

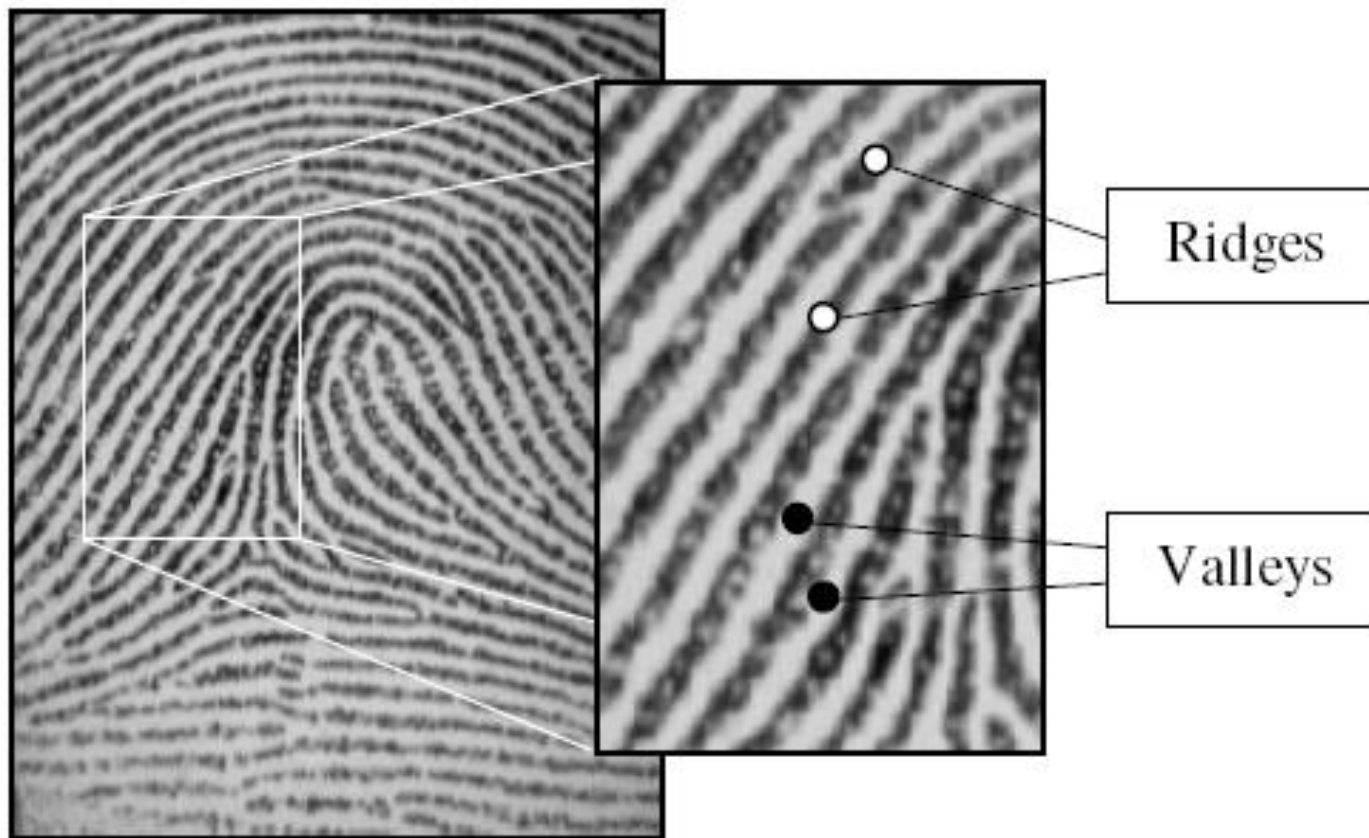
# Segmentation and Enhancement of Latent Fingerprints: A Coarse to Fine Ridge Structure Dictionary

Kai Cao

January 16, 2014

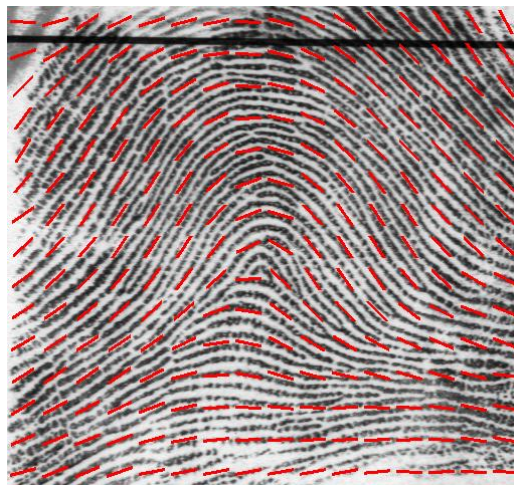
# Fingerprint

*Fingerprint Image*

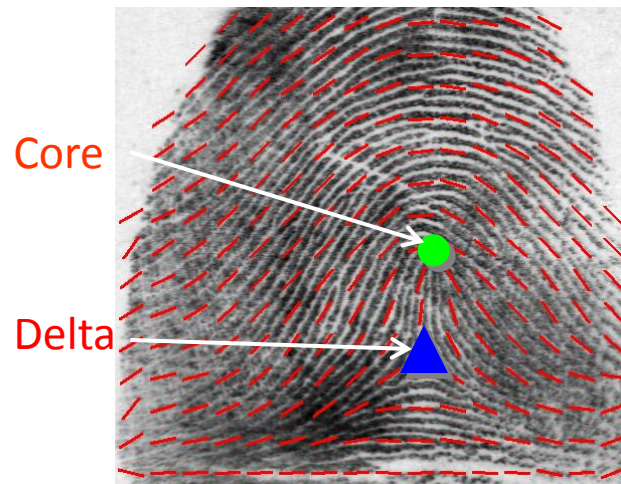


# Fingerprint level-1 features

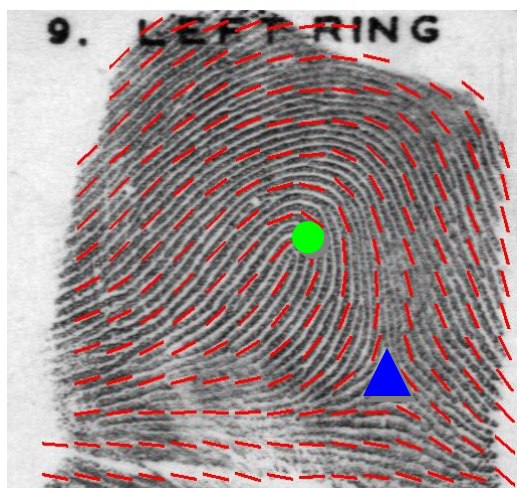
- 1) Pattern type
- 2) Orientation field
- 3) Singular points
- 4) Frequency field



