Automatic Latent Fingerprint Value Prediction

Tarang Chugh [†], Kai Cao[†], Jiayu Zhou [†],
Elham Tabassi [‡] and Anil K. Jain [†]

[†] Michigan State University
[‡] National Institute of Standards and Technology

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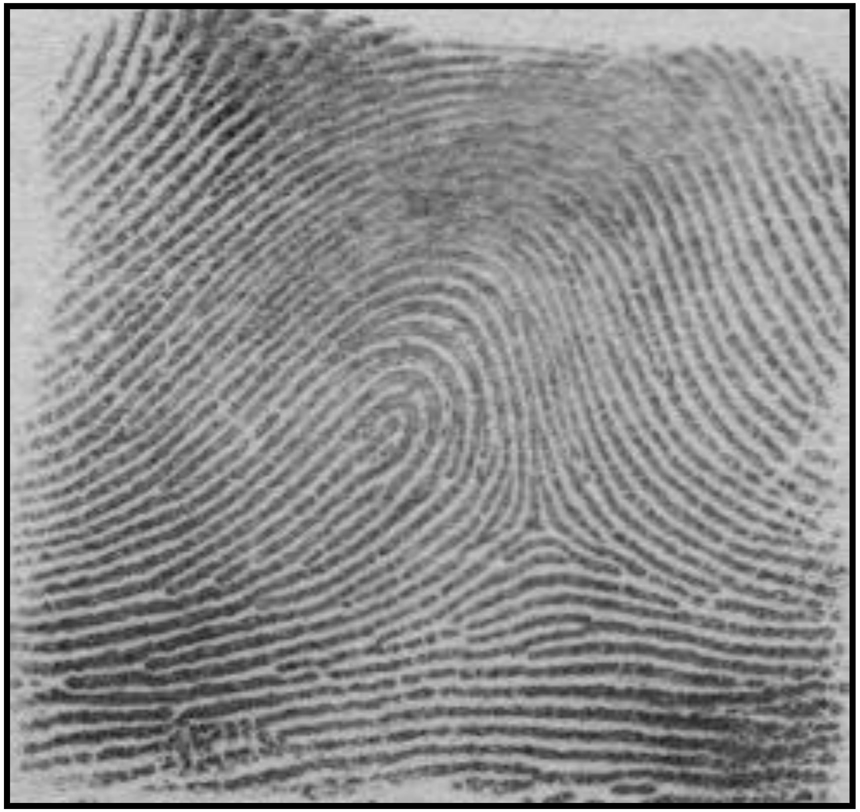
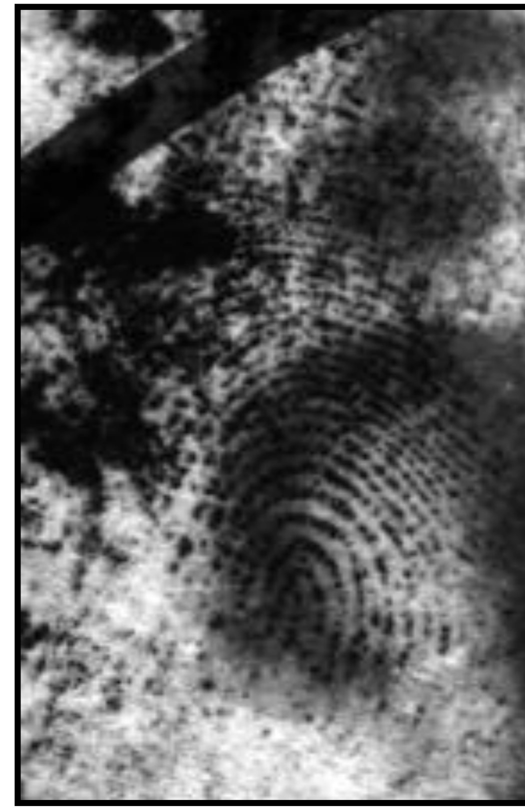
What are Latent Fingerprints?



