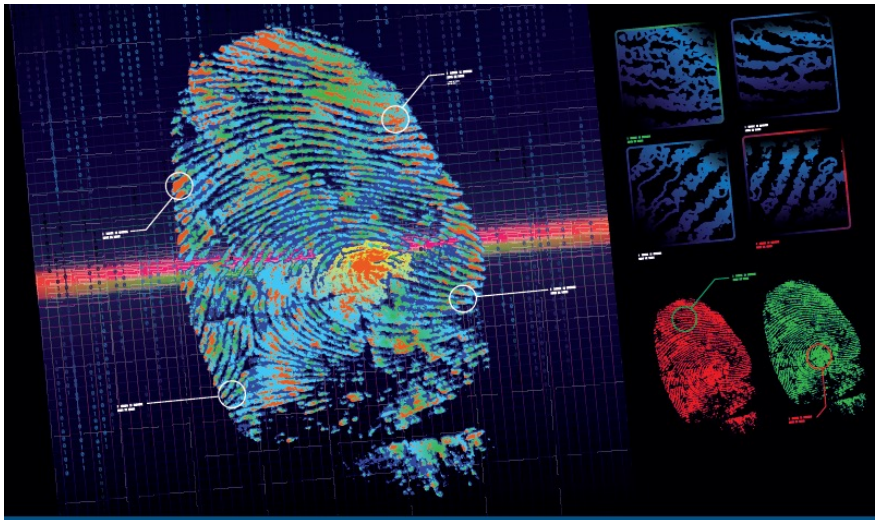

The push towards zero error biometrics

15 June 2021

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NIST
National Institute of Standards and Technology
U.S. Department of Commerce

Quality assessment for error suppression

Quality problem: “The Last 1%”

Or maybe “The Last 0.1% or 10%”

- Fraction of samples that should not be sent to the matcher
  - Core algorithmic capability of current matchers are reaching their asymptote. Performance improvements should be and could be achieved by improving data quality and integrity.
  - Quality assessment should be done based on only one instance most of the times (representation).
  - Providing constructive feedback only possible if cause of poor quality is known

character

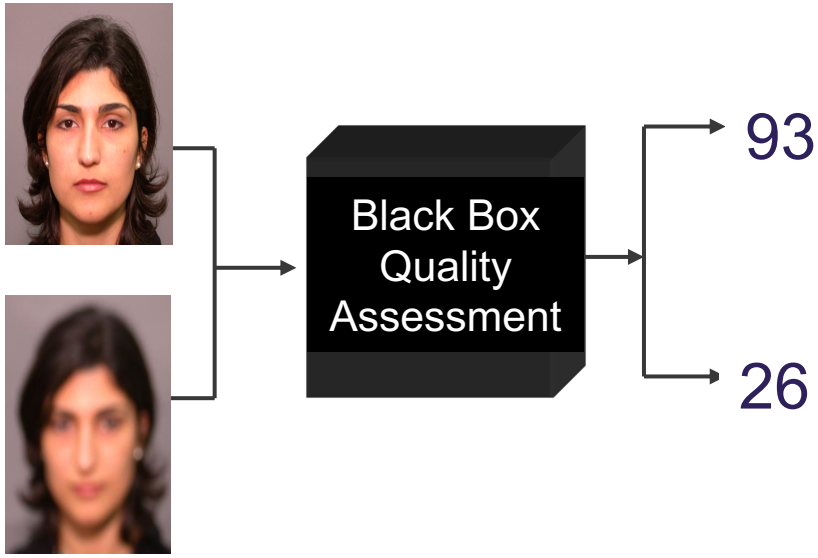
behavior

environment

Imaging/system

GIGO

Predictive of performance



A biometric quality assessment method derives a numerical quality value from an input biometric sample. The quality value is related to the biometric error rates that are likely to be realized when the sample is matched.

Uses of quality assessment

Subject presentation

- Improper presentation detection
- Presentation attack detection

Acquisition device

- Hardware built-in. Quality in capture loop.
- `peak' imaging capability
- No control on FTA - Hard to tweak to certain applications

Beyond scanner

- Automated (e.g., NFIQ) or visual by human
- Automated at client-side or backend
- Actionable feedback for re-capture

Operator review

- Particularly for high value images
- It is expensive
  - Requires training of operators + takes time

Allows for

- Adopting threshold for specific scenario
- Monitoring Seasonal variations, atypical collection site/queue/device, etc.
- Examine the bias of algorithms (age, aging, gender, etc.)

Challenges in development a fingerprint quality assessment algorithm

Technical

- Agnostic to comparison algorithm
  - Capability to predict performance of different comparison algorithms
- Sufficient resolution
  - How many levels are too many?
- Pairwise (no reference) quality
  - $Q_1 = F(image_1)$; $Q_2 = F(image_2)$;
  - $Q_{12} = G(image_1, image_2)$;
- Calibration
  - What FNMR is expected for each quality level/score?
- Quality of quality
  - Performance measures

Way forward

- Get a good representation of the current (state-of-the-art) comparison algorithm for training
  - Include as many as possible + requires building community
- We really don't know.
- Robust method for labeling training data + ultimately visual inspection
- Devise + revise metrics and visualization techniques

Challenges in development a fingerprint quality assessment algorithm

Technical, etc.	Way forward
» Data + Data sharing issues – training (particularly low quality) – testing (Images with specific defects)	» Data cannot leave a site, but an open source algorithm can be ran on the data and Results can then be shared
» Agnostic to application scenario – `sufficient quality' is different for enrolment vs. verification – Ditto 1:1 and 1:N.	» Go for the best recommended by the community
» Meet unknown System requirements – Timing, hardware, etc.	» Develop technical guidance and best practice – In collaboration with end users of the particular application
» Robust – Zero failure to compute rate	» Good coding practice

NIST Fingerprint Image Quality (NFIQ)

NIST Fingerprint Image Quality (NFIQ)

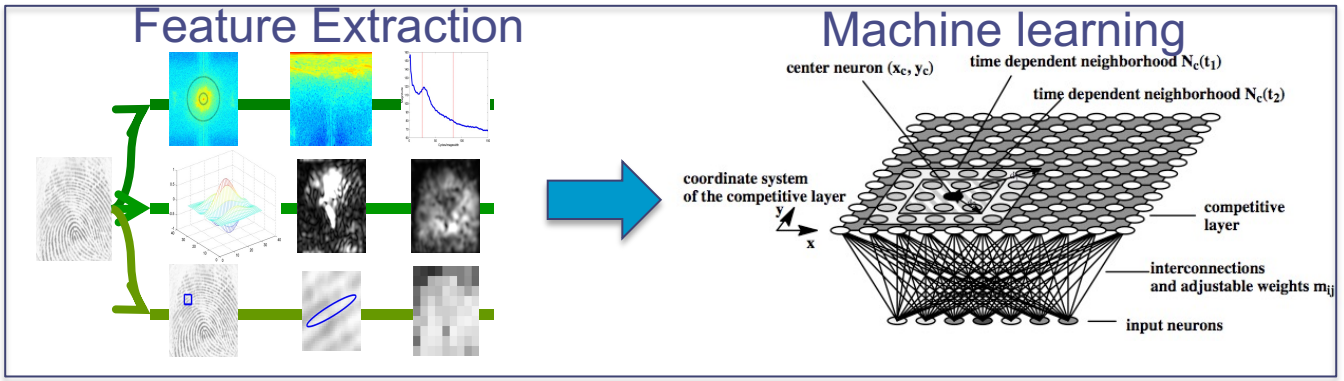
NFIQ1.0

quality number =5

NIST Fingerprint Image Quality (NFIQ)

NFIQ1.0 → quality number =5

NFIQ2.0 → quality number =[0,100]



NFIQ 2.0 Community

Team Members

- NIST (US)
- BSI (Germany)
- BKA (Germany)
- Fraunhofer IGD
- MITRE (US)
- Hochschule Darmstadt / CASED
- Secunet Security Networks AG
- NFIQ 2.0 Participants
- *...and the whole biometrics community*

