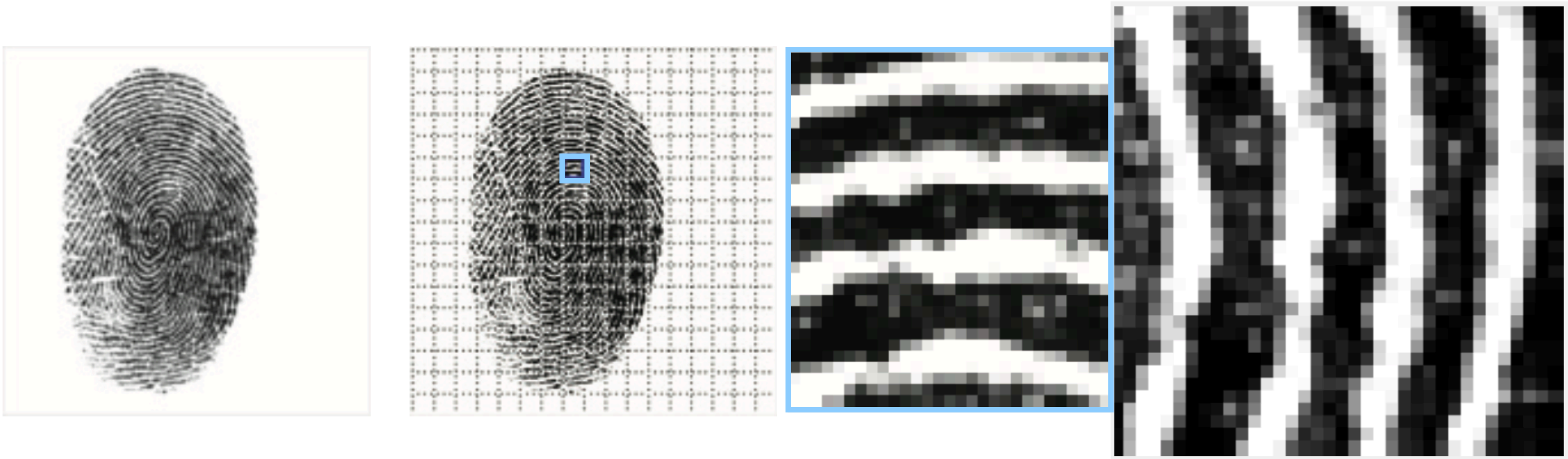


- Illustration of block and pixel indexing within an image $\boldsymbol{I}$
  - with dimensions I_w , I_h .
  - shown is the pixel $I(1,1)$ and the block $V(1,1)$ with dimensions V_w , V_h

ISO/IEC-29794-4: Finger Image Quality

Image Preprocessing

- Local algorithms operate in a block-wise manner



a) Input finger image **b) division into local regions** **c) enlarged view of *V*(8,5)** **d) *V*(8,5) rotated according to its dominant ridge orientation as determined using Formula (10)**

- for 500 dpi a ridge and valley pair are 8-12 pixels wide
- to cover two ridges lines a block must have at least 24 pixels
  - the size for each local region shall be 32x32 pixels

Source: ISO/IEC 29794-4:2017

Image Preprocessing

- Computing the block orientation from gradients
  - numerical gradient of the block is determined using finite central difference for all interior pixels
    - in the x-direction and
    - the y-direction

$$f_x = \frac{I(x+1,y) - I(x-1,y)}{2}$$

$$f_y = \frac{I(x,y+1) - I(x,y-1)}{2}$$

$$a = \overline{f_x{}^2}$$

$$b = \overline{f_y{}^2}$$

$$c = \overline{f_x \cdot f_y}$$

$$C = \begin{bmatrix} a & c \\ c & b \end{bmatrix}$$

$$d = \sqrt{c^2 + (a-b)^2} + \epsilon$$

Source: Olsen, IET, 2016

ISO/IEC-29794-4: Finger Image Quality

Finger image quality metrics

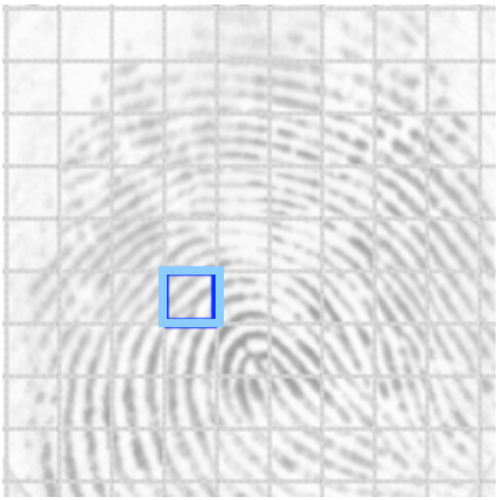
- OCL - Orientation certainty level (mean, sd)
- LCS - Local clarity score (mean, sd)
- FDA - Frequency domain analysis (mean, sd)
- RVU - Ridge valley uniformity (mean, sd)
- OFL - Orientation flow (mean, sd)
- MU - Arithmetic mean of pixel values
- MMB - Mean of block mean intensities
- MIN-CNT - Minutiae count in finger image
- MIN-COM - Minutiae count in center of mass region
- COH - RoI orientation map coherence sum
- COH - RoI relative orientation map coherence sum
- AREA - Region of image mean