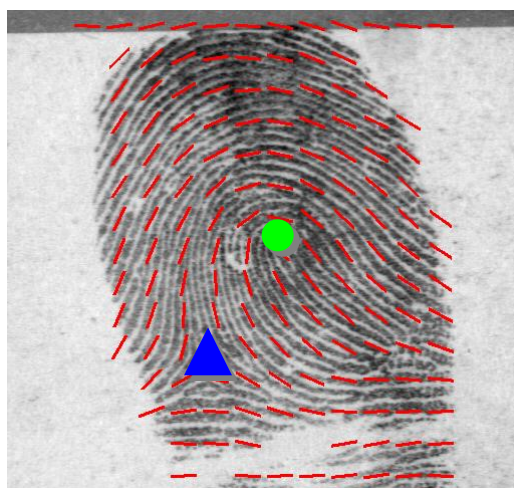
Arch



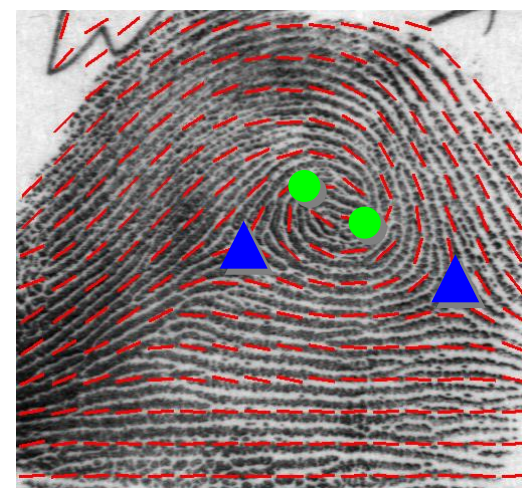
Tented arch



Left loop



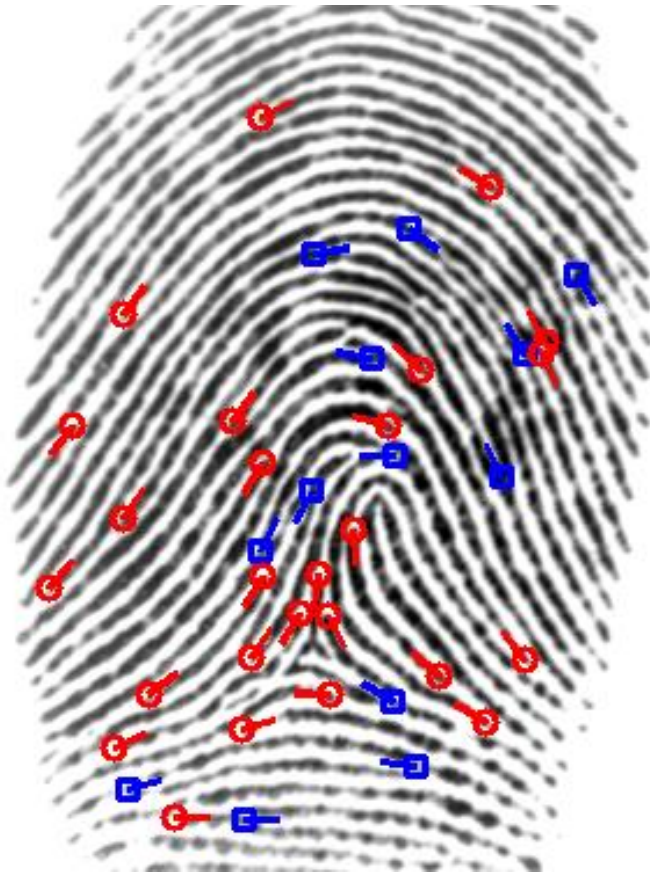
Right loop



Whorl

# Fingerprint level-2 features

- Minutiae: ridge endings and bifurcations



Ridge ending

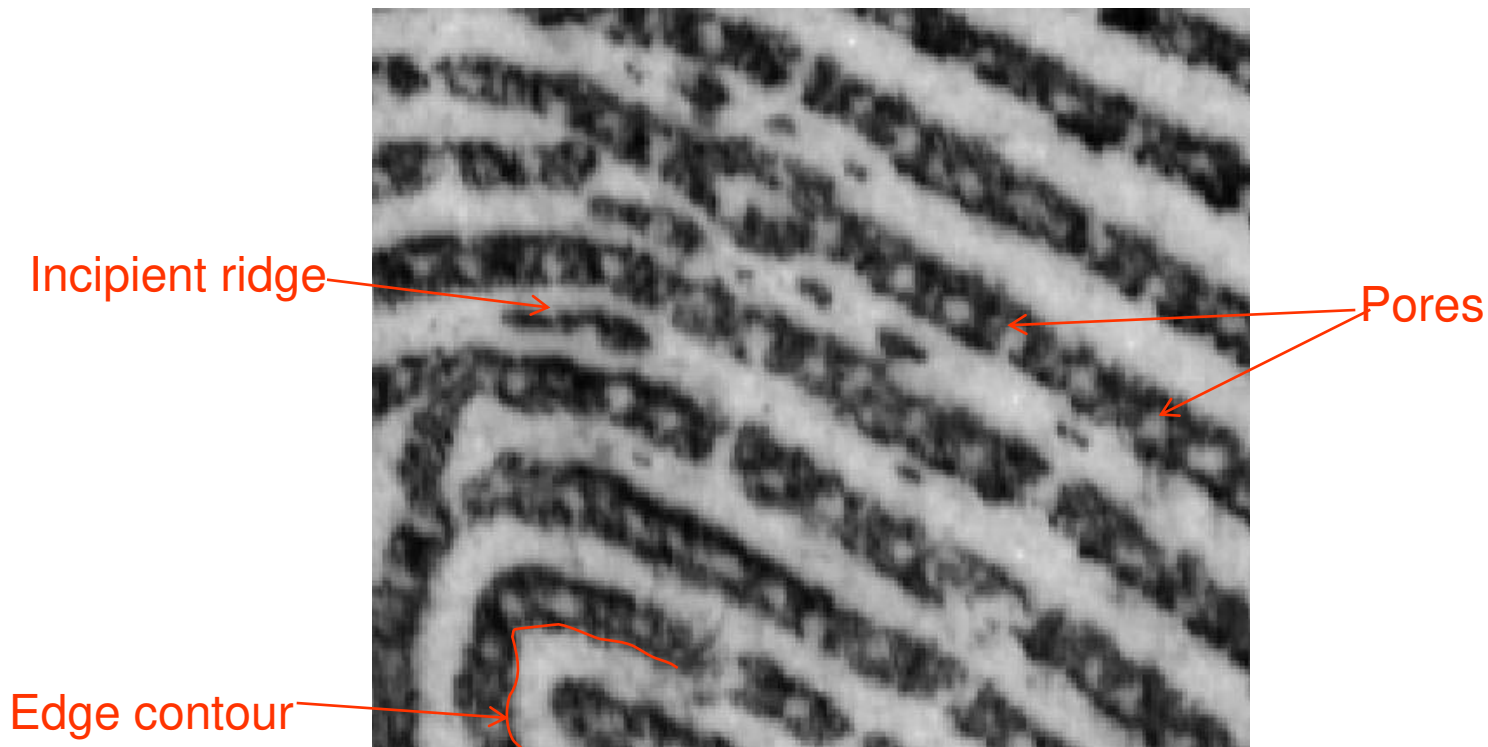


Ridge bifurcation



# Fingerprint level-3 features

- Include all dimensional attributes of the ridge such as pores, edge contour, incipient ridges and other permanent details