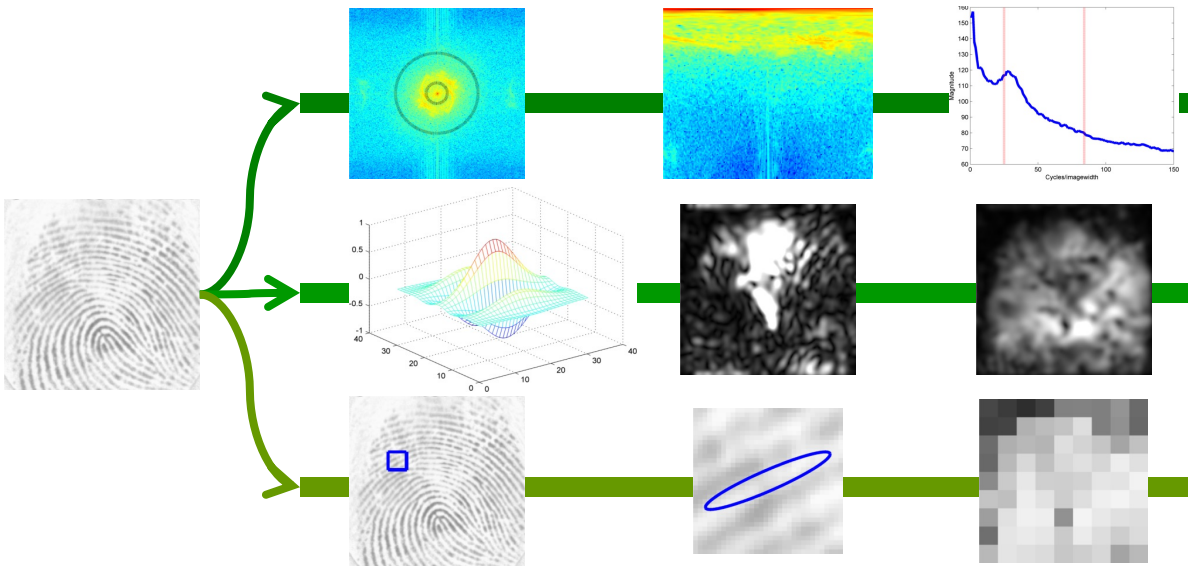
Sponsors

Department of Justice Federal Bureau of Investigation

Department of Homeland Security Science and Technology

Federal Office for Information Security

Bundeskriminalamt



NFIQ 2.0 Features

NFIQ 1.0 features

Recommended Features in ISO/IEC 29794-4:2009 + our modifications

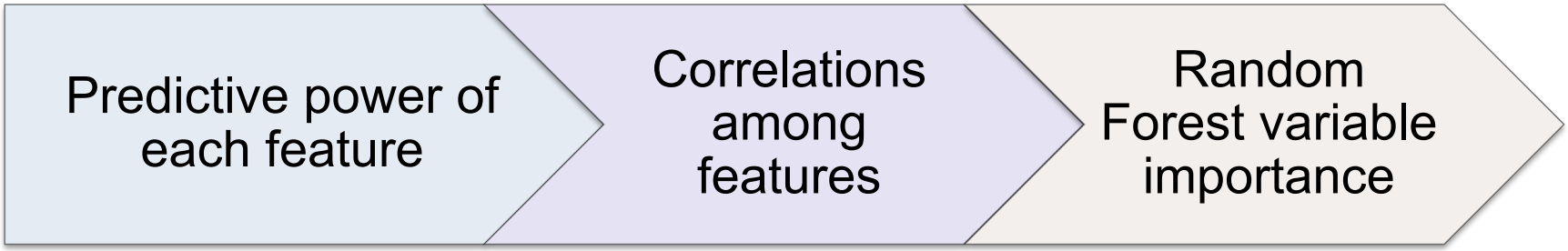
Surveyed literature + our modifications

Open source FingerJetFx minutiae extractor

~180 features …

Feature ID in Framework	Comments
NFIQ1_Feature_1	Original NFIQ1 Feature 1
NFIQ1_Feature_2	Original NFIQ1 Feature 2
NFIQ1_Feature_3	Original NFIQ1 Feature 3
NFIQ1_Feature_4	Original NFIQ1 Feature 4
NFIQ1_Feature_5	Original NFIQ1 Feature 5
NFIQ1_Feature_6	Original NFIQ1 Feature 6
NFIQ1_Feature_7	Original NFIQ1 Feature 7
NFIQ1_Feature_8	Original NFIQ1 Feature 8
NFIQ1_Feature_9	Original NFIQ1 Feature 9
NFIQ1_Feature_10	Original NFIQ1 Feature 10
NFIQ1_Feature_11	Original NFIQ1 Feature 11
NFIQ1_Time_All	Speed computation of NFIQ1 features in ms
FingerJetFX_MinutiaeCount	Number of detected minutiae (no limitation as in original FJFX source code)
FingerJetFX_MinutiaeQuality_0	Percentage of minutiae that have minutiae quality of 0 (= not calculated)
FingerJetFX_MinutiaeQuality_1	Percentage of minutiae that have minutiae quality between 1 and 10
FingerJetFX_MinutiaeQuality_2	Percentage of minutiae that have minutiae quality between 11 and 20
FingerJetFX_MinutiaeQuality_3	Percentage of minutiae that have minutiae quality between 21 and 30
FingerJetFX_MinutiaeQuality_4	Percentage of minutiae that have minutiae quality between 31 and 40
FingerJetFX_MinutiaeQuality_5	Percentage of minutiae that have minutiae quality between 41 and 50
FingerJetFX_MinutiaeQuality_6	Percentage of minutiae that have minutiae quality between 51 and 60
FingerJetFX_MinutiaeQuality_7	Percentage of minutiae that have minutiae quality between 61 and 70
FingerJetFX_MinutiaeQuality_8	Percentage of minutiae that have minutiae quality between 71and 80
FingerJetFX_MinutiaeQuality_9	Percentage of minutiae that have minutiae quality between 81 and 90
FingerJetFX_MinutiaeQuality_10	Percentage of minutiae that have minutiae quality between 91 and 100
FingerJetFX_AverageMinutiaeQuality	Arithemtic mean (average) of FJFX quality value of all minutiae
FingerJetFX_ROIBlockArea	Percentage of blocks that have at least one minutia in it (block size 32x32 pixels)
FingerJetFX_ROIBlockAbs	Absolute number of blocks that have at least one minutia in it (block size 32x32 pixels)
FingerJetFX_MinCount_COMMinRect200x200	Number of minutiae detected in rectangle of 200x200 pixels around centre of mass (based on minutiae locations)
FingerJetFX_MinCount_COMMinRect300x200	Number of minutiae detected in rectangle of 300x200 pixels around centre of mass (based on minutiae locations)
FingerJetFX_MinCount_COMMinCircle200	Number of minutiae detected in a circle of diameter 200 pixels around centre of mass (base on minutiae locations)
FingerJetFX_MinCount_COMMinCircle250	Number of minutiae detected in a circle of diameter 250 pixels around centre of mass (base on minutiae locations)
FingerJetFX_MinCount_COMGrayRect200x200	Number of minutiae detected in rectangle of 200x200 pixels around centre of mass (based on grayvalues)
FingerJetFX_MinCount_COMGrayRect300x200	Number of minutiae detected in rectangle of 300x200 pixels around centre of mass (based on grayvalues)
FingerJetFX_MinCount_COMGrayCircle200	Number of minutiae detected in a circle of diameter 200 pixels around centre of mass (base on grayvalues)
FingerJetFX_MinCount_COMGrayCircle250	Number of minutiae detected in a circle of diameter 250 pixels around centre of mass (base on grayvalues)
FingerJetFX_Time_All	Speed computation of FJFX feature extraction (of all features within this module, including COM and ROI based features) in ms
FingerJetFX_Time	Speed computation of FJFX minutiae extraction and ISO container parsing
Mu	Mu (= mean of all pixel values)
MMB	Mu Mu Block (MMB) (= mean of all blockwise mean intensity values)
Sigma	Sigma (= standard deviation of pixel values)
Mu_Time	Speed computation of Mu feature
MMB_Time	Speed computation of MMB feature
Sigma_Time	Speed computation of Sigma feature
ImgProcROIBlockArea	Percentage of ROI blocks in relation to all blocks of image (block size 32x32 pixels)
ImgProcROIBlockAbs	Absolute number of ROI blocks in image (block size 32x32 pixels)
ImgProcROIPixelArea	Percentage of ROI pixels in relation to total number of pixels of image
ImgProcROIPixelAbs	Absolute number of ROI pixels in image
ImgProcROIArea_Mean	Mean value (= Mu) of ROI blocks only
ImgProcROIArea_StdDev	Standard deviation (= sigma) of ROI blocks only
ImgProcROIArea_OCL	Orientation Certainty Level (OCL) feature value of ROI blocks only
ImgProcROIArea_Time	Speed computation of ImgProcROI features
ImgProcROIArea_OCL_Time	Speed computation of ImgProcROIArea_OCL feature
FJFXPos_Mu_AverageMinutiaeQuality	Average minutiae quality based on mean and stddev of pixel grayvalues (=Mu) of a 32x32 pixels block around minutiae location
FJFXPos_Mu_MinutiaeQuality_0	Percentage of Mu values (as defined above) that have value <= -0.5
FJFXPos_Mu_MinutiaeQuality_1	Percentage of Mu values (as defined above) that have value > -0.5 and <= 0
FJFXPos_Mu_MinutiaeQuality_2	Percentage of Mu values (as defined above) that have value > 0 and <= 0.5
FJFXPos_Mu_MinutiaeQuality_3	Percentage of Mu values (as defined above) that have value > 0.5
FJFXPos_COMMin_MMB_224	MMB value of square (size 224x224 pixels, block size 32x32 pixels) around centre of mass (based on minutiae locations)
FJFXPos_OCL_AverageMinutiaeQuality	Average of minutiae quality that was computed based on the OCL value around each minutiae location
FJFXPos_OCL_MinutiaeQuality_0	Percentage of minutiae quality values (based on OCL value around each minutiae location) between 0 and 20
FJFXPos_OCL_MinutiaeQuality_20	Percentage of minutiae quality values (based on OCL value around each minutiae location) between 20 and 40
FJFXPos_OCL_MinutiaeQuality_40	Percentage of minutiae quality values (based on OCL value around each minutiae location) between 40 and 60
FJFXPos_OCL_MinutiaeQuality_60	Percentage of minutiae quality values (based on OCL value around each minutiae location) between 60 and 80
FJFXPos_OCL_MinutiaeQuality_80	Percentage of minutiae quality values (based on OCL value around each minutiae location) between 80 and 100
FJFXPos_OCL_4Blocks_AverageMinQuality	Average of minutiae quality that was computed based on the mean of all OCL values around each minutiae location (4 blocks around
FJFXPos_Coherence_AvgMinQuality	Average of minutiae quality that was computed based on the coherence value of the orientation map field of the block in which the mi
FJFXPos_CMEnh_InhQual_AvgMinQual	Average of minutiae quality that was computed based on the inhomogenety quality value of the enhanced contrast map
