

Automatic Latent Fingerprint Value Prediction

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Aug. 11, 2016

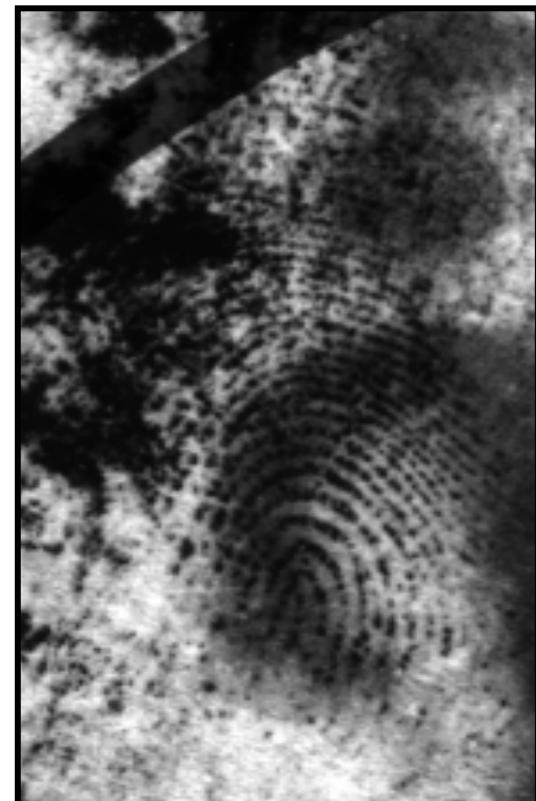
What are Latent Fingerprints?



Rolled



Plain



Latent

Challenges in Latent Matching



Poor Ridge Clarity



Partial Ridge Area



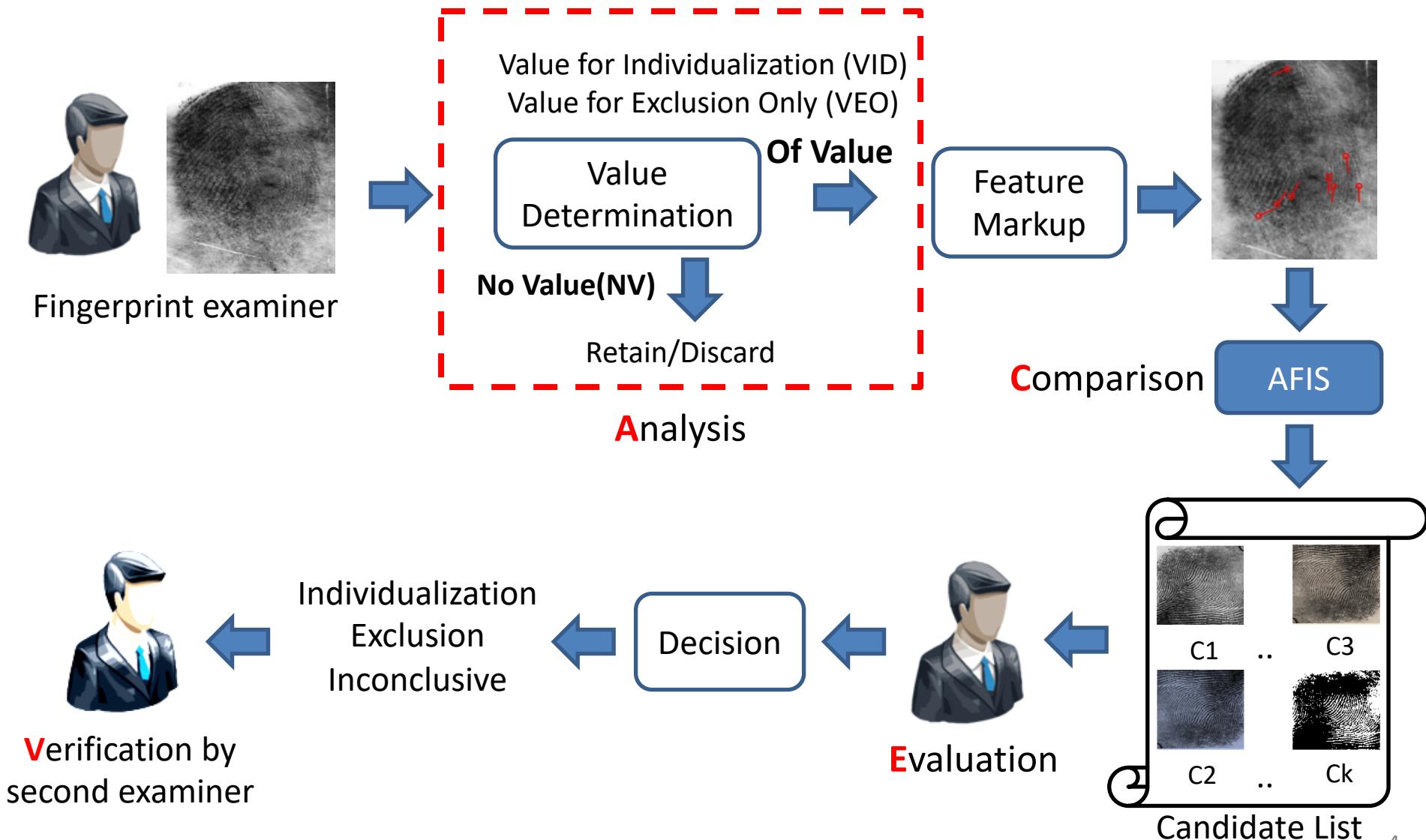
Complex Background

- AFIS Performance (Rank-1 accuracy)
 - Plain: 98.5%
 - **Latent: 67.2% (70.2% with image + markup)**

C. Watson, G. Fiumara, E. Tabassi, S. L. Cheng, P. Flanagan, W. Salamon. Fingerprint Vendor Technology Evaluation, NISTIR, 8034, 2012.

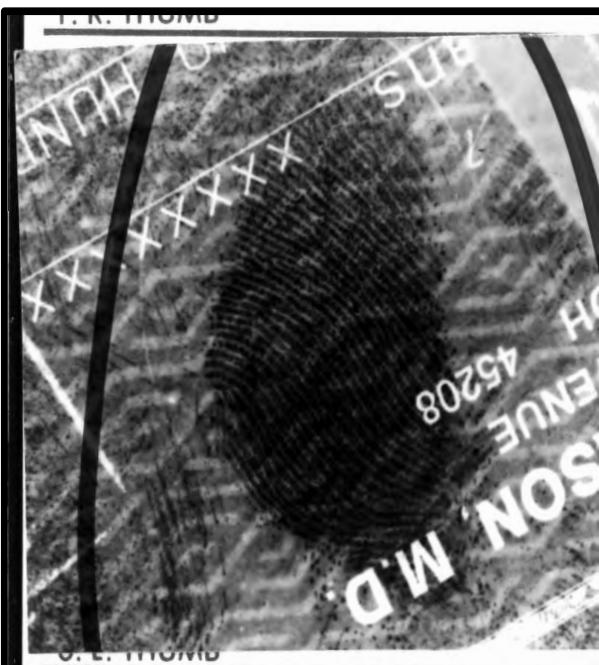
* M. Indovina, V. Dvornychenko, R. Hicklin, and G. Kiebzinski. ELFT-EFS Evaluation of Latent Fingerprint Technologies: Extended Feature Sets, NISTIR, 2012.

Latent Matching: ACE-V Protocol

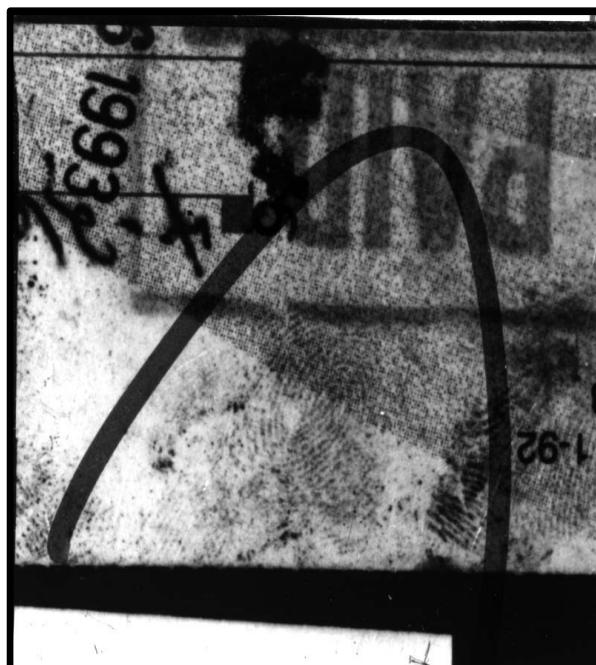


Latent Fingerprint Value

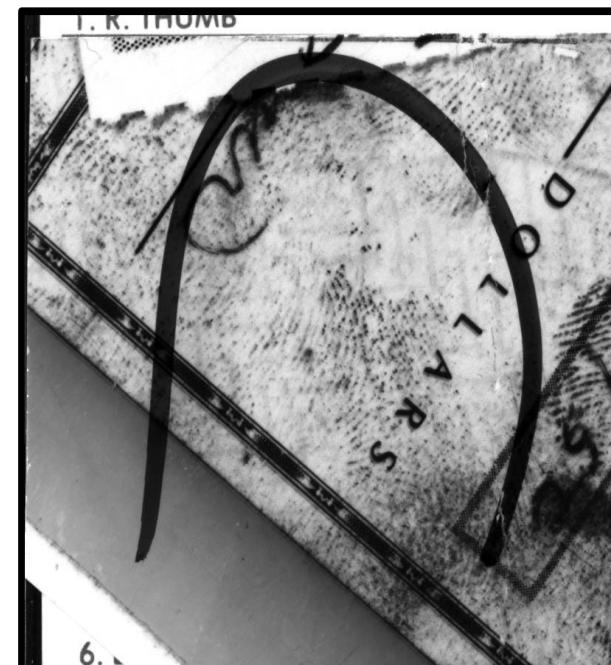
- Presumably based on two factors:
 - Image quality (e.g., clarity of friction ridges)
 - Information content (e.g., no. of minutiae)



VID
(Value for Identification)