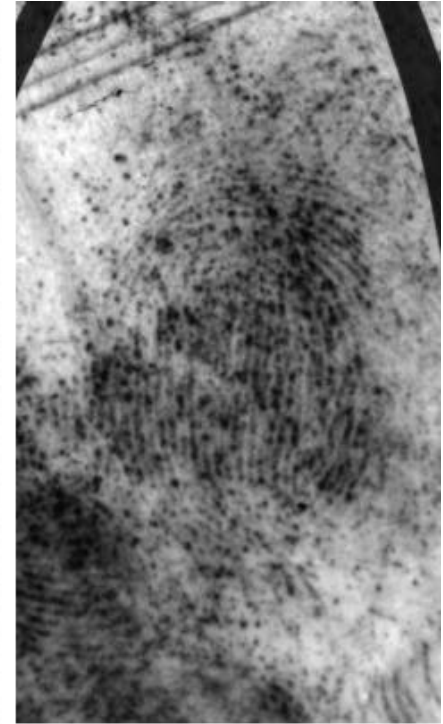
# Fingerprint types



Rolled fingerprint



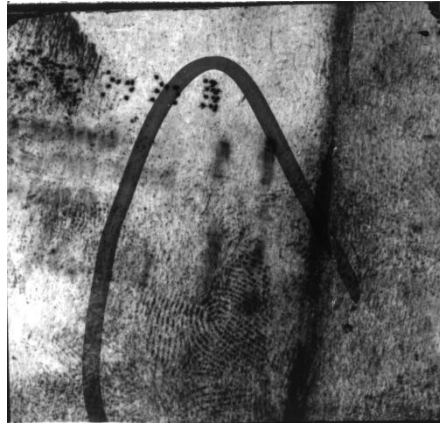
Plain fingerprint



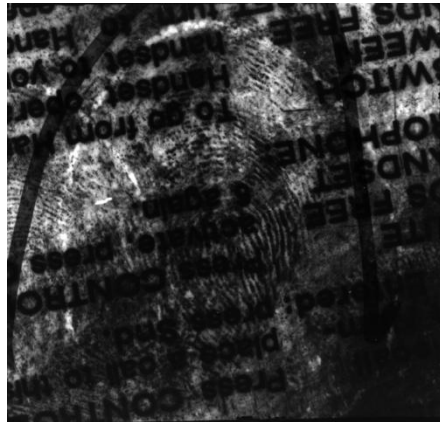
latent fingerprint

# Challenges in latent matching

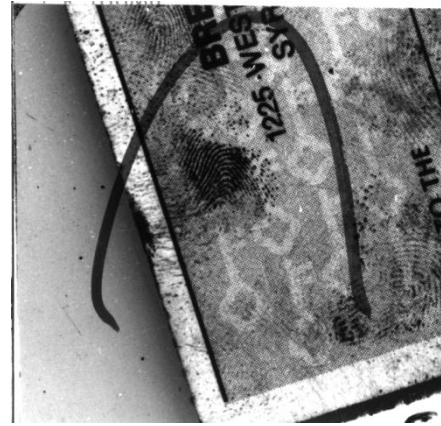
Reliable  
feature  
extraction



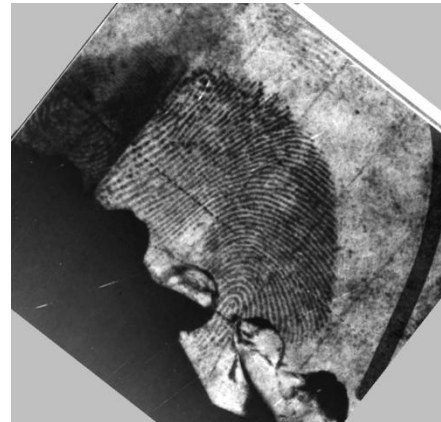
Unclear ridges



Complex background



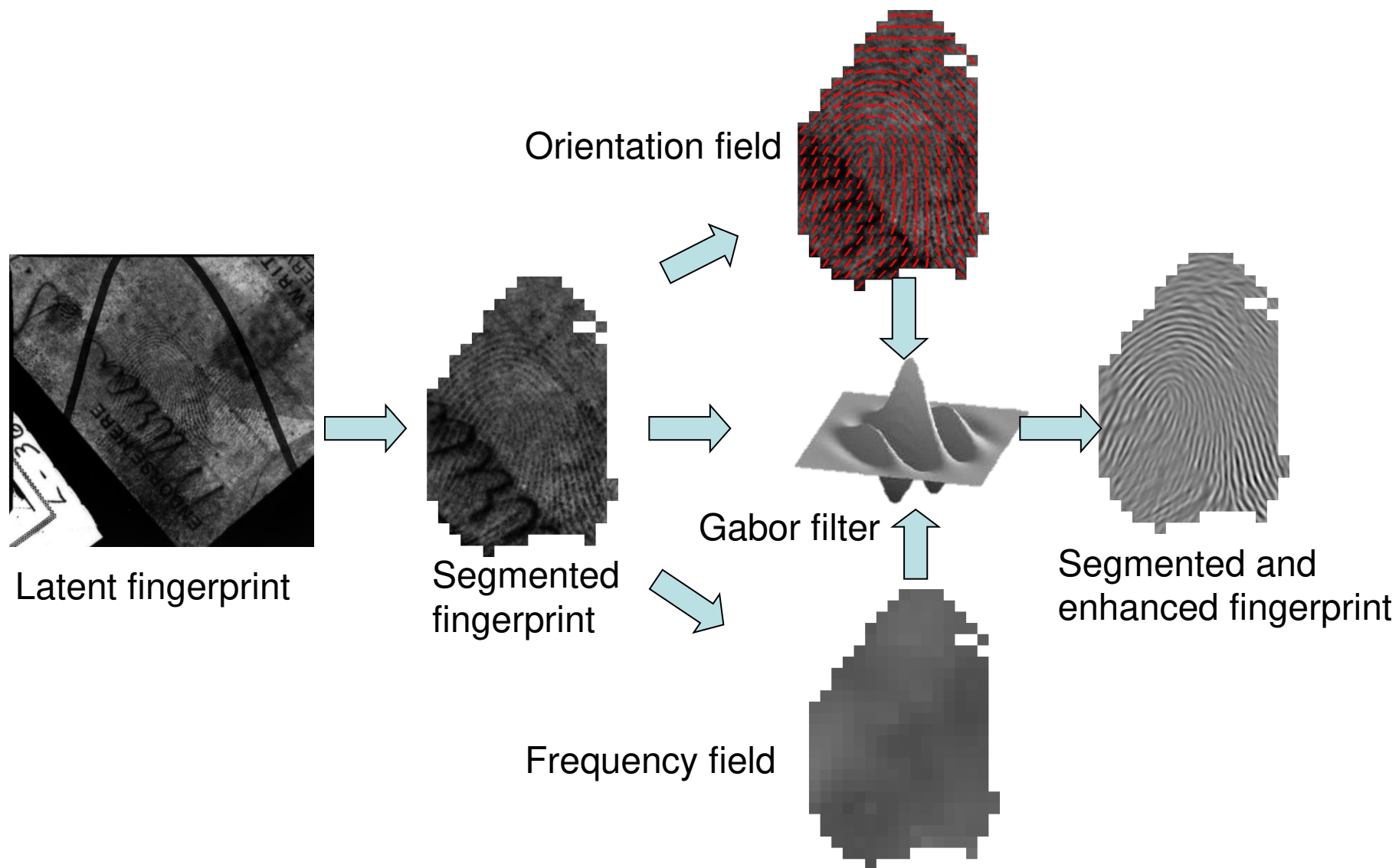
Partial fingerprint



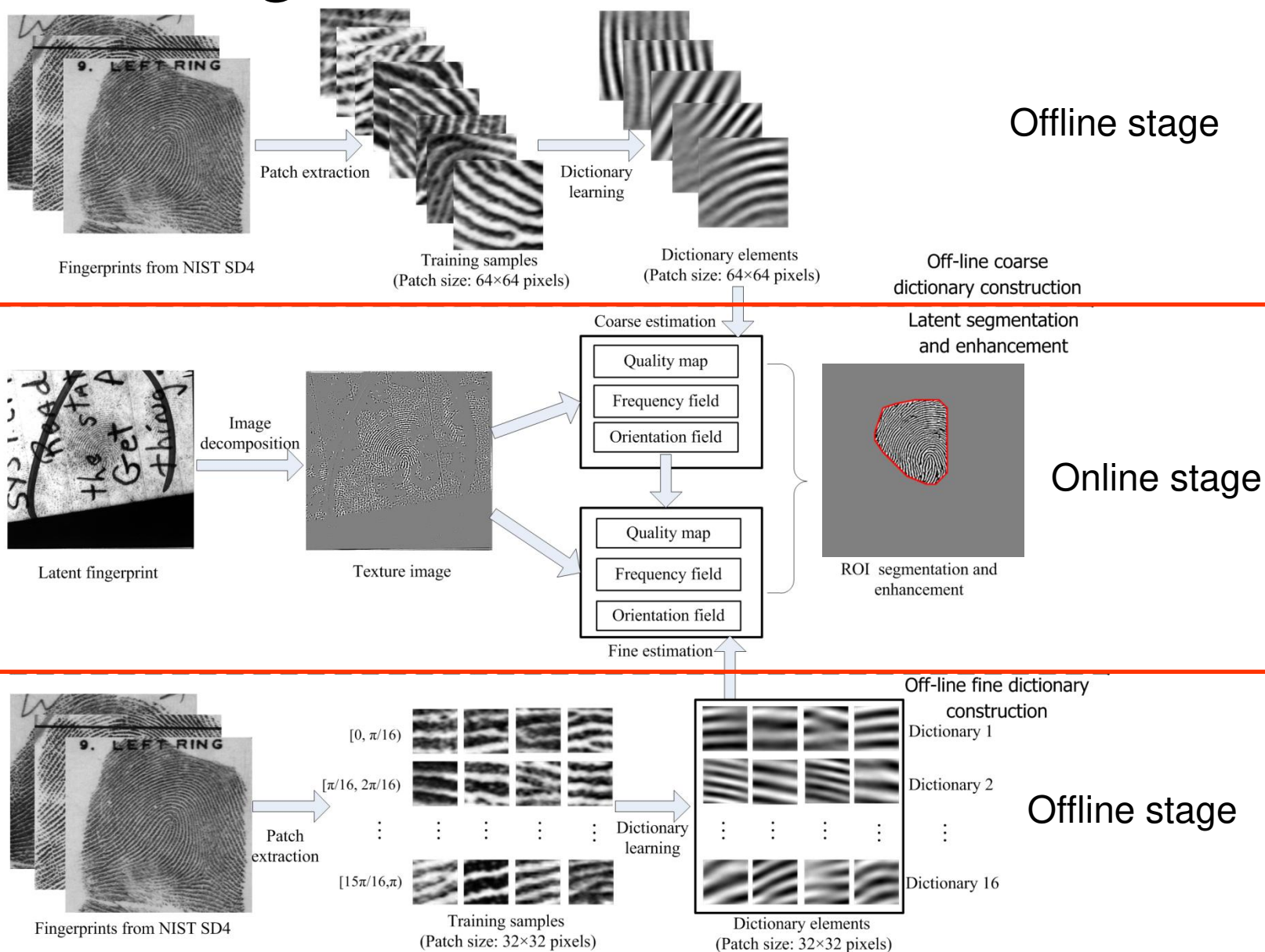
Large distortion

Robust  
feature  
matching

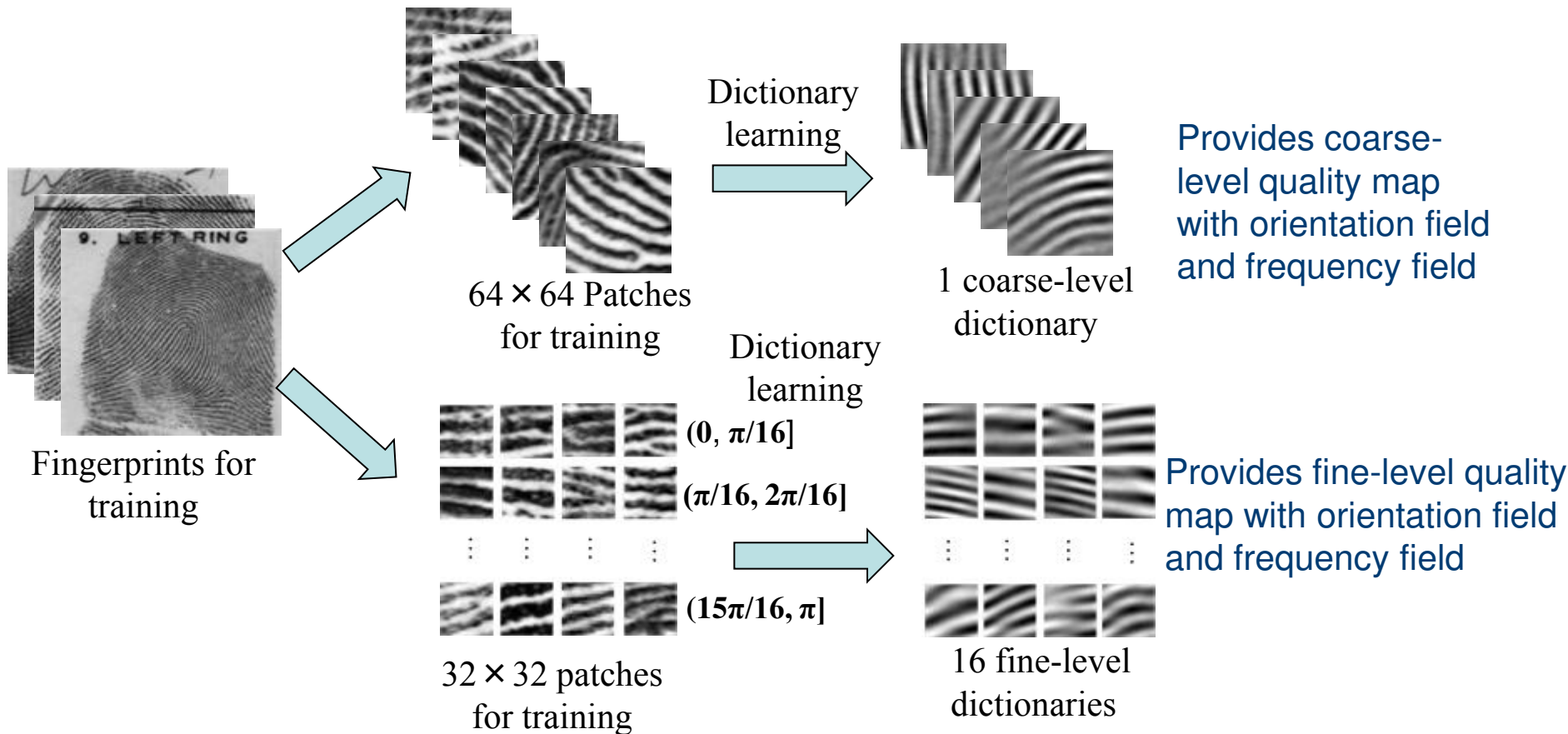
# Essential modules for feature extraction



# Algorithm flowchart



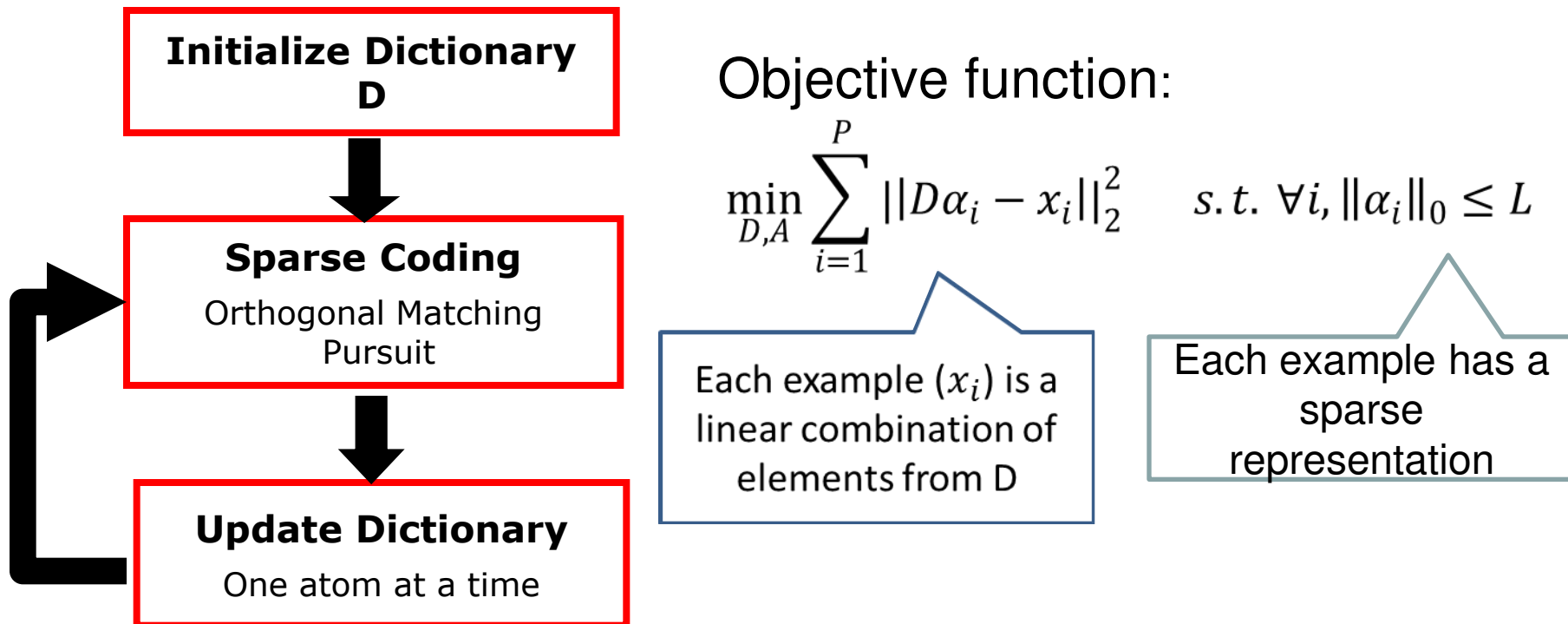
# Friction ridge dictionary learning



- (1) Fingerprint selection: NFIQ index  $\leq 2$
- (2) Patch selection: average quality  $\geq 3.75$