ISO/IEC-29794-4: Finger Image Quality

OCL - Orientation Certainty Level

- Measure of the consistency of the orientations of the ridges and valleys contained within the local region.
- Algorithm
  - 1. compute the intensity gradient (dx, dy) of each block
  - 2. perform Principal Component Analysis and compute the covariance matrix from the gradients

$$C = \frac{1}{N}\sum_{N}\left\{\begin{bmatrix} dx \\ dy \end{bmatrix}\begin{bmatrix} dx & dy \end{bmatrix}\right\} = \begin{bmatrix} a & c \\ c & d \end{bmatrix}$$



ISO/IEC-29794-4: Finger Image Quality

OCL - Orientation Certainty Level

- Algorithm - eigenvalue computation
  - 3. compute the eigenvalues to obtain OCL for each block

$$\lambda_{\min} = \frac{a+b-\sqrt{(a-b)^2+4c^2}}{2}$$

$$\lambda_{\max} = \frac{a+b+\sqrt{(a-b)^2+4c^2}}{2}$$

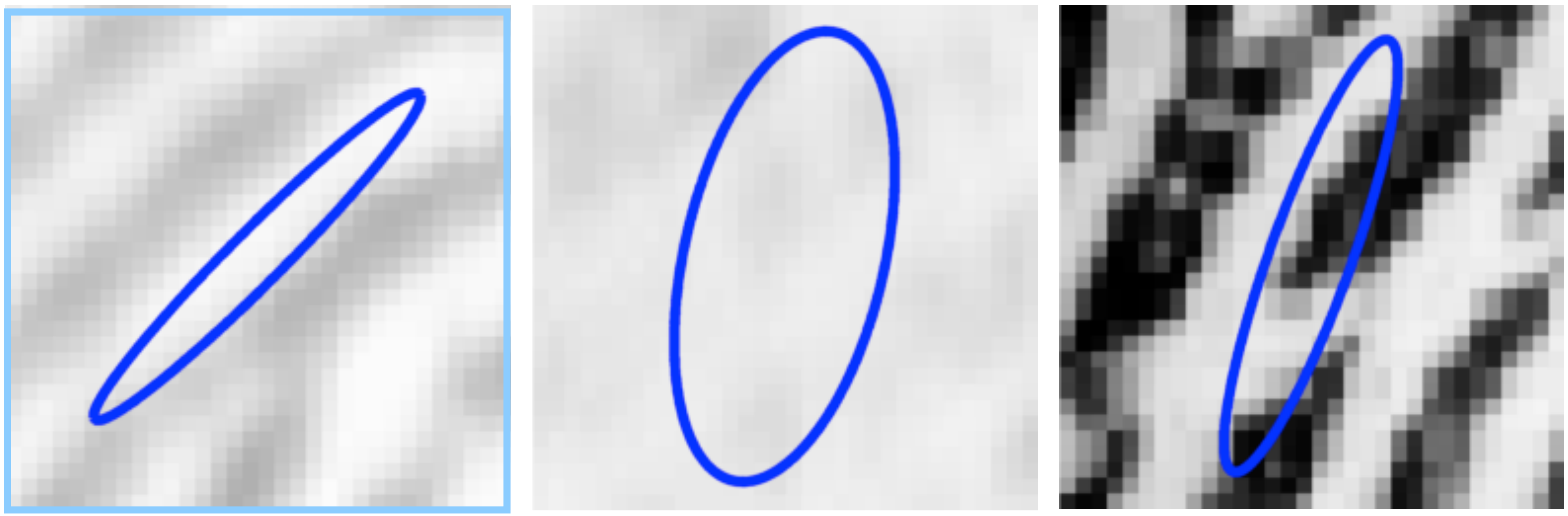


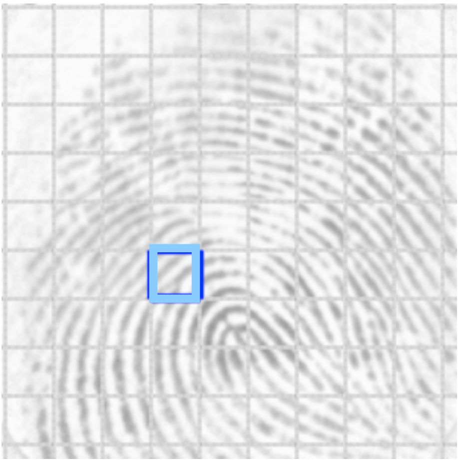
Image Source: FVC2000Db1A1

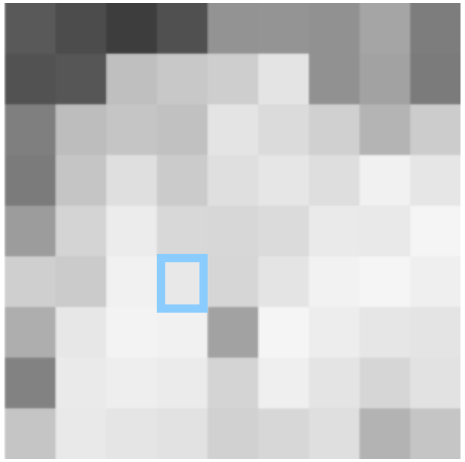
OCL - Orientation Certainty Level

- Algorithm - local orientation certainty level leads to a score
  - the ratio between the two eigenvalues gives an indication of how strong the energy is concentrated along the dominant direction

$$Q_{\mathrm{OCL}}^{local} = \begin{cases} 1 - \dfrac{\lambda_{\min}}{\lambda_{\max}}, & if \quad \lambda_{\max} > 0 \\ 0, & \text{otherwise} \end{cases}$$