Rolled

Plain



Latent

Challenges in Latent Matching

Poor Ridge Clarity

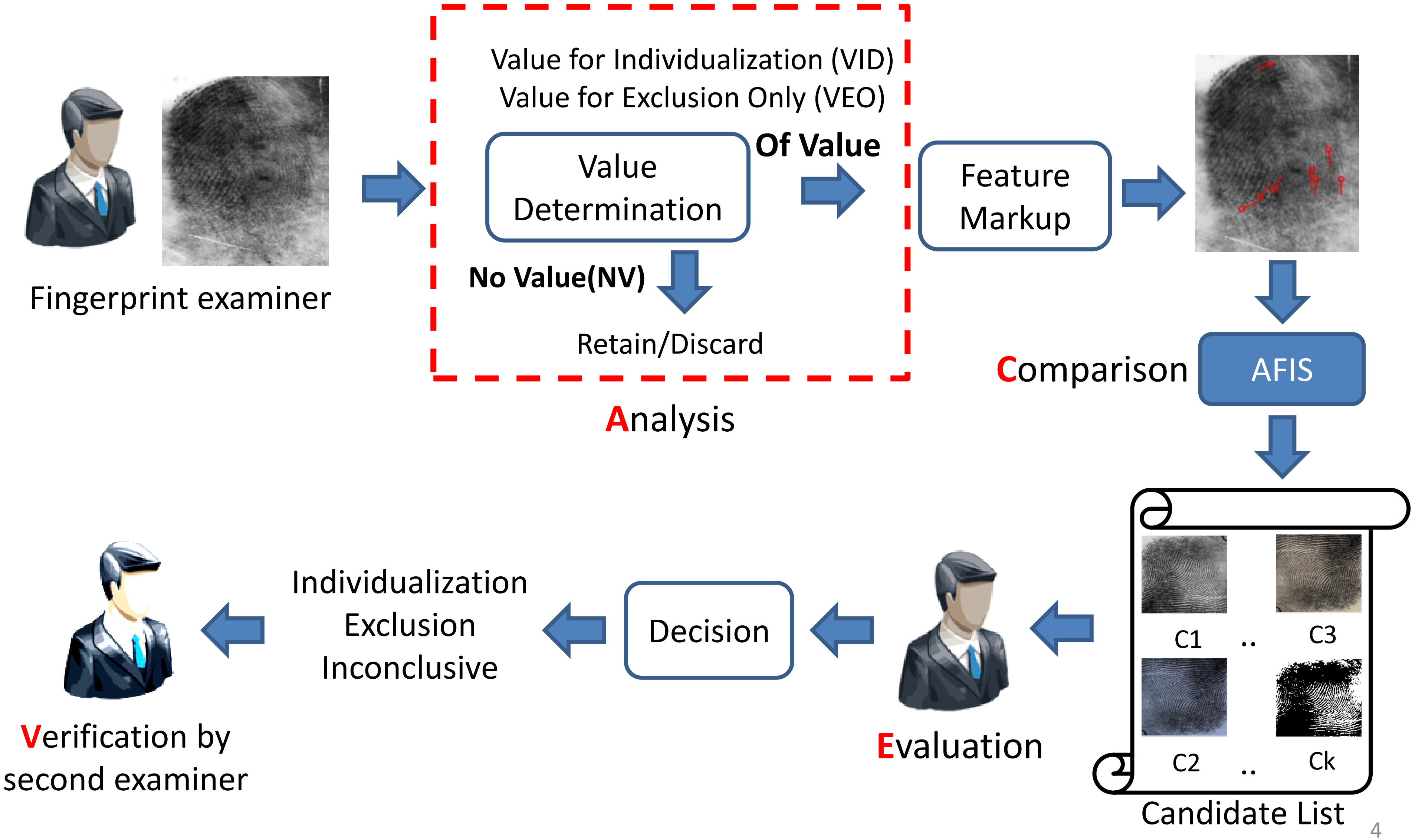
Partial Ridge Area

Complex Background

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

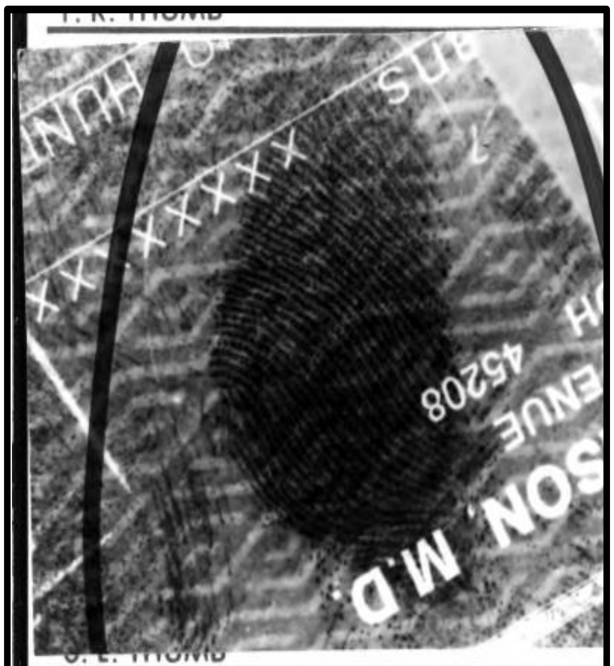
C. Watson, G. Fiumara, E. Tabassi, S. L. Cheng, P. Flanagan, W. Salamon. Fingerprint Vendor Technology Evaluation, NISTIR, 8034, 2012.
* M. Indovina, V. Dvornychenko, R. Hicklin, and G. Kiebuzinski. ELFT-EFS Evaluation of Latent Fingerprint Technologies: Extended Feature Sets, NISTIR, 2012.

Latent Matching: ACE-V Protocol

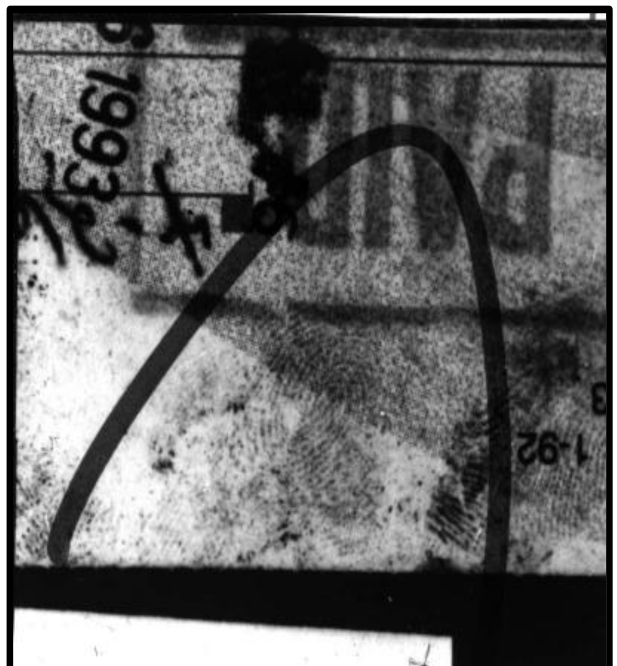


Latent Fingerprint Value

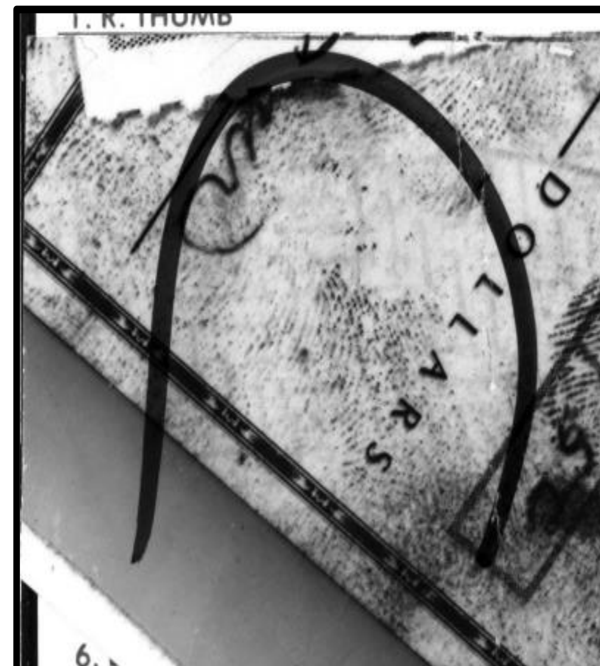
- Presumably based on two factors:
  - Image quality (e.g., clarity of friction ridges)
  - Information content (e.g., no. of minutiae)



VID
(Value for Identification)