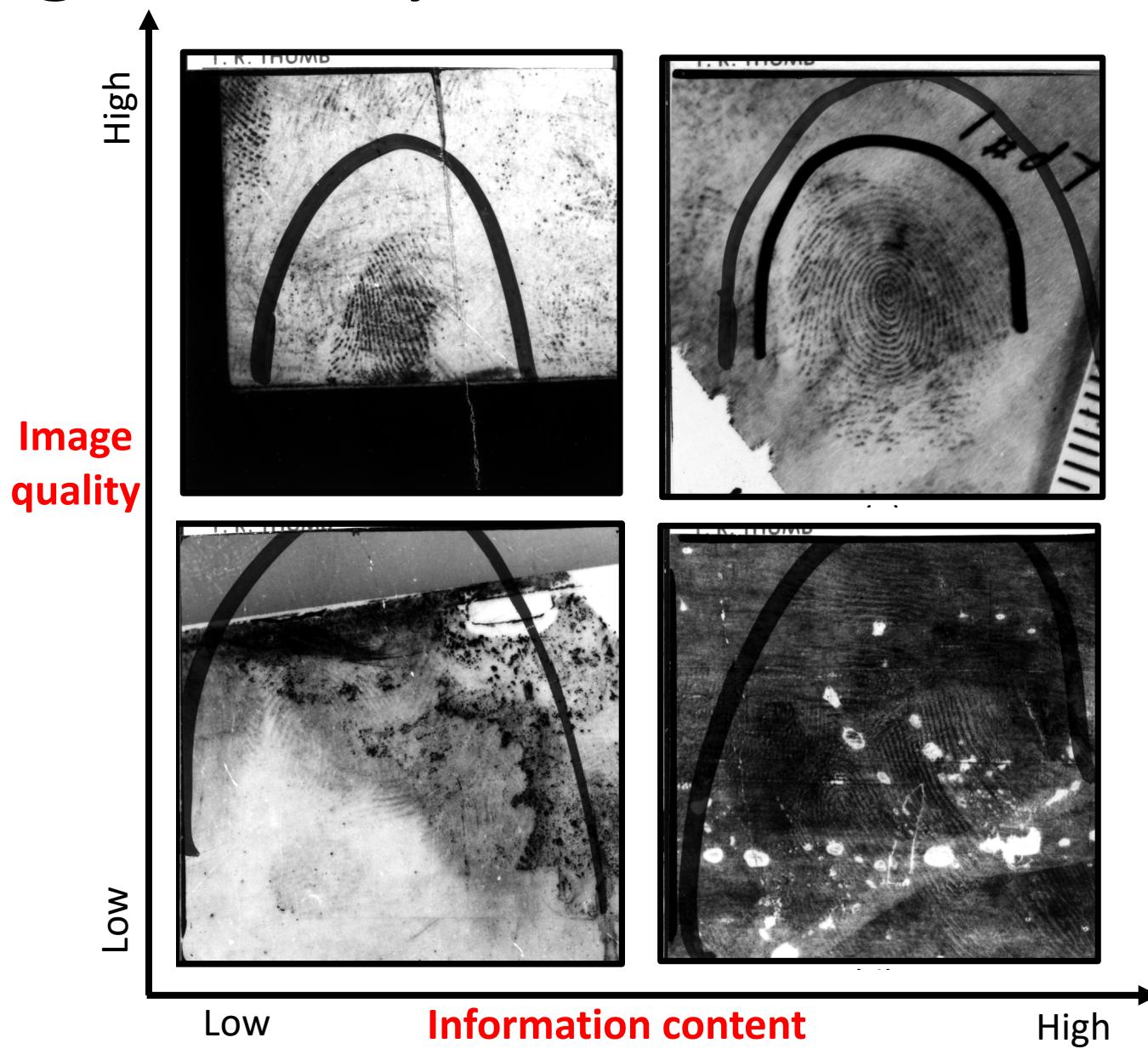


VEO
(Value for Exclusion Only)



NV
(No Value)

Image Quality v. Information Content



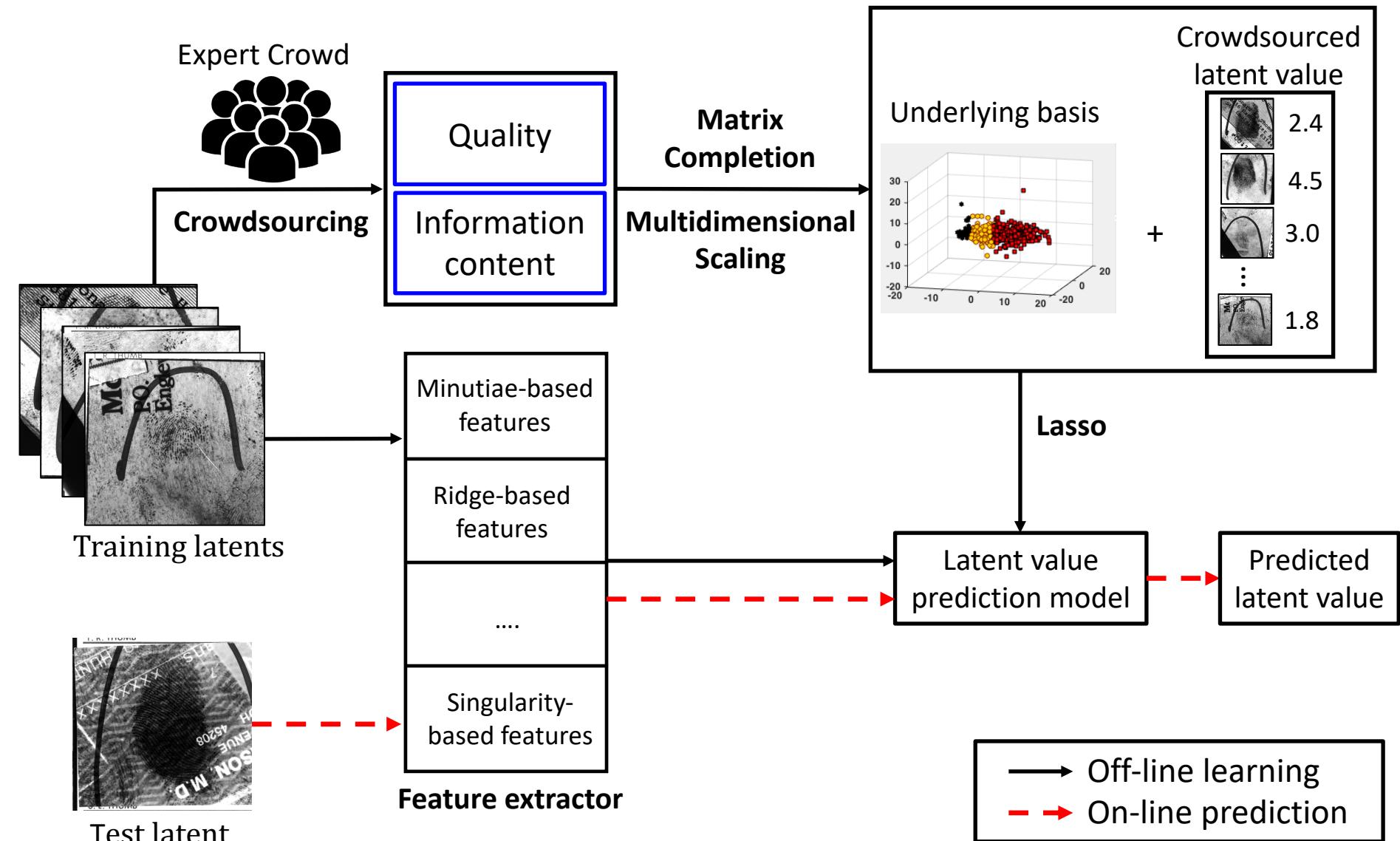
Limitations of Examiner Value Determination

- Highly subjective
 - repeatability (intra-examiner variability): 84.6%
 - reproducibility (inter-examiner similarity): 75.2%
- Depends upon examiner's skill and experience
- Time-consuming

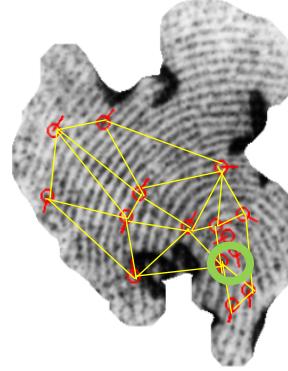
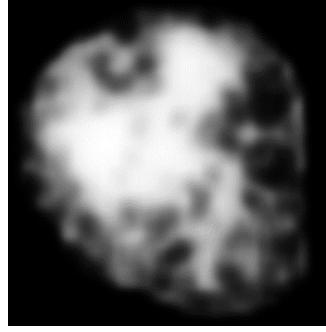
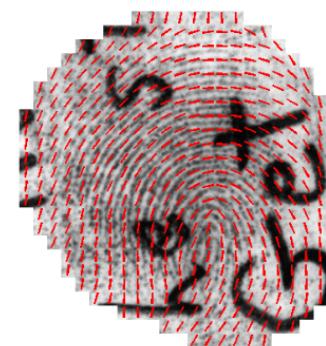
Need for automatic value determination

[1] Ulery et al., "Repeatability and reproducibility of decisions by latent fingerprint examiners," PloS one, 7(3):e32800, 2012.
[2] Ulery et al., "Accuracy and reliability of forensic latent fingerprint decisions," PNAS, 108(19):7733–7738, 2011.