FJFXPos_MinutiaeFusion_1	Average of fused minutiae quality that was computed based on OCL, Mu, coherence values and enhanced constrast map values
FJFXPos_AvgMinReliability_QMEnh	Average of minutiae quality that was computed on the reliability value retrieved from the enhanced quality map
FJFXPos_AvgMinReliability_QMAdv	Average of minutiae quality that was computed on the reliability value retrieved from the advanced quality map
FJFXPos_MinutiaeFusion_2	Average of fused minutiae quality that was computed based on OCL, Mu, coherence values, enhanced quality map zones and enhan
FJFXPos_QualityMapEnh_AvgMinQual	Average of minutiae quality that was computed based on the quality zones determined by the enhanced quality map
FJFXPos_LCS_AverageMinutiaeQuality	Average of minutiae quality that was computed based on block-wise LCS
FJFXPos_RVU_AverageMinutiaeQuality	Average of minutiae quality that was computed based on block-wise RVU
FJFXPos_LowFlow_AverageMinutiaeQuality	Average of minutiae quality that was computed based on block-wise values returned by the low flow map
FJFXPos_Time_All	Speed computation of minutiae quality computation values
OCL	Orientation Certainty Level (OCL) of whole image
OCL_Time	Speed computation of OCL computation
QualityMap_HighContrastBlocks	Number of blocks that have high contrast according to NFIQ1 low contrast map (re-implemented using OpenCV)
QualityMap_Time	Speed computation of quality map computation (low contrast map, enhanced orientation map, high curve map)
OrientationMap_Time	Speed computation of orientation map (without ROI filtering)
OrientationMap_ROIFilter_Time	Speed computation of orientation map determination with ROI filtering
QualityMapEnh_Time	Speed computation of enhanced quality map computation (enhanced low contrast map, enhanced orientation map, low flow map, high
QualityMapAdv_Time	Speed computation of advanced quality map computation (enhanced low contrast map, enhanced orientation map, high curve map)
LowFlowMap_Time	Speed computation of low flow map
OrientationMap_ROIFilter_CoherenceSum	Sum of all blockwise coherence values based on orientation map computation (block size 16) with applied ROI filter of ImgProcROI m
OrientationMap_ROIFilter_CoherenceRel	Relative number of all blockwise coherence values based on orientation map computation (block size 16) with applied ROI filter of Img
OrientationMap_CoherenceSum	Sum of all blockwise coherence values based on orientation map computation (block size 16) of the whole image
OrientationMap_CoherenceRel	Relative number of all blockwise coherence values based on orientation map computation (block size 16) of the whole image
QualityMap_Foreground	Number of foreground blocks based on the quality map computation (similar but not identical to NFIQ1 quality map with block size 8)
QualityMap_RelCount_1	Relative number of quality map blocks that have an assigned value of 1 (similar but not identical to NFIQ1 quality map with block size
QualityMap_RelCount_2	Relative number of quality map blocks that have an assigned value of 2 (similar but not identical to NFIQ1 quality map with block size
QualityMap_RelCount_3	Relative number of quality map blocks that have an assigned value of 3 (similar but not identical to NFIQ1 quality map with block size
QualityMap_RelCount_4	Relative number of quality map blocks that have an assigned value of 4 (similar but not identical to NFIQ1 quality map with block size
ContrastMapEnh_HighContrastBlocks	Number of high contrast blocks according to the computation results of the enhanced contrast map
ContrastMapEnh_AvgInhomogenety	Average of block-wise inhomogenety values returned by enhanced contrast map
ContrastMapEnh_AvgSmoothness	Average of block-wise smoothness values returned by enhanced contrast map
ContrastMapEnh_AvgUniformity	Average of block-wise uniformity values returned by enhanced contrast map
ContrastMapEnh_AvgQuality	Average of block-wise quality values based on the returned inhomogenety, uniformity and smoothness values of the enhanced contra
ContrastMapEnh_Time	Speed computation of enhanced contrast map computation
QualityMapEnh_HighFlowBlocks	Number of high flow blocks determined by the enhanced quality map (low flow map)
QualityMapEnh_LowFlowBlocks	Number of low flow blocks determined by the enhanced quality map (low flow map)
QualityMapEnh_Foreground	Number of foreground blocks based on the quality map computation (similar but not identical to NFIQ1 quality map with block size 8)
QualityMapEnh_RelCount_1	Relative number of enhanced quality map blocks that have an assigned value of 1 (similar but not identical to NFIQ1 quality map with
QualityMapEnh_RelCount_2	Relative number of enhanced quality map blocks that have an assigned value of 2 (similar but not identical to NFIQ1 quality map with
QualityMapEnh_RelCount_3	Relative number of enhanced quality map blocks that have an assigned value of 3 (similar but not identical to NFIQ1 quality map with
QualityMapEnh_RelCount_4	Relative number of enhanced quality map blocks that have an assigned value of 4 (similar but not identical to NFIQ1 quality map with
QualityMapAdv_Foreground	Number of foreground blocks based on the quality map computation (similar but not identical to NFIQ1 quality map with block size 8)
QualityMapAdv_RelCount_1	Relative number of advanced quality map blocks that have an assigned value of 1 (similar but not identical to NFIQ1 quality map with
QualityMapAdv_RelCount_2	Relative number of advanced quality map blocks that have an assigned value of 2 (similar but not identical to NFIQ1 quality map with
QualityMapAdv_RelCount_3	Relative number of advanced quality map blocks that have an assigned value of 3 (similar but not identical to NFIQ1 quality map with
QualityMapAdv_RelCount_4	Relative number of advanced quality map blocks that have an assigned value of 4 (similar but not identical to NFIQ1 quality map with
LowFlowMap24_HighFlowBlocks	Number of high flow blocks determined by the low flow map (block size 24 x 24)
LowFlowMap24_Time	Speed computation of low flow map with block size 24 x 24
LowFlowMap32_HighFlowBlocks	Number of high flow blocks determined by the low flow map (block size 32 x 32)
LowFlowMap32_Time	Speed computation of low flow map with block size 32 x 32
Gab	Gabor feature
GSh	Gabor Shen feature
LCS	Local Clarity Score (LCS) feature
OCL_S	Orientation Certainty Level (OCL) feature based on Sobel filters
OCL_CD	Orientation Certainty Level (OCL) feature based on centered differences
RVU_P	Ridge Valley Uniformity (RVU) feature with padding (block size 32)
RVU_NP	Ridge Valley Uniformity (RVU) feature without padding (block size 32)
OF	Orientation Flow (OF) feature
RPS	Radial Power Spectrum (RPS) feature
FDA	Frequency Domain Analysis (FDA) feature