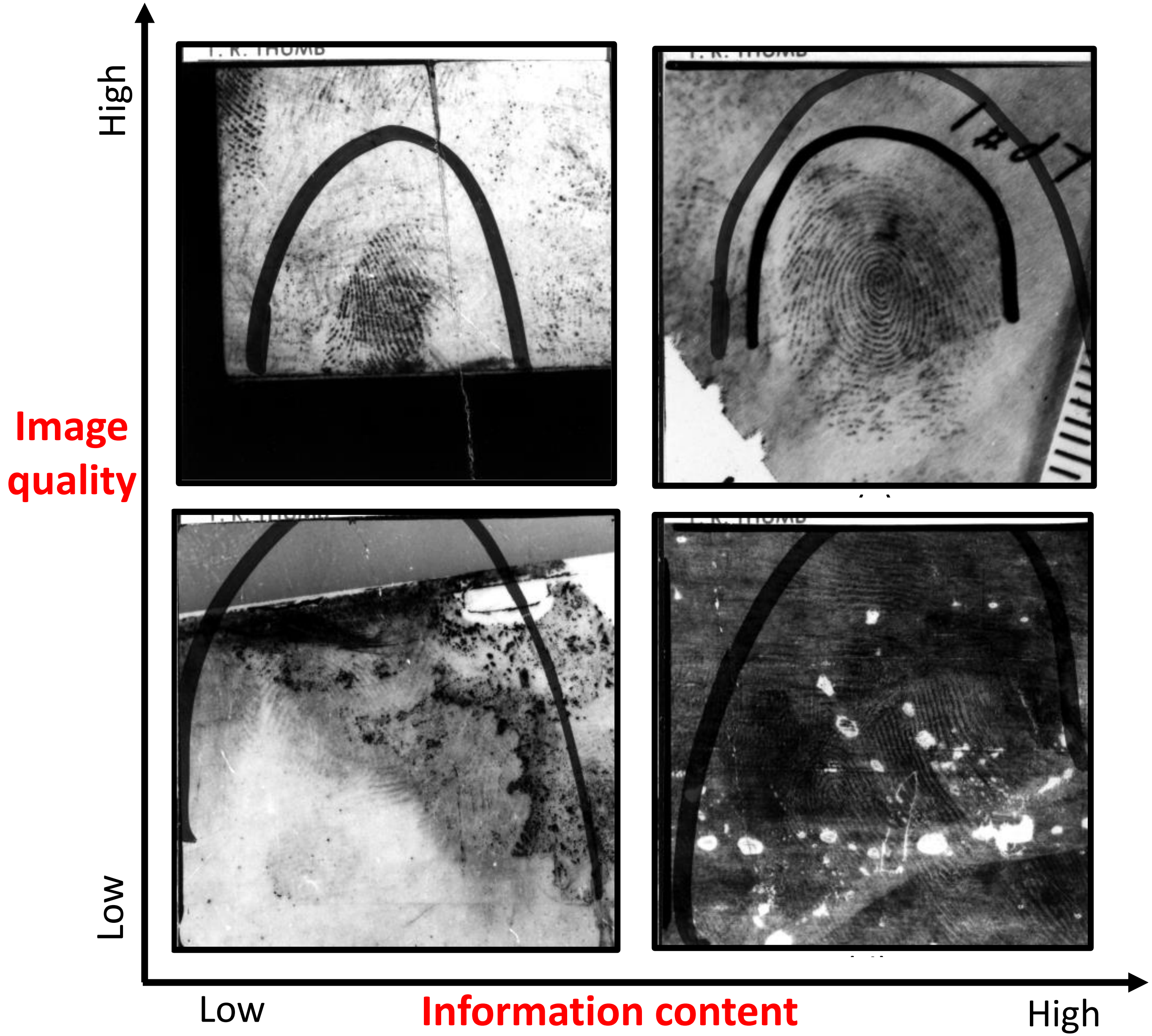


VEO
(Value for Exclusion Only)



NV
(No Value)

Image Quality v. Information Content



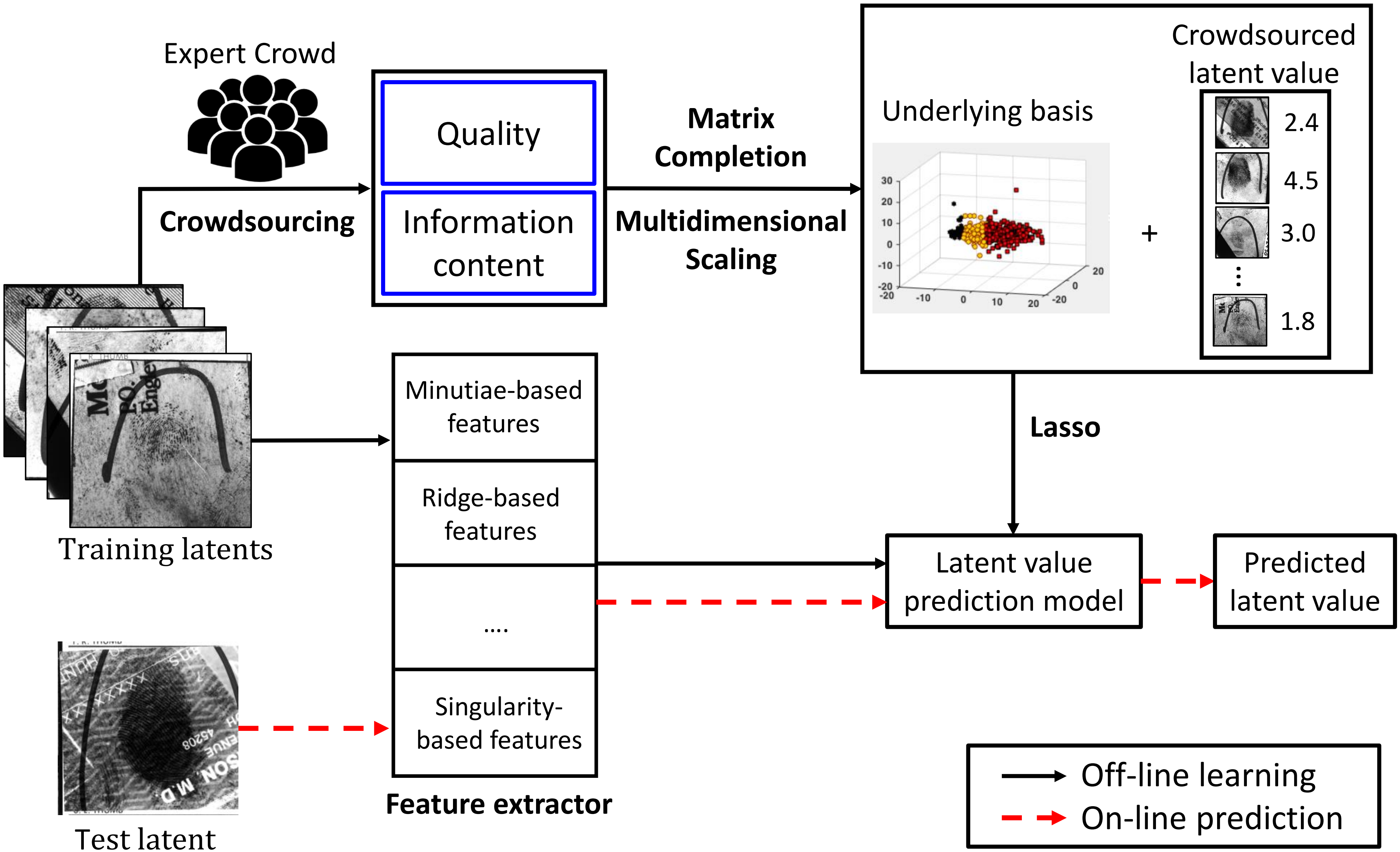
Limitations of Examiner Value Determination

- 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

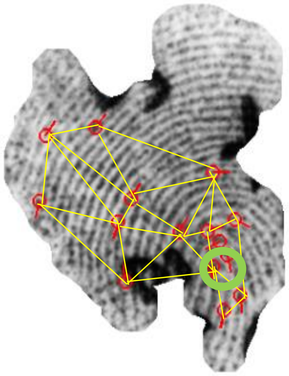
[1] Ulery et al.,"Repeatability and reproducibility of decisions by latent fingerprint examiners," PloS one, 7(3):e32800, 2012.
[2] Ulery et al., "Accuracy and reliability of forensic latent fingerprint decisions," PNAS, 108(19):7733–7738, 2011.