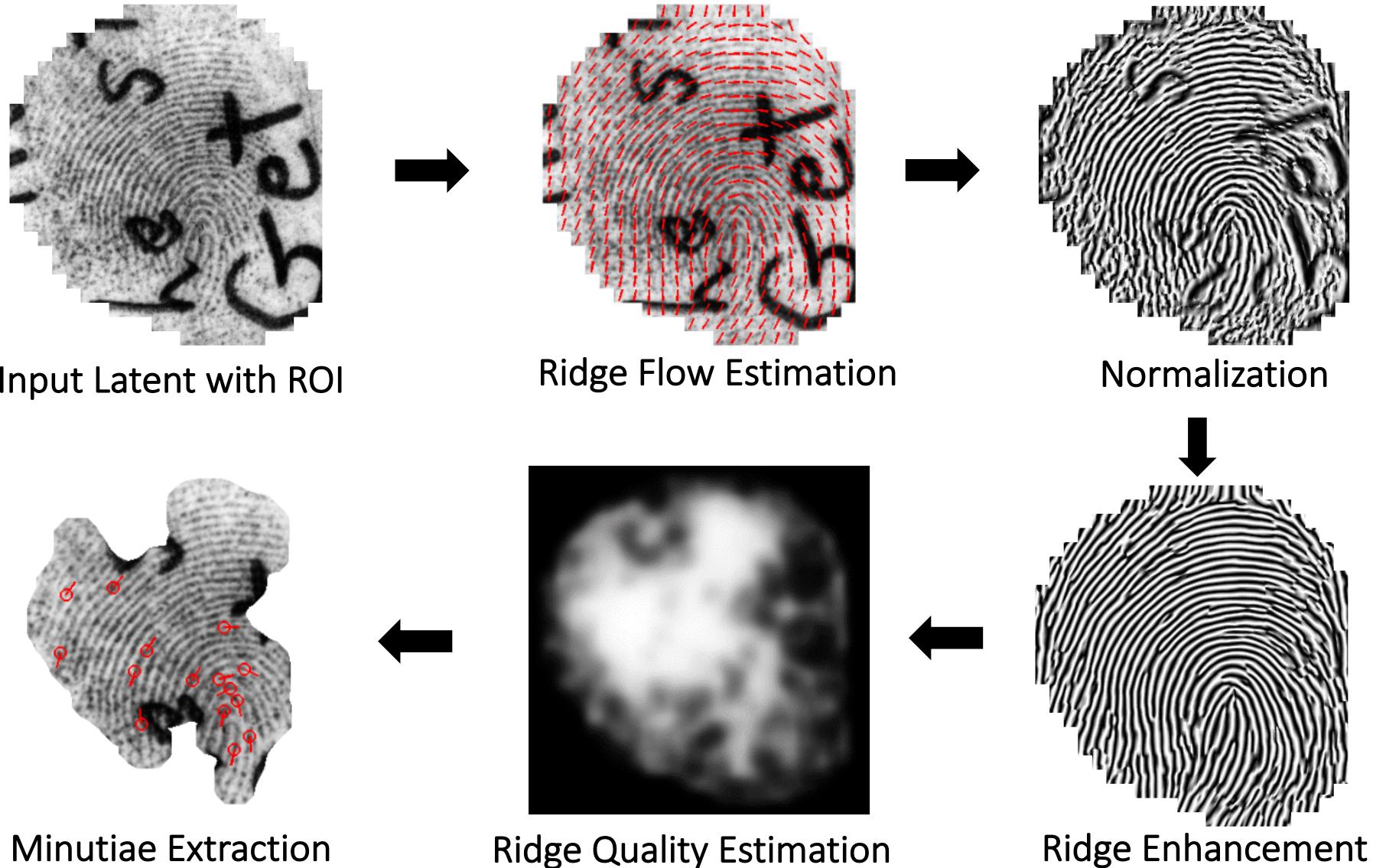
Proposed Method



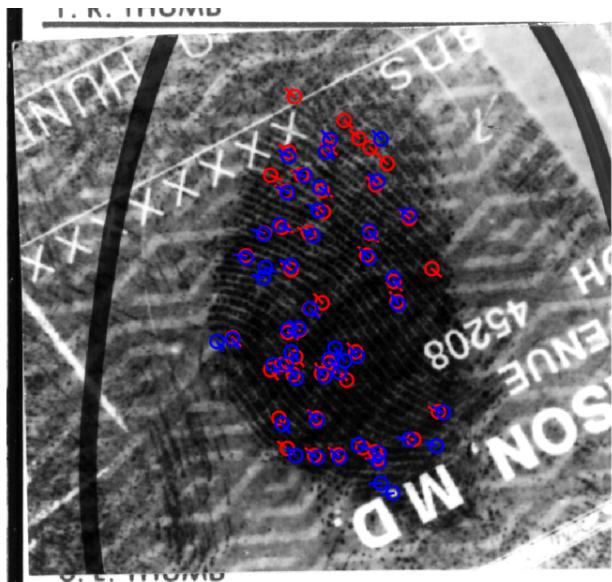
Features for Value Assessment

Feature No.	Description	
1	Number of minutiae	
2 - 8	Sum of minutiae reliability with reliability $\geq t$, $t= 0, 0.1, \dots, 0.6$	
9	Average area of minutiae Delaunay triangulation	
10	Area of the convex hull of minutiae set	
11 - 17	Sum of ridge quality blocks with quality value $\geq t$, $t= 0, 0.1, \dots, 0.6$	
18	Number of singular points (core and delta)	
19	Standard deviation of the ridge flow in the foreground	

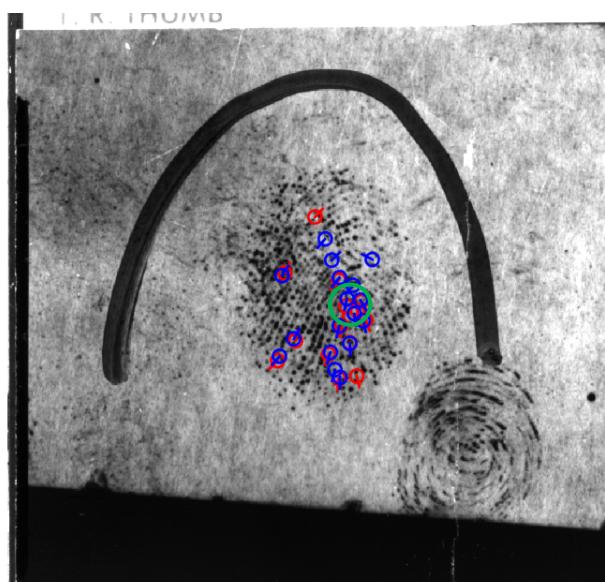
Feature Extraction



Minutiae and Singular Points Extraction



Latent ID: G007



Latent ID: B106



Latent ID: U228

- — Manually marked minutiae
- — Automatic extracted minutiae
- — Automatic detected core point

FingerprintMash: A Crowdsourcing Tool



PRIP Lab, Michigan State University

Welcome user

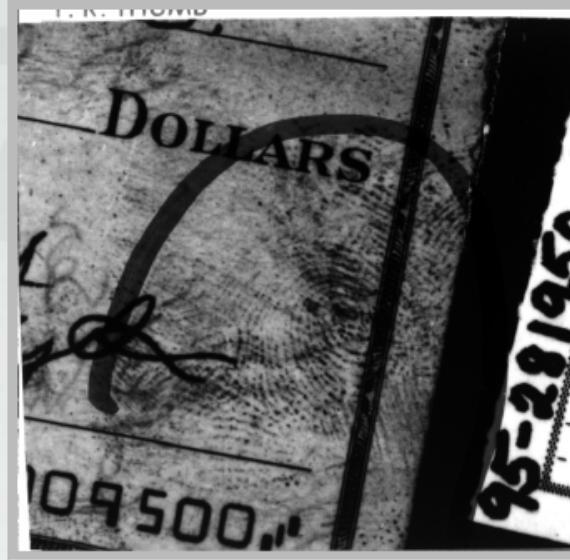
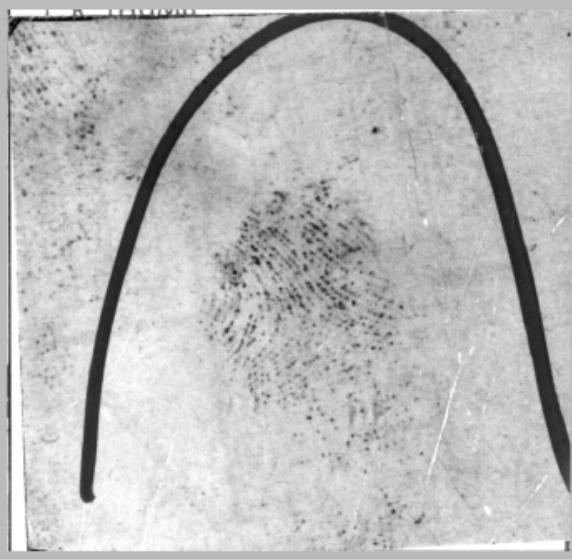
[Sign Out](#)

Indicate (a) quality of each latent, and (b) which one (left or right) has more information for identification

click on any image to zoom

QUALITY

High



QUALITY

High



INFORMATION CONTENT



Left latent has much more



slightly more



similar



slightly more



Right latent has much more

[Undo Previous](#)

[Submit](#)

[Skip to Next](#)

24/100 Completed

Time elapsed: 215 second(s)

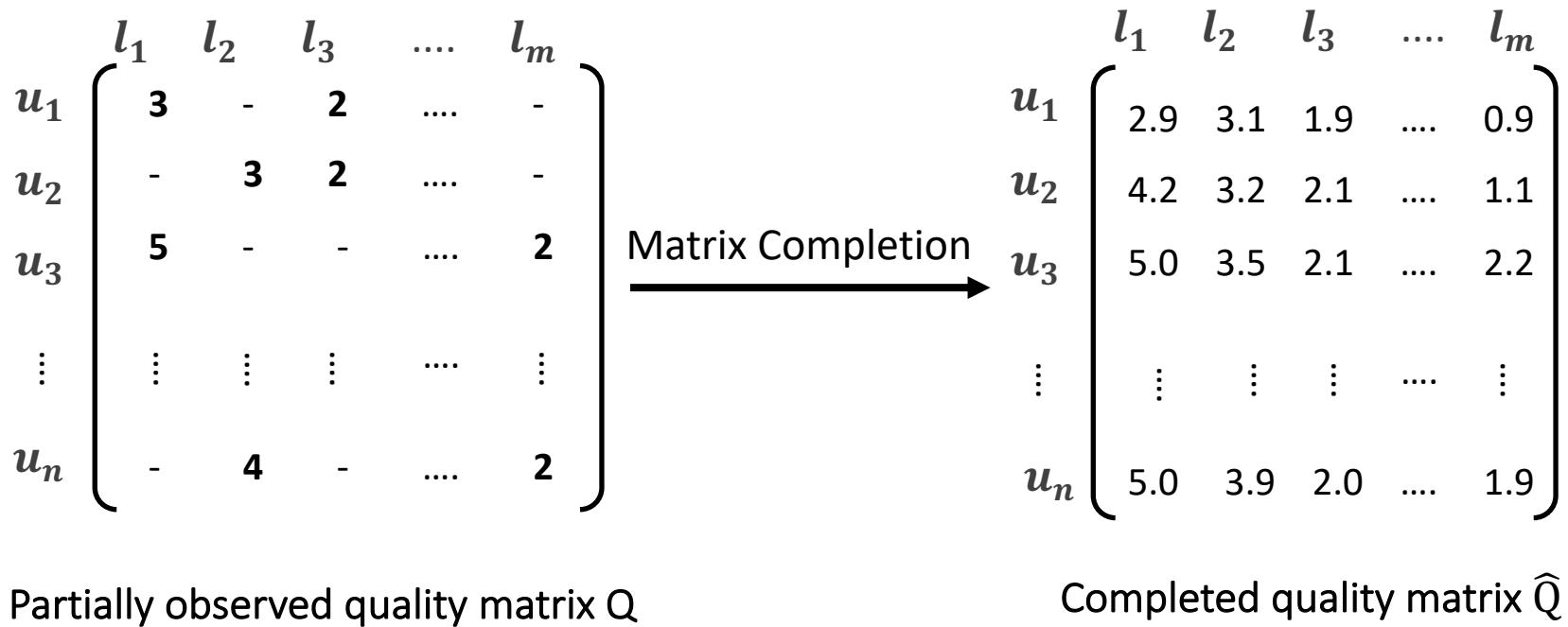
<http://fingerprintmash.org>

Crowdsourcing Details

- **Expert Crowd**
 - 31 experts (latent examiners and researchers)
- **Dataset**
 - 258 latents from NIST SD27
 - 258 latents from the Michigan State Police (MSP)
- **Protocol**
 - 5 levels for numerical quality rating; 1: low, 5: high
 - 5 relative levels for information content; 1: left is better
 - 100 randomly selected pairs presented to each expert
 - 1 pair is repeated at every 5th comparison for validity