# Friction ridge dictionary learning

- Learning algorithm: K-SVD<sup>[1]</sup>
- Database: High quality patches in NIST DB 4



[1] M. Aharon, M. Elad and A. Bruchstein, "K-SVD: An Algorithm for Designing Overcomplete Dictionaries for Sparse Representation", *IEEE TSP*, 54(11): 4311-4322, 2006.

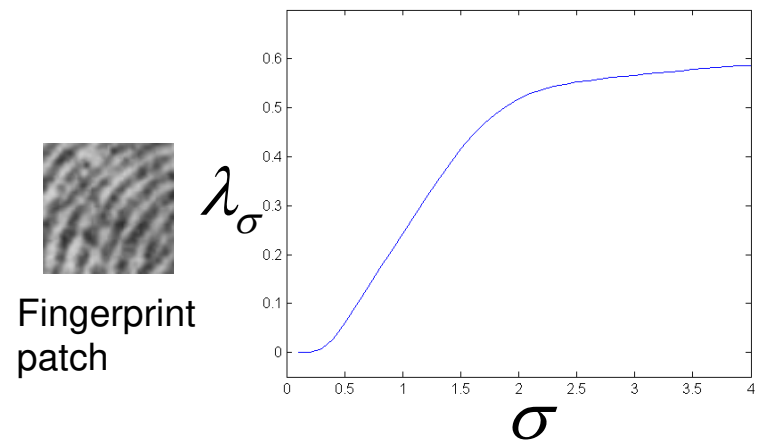
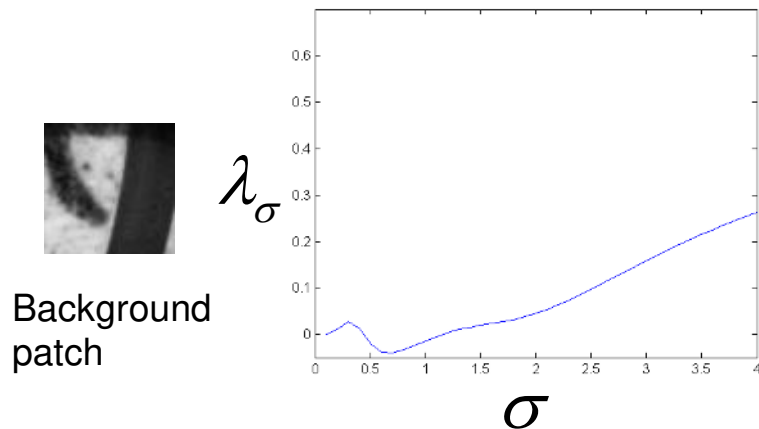
# Latent fingerprint decomposition

- *local total variation*<sup>[1]</sup> (LTV)

$$LTV_{\sigma}(f) = L_{\sigma} * |\nabla f| (x), \quad \hat{L}_{\sigma}(\xi) := \frac{1}{1 + (2\pi\sigma|\xi|)^4}.$$

- *relative reduction rate of LTV*

$$\lambda_{\sigma}(x) := \frac{LTV_{\sigma}(f)(x) - LTV_{\sigma}(L_{\sigma} * f)(x)}{LTV_{\sigma}(f)(x)}$$



[1] A. Buades, T. Le, J.-M. Morel, and L. Vese, "Fast cartoon + texture image filters," *IEEE Transactions on Image Processing*, 19(8):1978–1986, 2010.