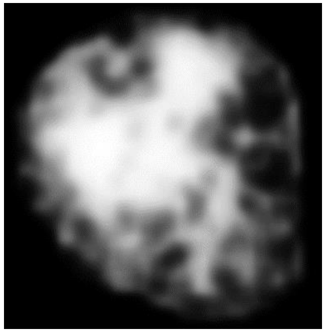
Proposed Method



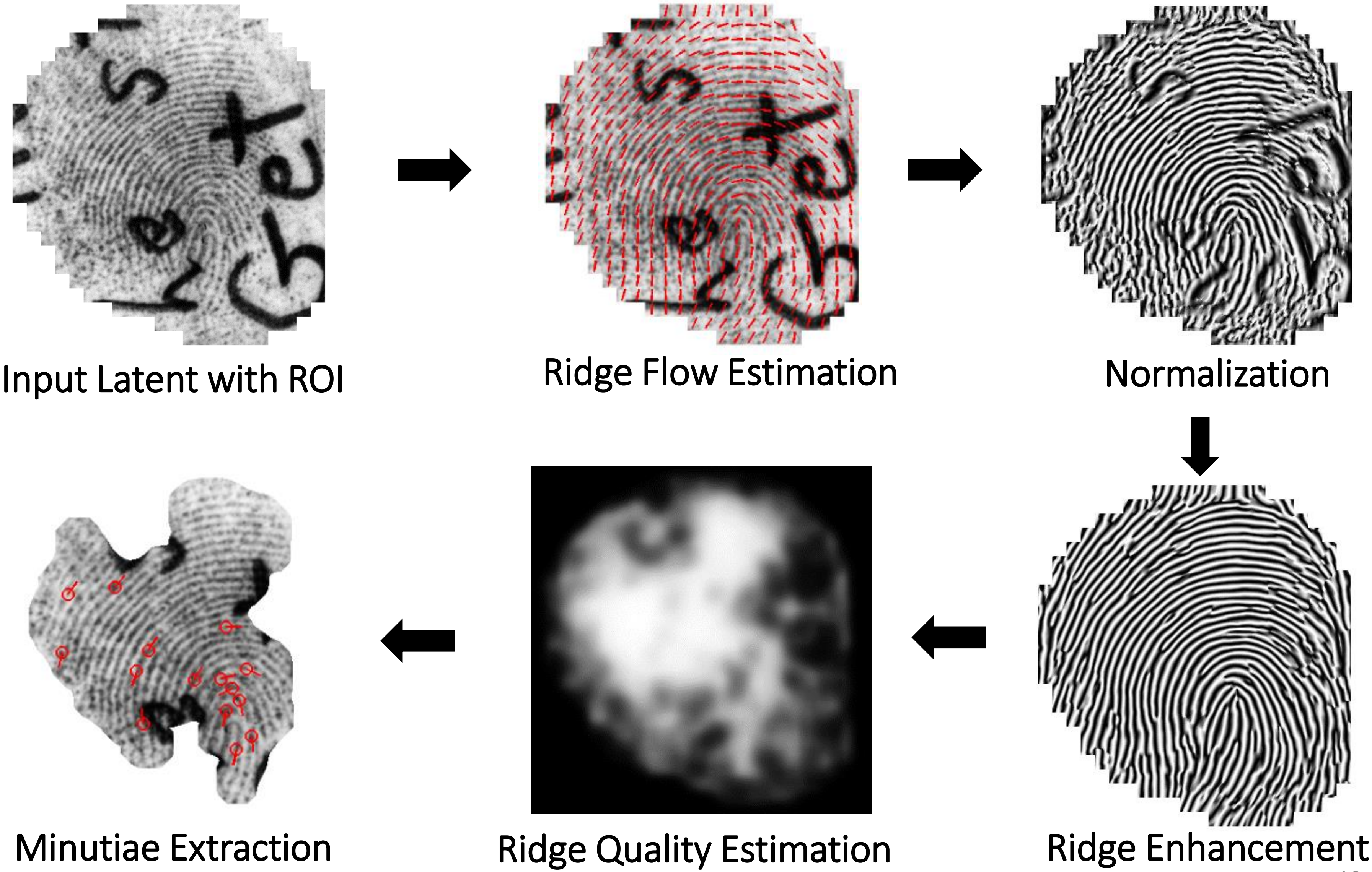
Features for Value Assessment

Feature No.	Description
1	**Number of minutiae**
2 - 8	Sum of **minutiae reliability** with reliability ≥ t, t= 0, 0.1, ..., 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 ≥ t, t= 0, 0.1, ..., 0.6
18	Number of **singular points** (core and delta)
19	**Standard deviation of the ridge flow** in the foreground