  - a ratio in the interval [0, 1]
    - where 1 is the highest certainty level
    - and 0 is the lowest certainty level



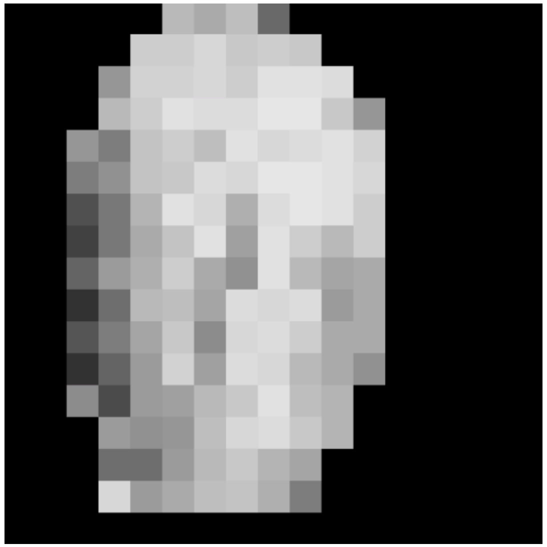


ISO/IEC-29794-4: Finger Image Quality

OCL - Orientation Certainty Level

- Computing the image quality score
  - 4. Final score is the mean value of the block Q_{OCL}^{local} values
    - global orientation certainty level
    - consider the foreground fingerprint area

$$Q_{\mathrm{OCL}} = \frac{1}{B}\sum_{i=1}^{B} b_i$$



Source: ISO/IEC 29794-4:2017

ISO/IEC-29794-4: Finger Image Quality

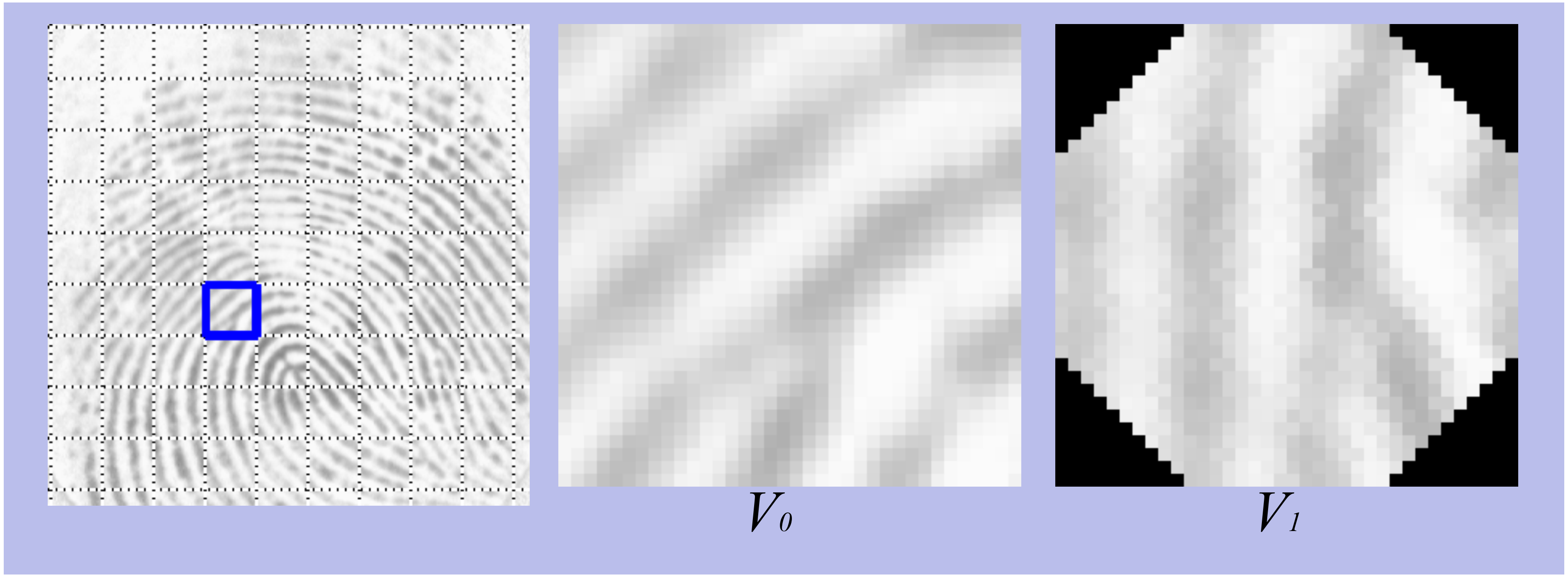
LCS - Local Clarity Score Overview

- Good finger images cannot have ridges that are too close or too far apart, the nominal ridge and valley thickness can be used as a measure of the quality
- Measure of the ridge-valley structure clarity
  - computes local quality and operates in a block-wise manner
  - blocks represent local regions of size 32 x 32 pixels
- Inside each local region, an orientation line, which is perpendicular to the ridge direction, is computed
- At the centre of the local region, a local region of size 32 × 16 pixels shall be extracted
  - and transformed to a vertically aligned local region
- On the local region a linear regression determines the threshold (DT), to segment the ridge or valley regions