Matrix Completion

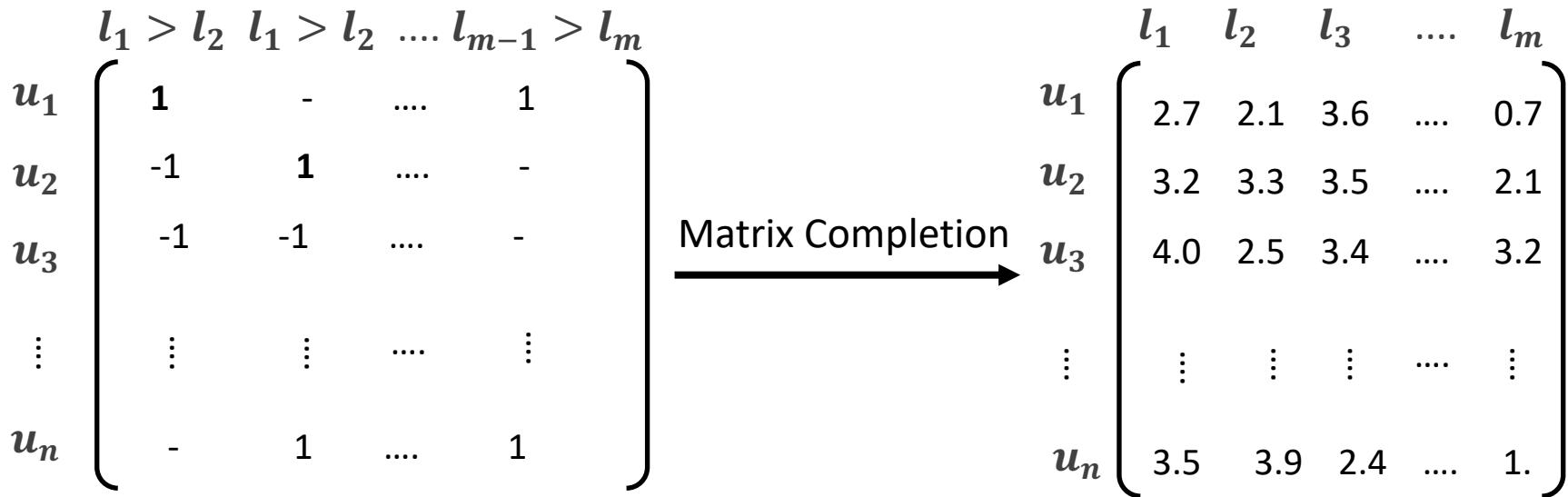
Numerical Quality



Zhang et al., "Solving a Low-Rank Factorization Model for Matrix Completion by a Nonlinear Successive Over-Relaxation Algorithm," Mathematical Programming Computation, vol. 4, no. 4, pp. 333–361, 2012.

Matrix Completion

Pairwise Information Content

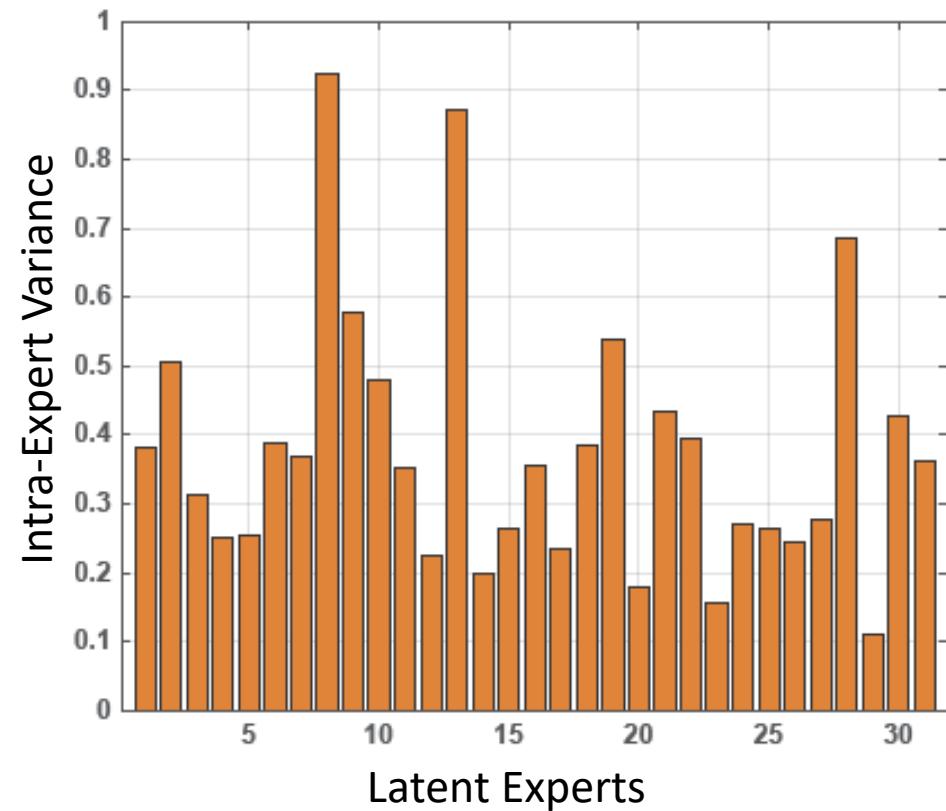


Partially observed pairwise information content \mathbf{C}

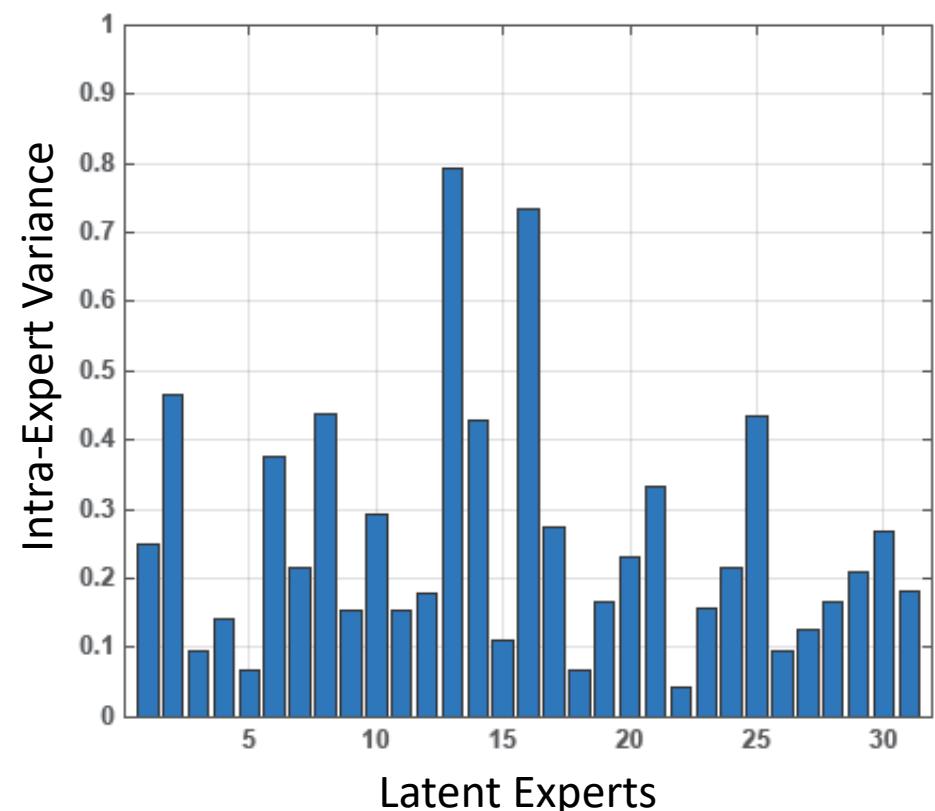
Completed information content $\widehat{\mathbf{C}}$

Latent value $\mathbf{v} = (\widehat{\mathbf{Q}} + \widehat{\mathbf{C}})/2$

Intra-Expert Variance



Numerical rating

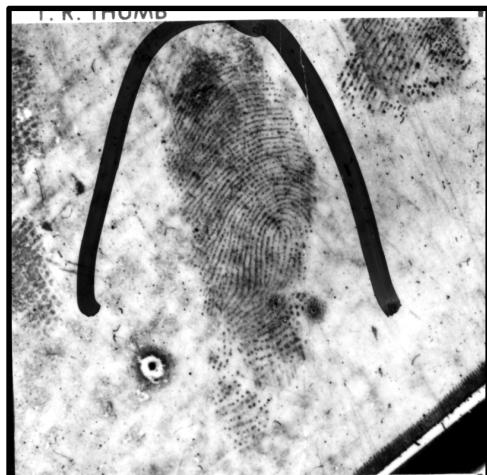


Pairwise comparison

Intra-Expert Variance

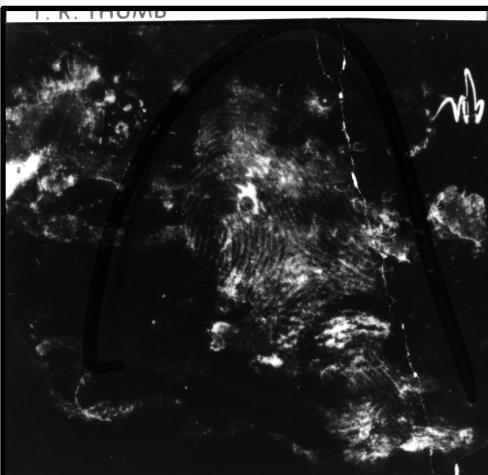
Numerical Rating

Mean = 0.35; Std. Dev. = 0.16



Low variance

Values = [4,4,4,4]