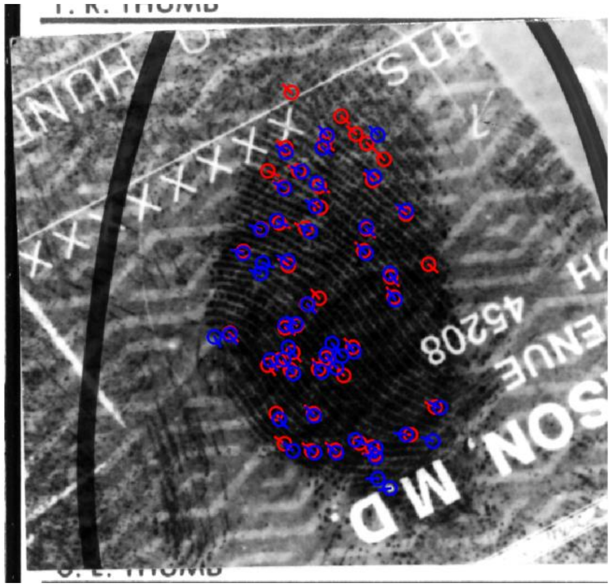




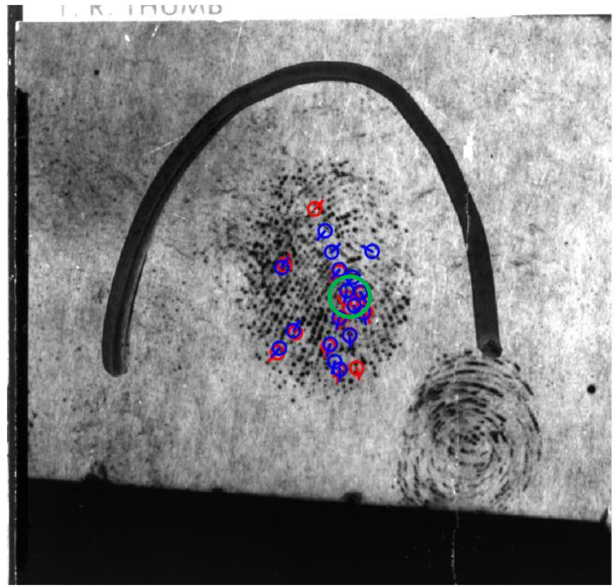
Feature Extraction



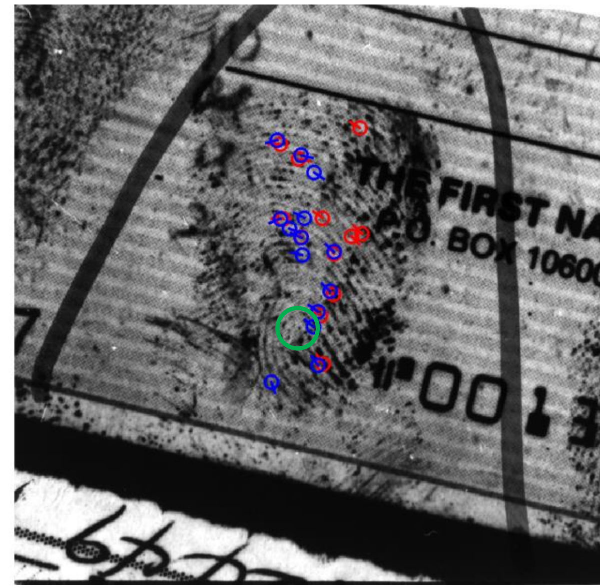
Minutiae and Singular Points Extraction



Latent ID: G007



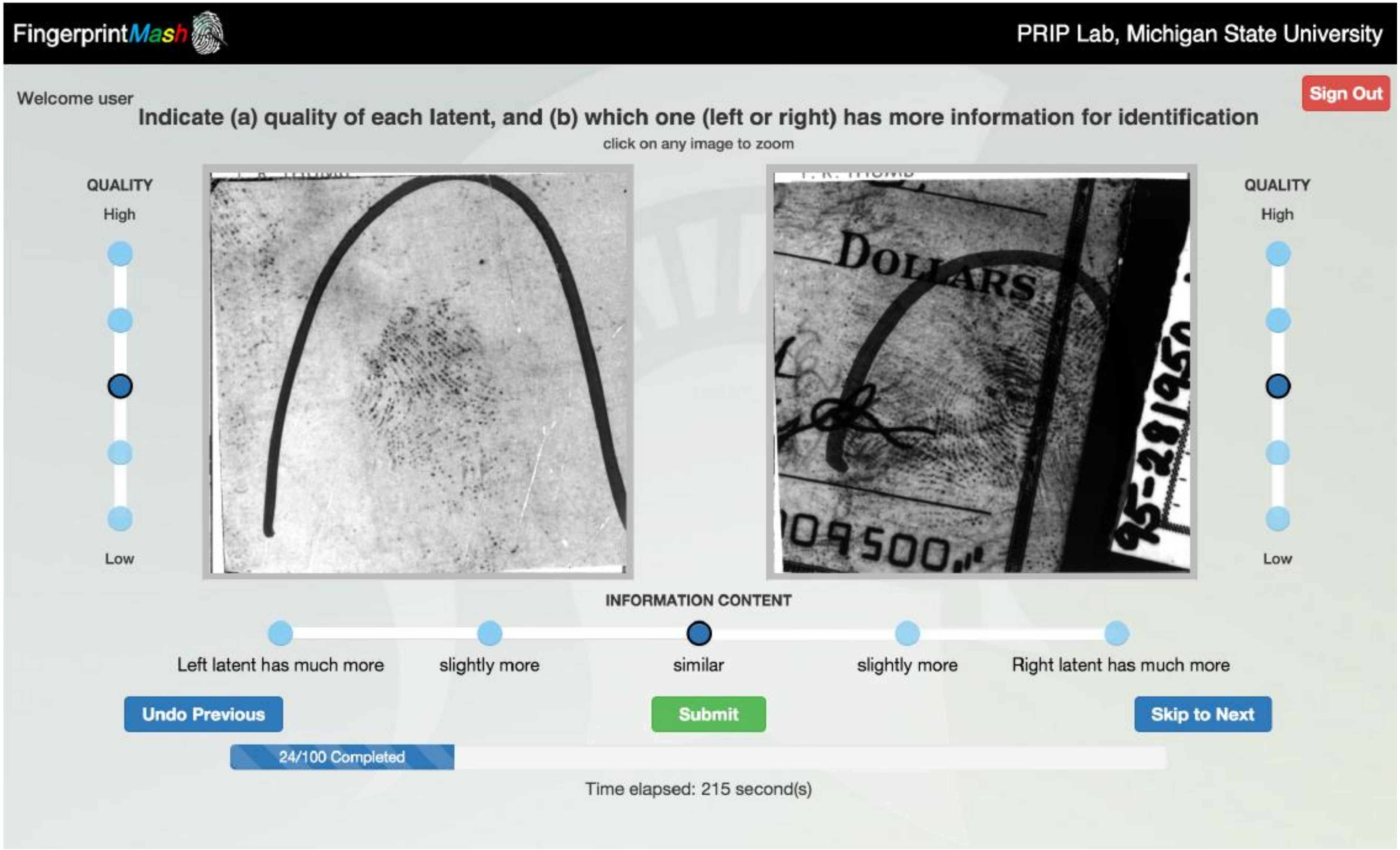
Latent ID: B106



Latent ID: U228

- Manually marked minutiae (blue)
- Automatic extracted minutiae (red)
- Automatic detected core point (green)

Fingerprint*Mash*: A Crowdsourcing Tool



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

	l_1	l_2	l_3	....	l_m
u_1	**3**	-	**2**	....	-
u_2	-	**3**	**2**	....	-
u_3	**5**	-	-	....	**2**
⋮	⋮	⋮	⋮	....	⋮
u_n	-	**4**	-	....	**2**

Partially observed quality matrix Q

Matrix Completion →

	l_1	l_2	l_3	....	l_m
u_1	2.9	3.1	1.9	....	0.9
u_2	4.2	3.2	2.1	....	1.1
u_3	5.0	3.5	2.1	....	2.2
⋮	⋮	⋮	⋮	....	⋮
u_n	5.0	3.9	2.0	....	1.9

Completed quality matrix $\widehat{Q}$

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

	$l_1 > l_2$	$l_1 > l_2$	....	$l_{m-1} > l_m$
u_1	**1**	-	....	1
u_2	-1	**1**	....	-
u_3	-1	-1	....	-
$\vdots$	$\vdots$	$\vdots$	....	$\vdots$
u_n	-	1	....	1

Matrix Completion →

	l_1	l_2	l_3	....	l_m
u_1	2.7	2.1	3.6	....	0.7
u_2	3.2	3.3	3.5	....	2.1
u_3	4.0	2.5	3.4	....	3.2
$\vdots$	$\vdots$	$\vdots$	$\vdots$	....	$\vdots$
u_n	3.5	3.9	2.4	....	1.

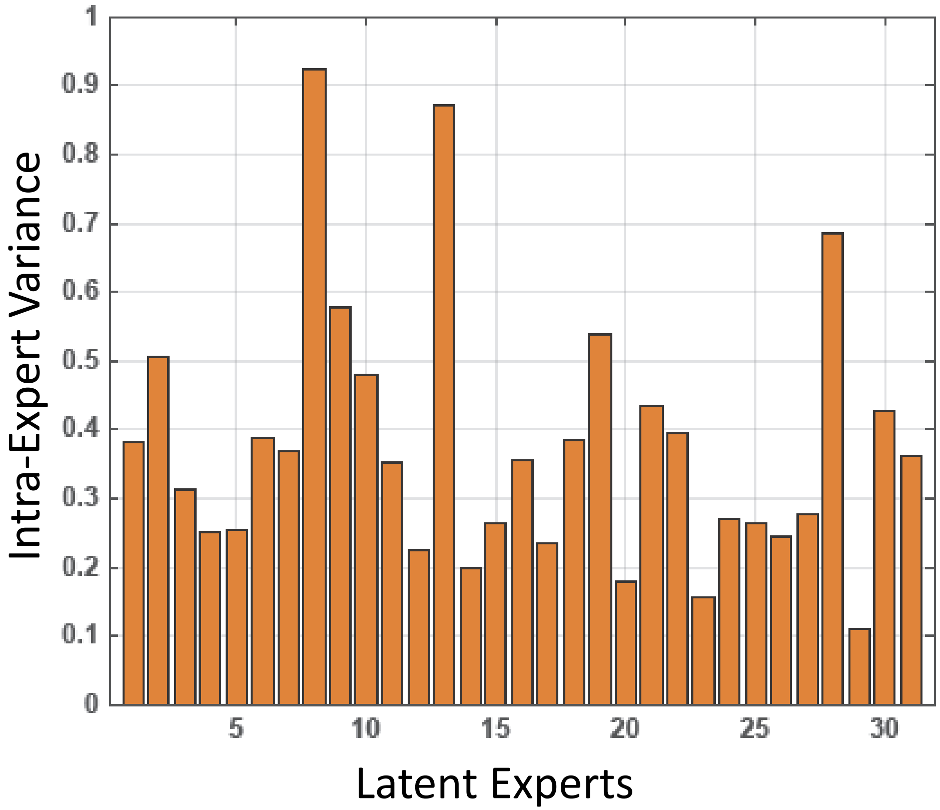
Partially observed pairwise information content **C**

