On Latent Fingerprint Image Quality

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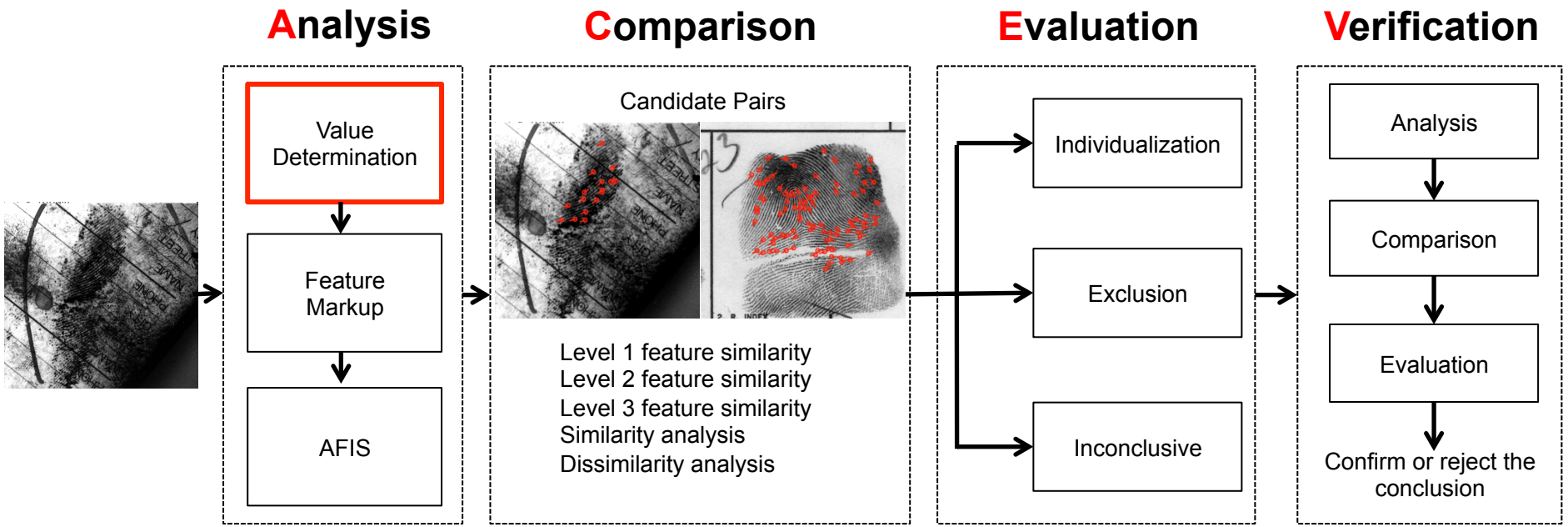
Latent Examination: ACE-V Methodology



- Latents are classified into one of three quality levels by examiners in the analysis phase:
  - Value for Individualization (VID)
  - Value for Exclusion Only (VEO)
  - No Value (NV)

Reliability of Value Determination by Examiners

Not-VID latents (either VEO or NV as determined by examiners) can be successfully identified by AFIS

Latents whose mates are retrieved at rank-1 from a database of 31,998 prints using AFIS with manually marked minutiae

1. Indovina, M., Dvornychenko, V., Hicklin, R.A., Kiebuzinski, G.I.: Evaluation of Latent Fingerprint Technologies: Extended Feature Sets [Evaluation #2]. NISTIR 7859 (2012)

Consistency of Value Determination by Examiners

- Unanimous decisions (either VID or not-VID) were made for only about 43% of the latents (356 latents were used; each latent was reviewed by 23 examiners on average)
- Only 55% of VEO decisions were repeated by the same examiner after a time gap (7 months)
- 93% of VID decisions and 85% of NV decisions were repeated

1. Bradford T. Ulery *et al*., "Repeatability and reproducibility of decisions by latent fingerprint examiners:, PloS One, vol. 7, no. 3, pp. e32800, 2012
2. Ulery, B.T., Hicklin, R.A., Buscaglia, J., Roberts, M.A.: Accuracy and Reliability of Forensic Latent Fingerprint Decisions. Proceedings of the National Academy of Sciences 108(19) (2011) 7733–7738

Latents Successfully Identified by AFIS in "Lights-Out" Mode

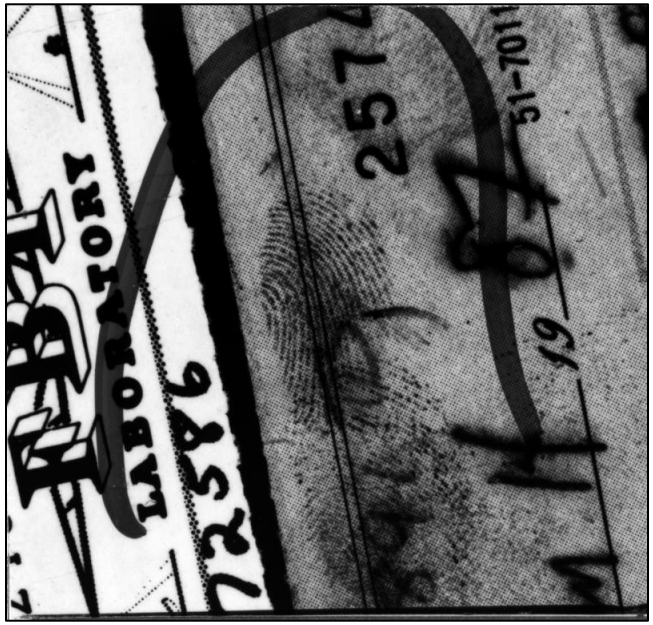
- "Lights-Out" identification system: A system that requires only fingerprint images as input (query) and returns a short list of reference prints as potential mates