ISO/IEC-29794-4: Finger Image Quality

LCS - Local Clarity Score

- Algorithm
  - for each block V_0 in the image determine the dominant ridge flow orientation to create an orientation line which is perpendicular to the ridge flow
  - align V_0 such that the orientation line is horizontal to create V_1

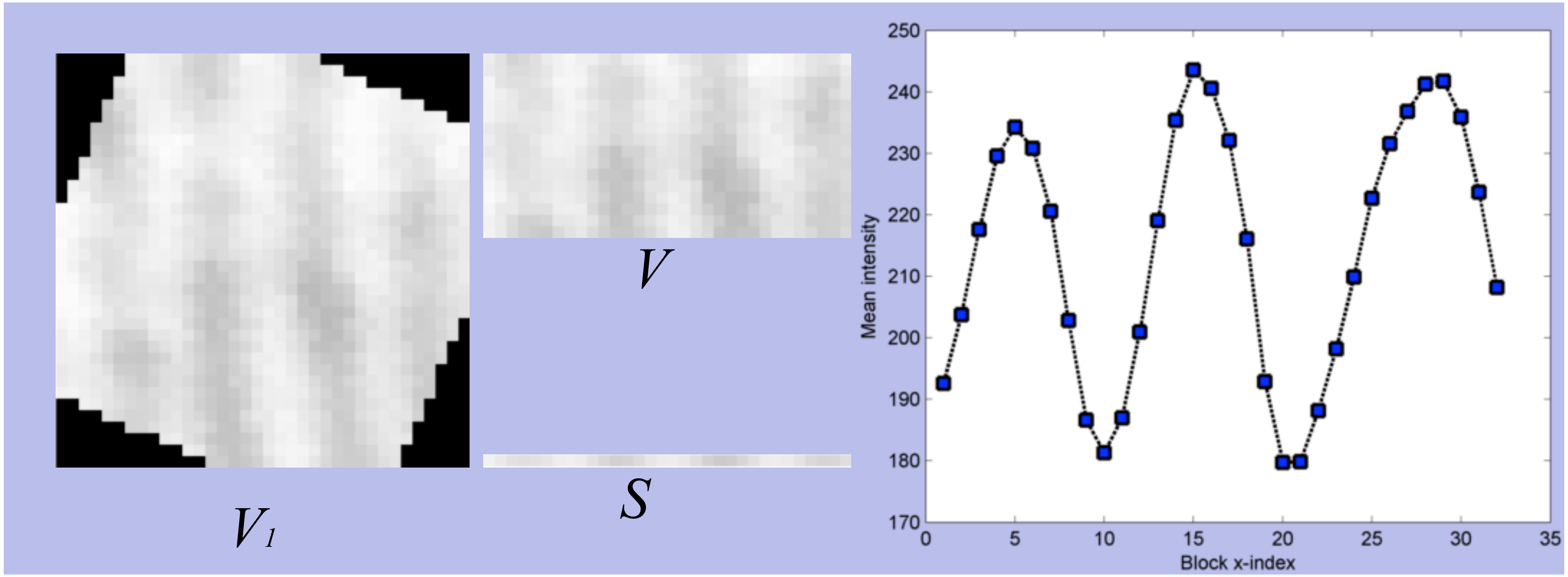


ISO/IEC-29794-4: Finger Image Quality

LCS - Local Clarity Score

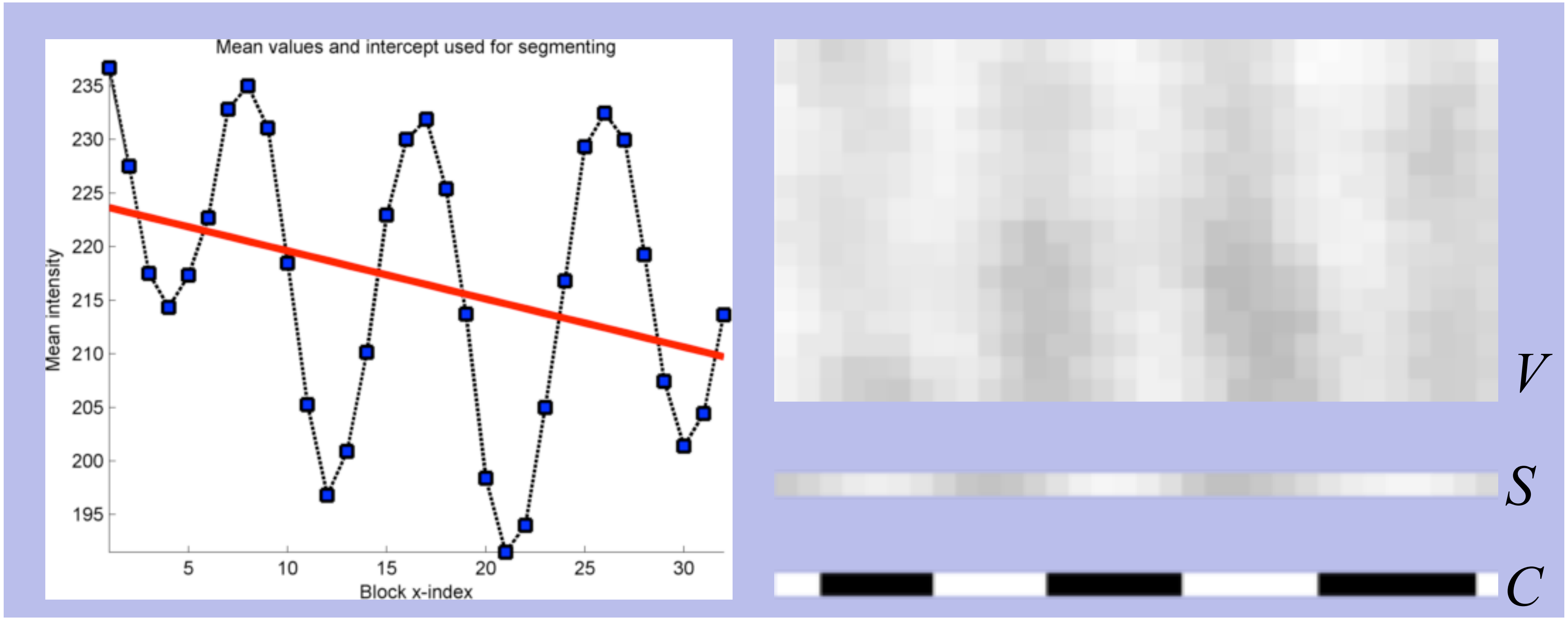
- Algorithm - Computing the average profile of a block
  - from V_1 extract a centered and oriented block V
  - given the local region V compute the ridge valley signature S