# Latent fingerprint decomposition

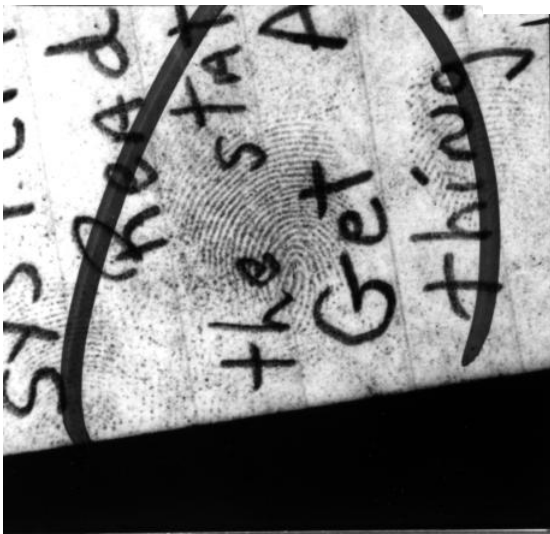
- Cartoon part and texture part

$$u(x) = w(\lambda_\sigma(x))(L_\sigma * f)(x) + (1 - w(\lambda_\sigma(x)))f(x),$$

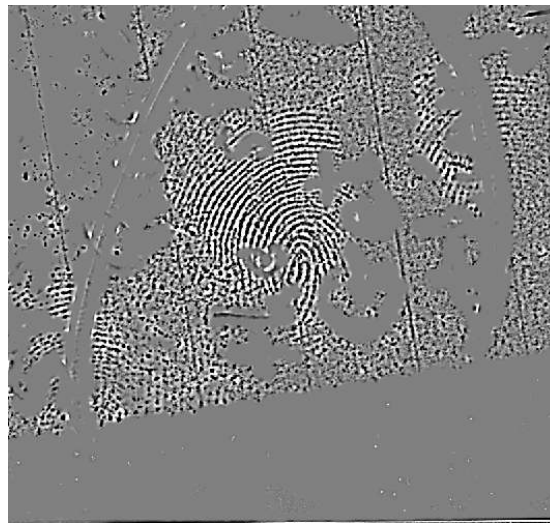
Cartoon part

$$v(x) = f(x) - u(x)$$

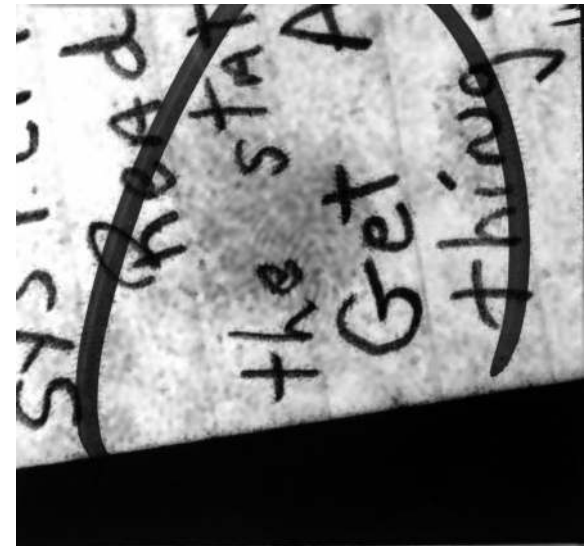
Texture part



Gray image



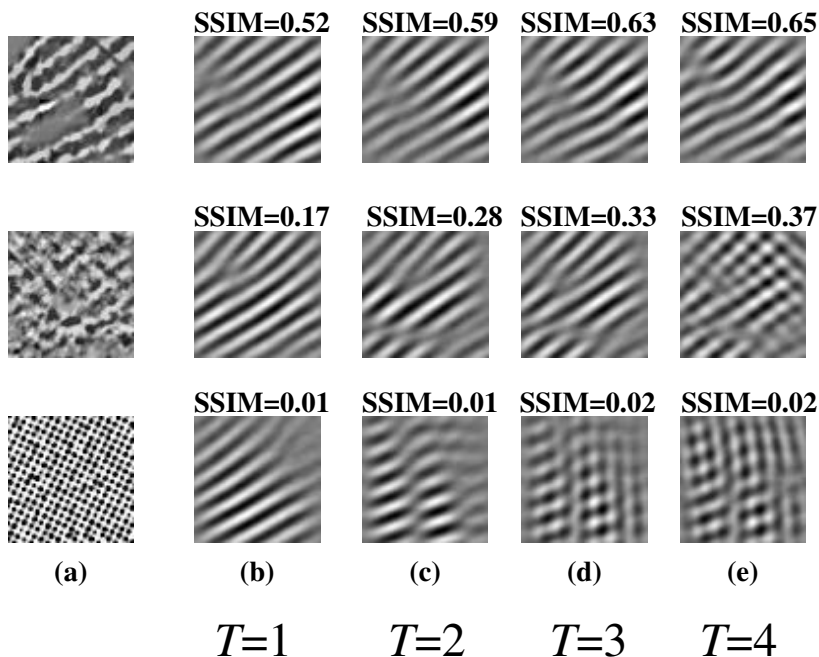
Texture part



Cartoon part

# Patch reconstruction

- Patch reconstructed with  $T$  dictionary elements
- Structure similarity (SSIM<sup>[2]</sup>) measures the quality

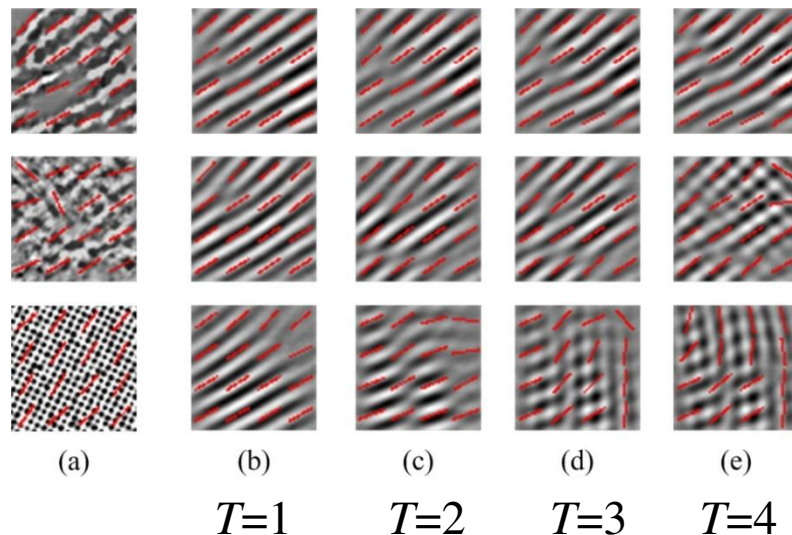


Quality estimation

$$SSIM(x, y) = \frac{2\mu_x\mu_y + C_1}{\mu_x^2 + \mu_y^2 + C_1} \frac{\sigma_{xy} + C_2}{\sigma_x^2 + \sigma_y^2 + C_2}$$

# Patch reconstruction

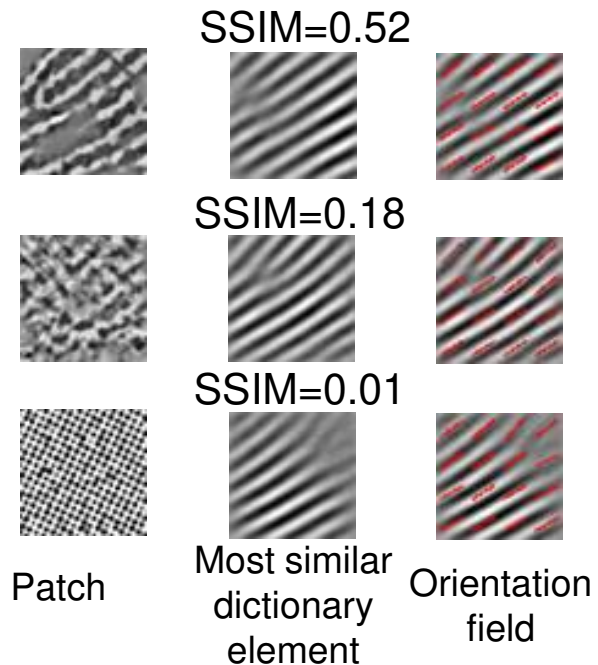
- Patch reconstructed by sparse coding
- Structure similarity (SSIM<sup>[2]</sup>) measures the quality
- Orientation and frequency fields are estimated from the reconstructed patch



Orientation field estimation

[2] Wang et al., “Image Quality Assessment: From Error Visibility to Structural Similarity”, *IEEE Transaction on Image Processing*, 13(4): 600-612, 2004.