Feature selection

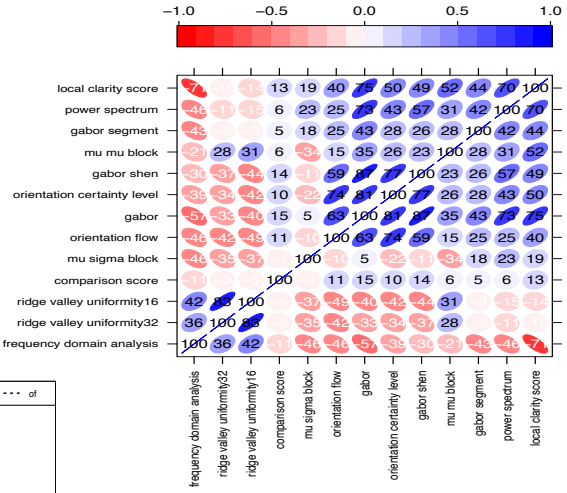


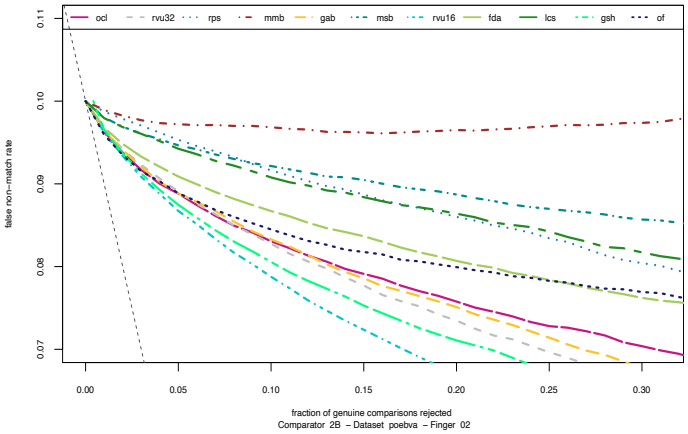
Feature selection

Predictive power of each feature

Correlations among features

Random Forest variable importance





Feature selection

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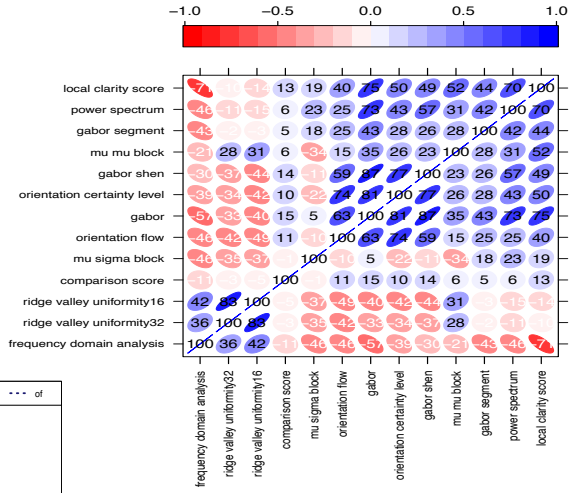
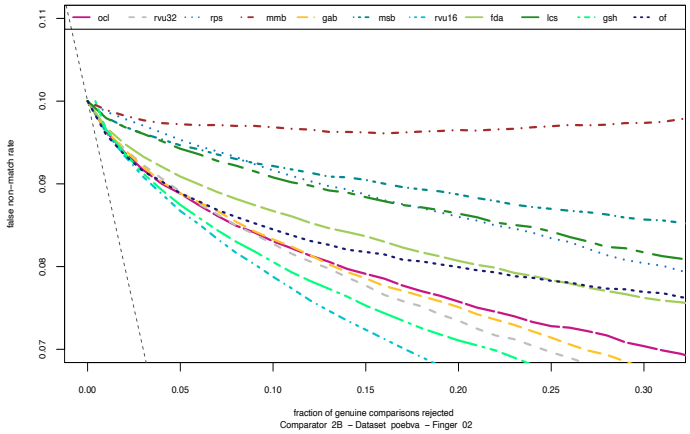
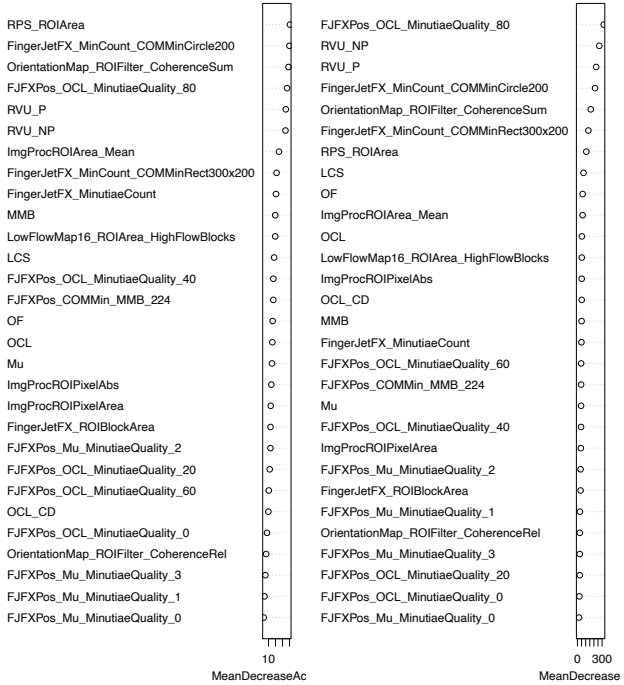
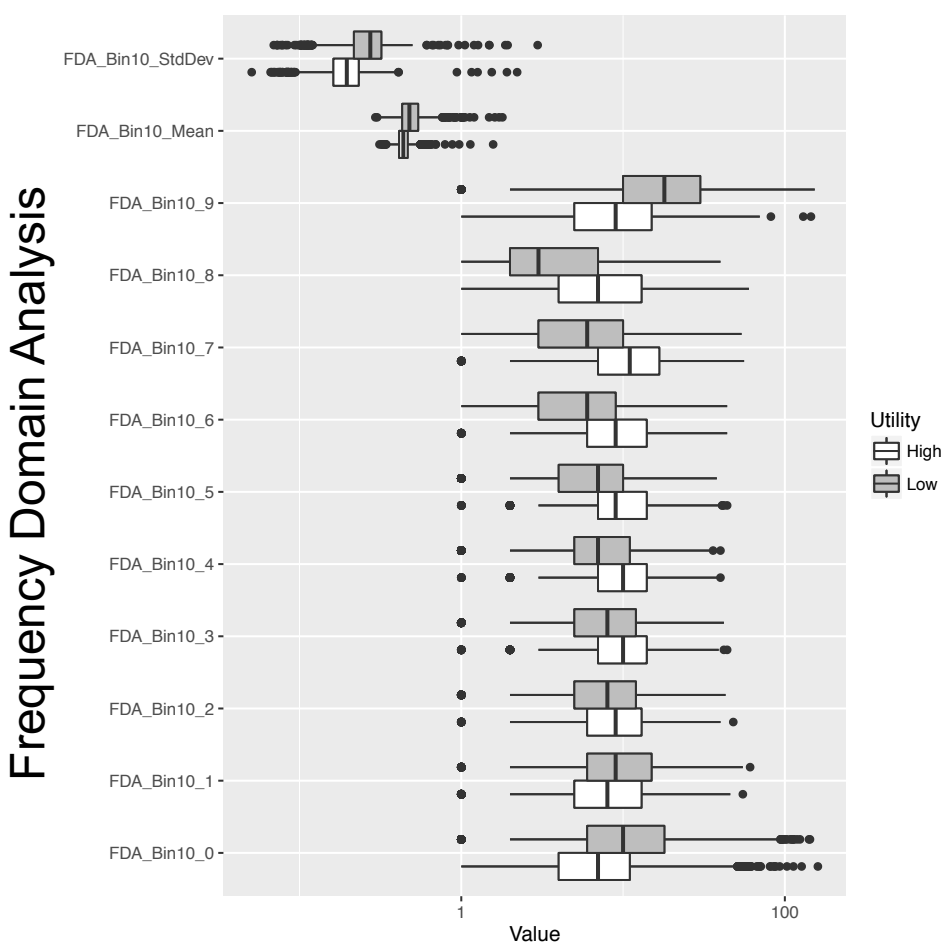
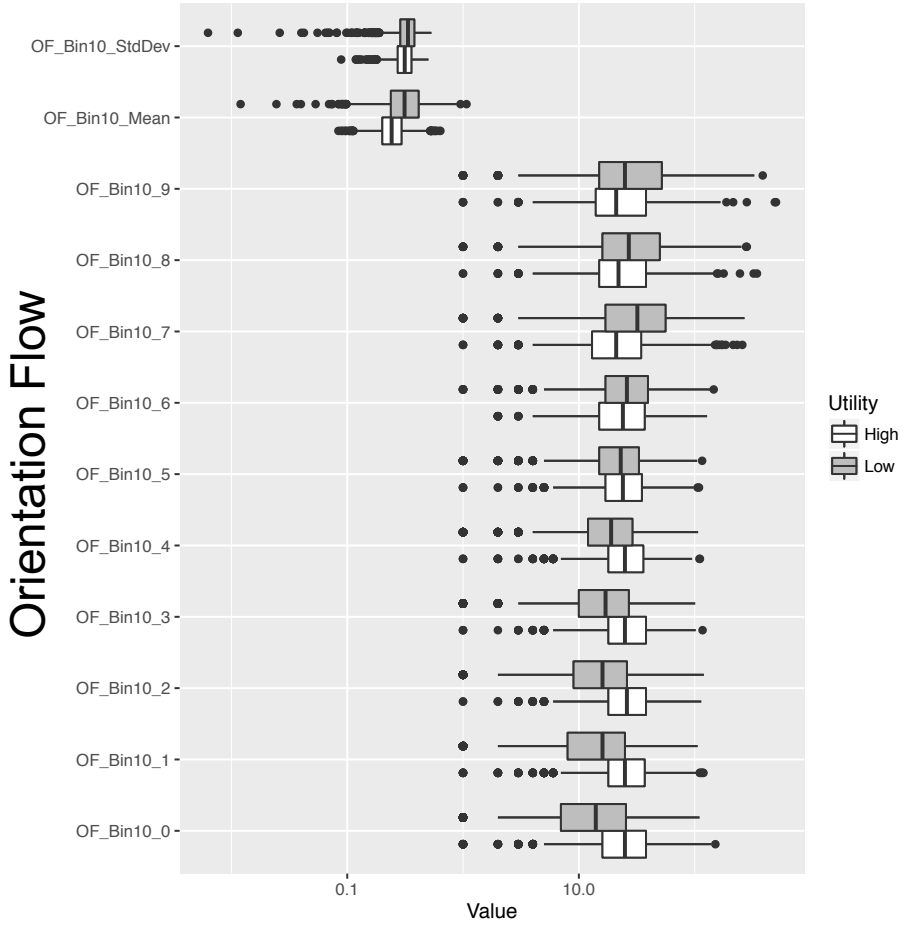