$$\boldsymbol{s}(x) = \frac{\sum_{y=1}^{16} \boldsymbol{V}(x,y)}{16}$$



LCS - Local Clarity Score

- Algorithm - Ridge valley segmentation
  - determine a threshold DT by applying linear regression on S
  - classify columns in V as ridge (1) or valley (0)
  - determine ridge-valley transition vector C

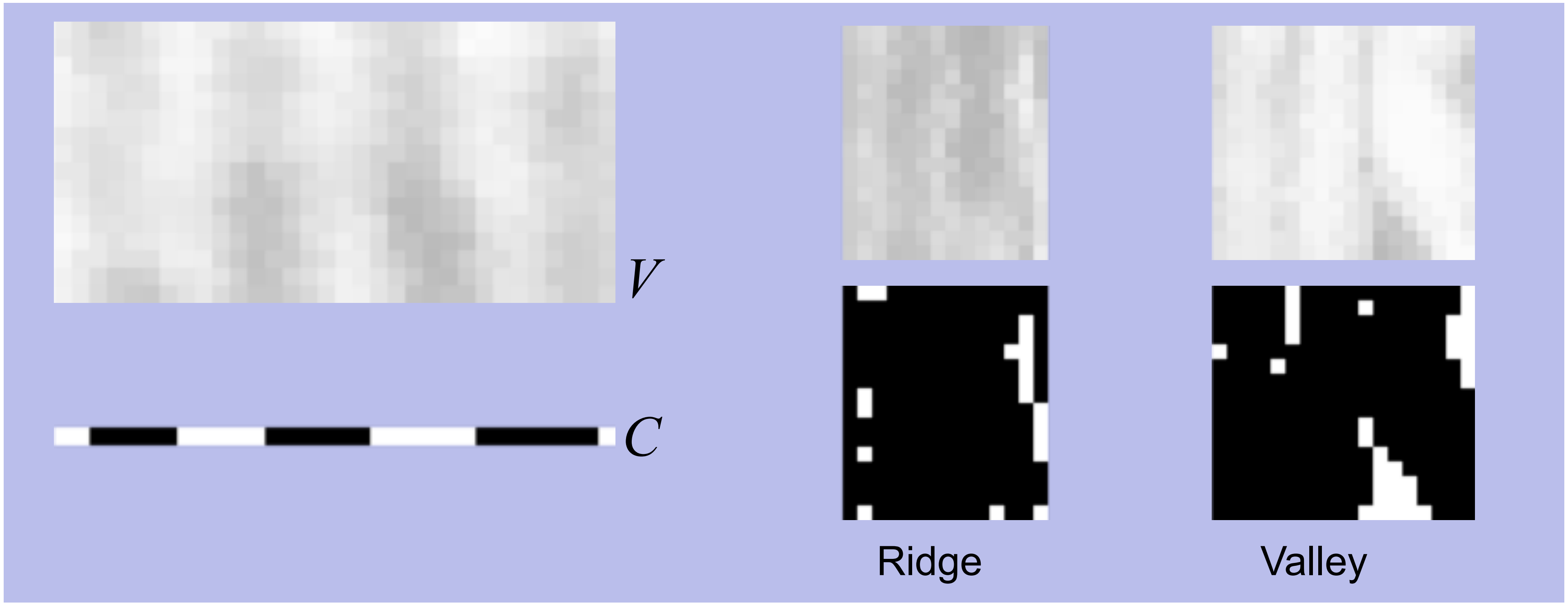


LCS - Local Clarity Score

- Algorithm - Ratios of misclassified pixels
  - determine proportion of misclassified pixels in valley and ridge region

v_B number of pixels in valley region with intensity < DT
v_T total number of pixels in valley region
r_B number of pixels in ridge region with intensity > DT
r_T total number of pixels in ridge region