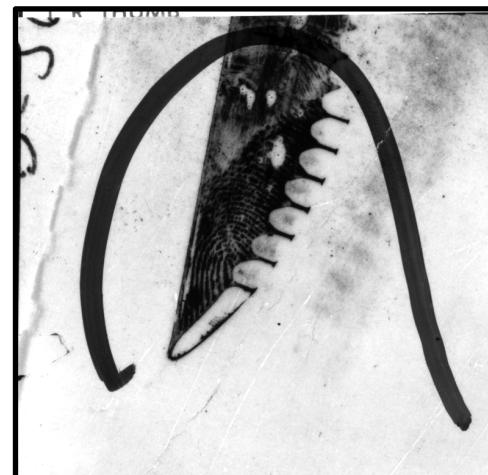


High variance

Values = [1,2,2,4]

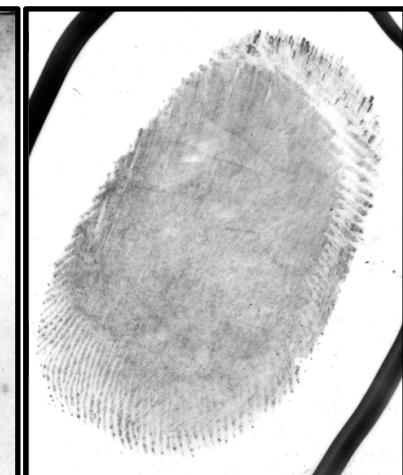
Pairwise Comparison

Mean = 0.24; Std. Dev. = 0.15



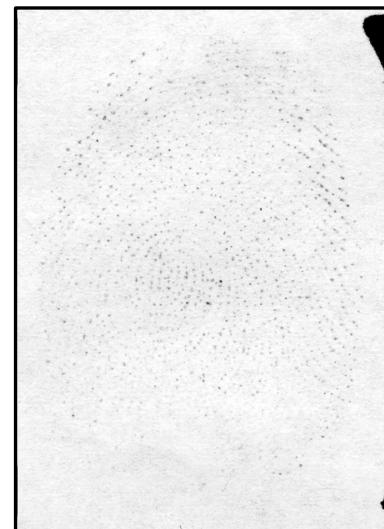
High variance in comparison

Value ranged from 1 to 4



Inter-Expert Variance

Examples of strong
agreement among experts

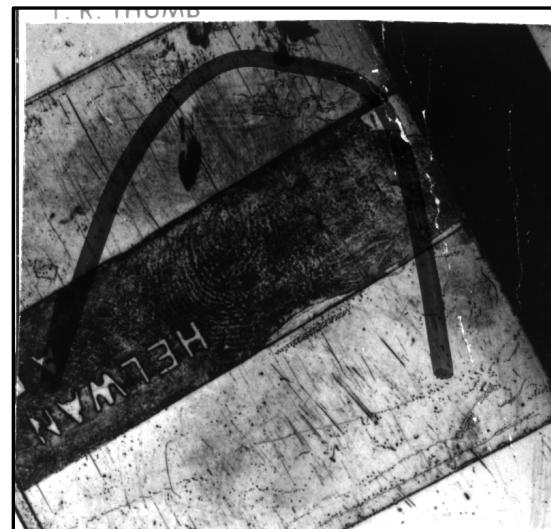


Low Value (1)



High Value (5)

Examples of strong
disagreement among experts

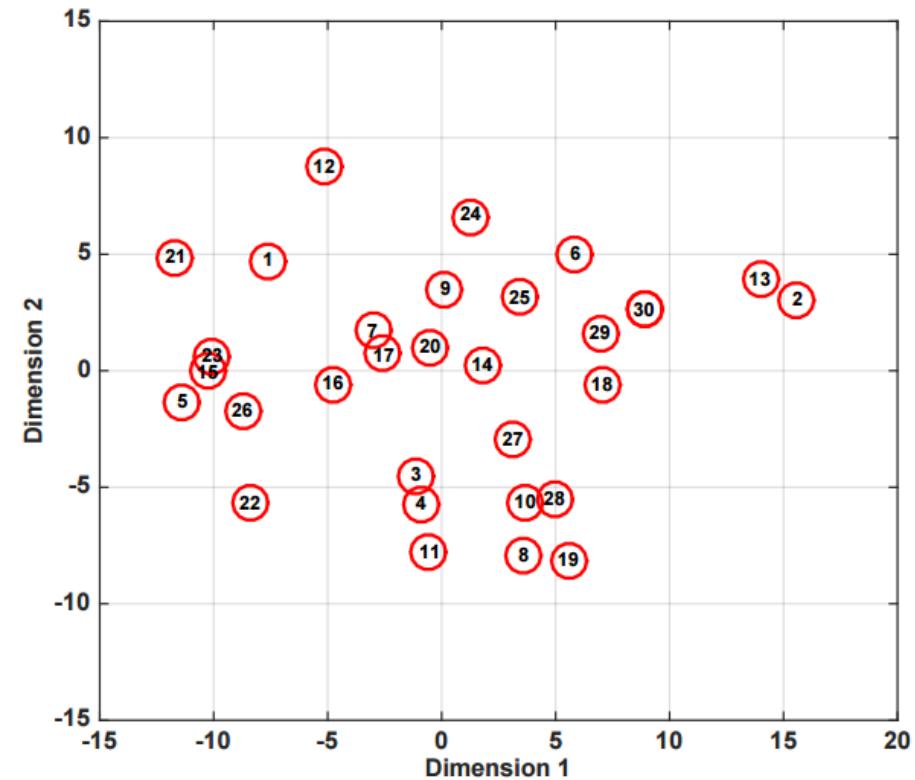


Value Range (2-5)

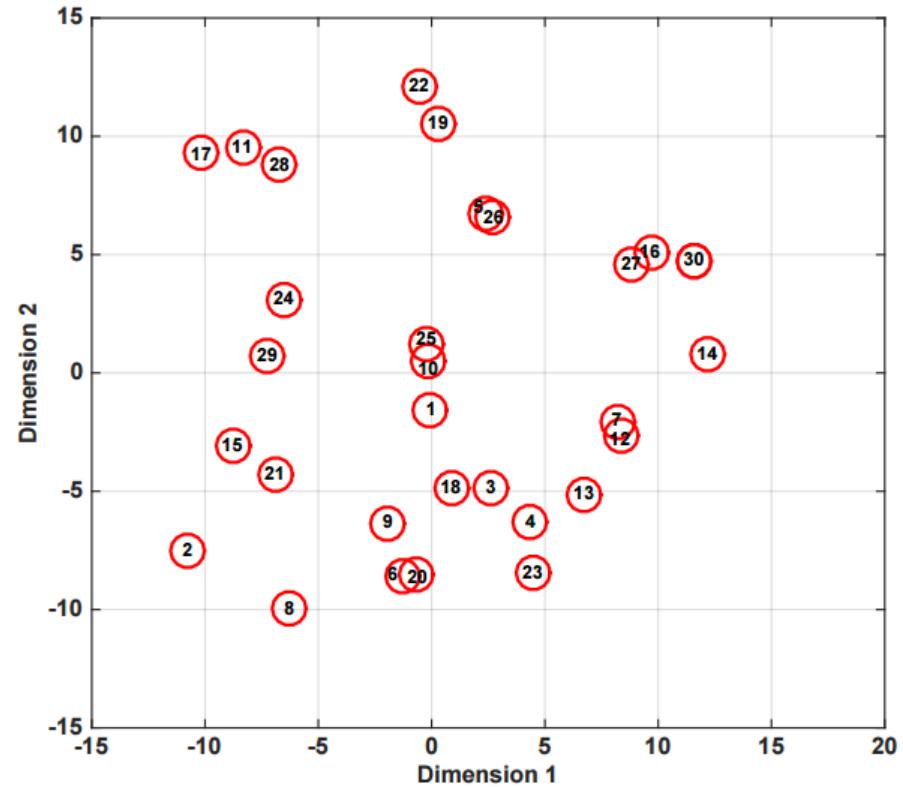


Value Range (1-5)

Inter-Expert Variance



numerical ratings



pairwise comparisons

Visualization of all 30 experts in a two-dimensional MDS space

Expert Crowd v. Value Determination

- NIST SD27: 210 VID, 41 VEO, and 7 NV from [4]