Latents whose true mates are retrieved at rank-1 in the "Lights-Out" mode

Different Matchers Perform Differently

- Two different AFIS are used to match the same latent
- In some cases, the matching results are very different which suggests that a latent quality assessment algorithm should be designed for a specific matcher

Retrieval rank by AFIS 1: 1490
Retrieval rank by AFIS 2: 1



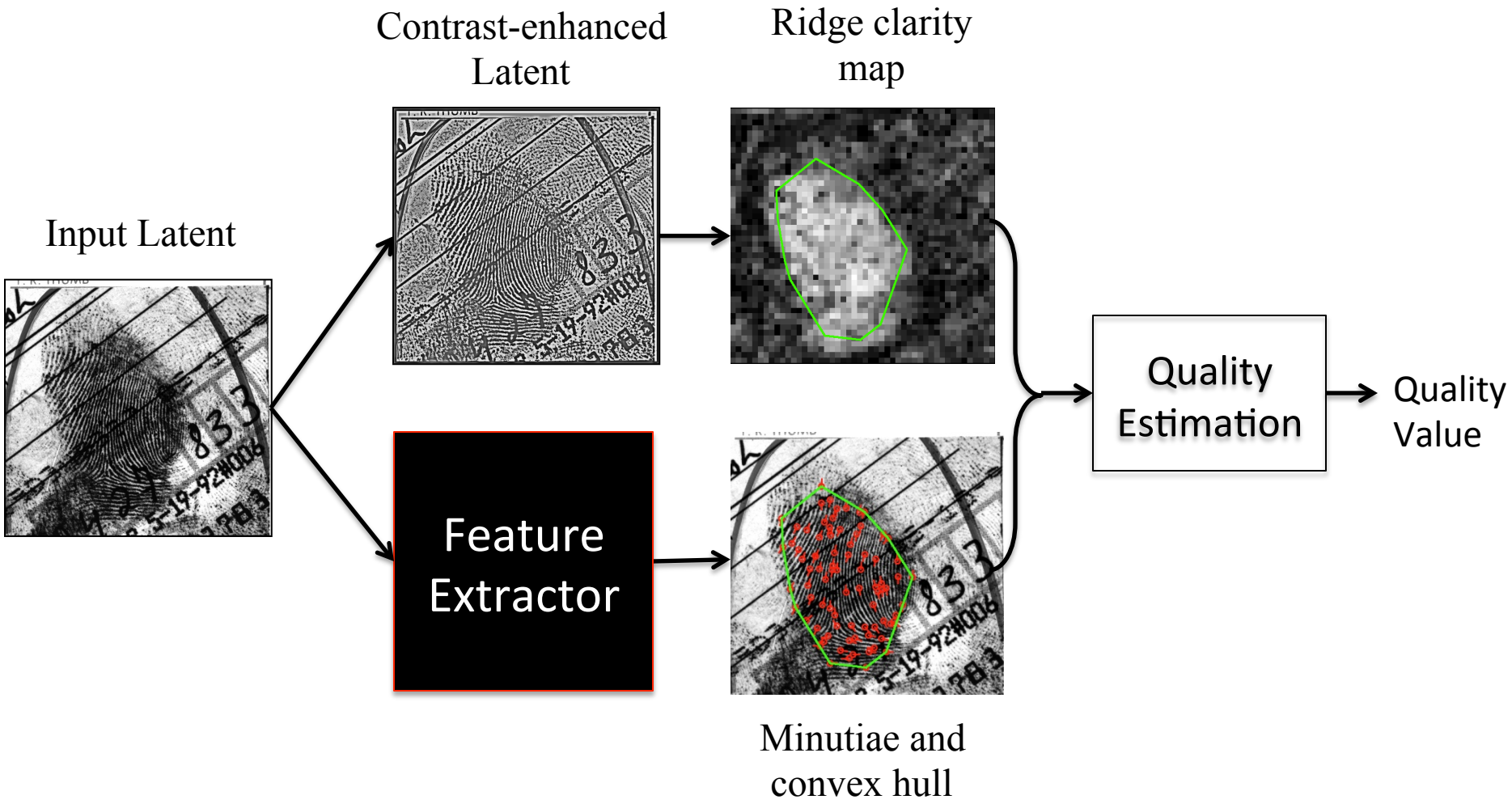
Retrieval rank by AFIS 1: 1
Retrieval rank by AFIS 2: 19355

Goals of Latent Quality Estimation

- Identify good quality latents which can be processed in "Lights-out" mode
  - 24% of latents in NIST SD27 can be processed in "lights-out" mode by an AFIS*
- Provide an objective latent quality measure and remove effect of human factors in latent value determination
- Develop a "matcher-dependent" latent quality estimator

* AFIS used in this experiment is not a latent matcher, but a state-of-the-art tenprint matcher