$$\alpha = \frac{v_B}{v_T} \qquad \beta = \frac{r_B}{r_T}$$



LCS - Local Clarity Score

- Computing the local clarity score
  - The local quality score $\boldsymbol{Q}_{\mathrm{LCS}}^{local}$ is the constrained average value of α and β with a range between 0 and 1

$$\boldsymbol{Q}_{\mathrm{LCS}}^{local} = \begin{cases} 1 - \dfrac{\alpha + \beta}{2}, & \mathit{if} \left(W_v^{nmin} < \overline{W_v} < W_v^{nmax} \right), \left(W_r^{nmin} < \overline{W_r} < W_r^{nmax} \right) \\ 0, & \mathit{otherwise} \end{cases}$$

  - where W_r^{nmin} and W_v^{nmin} are minimum values for the width
  - and W_v^{nmax} and W_v^{nmax} are maximum values for the width

ISO/IEC-29794-4: Finger Image Quality

MU - Mean Pixel Intensity Score

- Compute the arithmetic mean of the pixel intensities of all pixels in the input image
- The feature computes global quality
- Algorithm
  - Compute Q_{MU} as the arithmetic mean of pixel intensities in I

ISO/IEC-29794-4: Finger Image Quality

MIN-CNT - Minutiae Count in finger image

- The FingerJet FX (FJFX) minutiae extractor provides a count of detected minutiae in the finger image
- The minutiae count has a bearing on the mated comparison score
- The feature computes global quality
- Algorithm
  - $\boldsymbol{Q}_{\mathrm{MIN}}^{cnt}$ is the number of detected minutiae in the finger image as determined by FJFX

ISO/IEC-29794-4: Finger Image Quality

The ISO/IEC 29794-4 quality feature vector

- The feature vector is specified as

$$
\begin{aligned}
\boldsymbol{Q}_{29794-4} = \{ \; & Q^{\mu}_{\mathrm{OCL}}, Q^{\mu}_{\mathrm{LCS}}, Q^{\mu}_{\mathrm{FDA}}, Q^{\mu}_{\mathrm{RVU}}, Q^{\mu}_{\mathrm{OFL}}, \\
& Q^{\sigma}_{\mathrm{OCL}}, Q^{\sigma}_{\mathrm{LCS}}, Q^{\sigma}_{\mathrm{FDA}}, Q^{\sigma}_{\mathrm{RVU}}, Q^{\sigma}_{\mathrm{OFL}}, \\
& \boldsymbol{Q}_{\mathrm{OCL}}, \boldsymbol{Q}_{\mathrm{LCS}}, \boldsymbol{Q}_{\mathrm{FDA}}, \boldsymbol{Q}_{\mathrm{RVU}}, \boldsymbol{Q}_{\mathrm{OFL}}, \\
& Q_{\mathrm{MU}}, Q_{\mathrm{MMB}}, Q^{rel}_{\mathrm{COH}}, Q^{sum}_{\mathrm{COH}}, Q^{\mu}_{\mathrm{AREA}}, \\
& Q^{cnt}_{\mathrm{MIN}}, Q^{com}_{\mathrm{MIN}}, Q^{\mathrm{mu}}_{\mathrm{MIN}}, Q^{ocl}_{\mathrm{MIN}} \}
\end{aligned}
$$

NFIQ2.0 - Training

The unified quality score

- Obtain a single or unified output from all the quality metrics
- Each of the quality metrics shall be normalized to the range between 0 and 100 prior to combining them
- With the feature vector a Random Forest shall be trained, where
  - Class 0 represents images of very low utility and
  - Class 1 represents images of very high utility
- The trained random forest outputs class membership along with its probability score

NFIQ2.0 - Training

Training parameters and results

- The trained random forest has 100 trees and out of bag error of 0.24

	Name	MeanDreaseGini
$Q^{\sigma}_{\mathrm{FDA}}$	Frequency Domain Analysis_Standard Deviation	140.760
Q^{com}_{MIN}	FingerJet FX OSE COM Minutiae Count	92.089
Q^{ocl}_{MIN}	FingerJet FX OSE OCL MinutiaeQuality	83.027
Q^{μ}_{RVU}	Ridge Valley Uniformity_Mean	69.517
Q^{μ}_{FDA}	Frequency Domain Analysis_Mean	62.229
Q^{cnt}_{MIN}	FingerJet FX OSE Total Minutiae Count	57.565
$Q^{\sigma}_{\mathrm{RVU}}$	Ridge Valley Uniformity_Standard Deviation	50.946
Q^{7}_{LCS}	Local Clarity Score_Bin_7	50.688
Q^{8}_{LCS}	Local Clarity Score_Bin_8	50.100
Q^{9}_{FDA}	Frequency Domain Analysis_Bin_9	47.844
Q^{sum}_{COH}	ROI Orientation Map Coherence Sum	38.104
Q^{2}_{OFL}	Orientation Flow_Bin_2	37.172
Q^{μ}_{LCS}	Local Clarity Score_Mean	36.483
Q^{5}_{RVU}	Ridge Valley Uniformity_Bin_5	35.617
Q^{3}_{RVU}	Ridge Valley Uniformity_Bin_3	35.139
Q^{μ}_{AREA}	ROI Area Mean	34.932
Q^{1}_{OFL}	Orientation Flow_Bin_1	33.751
Q^{0}_{OFL}	Orientation Flow_Bin_0	33.513
Q_{MU}	MU	32.914