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

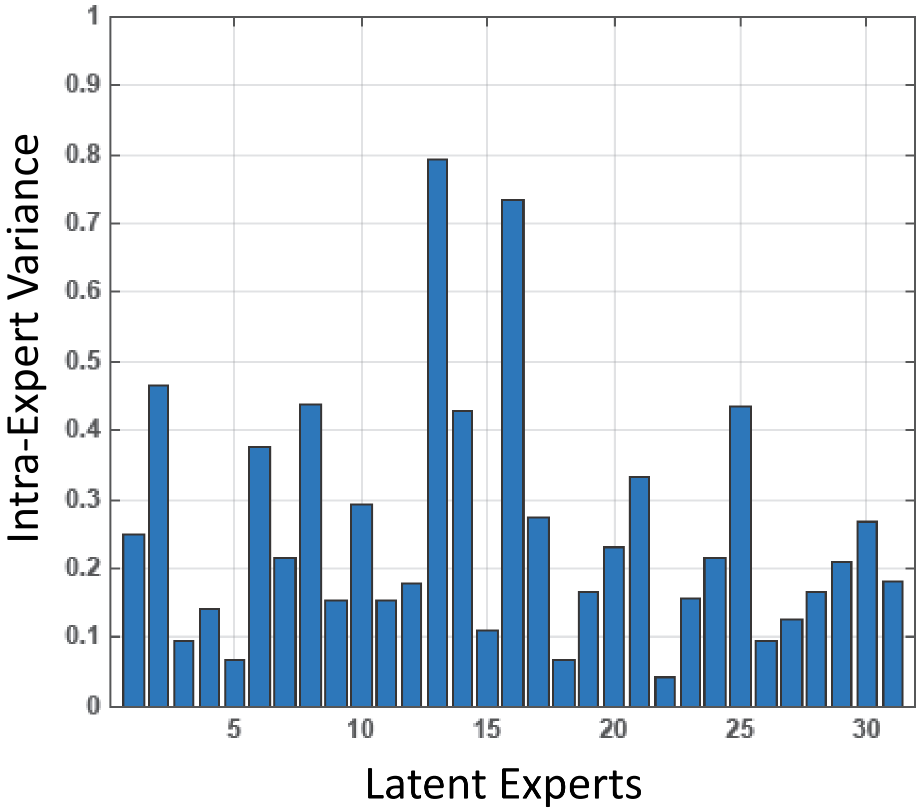
Latent value $\quad \mathbf{V} = (\widehat{\mathrm{Q}} + \widehat{\mathrm{C}})/\mathbf{2}$

Yi et al., Inferring User's Preferences from Crowdsourced Pairwise Comparisons: A Matrix Completion Approach, In HCOMP, 2013

Intra-Expert Variance



Numerical rating



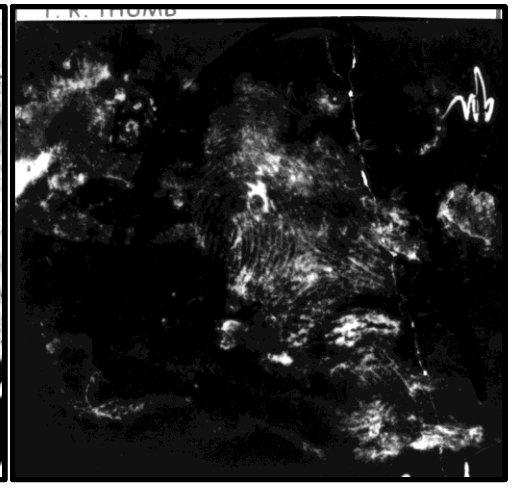
Pairwise comparison

Intra-Expert Variance

Numerical Rating

Mean = 0.35; Std. Dev. = 0.16

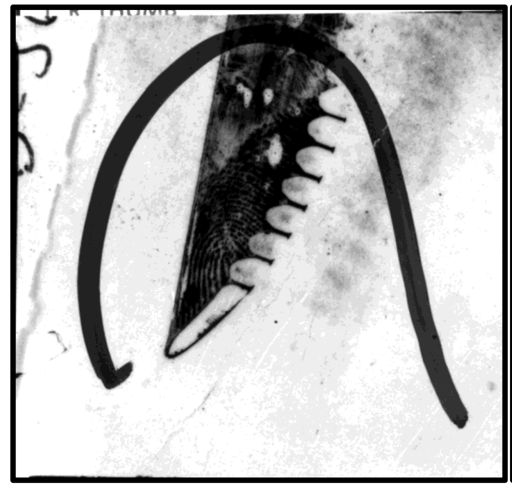
Low variance
Values = [4,4,4,4]



High variance
Values = [1,2,2,4]

Pairwise Comparison

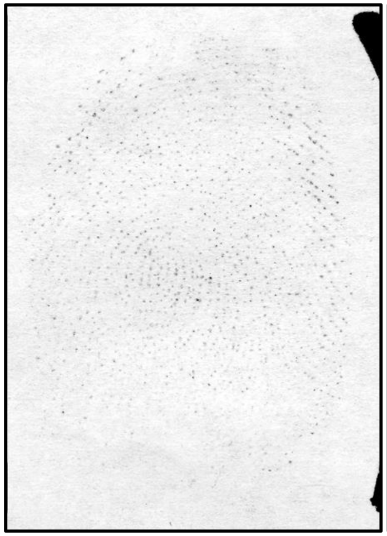
Mean = 0.24; Std. Dev. = 0.15



High variance in comparison
Value ranged from 1 to 4

Inter-Expert Variance

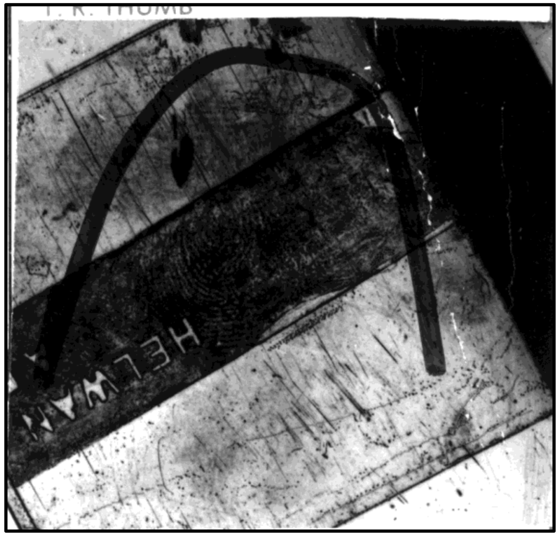
Examples of strong agreement among experts



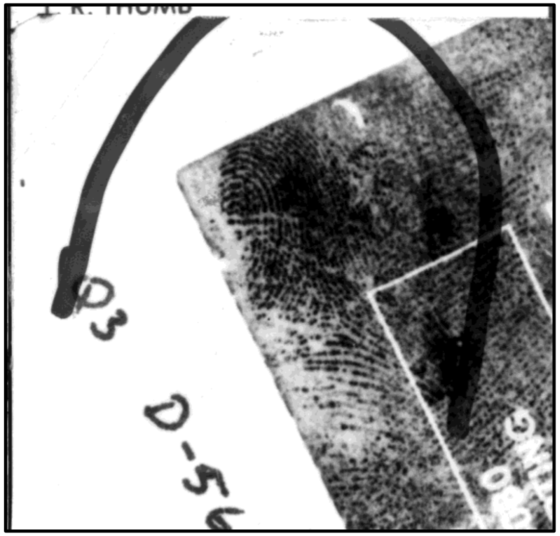
Low Value (1)

High Value (5)