System Flow Chart



Contrast Enhancement

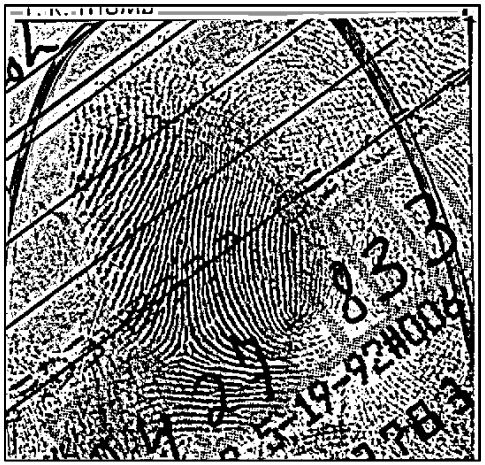
Original Image

I

Local Mean Image

$\bar{I}$

15x15 averaging filter



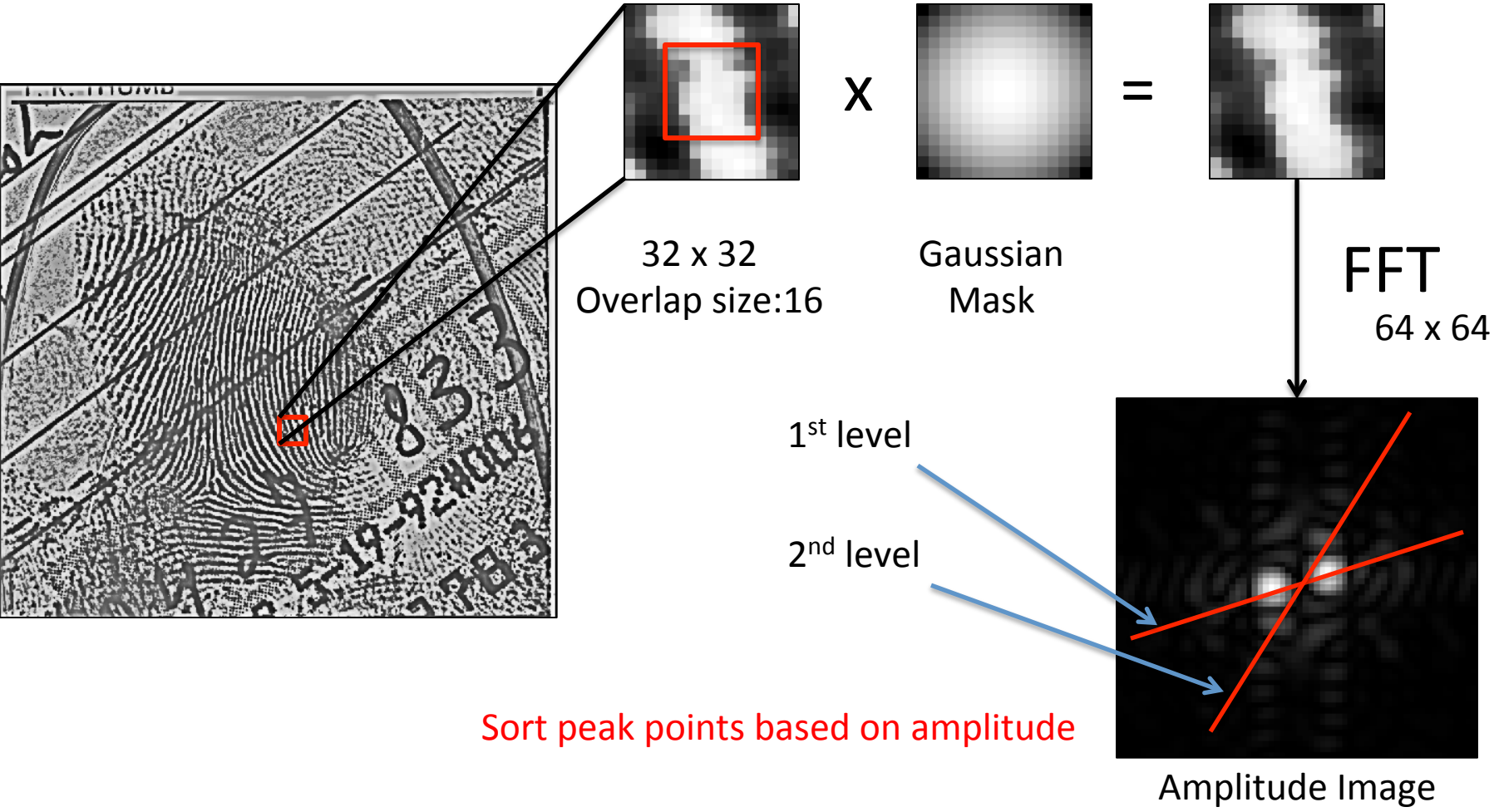
Sign Image

$\text{sign}(I - \bar{I})$

Enhanced Image

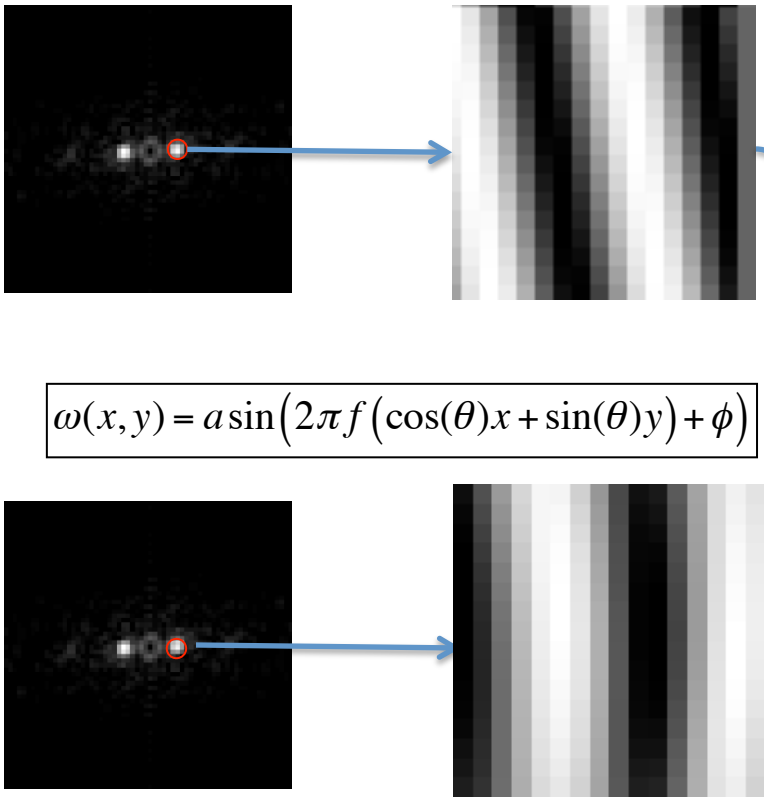
$\text{sign}(I - \bar{I}) \times \log(1 + |I - \bar{I}|)$