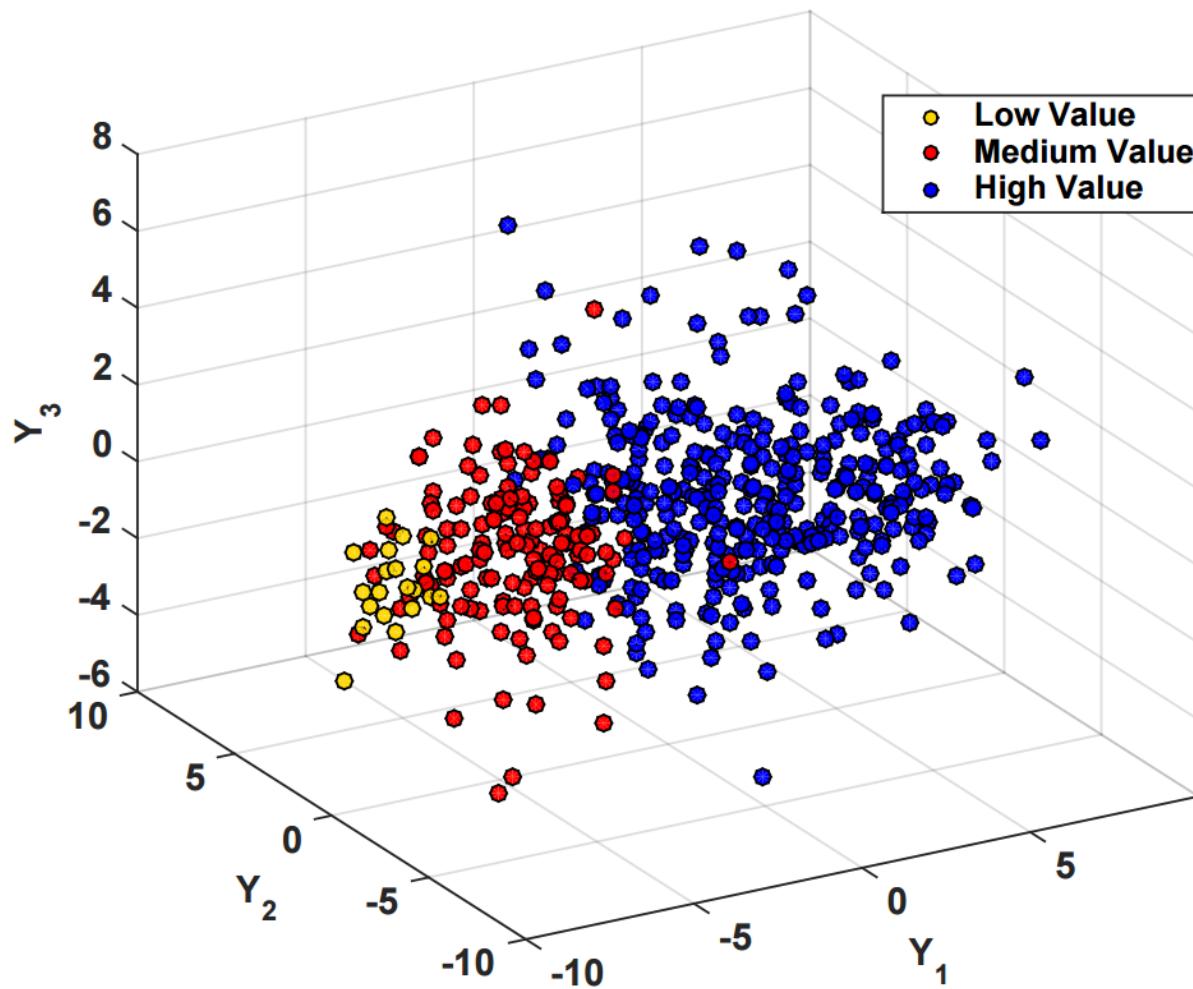
Rank-1 hit rates from AFIS; 250K reference prints

Value Determination	VID	VEO	NV
	163/210	12/41	0/7
Expert Crowd (Median Value)	High Value	Medium Value	Low Value
	170/210	6/41	0/7

For a fair comparison, we identify, from crowdsourced value data, the top 210 valued latents as high value, next 41 as medium value and the remaining 7 as low value.

[4] R. A. Hicklin, et al, "Latent Fingerprint Quality: A Survey of Examiners," Journal of Forensic Identification, vol. 61, no. 4, pp. 385–419, 2011.

Multidimensional Scaling Analysis



Underlying Bases

Feature No.	Description
1	Number of minutiae
2 - 8	Sum of minutiae reliability with reliability $\geq t$, $t = 0, 0.1, \dots, 0.6$
9	Average area of minutiae Delaunay triangulation
10	Area of the convex hull of minutiae set
11 - 17	Sum of ridge quality blocks with quality value $\geq t$, $t = 0, 0.1, \dots, 0.6$
18	Number of singular points (core and delta)
19	Standard deviation of the ridge flow in the foreground

Value Prediction

- Learned a predictor for value assignment
- Average MSE for predicted value = 0.24

Examples of **correctly**
predicted latent value



Crowd : 4.67
Predicted : 4.68

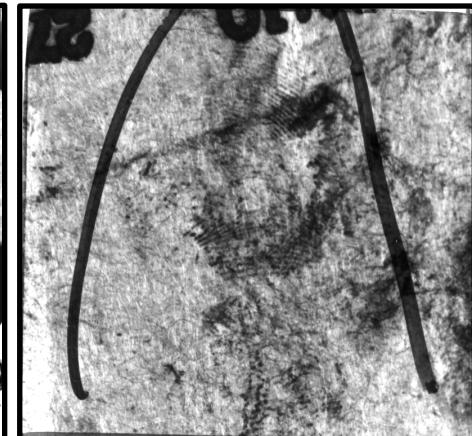


Crowd : 2.08
Predicted : 2.04

Examples of **incorrectly**
predicted latent value



Crowd : 2.99
Predicted : 4.02



Crowd : 2.96
Predicted : 2.02

Value Prediction



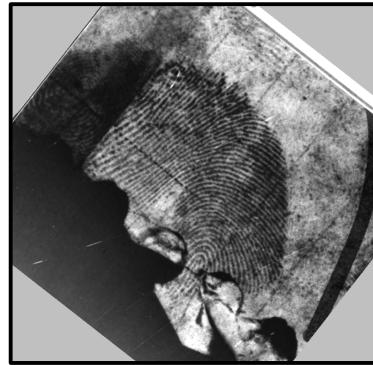
Source: MSP
Rank Retrieval: 1
Predicted Value: 4.96



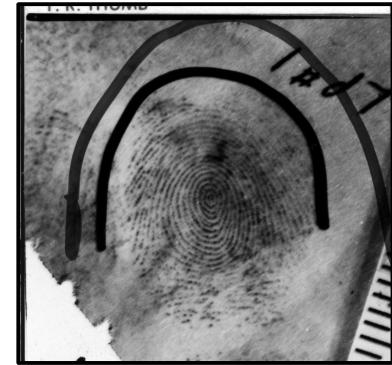
Source: MSP
Rank Retrieval: 1
Predicted Value: 4.62



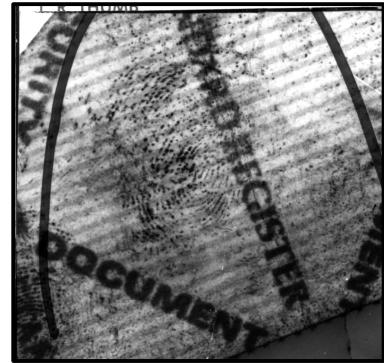
Source: MSP
Rank Retrieval: 1
Predicted Value: 4.23



Source: NIST SD27
Rank Retrieval: 1
Predicted Value: 4.19



Source: NIST SD27
Rank Retrieval: 1
Predicted Value: 4.02



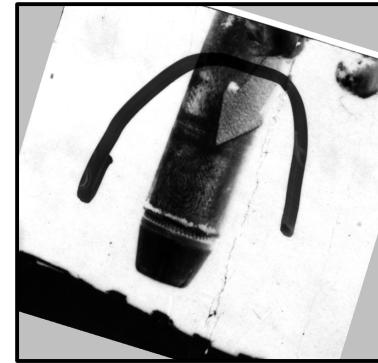
Source: NIST SD27
Rank Retrieval: 14,806
Predicted Value: 1.37



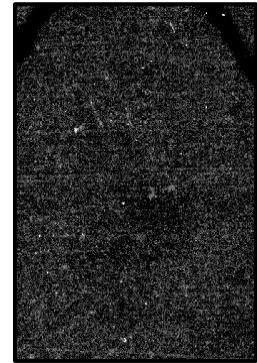
Source: MSP
Rank Retrieval: 11
Predicted Value: 1.25



Source: NIST SD27
Rank Retrieval: 22,442
Predicted Value: 1.19

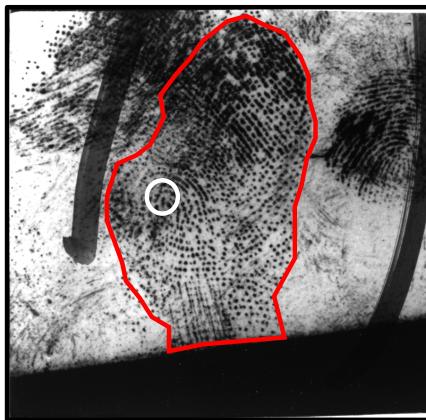


Source: NIST SD27
Rank Retrieval: 21,662
Predicted Value: 1.08

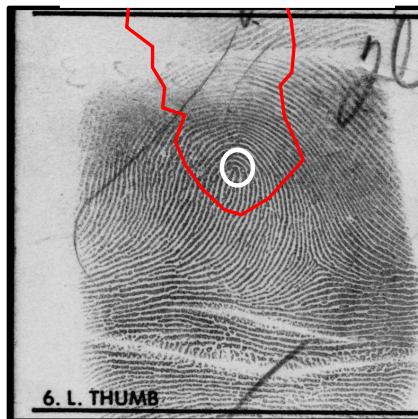
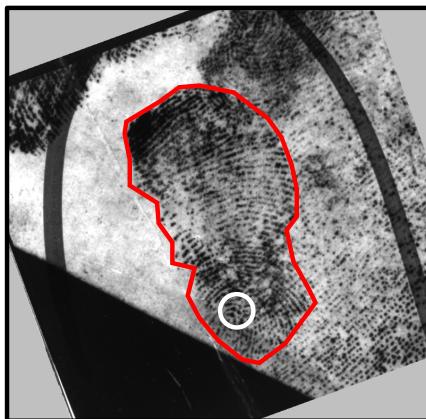


Source: MSP
Rank Retrieval: 50,980
Predicted Value: 1.01

High Latent Fingerprint Value Low AFIS performance



Predicted Value: 3.34
AFIS Retrieval Rank: 18,789



Predicted Value: 2.95
AFIS Retrieval Rank: 19,456

Summary

- Developed a crowdsourcing-based framework for understanding expert latent value assignment from the perspectives of latent quality and information content
- Used MDS to identify the underlying bases for expert latent value assignment
- predicted quantitative latent value based on the underlying bases.
- **Wisdom of crowd** leads to better decision making over a single examiner

Thank You

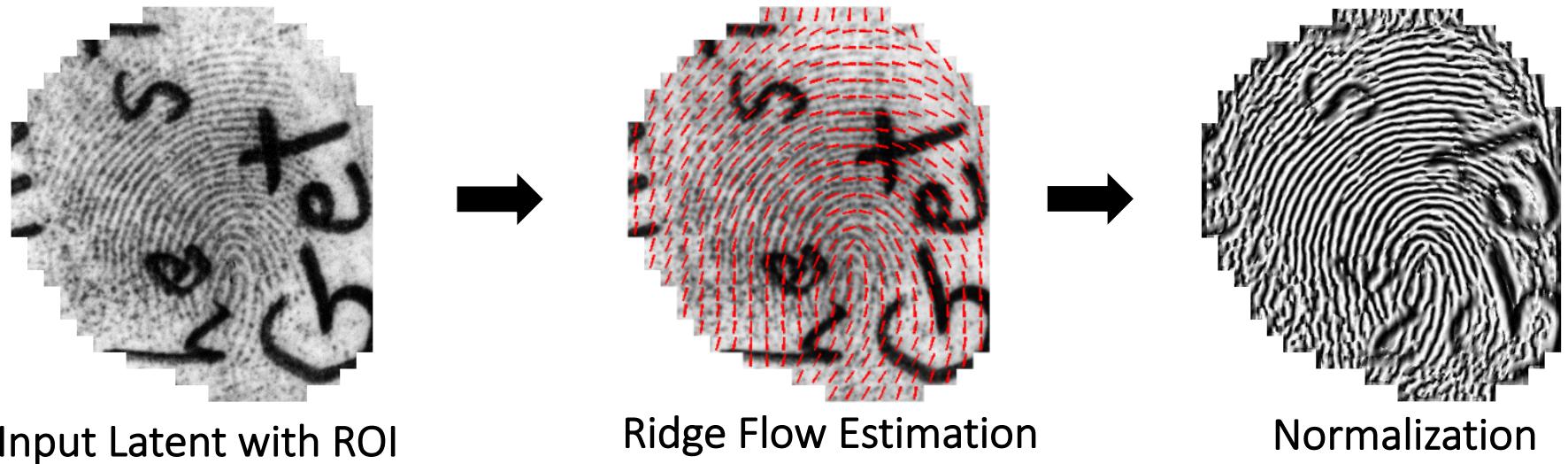
Any Questions?