ISO/IEC-29794-4: Finger Image Quality

Quality metric identifier (normative)

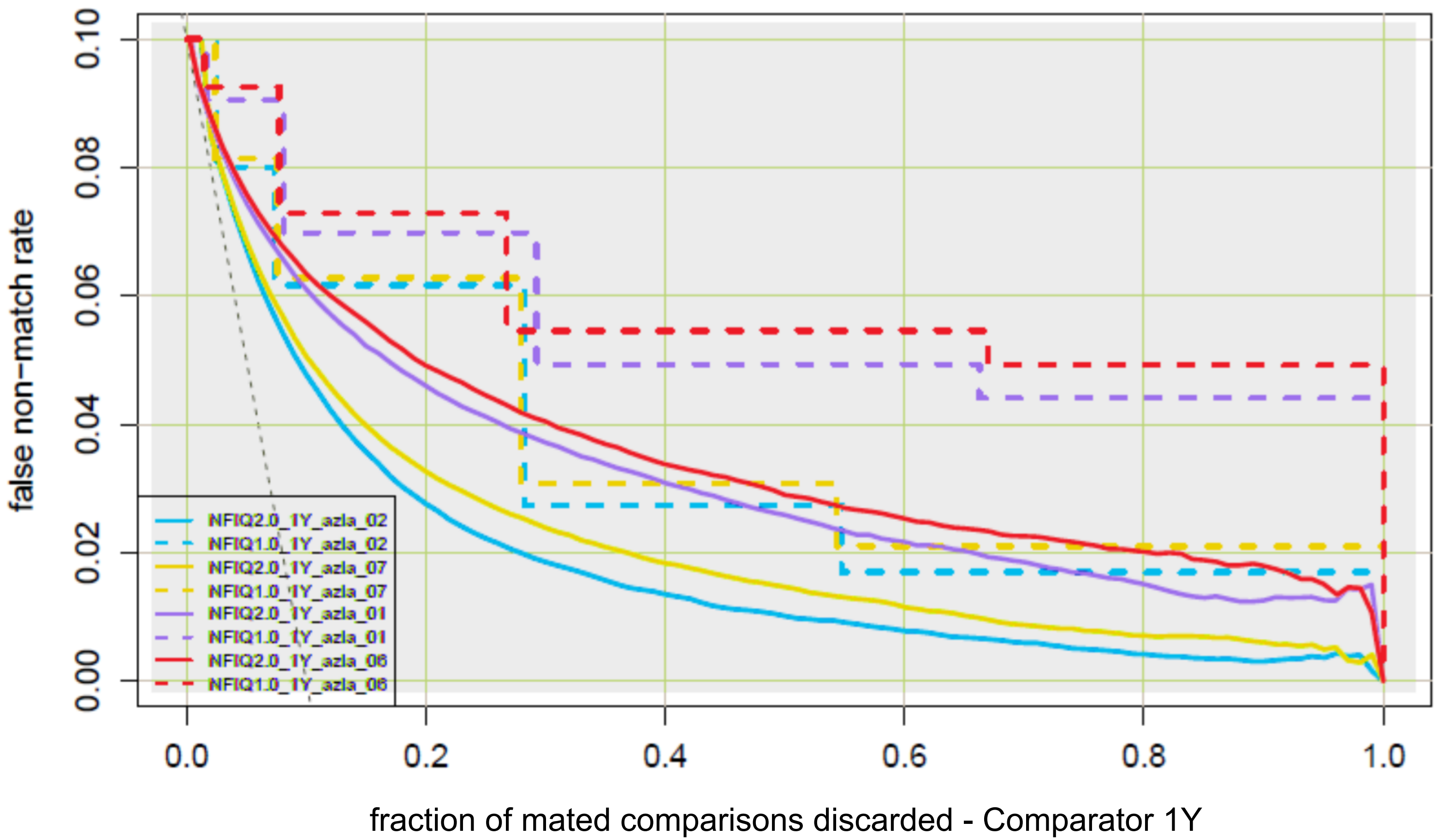
Quality algorithm identifier Hex	Quality algorithm identifier decimal	Quality metric	Algorithm feature name	Governing subclause + description
01_{Hex}	01	Unified quality score ($Q_{29794\text{-}4}$)		Finger image quality score (5.4)
02_{Hex}	02	Mean of local orientation certainty level (Q^{μ}_{OCL})	OCL	5.2.2, 5.2.16.2
03_{Hex}	03	Standard deviation of local orientation certainty level (Q^{σ}_{OCL})	OCL	5.2.2, 5.2.16.3
04_{Hex}	04	Mean of local clarity score (Q^{μ}_{LCS})	LCS	5.2.3, 5.2.16.2
05_{Hex}	05	Standard deviation of local clarity score (Q^{σ}_{LCS})	LCS	5.2.3, 5.2.16.3
06_{Hex}	06	Mean of local frequency domain analysis (Q^{μ}_{FDA})	FDA	5.2.4, 5.2.16.2
07_{Hex}	07	Standard deviation of local frequency domain analysis (Q^{σ}_{FDA})	FDA	5.2.4, 5.2.16.3
08_{Hex}	08	Mean of local ridge valley uniformity (Q^{μ}_{RVU})	RVU	5.2.5, 5.2.16.2
09_{Hex}	09	Standard deviation of local ridge valley uniformity (Q^{σ}_{RVU})	RVU	5.2.5, 5.2.16.3
$0A_{Hex}$	10	Mean of local orientation flow (Q^{μ}_{OFL})	OFL	5.2.6, 5.2.16.2
$0B_{Hex}$	11	Standard deviation of orientation flow (Q^{σ}_{OFL})	OFL	5.2.6, 5.2.16.3
$0C_{Hex}$	12	MU (Q_{MU})	MU	5.2.7
$0D_{Hex}$	13	MMB (Q_{MMB})	MMB	5.2.8
$0E_{Hex}$	14	Minutiae count (Q^{cnt}_{MIN})	MIN^{CNT}	5.2.9
$0F_{Hex}$	15	Minutiae count in center of mass (Q^{com}_{MIN})	MIN^{COM}	5.2.10
10_{Hex}	16	Minutiae quality based on image mean (Q^{mu}_{MIN})	MIN^{MU}	5.2.11
11_{Hex}	17	Minutiae quality based on orientation certainty level (Q^{ocl}_{MIN})	MIN^{OCL}	5.2.12
12_{Hex}	18	Region of interest image mean (Q^{μ}_{AREA})	AREA	5.2.13
13_{Hex}	19	Region of interest orientation map coherence sum (Q^{sum}_{COH})	COH^{SUM}	5.2.14
14_{Hex}	20	Region of interest relative orientation map coherence sum (Q^{rel}_{COH})	COH^{REL}	5.2.15