Frequency Domain Analysis



1. Anil K. Jain and Jianjiang Feng, “Latent Palmprint Matching”, Transactions on Pattern Analysis and Machine Intelligence, vol.31, no. 6, pp. 1032-1047, 2009

Ridge Continuity



$$\omega(x,y) = a\sin\left(2\pi f\left(\cos(\theta)x + \sin(\theta)y\right) + \phi\right)$$

$$\begin{cases} \min\left\{|\theta_1 - \theta_2|, \pi - |\theta_1 - \theta_2|\right\} < \frac{\pi}{8} \\ \left|\frac{1}{f_1} - \frac{1}{f_2}\right| \le 3 \\ \frac{1}{16}\sum_{(x,y)\in L}\left|\frac{\omega_1(x,y)}{a_1} - \frac{\omega_2(x,y)}{a_2}\right| \le 0.7 \end{cases}$$

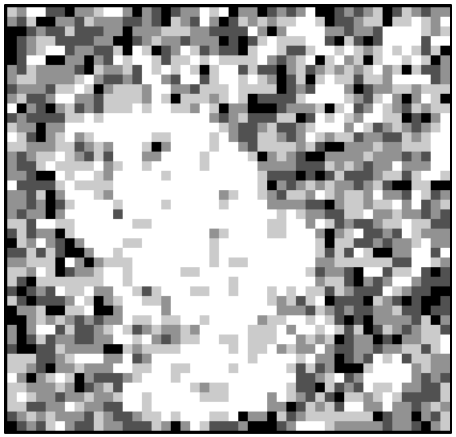
Amplitude images of two adjacent blocks

Sine wave from peak points

Continuity Conditions

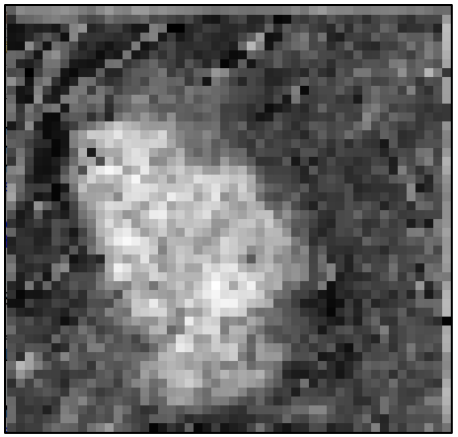
Ridge Clarity Map

Latent



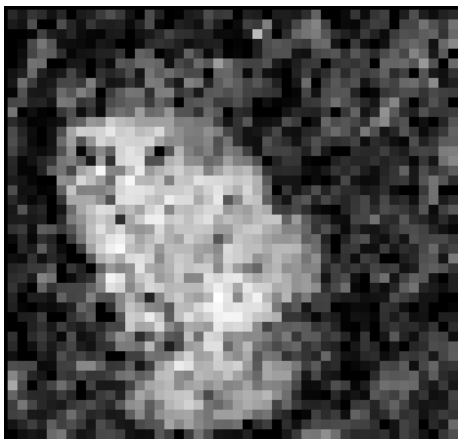
Ridge continuity map

No. of neighboring blocks which are continuous with the central block



Amplitude map

Amplitude of first level ridge wave of the central block

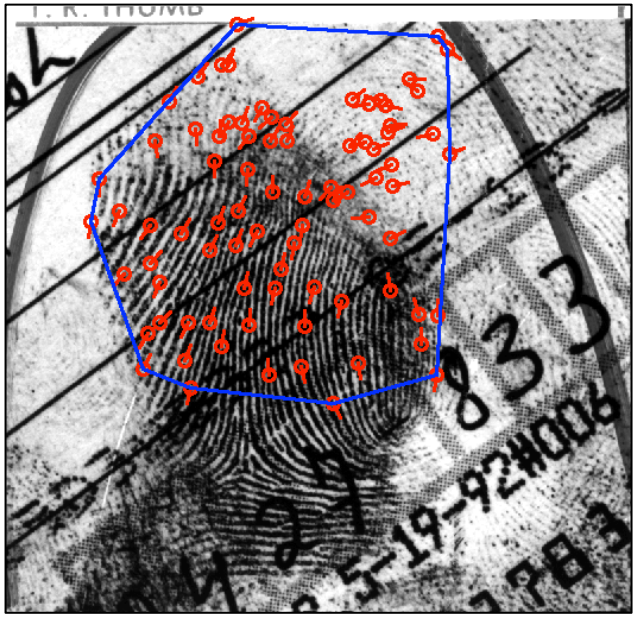


Ridge clarity map

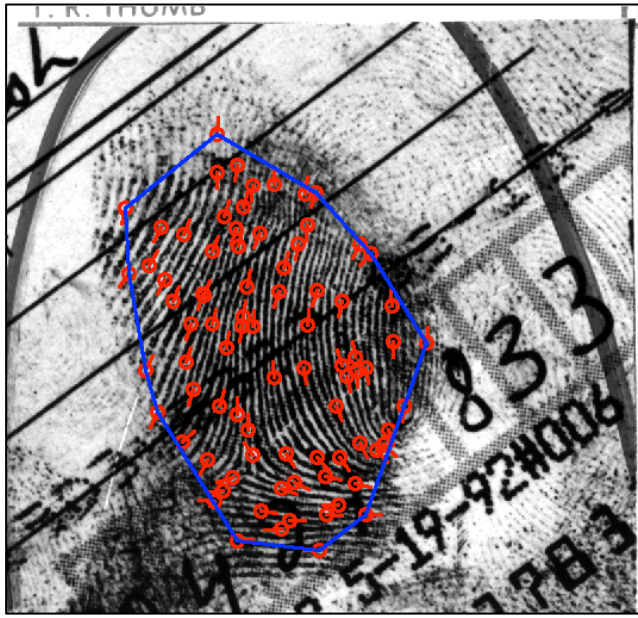
Multiplication of ridge continuity and amplitude

Minutiae Features

Latent



Minutiae extract by AFIS and convex hull

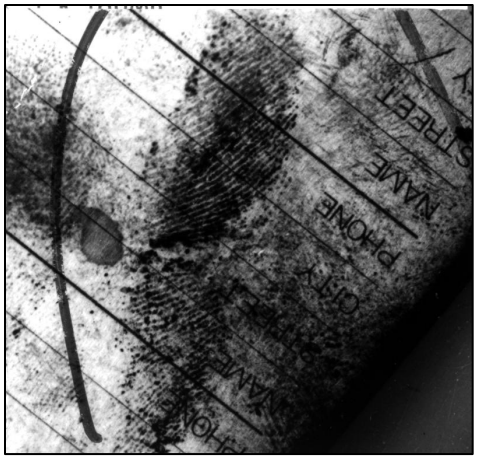


Minutiae marked by examiners and convex hull