NFIQ 2.0 Features





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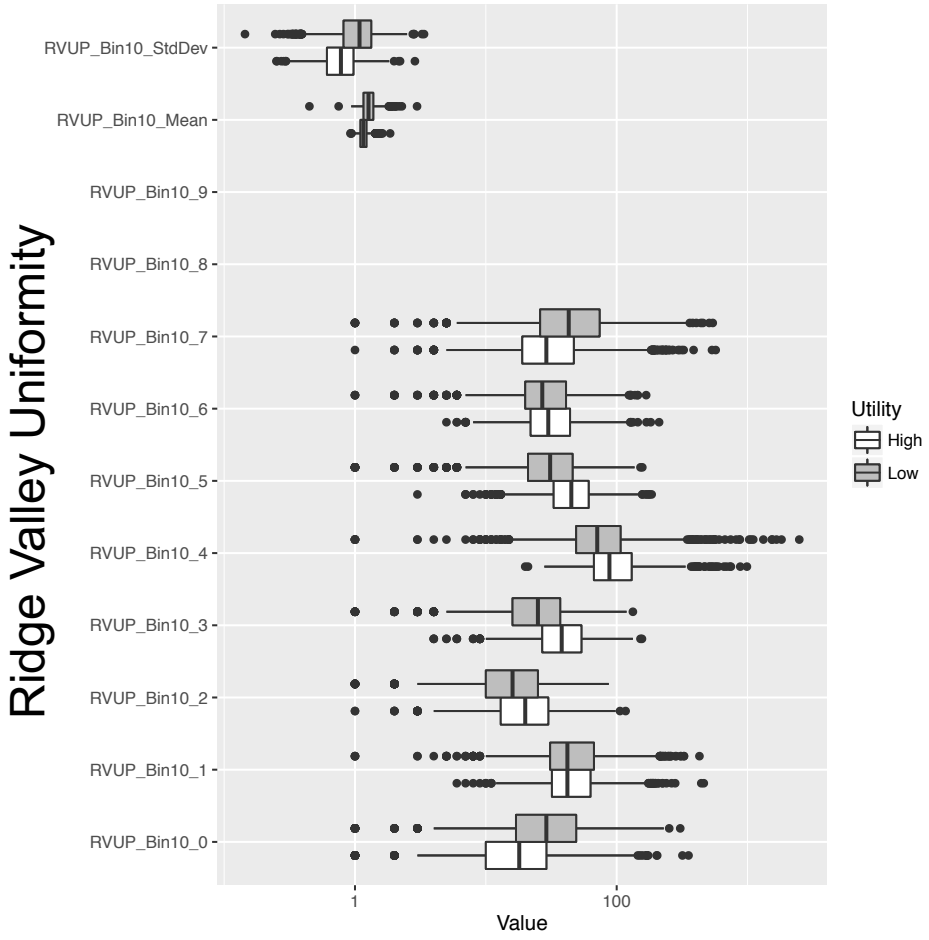
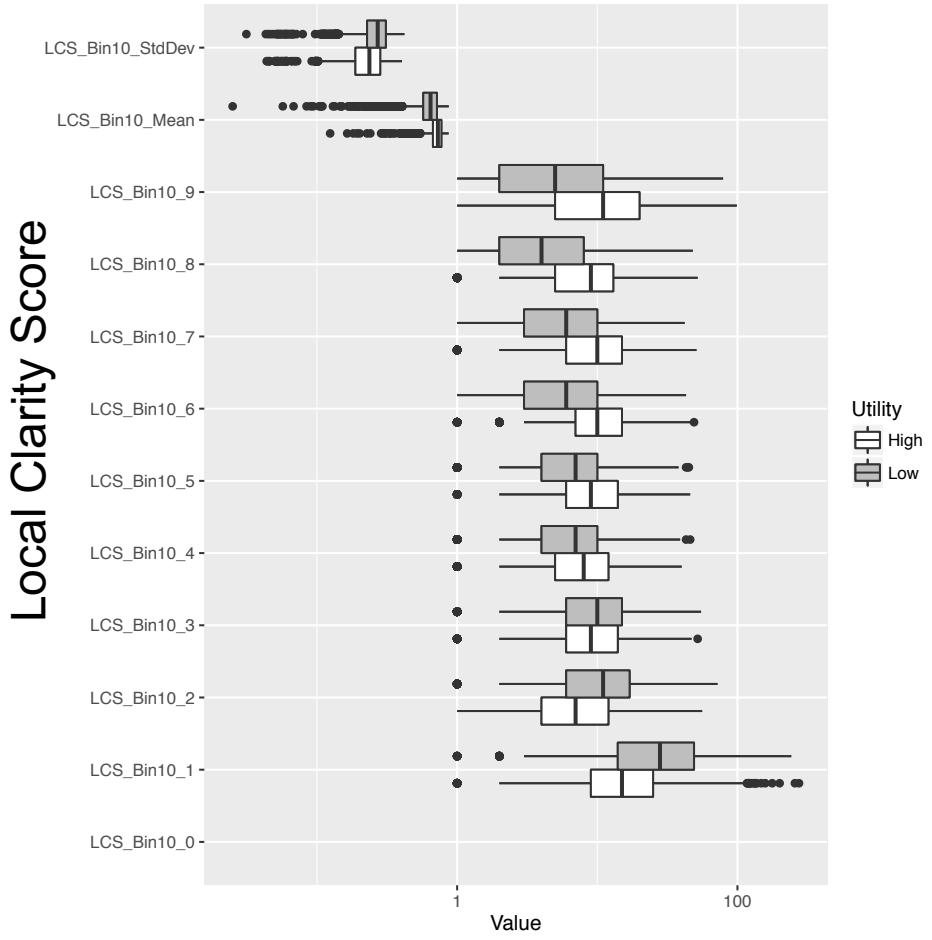
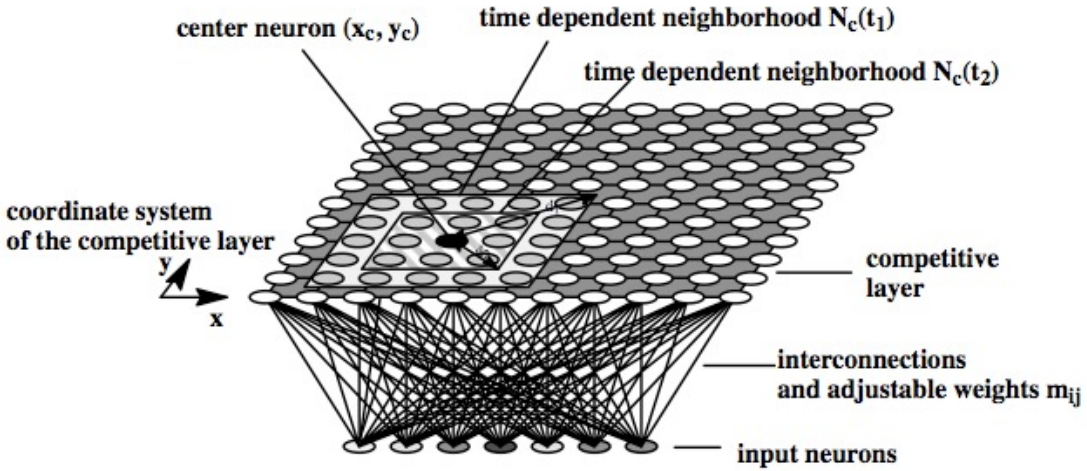
NFIQ 2.0 Features