Examples of strong disagreement among experts

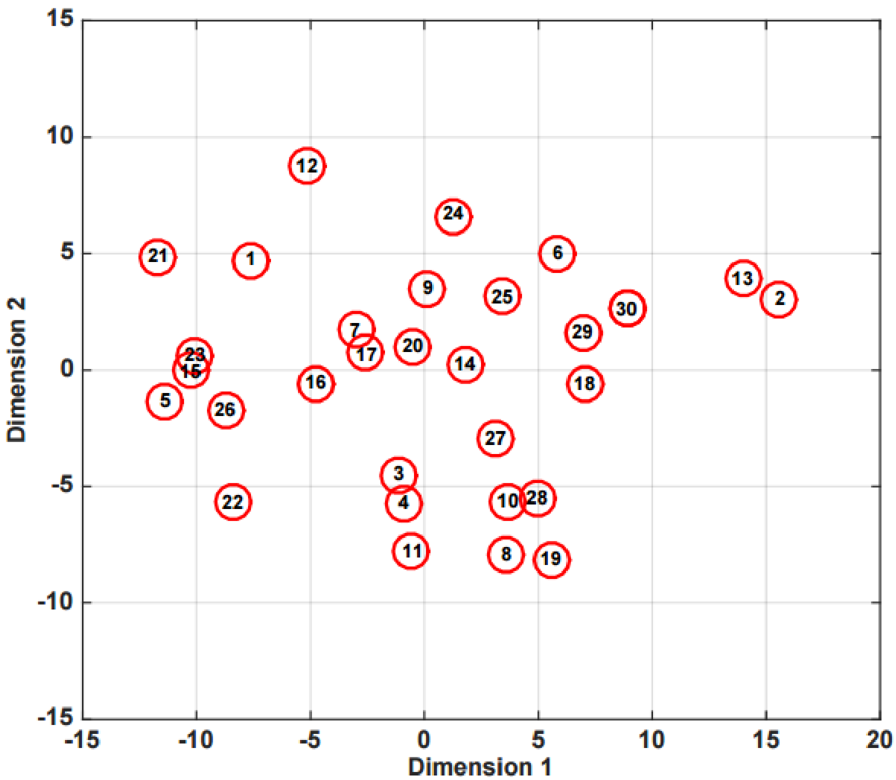


Value Range (2-5)

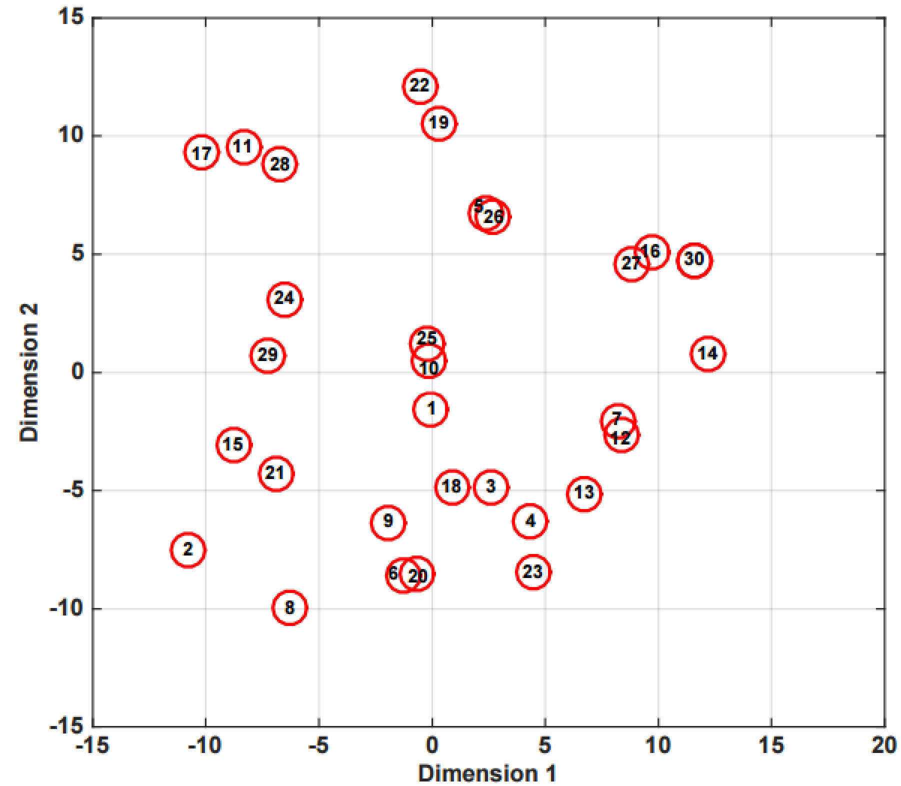


Value Range (1-5)

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]

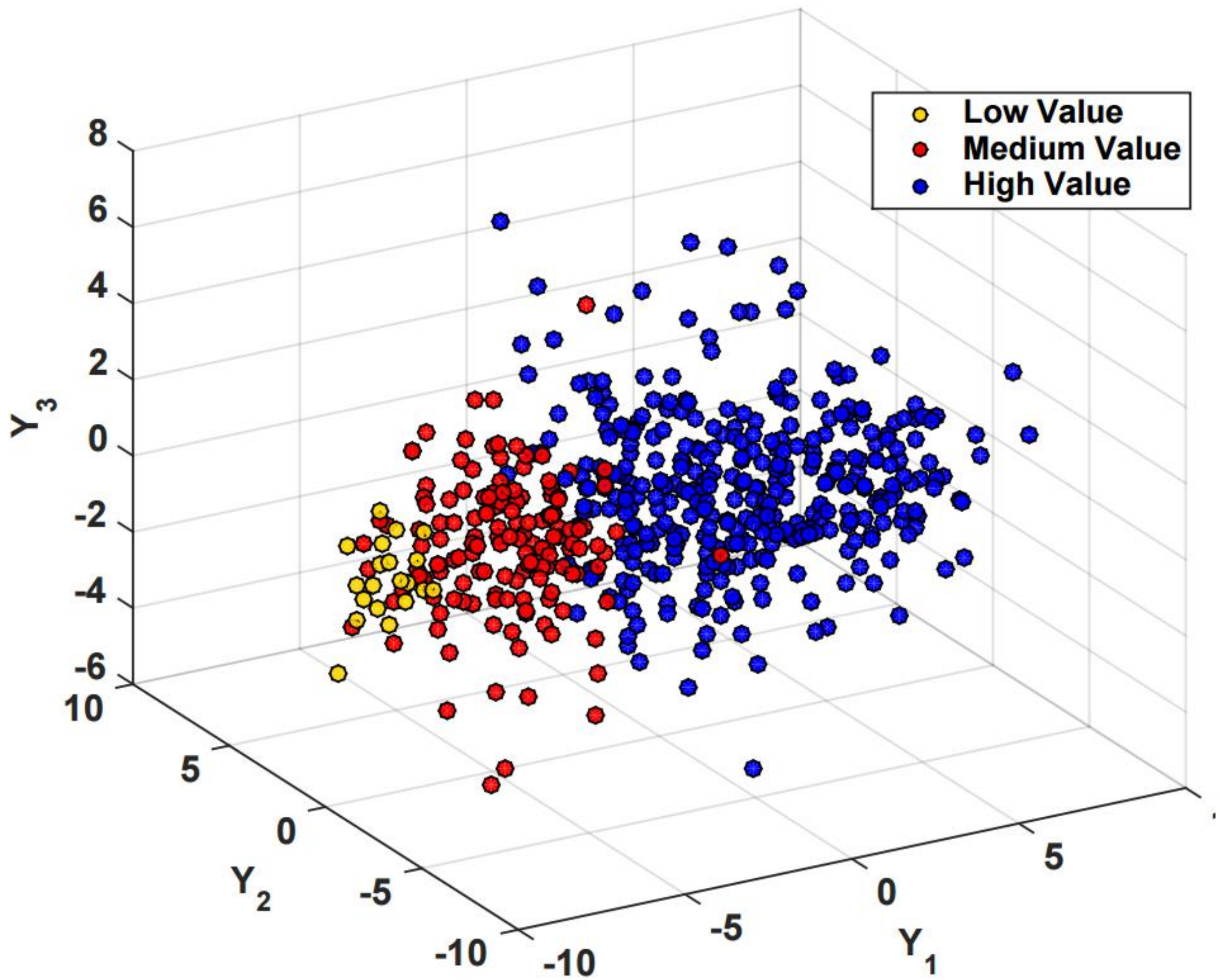
Rank-1 hit rates from AFIS; 250K reference prints