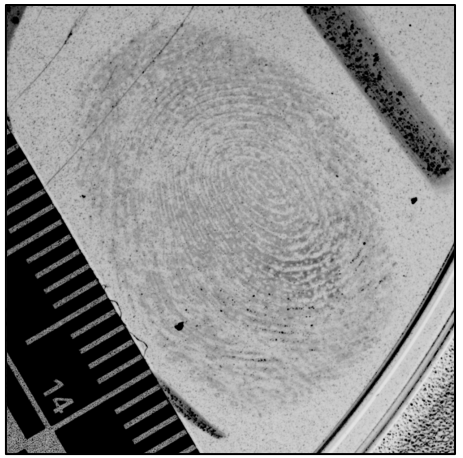
Databases and Matching Algorithm

Databases:

- NIST SD27
  - 258 latents + 258 mated prints
- WVU
  - 449 latents + 449 mated prints + 4,291 rolled prints
- NIST SD14
  - 27,000 rolled prints as background database



Latent from NIST SD27



Latent from WVU

*Latents in these two databases are different in background noise

Matcher:

- Fused matcher

$$\text{Score} = r \times \text{NormScore}_A + (1-r) \times \text{NormScore}_B$$

*We do not have access to any commercial latent matcher, so we build the 'best' latent matcher by fusing two matchers.

1. A. A. Paulino *et al.*, "Latent Fingerprint Matching using Descriptor-based Hough Transform", IEEE Transaction on Information Forensic and Security, 2012 (To appear)

Latent Value Determination as a Classification Problem

- Classification problem
  - Is a given latent VID or not-VID for identification?
  - What features are useful in predicting matching performance?

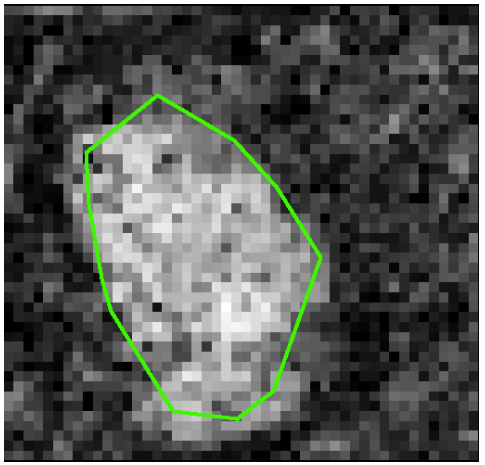
- Latent value determination by AFIS
  - A latent is VID if its mate is retrieved within rank-100 by an AFIS
  - Otherwise, it is not-VID

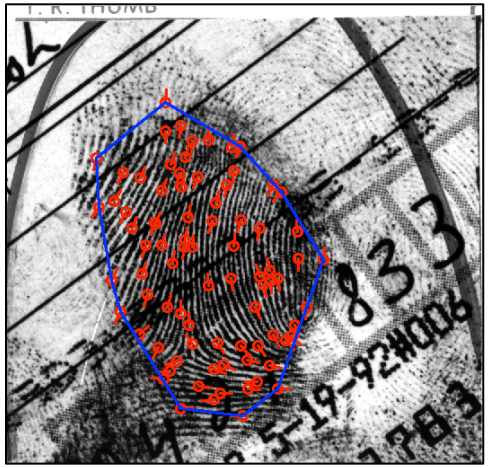
Feature Vectors

- Feature vectors
  - x1 = (N_M)
  - x2 = (Q_R, N_M, Q_M, A_M)