MACHINE LEARNING

We examined:

Random Forest

Support vector machine

K-nearest neighbor

Machine Learning

Random Forest

- Ensemble classifier using stochastic process
  - Uses vote to determine class memberships
  - Provides class probability in predictions
  - Analysis of features importance and their ranking
    - We used this to do our final feature selection

Two class prediction

- High vs. Low performers
  - 1: High performers are images that result in high genuine scores and have NFIQ1=1 with activation score > 0.7.
    - genscore > $CDF^{-1}(0.9)$ & NFIQ1.0 =1
  - 0: Low performers are images that result in false reject and have NFIQ 1.0=5 with activation score > 0.9.
    - FRR at Threshold at FMR=0.0001
  - Training data: intersection of images in Class 0 (or Class 1) across all providers
  - Quality score is the probability that a given image belongs to class 1.
- Map quality score to recognition rate.

Training

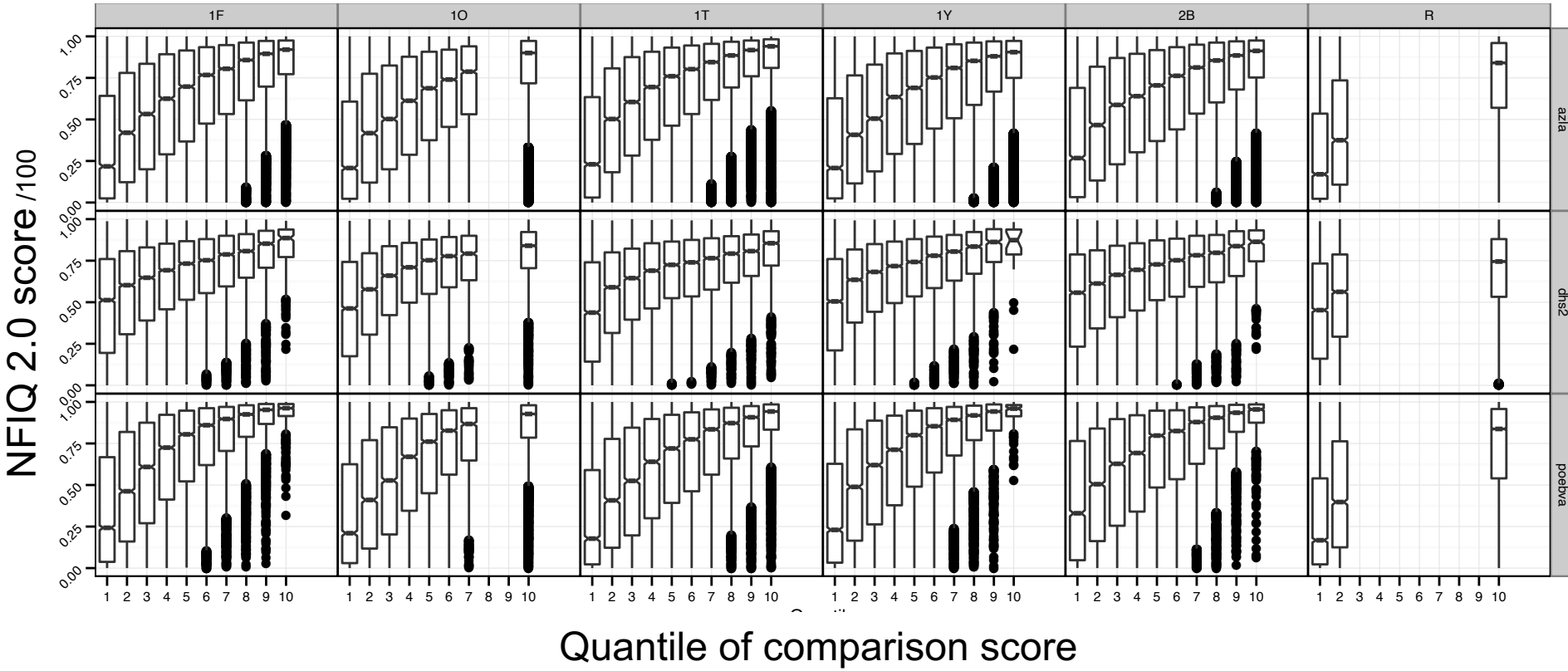
- Features: image processing + #minutiae + minutiae quality
- ~3500 samples in each of the low and high performers classes
- 1000 trees in forest

Test

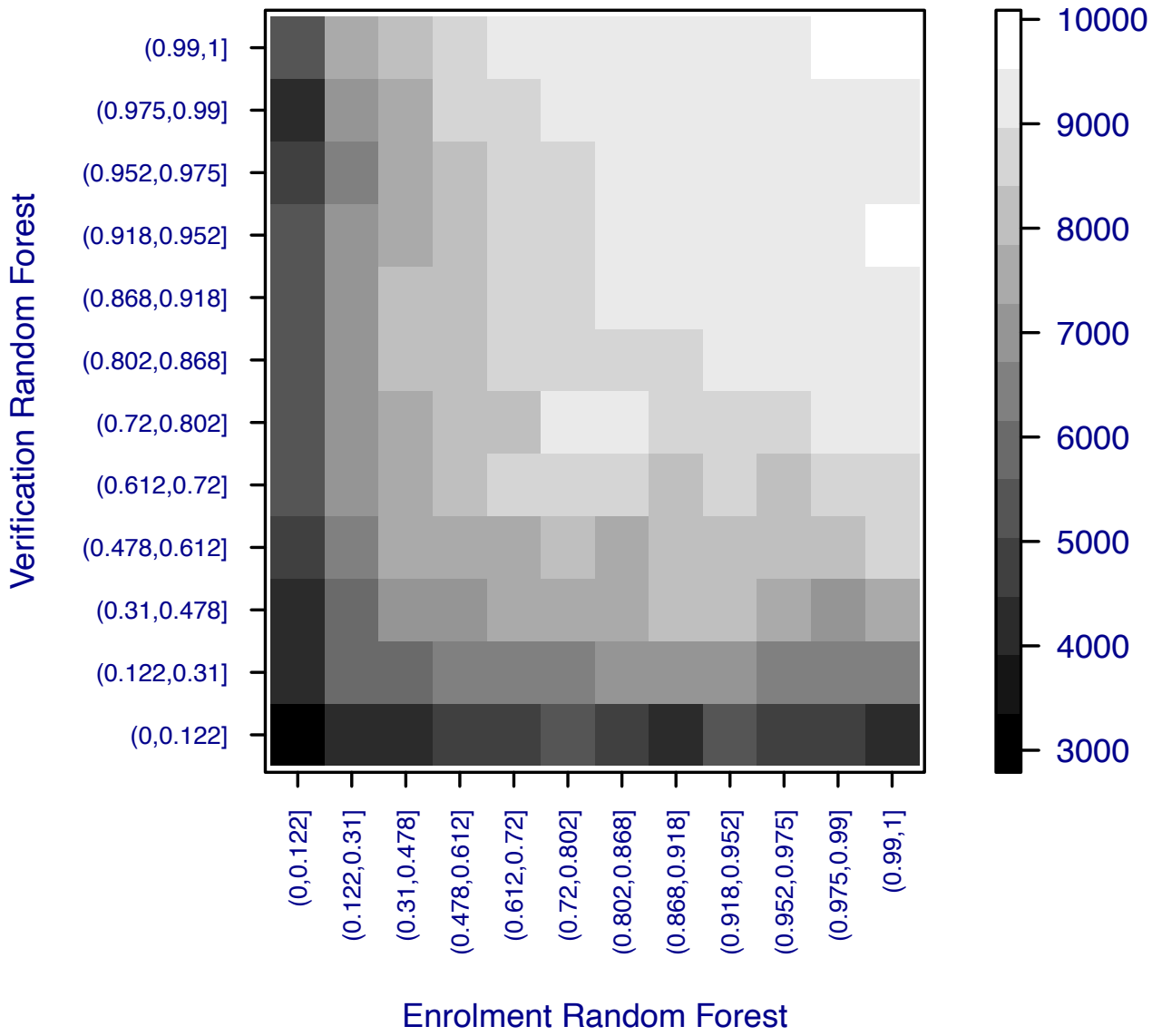
- 75000 comparison scores

So, Does It Work?