Why Value Determination?

- Triage for Large Caseload
 - FBI's IAFIS conducted 14,311 latent feature searches and 2,370 latent image searches (Dec. 2015)
- **Of Value** [VID, VEO] latent classified as **No Value** (NV) latent is a missed opportunity to identify the suspect
- **No Value** latent determined as **Of Value** leads to ineffective use of examiner's effort in feature markup & verification

Feature Extraction



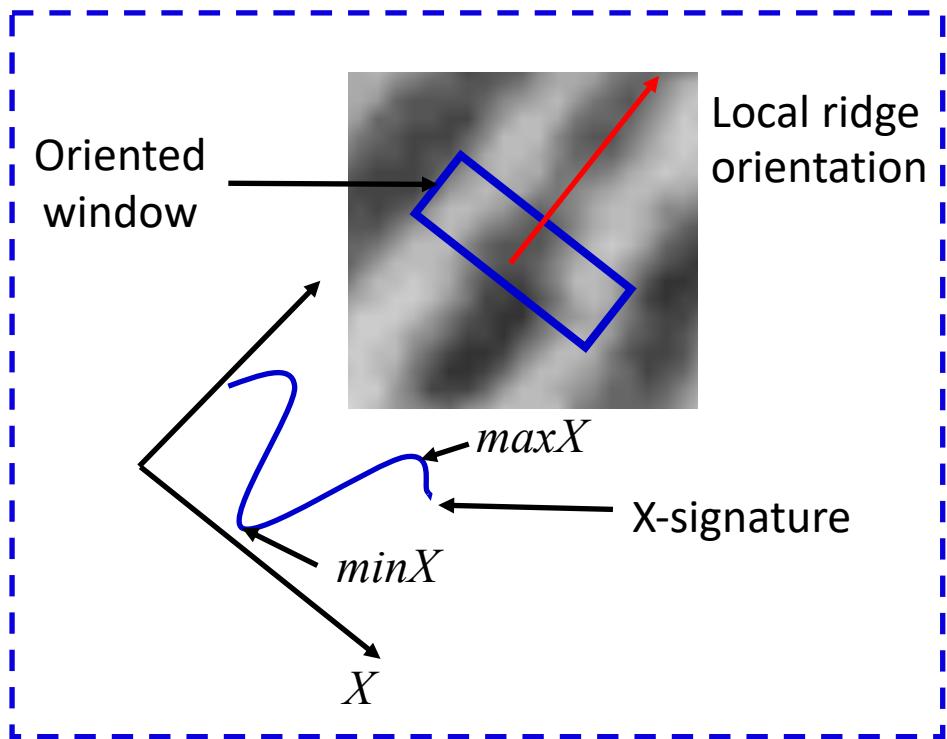
Input Latent with ROI

Ridge Flow Estimation

Normalization

[3] K. Cao and A. K. Jain, *Latent Orientation Field Estimation via Convolutional Neural Network*, ICB, 2015