Source: ISO/IEC 29794-4:2017 - Table 2

NFIQ2.0 Evaluation

Error versus reject/discard characteristic curve (EDC)

- a stronger decrease of the EDC curve indicates a better prediction, meaning really the poorest samples are out



Summary

- Image quality metrics from a single image are useful to ensure the captured image is suitable for recognition
- NFIQ2 is
  - NOT based on CNN and Deep Learning
  - Explainable algorithms
  - Standardised with ISO/IEC 29794-4
  - Open source and free
  - Maintained

Summary

Further reading

- ISO/IEC 24794-4:2017 Biometric sample quality - Part 4 Finger image data
  https://www.iso.org/standard/62791.html
- M. Olsen, V. Smida, C. Busch: „Finger image quality assessment features – definitions and evaluation, in IET biometrics, (2016)
  https://ietresearch.onlinelibrary.wiley.com/doi/10.1049/iet-bmt.2014.0055

INTERNATIONAL STANDARD

ISO/IEC 29794-4

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Part 4:
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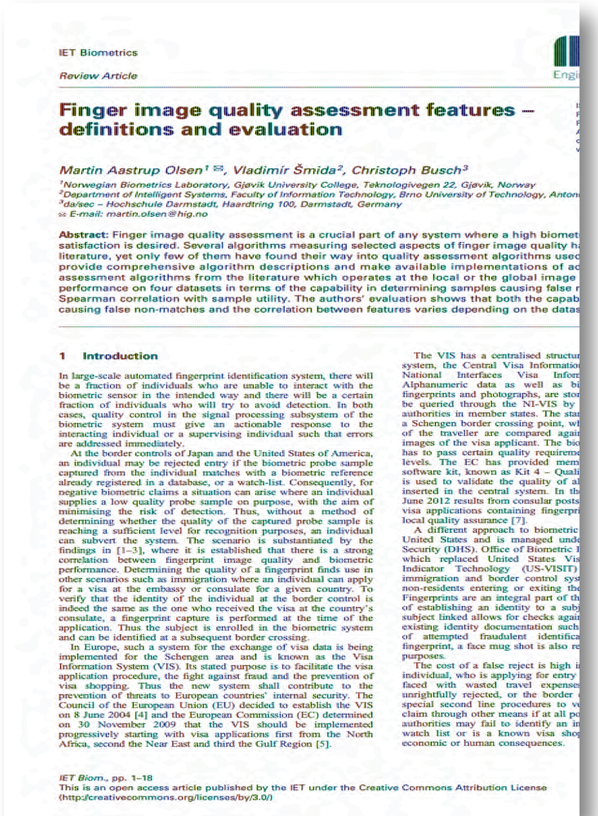

IET Biometrics

Review Article

Finger image quality assessment features – definitions and evaluation

Martin Aastrup Olsen[1] ✉, Vladimír Šmida[2], Christoph Busch[3]

IET Biom., pp. 1–18
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- NIST Fingerprint Image Quality
  http://www.nist.gov/itl/iad/ig/development_nfiq_2.cfm
  https://github.com/usnistgov/NFIQ2
- Christoph's project homepage
  https://christoph-busch.de/projects-nfiq2.html

Complementary reading

- ISO/IEC 24794-1:2016 Biometric Sample Quality - Part 1: Framework
  https://www.iso.org/standard/62782.html
- M. Olsen, H. Xu and C. Busch: "Gabor Filters as Candidate Quality Measure for NFIQ 2.0", in International Conference on Biometrics (ICB), (2012)
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  https://christoph-busch.de/files/Funk-FingerprintCompressionImpact-IEEE-IAW-2005.pdf

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