# Sparsity control



## Advantages of $T=1$ :

- 1) A single dictionary element is good enough to recover level-1 features (orientation and frequency)
- 2) No matrix inversion needed in orthogonal matching pursuit
- 3) Orientation and frequency fields of the dictionary elements can be estimated offline

# Coarse to fine strategy

- Why do we need a coarse to fine strategy?

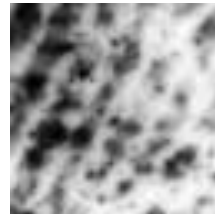
1) Small patch is easy affected by background noise



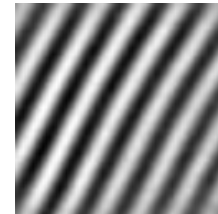
Patch  
32\*32



Most similar  
dictionary  
element



Patch  
64\*64

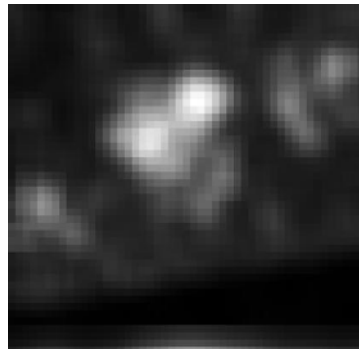


Most similar  
dictionary  
element

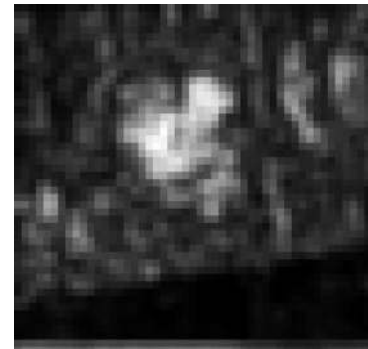
2) Large patch is not able to capture details



Latent



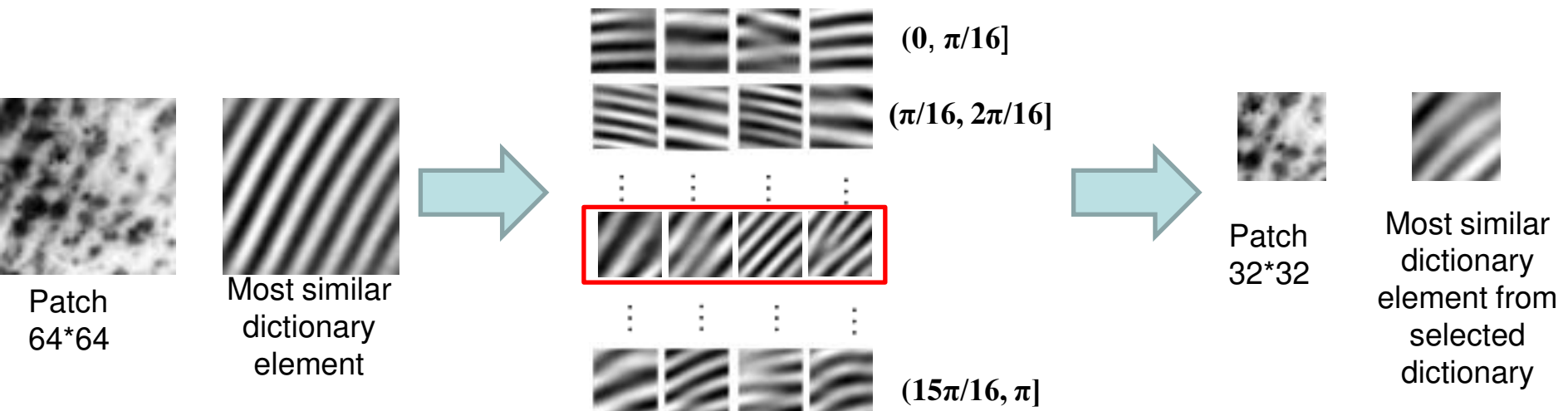
Coarse-level  
quality



Fine-level quality

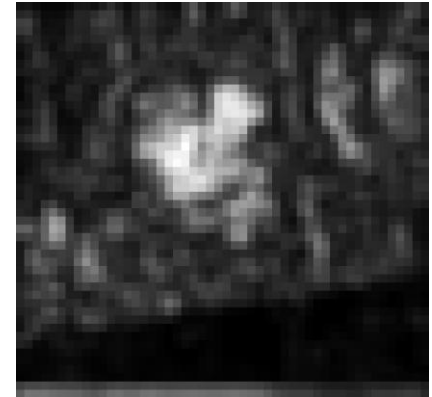
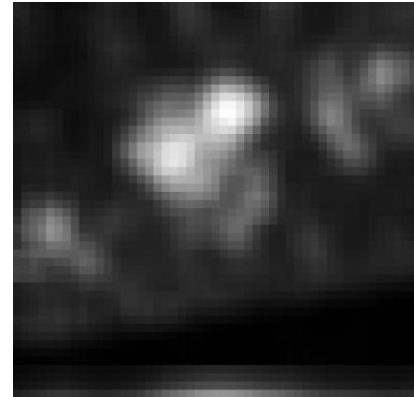
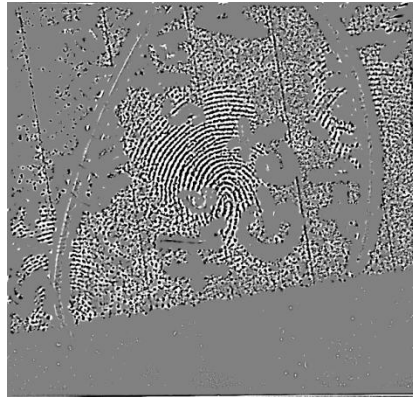
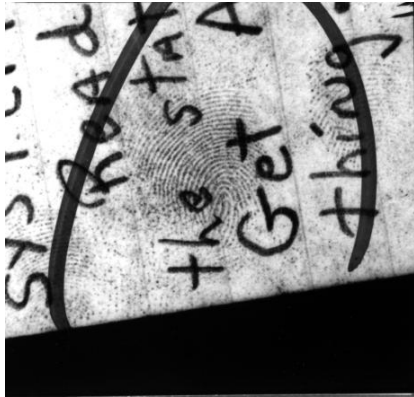
# Coarse to fine strategy

- How does coarse to fine strategy work?

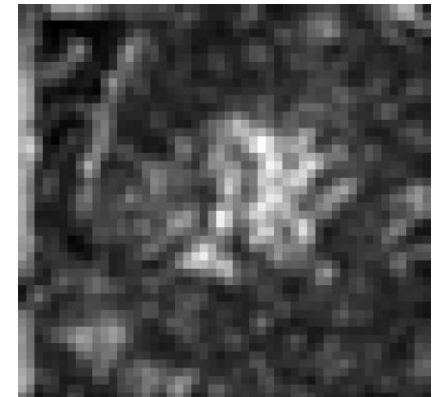
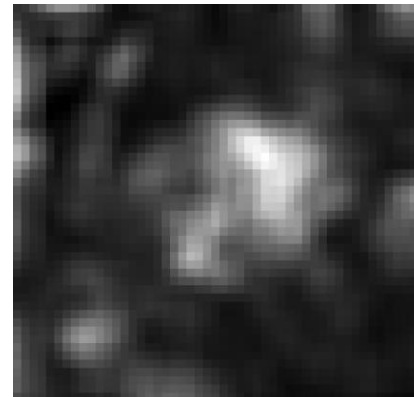
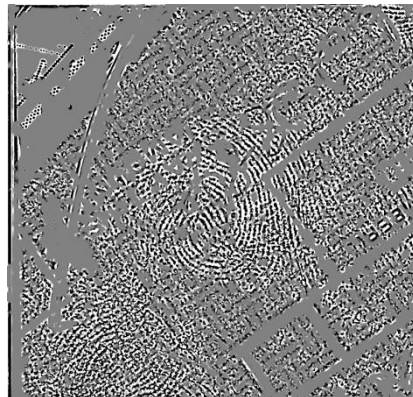