Image Normalization



Oriented window and X-signature

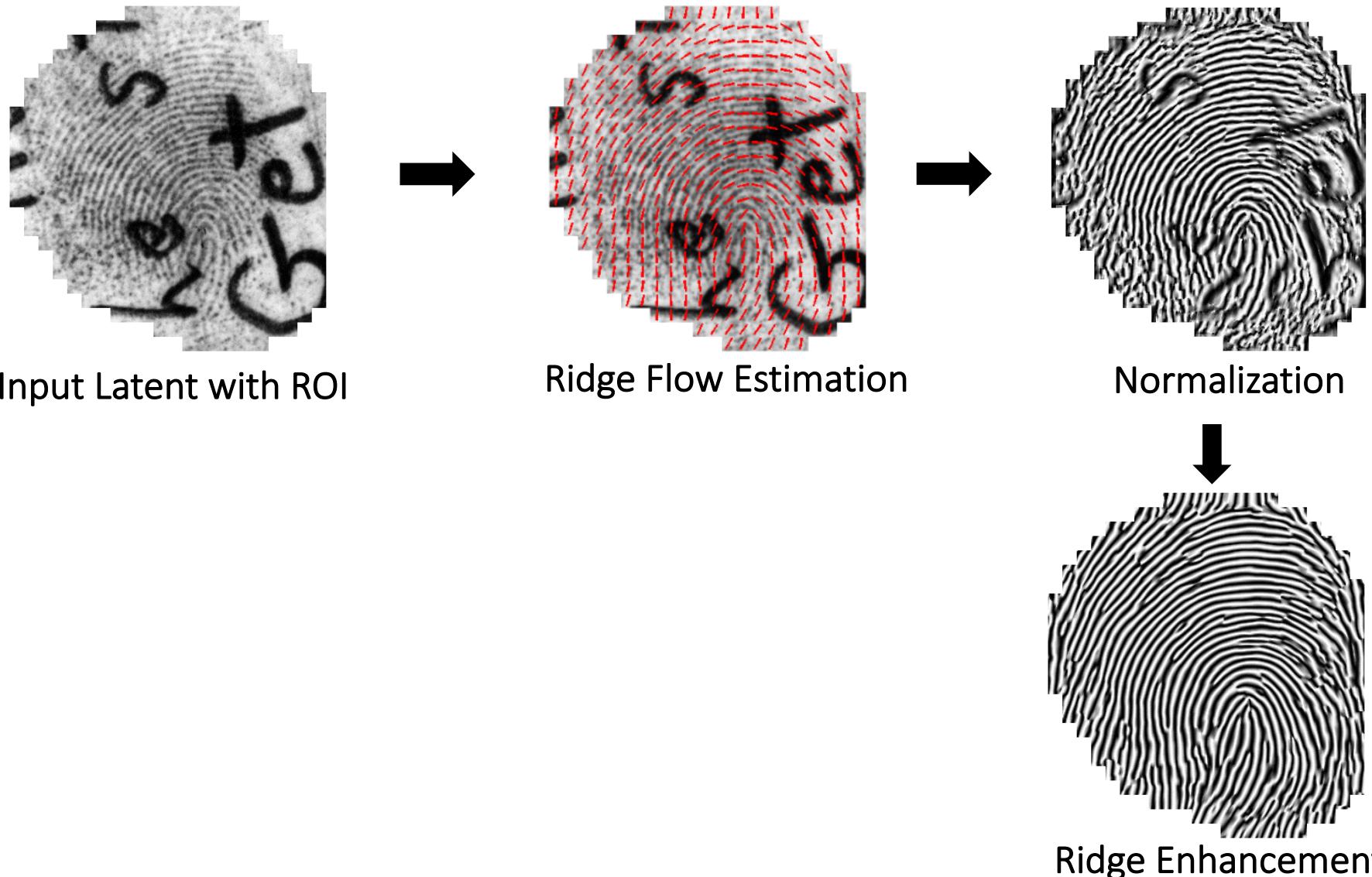


Input latent image



Normalized image

Feature Extraction



Ridge Enhancement

- Dictionary construction
- Ridge enhancement using dictionary



Input latent



Enhanced by Gabor filtering



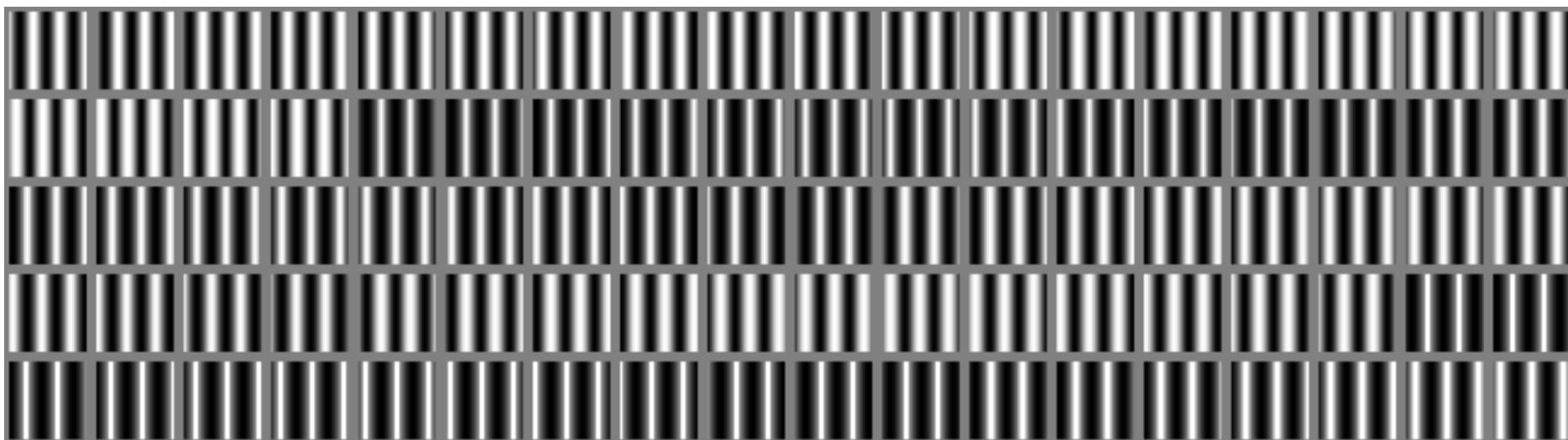
Enhanced by dictionary

Ridge Enhancement

- Dictionary construction

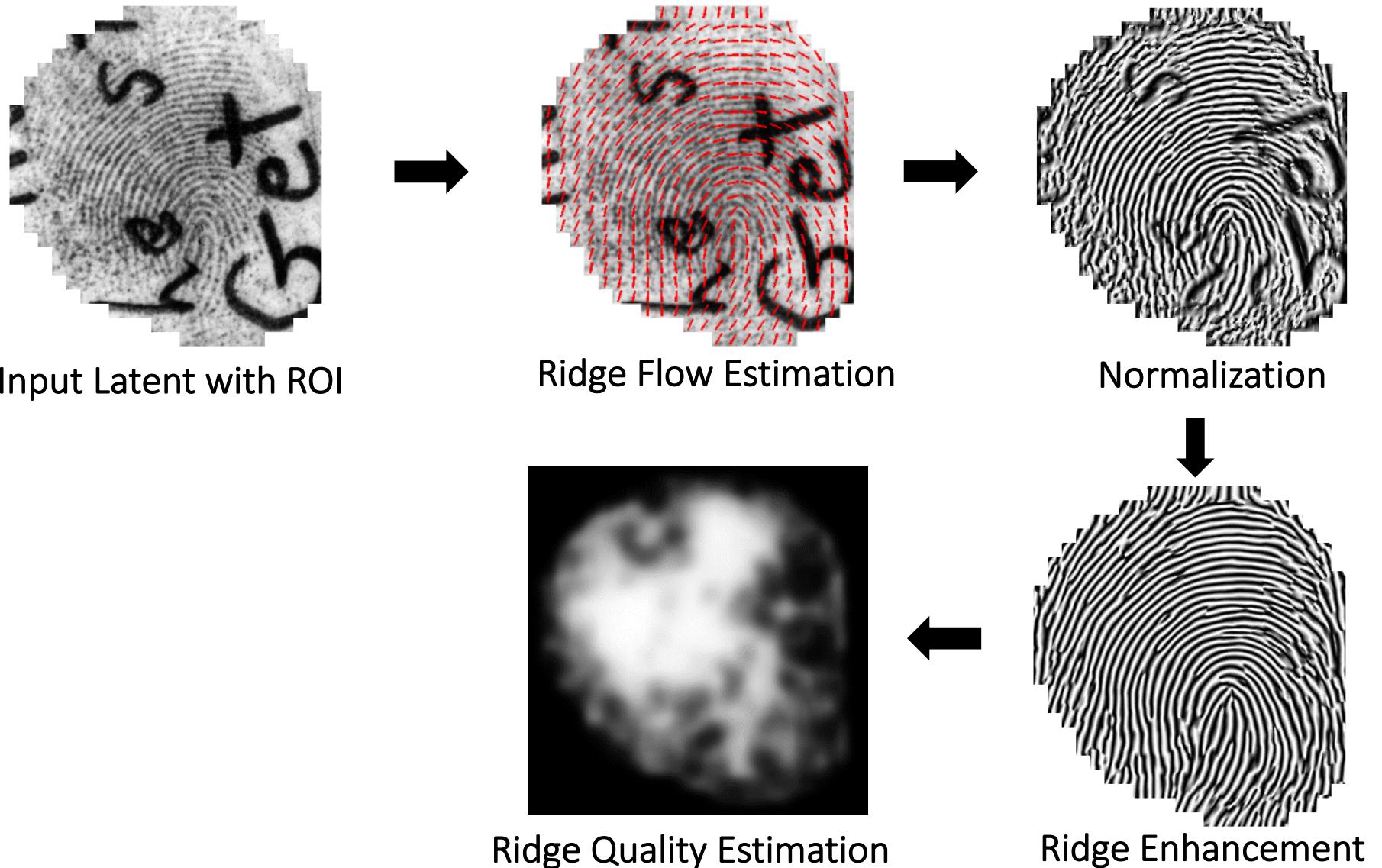
$$\text{Dictionary element} = \text{Valley image} + \text{Ridge image}$$

Note that ridge and valley widths can be different



A subset of dictionary elements used for latent ridge enhancement

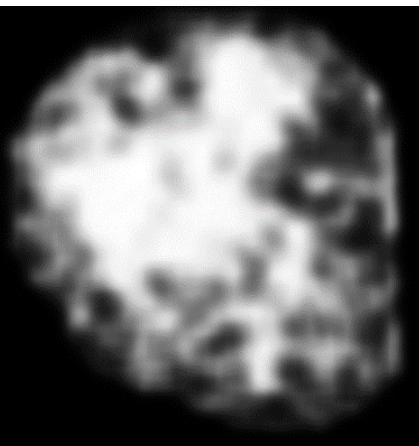
Feature Extraction



Ridge Quality Estimation



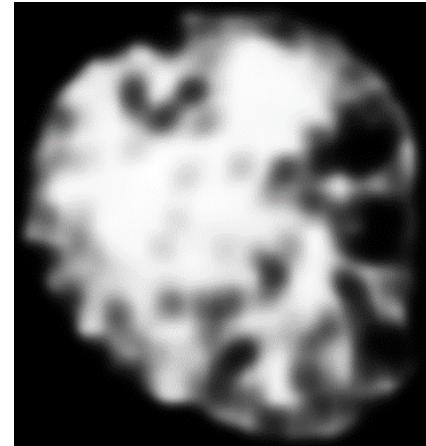
(a) Normalization of input latent



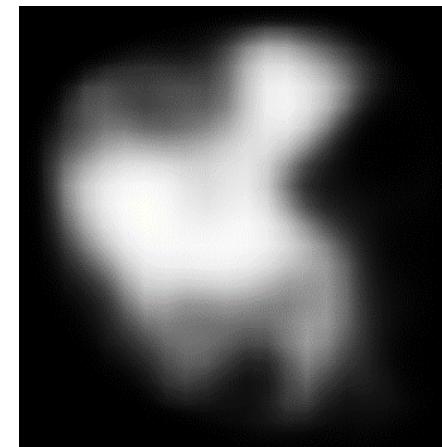
(c) Orientation coherence of (a)



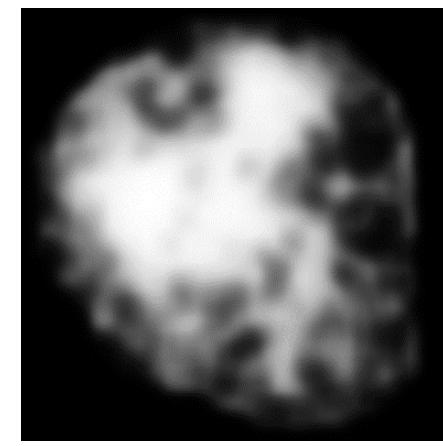
(b) Normalization of Enhanced latent



(d) Orientation coherence of (b)



(e) Similarity between (a) and (b)



(f) Fused Quality map of (c), (d) & (e)

Matrix Completion: Numerical Quality

$$\begin{array}{c} \text{Matix Completion} \\ \xrightarrow{\hspace{10em}} \end{array}$$

$u_1 \begin{bmatrix} l_1 & l_2 & l_3 & \dots & l_m \\ 3 & - & 2 & \dots & - \\ - & 3 & 2 & \dots & - \\ 5 & - & - & \dots & 2 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ - & 4 & - & \dots & 2 \end{bmatrix}$	$u_1 \begin{bmatrix} l_1 & l_2 & l_3 & \dots & l_m \\ 2.9 & 3.1 & 1.9 & \dots & 0.9 \\ 4.2 & 3.2 & 2.1 & \dots & 1.1 \\ 5.0 & 3.5 & 2.1 & \dots & 2.2 \\ \vdots & \vdots & \vdots & \ddots & \vdots \\ 5.0 & 3.9 & 2.0 & \dots & 1.9 \end{bmatrix}$
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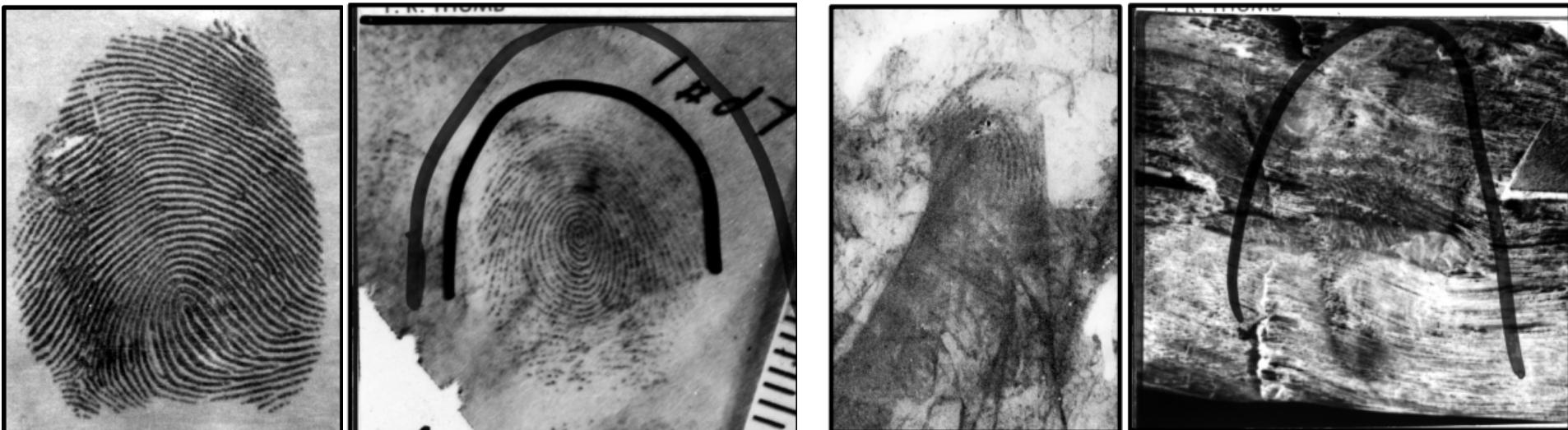
Partially observed quality matrix Q

Completed quality matrix \widehat{Q}

$$U, V = \arg \min_{U, V} \frac{1}{2} \|UV - Q\|_F^2$$

$$\widehat{Q} = UV$$

Value Prediction



Source: MSP
Rank retrieval: 1
Predicted value: 4.62

Source: NIST SD27
Rank retrieval: 1
Predicted value: 4.02

Source: MSP
Rank retrieval: 11
Predicted value: 1.25

Source: NIST SD27
Rank retrieval: 22,442
Predicted value: 1.19

State of the art AFIS; 250K reference prints