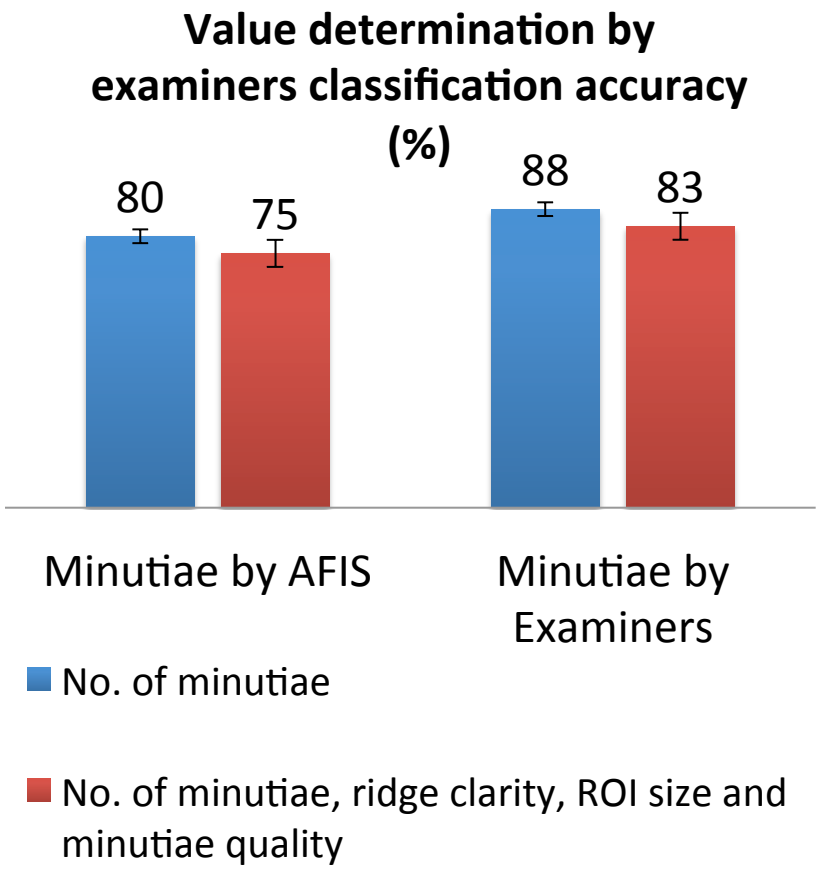
  - N_M: no. of minutiae
  - Q_R: average ridge clarity in convex hull
  - Q_M: average minutiae quality
  - A_M: size of convex hull
  - Minutiae were either extracted by AFIS or marked by latent examiners

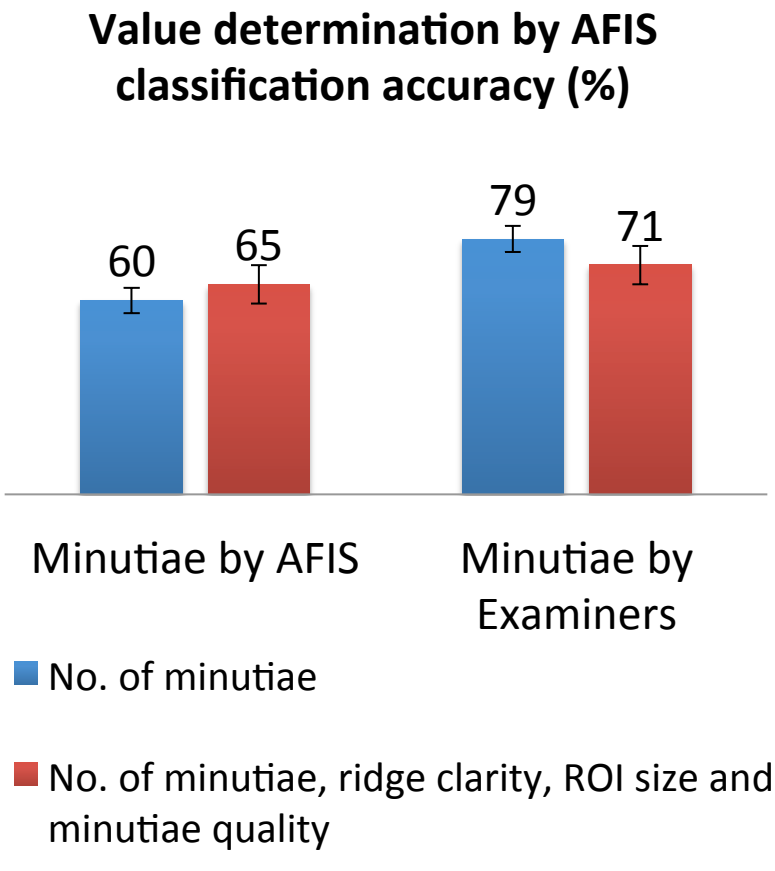
- Training and testing
  - Tree classifier
  - 10-fold cross validation





Classification Accuracy of Latent Value Determination



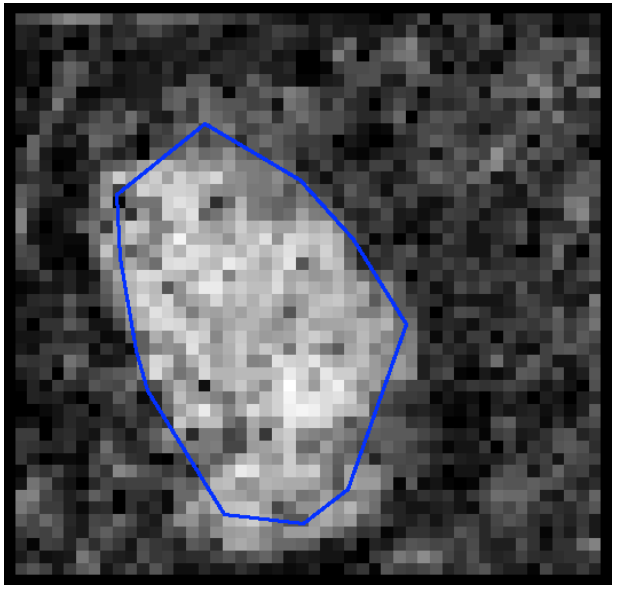


In "lights-out" mode where minutiae are extracted by AFIS and latent values are also determined by AFIS, additional features from ridge quality and minutiae properties help to improve the classification accuracy.