# Some results on NIST SD27

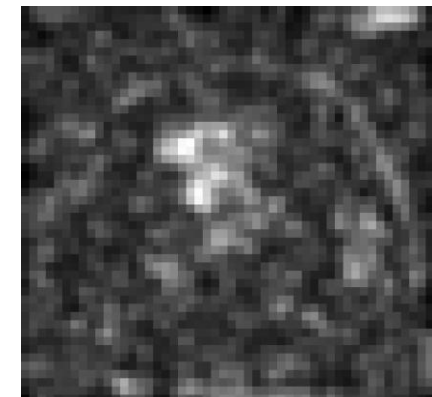
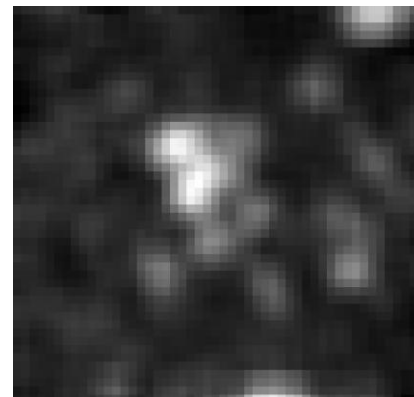
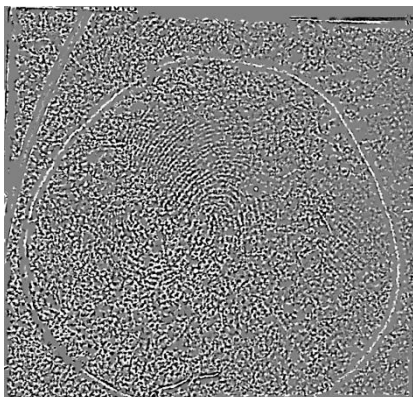
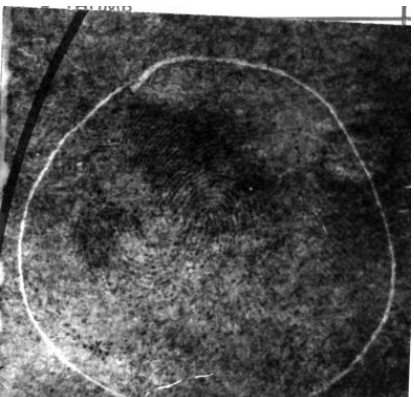
Good  
latent



Bad  
latent



Ugly  
latent



(a) Gray image

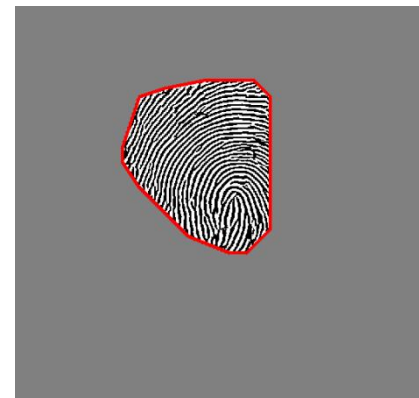
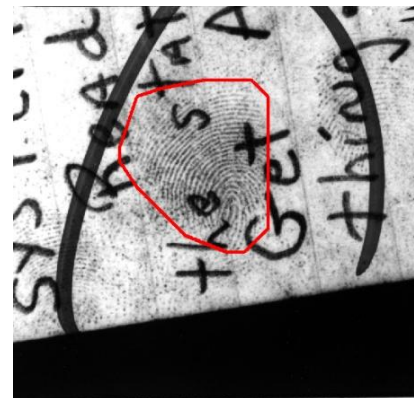
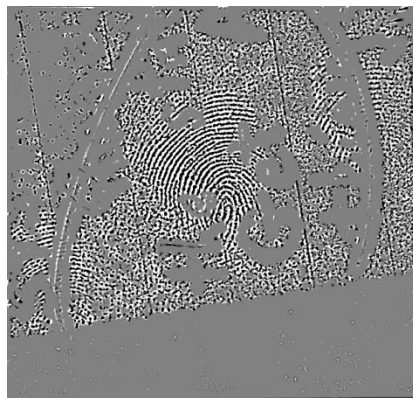
(b) Texture image

(c) Coarse quality map

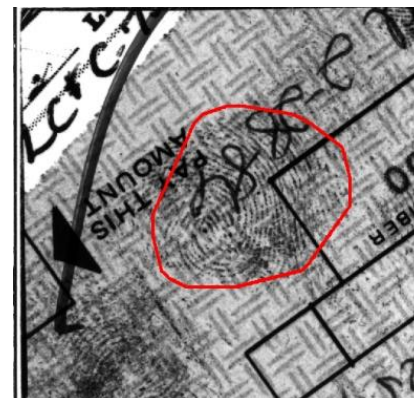
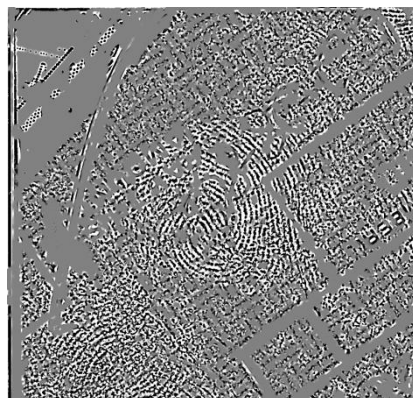
(d) Fine quality map

# Some results on NIST SD27

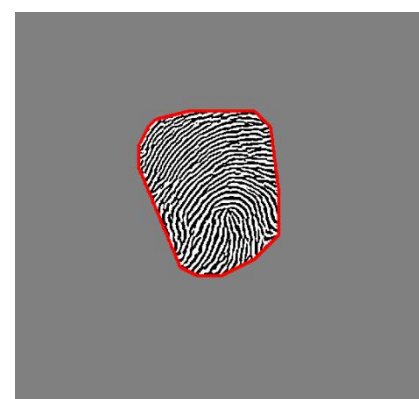
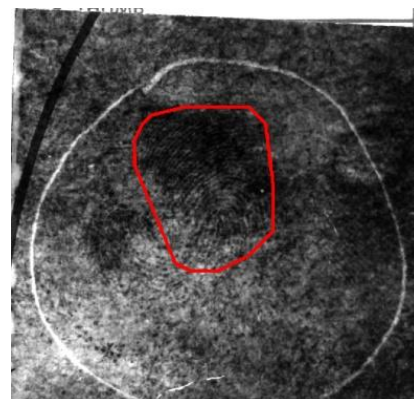
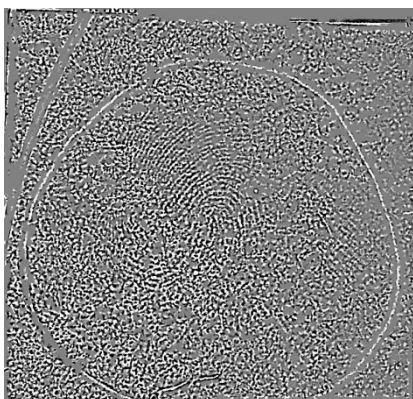
Good  
latent



Bad  
latent



Ugly  
latent



(a) Gray image

(b) Texture image

(c) Segmentation result

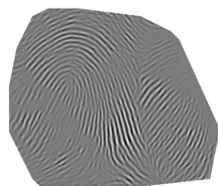
(d) Segmentation and  
enhancement result

# Performance evaluation

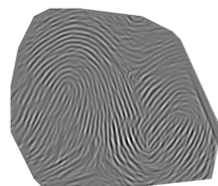
- **Latent Database:** 258 latents in NIST SD27 and 449 latents in WVU DB
- **Background Database :** 27,258 rolled prints in NIST SD27 (258) and NIST SD14 (27,000)
- **Matcher:** Commercial off the shelf (COTS) **tenprint** matcher



(a)



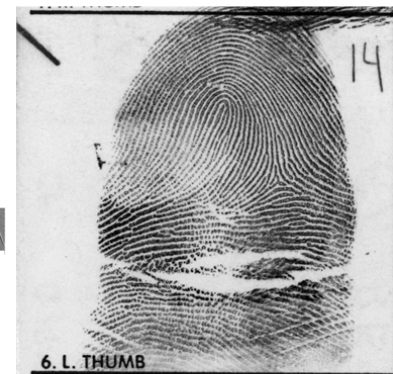
(b)



(c)



(d)



(e)