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 ≥ t, t= 0, 0.1, ..., 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 ≥ t, t= 0, 0.1, ..., 0.6
18	Number of **singular points** (core and delta)
19	**Standard deviation of the ridge flow** in the foreground

First Basis: features 1, 2 - 8, 11 - 17, 18, 19

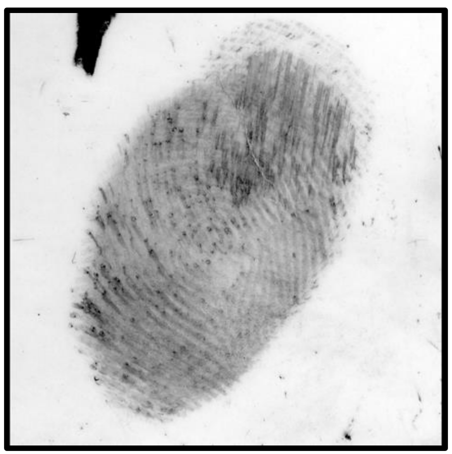
Second Basis: features 9, 10, 18, 19

Value Prediction

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

Examples of correctly predicted latent value

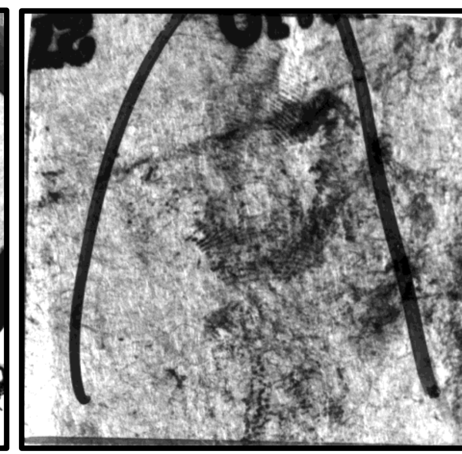
Crowd : 4.67
Predicted : 4.68



Crowd : 2.08
Predicted : 2.04

Examples of incorrectly predicted latent value

Crowd : 2.99
Predicted : 4.02



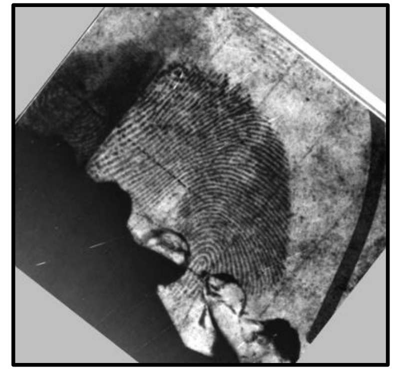
Crowd : 2.96
Predicted : 2.02

Value Prediction

Source: MSP
Rank Retrieval: 1
Predicted Value: 4.96

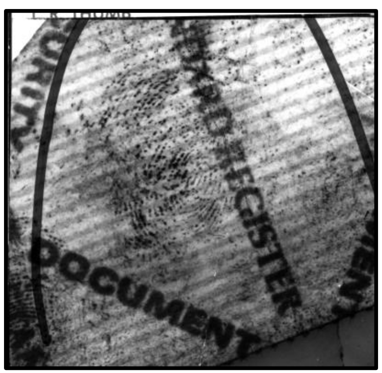
Source: MSP
Rank Retrieval: 1
Predicted Value: 4.62

Source: MSP
Rank Retrieval: 1
Predicted Value: 4.23



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

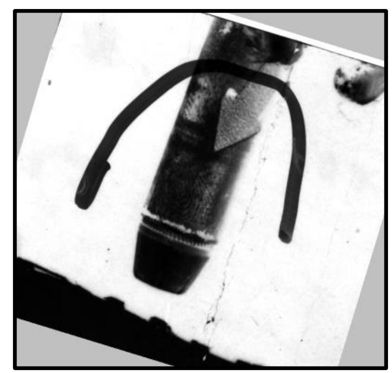
Source: NIST SD27
Rank Retrieval: 1
Predicted Value: 4.02



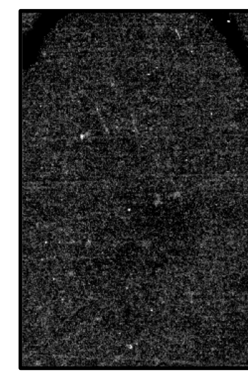
Source: NIST SD27
Rank Retrieval: 14,806
Predicted Value: 1.37

Source: MSP
Rank Retrieval: 11
Predicted Value: 1.25

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

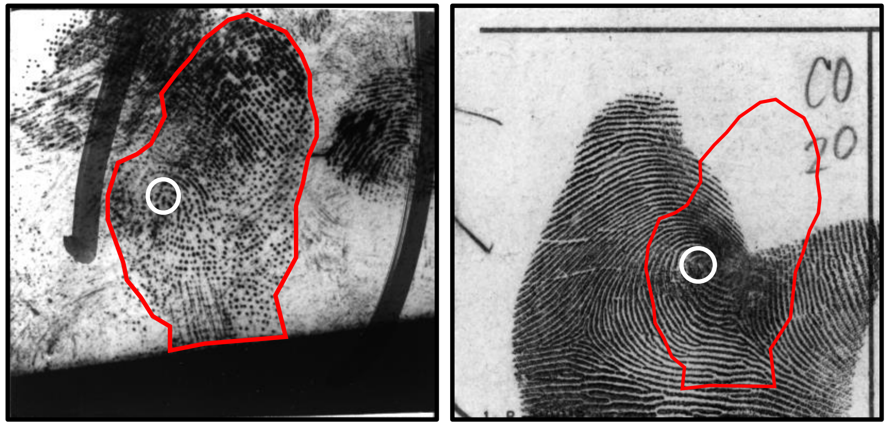


Source: NIST SD27
Rank Retrieval: 21,662
Predicted Value: 1.08

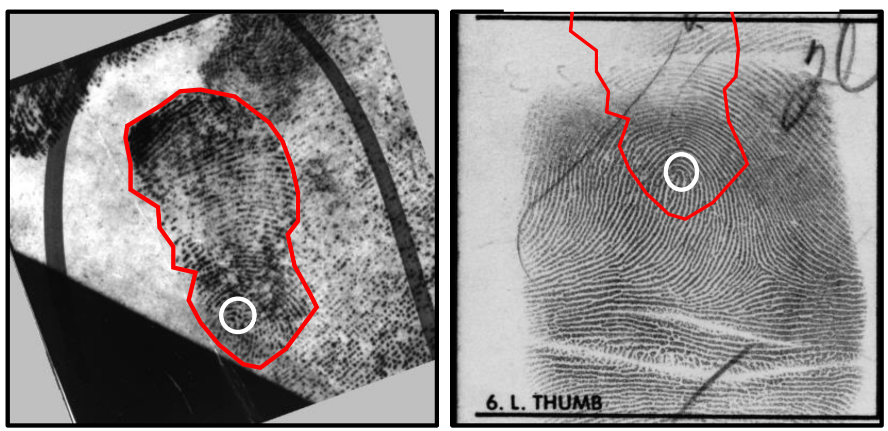


Source: MSP
Rank Retrieval: 50,980
Predicted Value: 1.01

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?