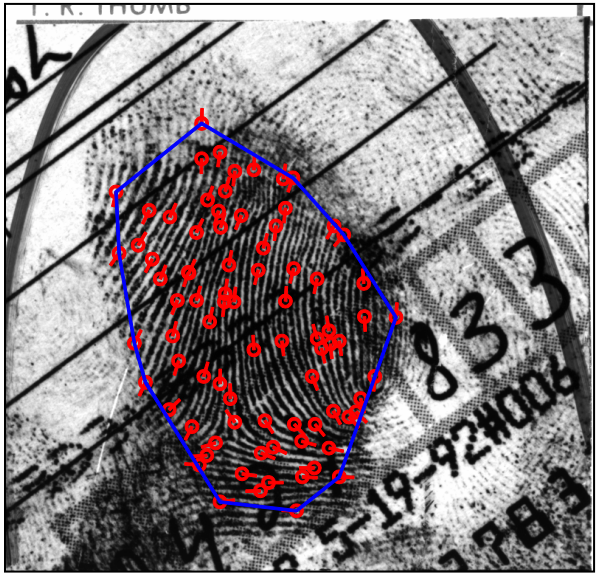
Latent Fingerprint Image Quality

Latent

Ridge clarity map



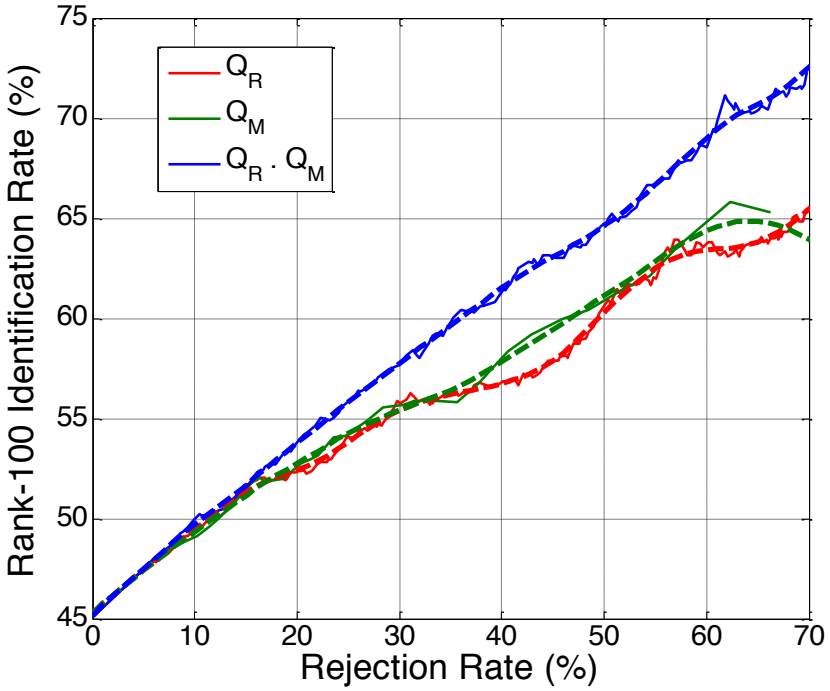
Minutiae and convex hull



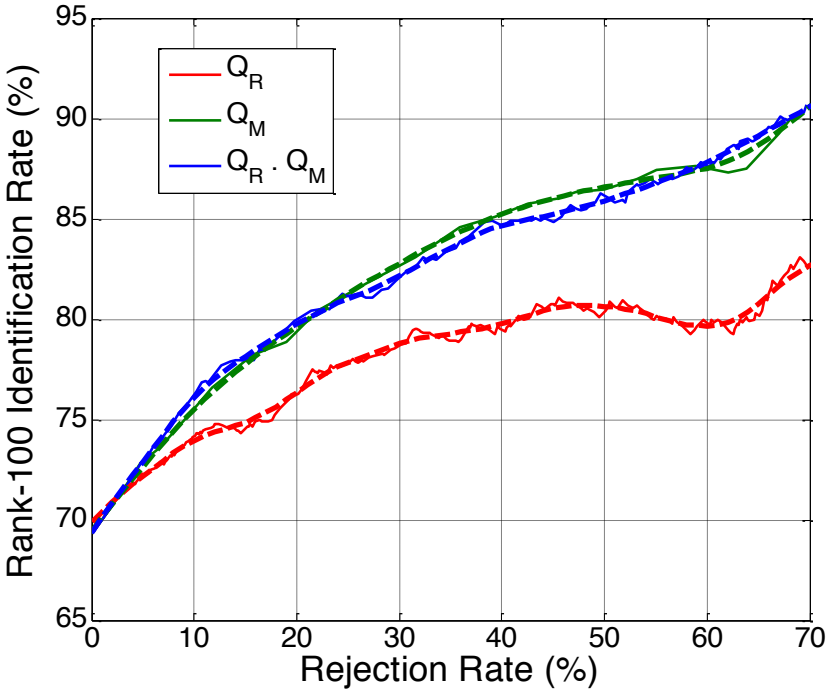
$$\text{LFIQ} = Q_R \cdot N_M$$

Q_R is the average ridge clarity in the convex hull of the minutiae and N_M is the no. of minutiae; Larger the LFIQ, better the latent quality (LFIQ>=0).