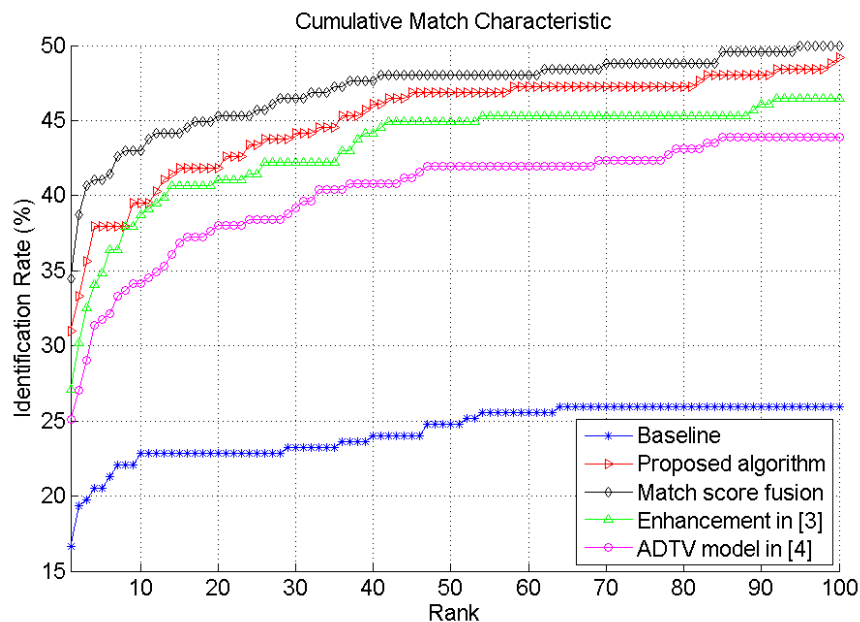
Four latent image types (templates) that can be input to a COTS matcher. (a) Original latent image (G084 from NIST SD 27), (b) latent segmented and enhanced by the proposed algorithm, (c) latent segmented by the proposed segmentation algorithm, but enhanced by the algorithm in [3] and (d) latent segmented and enhanced by the ADTV model [4], (e) the true mate (rolled print). The retrieved ranks of the mated rolled print by COTS for (a), (b), (c) and (d) are 5536, 1, 66 and 12462, respectively.

[3] J. Feng, J. Zhou, and A. K. Jain, "Orientation field estimation for latent fingerprint enhancement," *IEEE TPAMI*, vol. 54, no. 4, pp. 925–940, 2013.

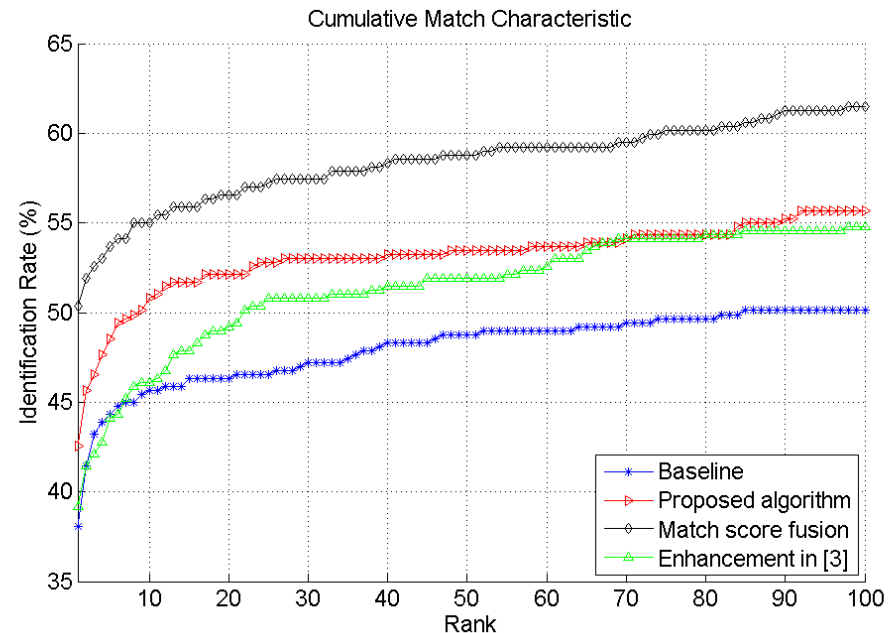
[4] J. Zhang, R. Lai, and C.-C. Kuo, "Adaptive directional total variation model for latent fingerprint segmentation," *IEEE TIFS*, vol. 8, no. 8, pp. 1261–1273, 2013.

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(a) NIST SD27



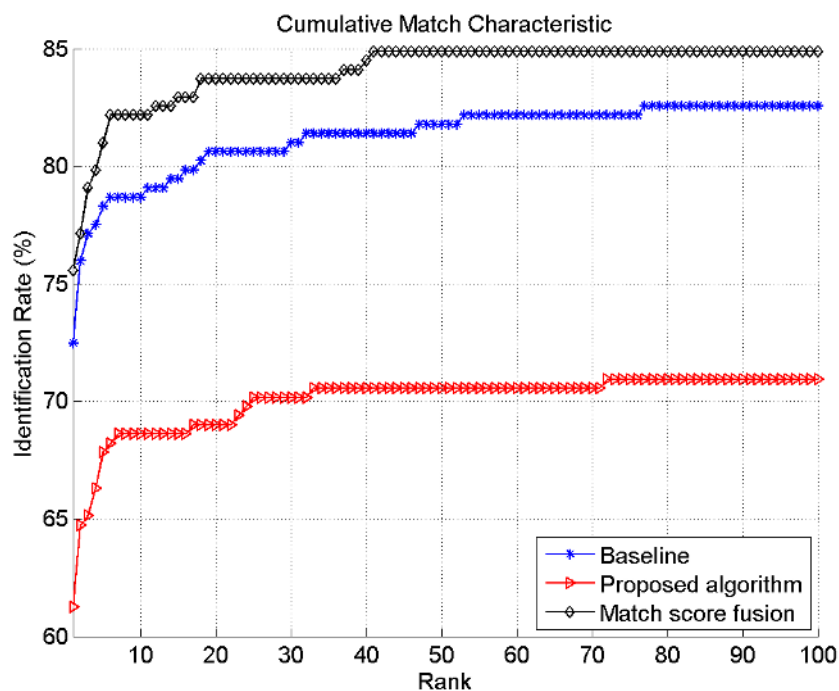
(b) WVU DB

[3] J. Feng, J. Zhou, and A. K. Jain, "Orientation field estimation for latent fingerprint enhancement," *IEEE TPAMI*, vol. 54, no. 4, pp. 925–940, 2013.

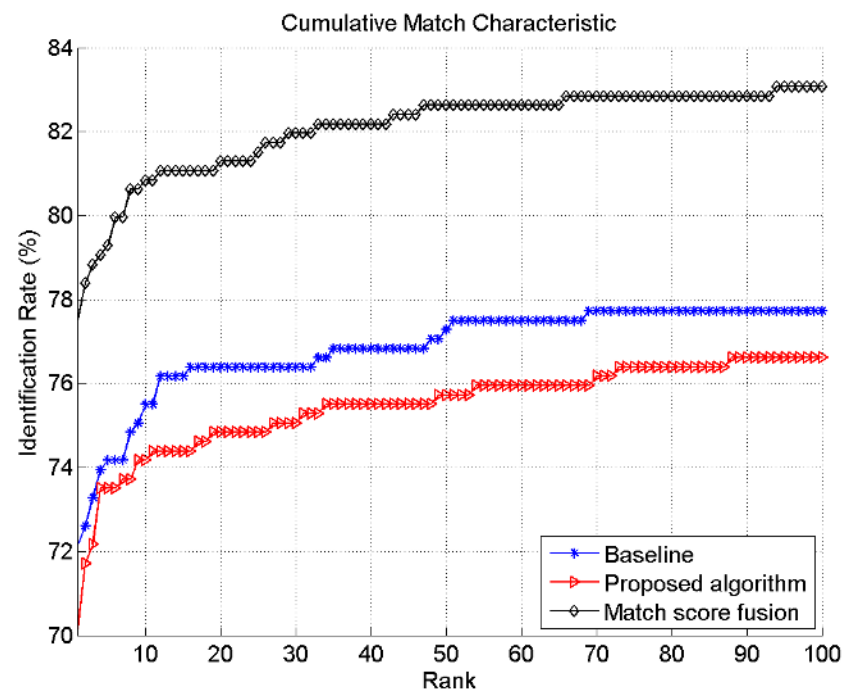
[4] J. Zhang, R. Lai, and C.-C. Kuo, "Adaptive directional total variation model for latent fingerprint segmentation," *IEEE TIFS*, vol. 8, no. 8, pp. 1261–1273, 2013.

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(a) NIST SD27



(b) WVU DB

Thanks!