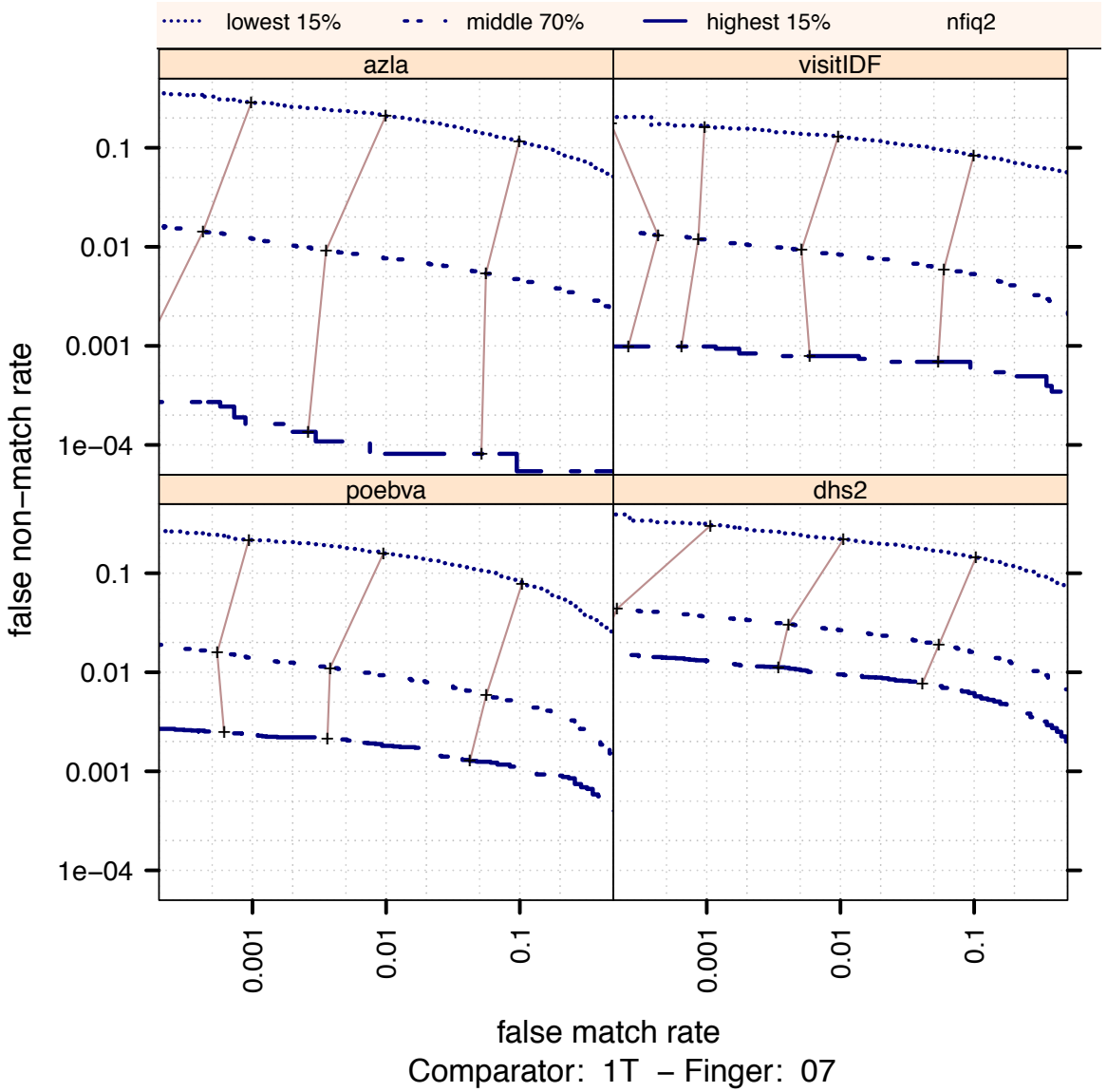
NFIQ 2.0 vs genuine score



Pairwise performance

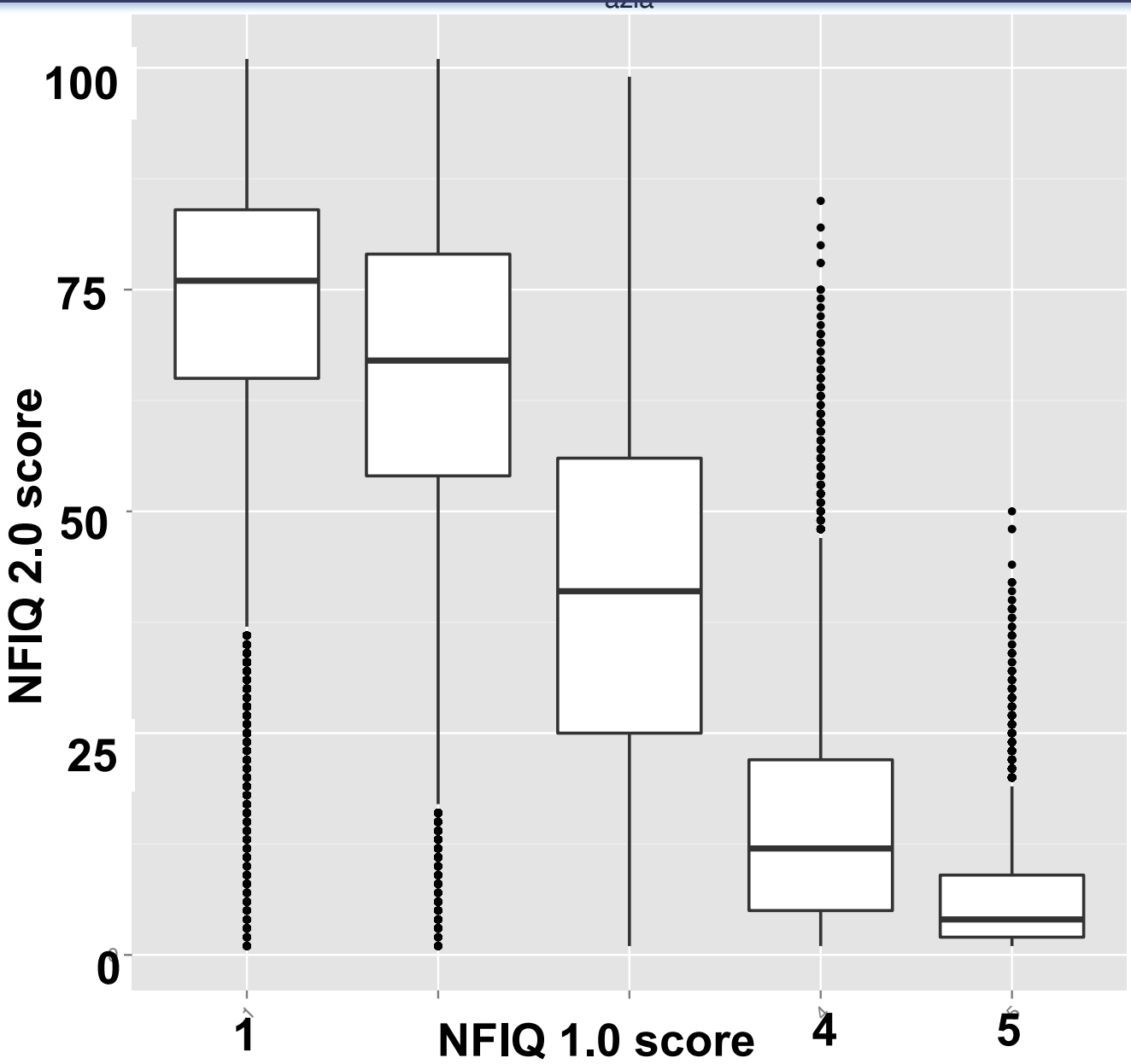


NFIQ 2.0 predictive of performance

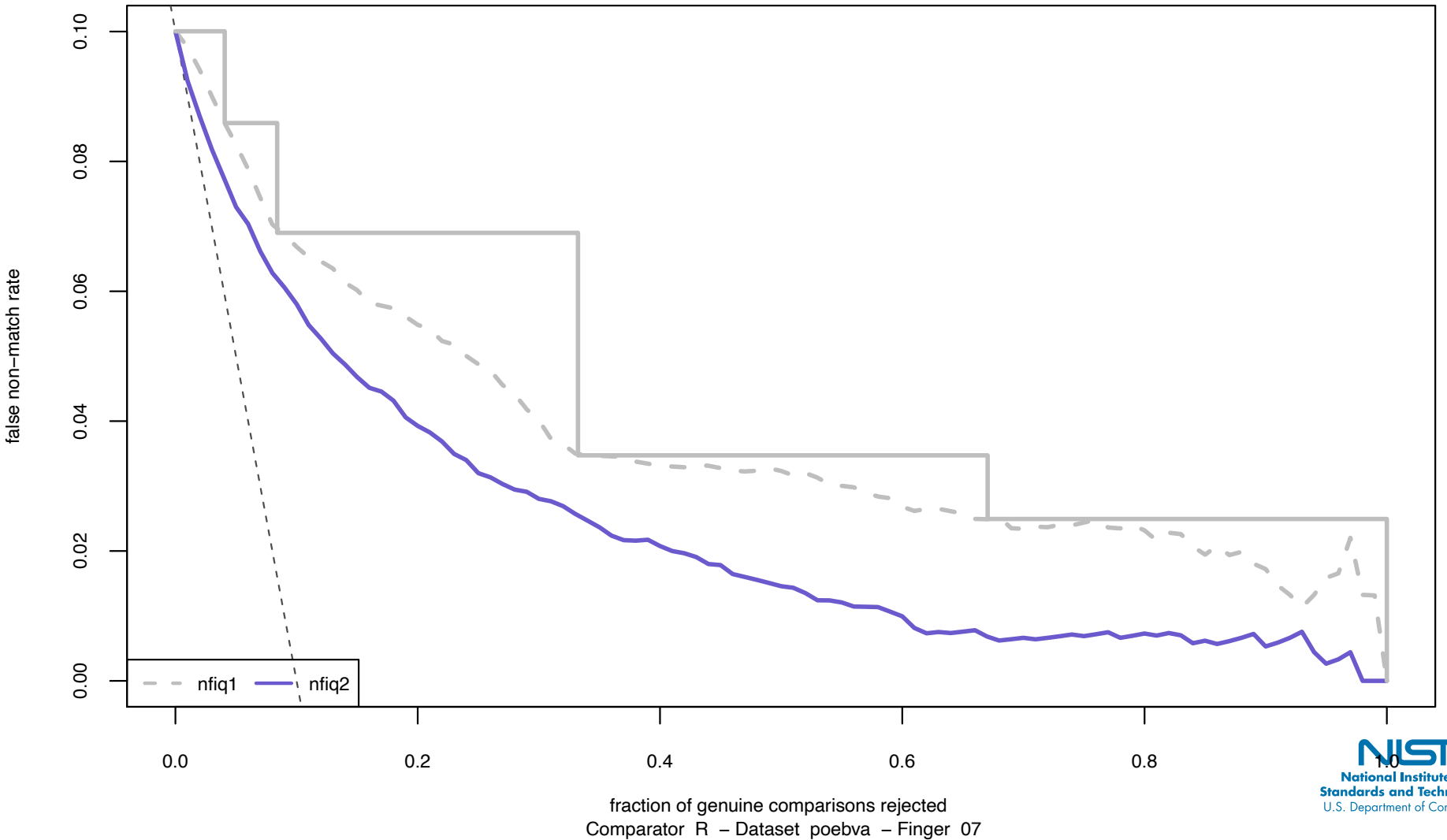


NFIQ 1.0 VS NFIQ 2.0

NFIQ 1.0 vs NFIQ 2.0



NFIQ 1.0 vs. 2.0 performance



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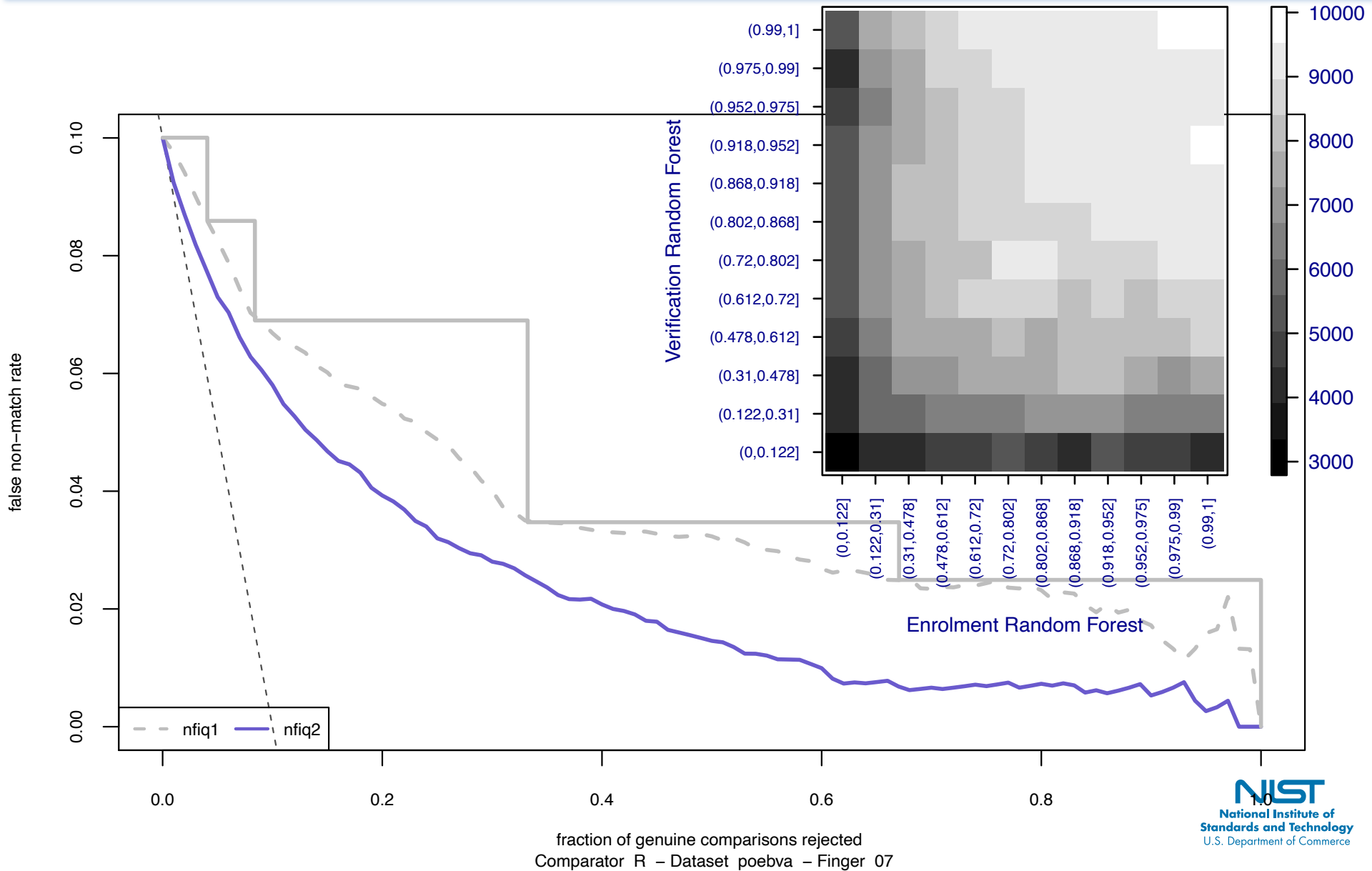
NFIQ 1.0 vs. 2.0 performance



Comparator R – Dataset poebva – Finger 07

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At a glance

NFIQ 1.0

- 5 levels.
  - 1(highest) to 5(lowest)
- 11 features
- Comparison scores of 3 algorithms used for training
- 3400 training images
- Neural network
- ~300 msec per image

NFIQ 2.0

- 100 levels
  - 0(lowest) to 100(highest)
- 14 (69) features
- Comparison scores of 7 algorithms used for training
- ~5000 training images
- Random forest
- ~ 120 msec per image
- Actionable quality
  - Flags for blank image, low contrast
- Design for NFIQ Mobile

Tools for easier adaption and migration

Calibration :: setting quality threshold

General: based on large scale operational data

- Calibration:
  - general calibration curves or tables for NFIQ 1.0 → NFIQ 2.0.
- Decision Table
  - For enrollment and verification quality threshold setting
  - Tabulation of estimated rejection rate and improvement in FNMR for each value of NFIQ 2.0 (i.e., [0,100]).

On-demand: based on application-specific data

- Calibration
  - software tools and technical guidance on how to compute calibration curves.
- Decision Table
  - Ditto above.
- This allows for optimal calibration and decision making considering data properties.

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THANK YOU.

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