Predicting Latent Identification Performance by LFIQ



Minutiae extracted by AFIS

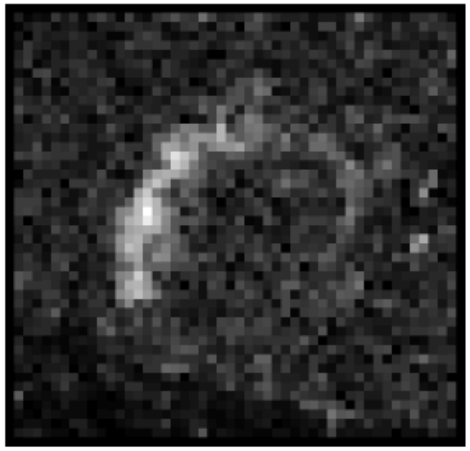


Minutiae marked by examiners

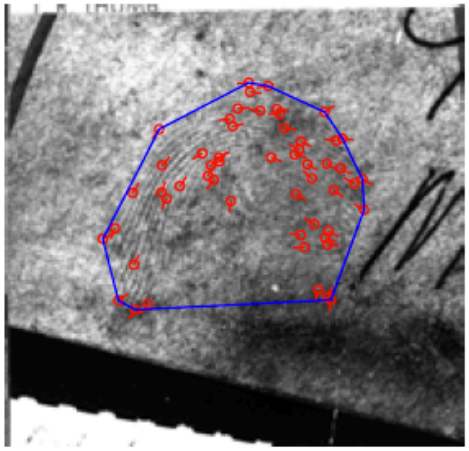
- The number of minutiae is informative in predicting latent identification performance
- Ridge clarity contributes to predicting matching performance in “lights-out” identification mode

Successful Example

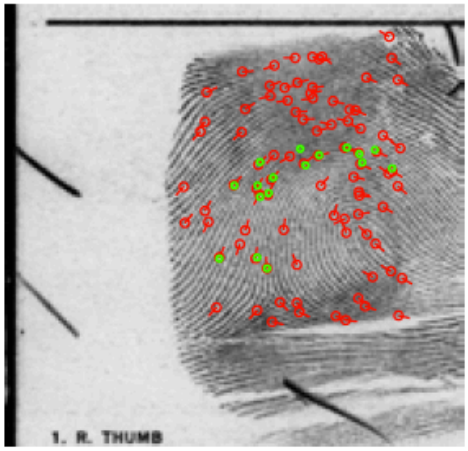
Latent in NIST SD27



Ridge Clarity Map



Minutiae set and convex hull



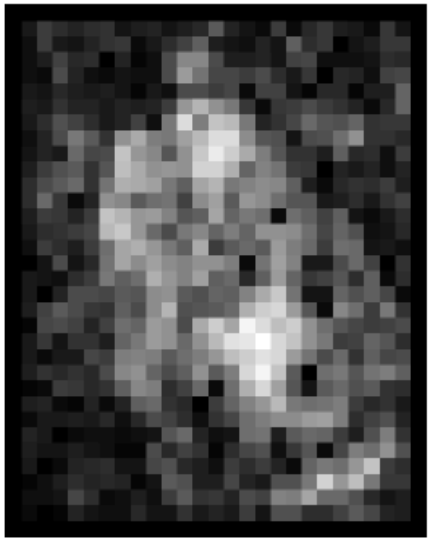
Mated reference print and minutiae

- A latent with predicted high quality value (corresponding to rejection rate of 88%) and its mate retrieved at rank 1

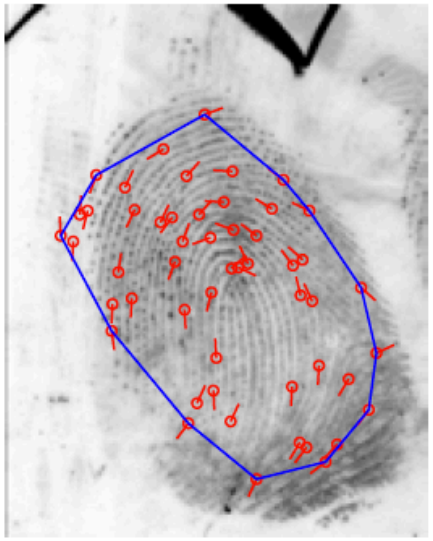
- The value determination by latent examiners was not-VID.

Failure Example

Latent in WVU: W944F08B_N



Ridge Clarity Map



Minutiae set and convex hull

Mated reference print and minutiae

- This latent is determined to be a high quality based on the proposed LFIQ (corresponding to the rejection rate of 88%), but retrieval rank of mated reference print is 4,658 due to many missed minutiae by AFIS

Conclusions and Future Work

- An objective latent value determination is defined by directly relating the latent quality to an AFIS's matching performance
- Salient features (average ridge clarity and no. of minutiae) are used to define latent fingerprint image quality (LFIQ)
- The proposed LFIQ is compared to NFIQ
  - Rank-100 identification rate is 80% when rejecting 80% of latents determined as the worst quality in NFIQ (i.e., NFIQ = 5)
  - The same rank-100 identification rate can be achieved by rejecting only 21% of latents determined as poor quality by the proposed LFIQ
- Future work
  - Designing a systematical method for feature selection for quality prediction
  - Taking rolled print quality into consideration during latent quality prediction

Thank you!