**BioLab - Biometric System Lab**
University of Bologna - ITALY
**http://biolab.csr.unibo.it**

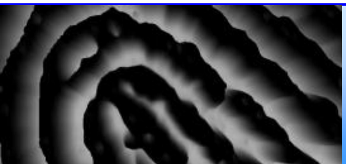
# Minutia Cylinder-Code:

## A new representation and matching technique for fingerprint recognition

**Dott. Matteo Ferrara**

# Topics

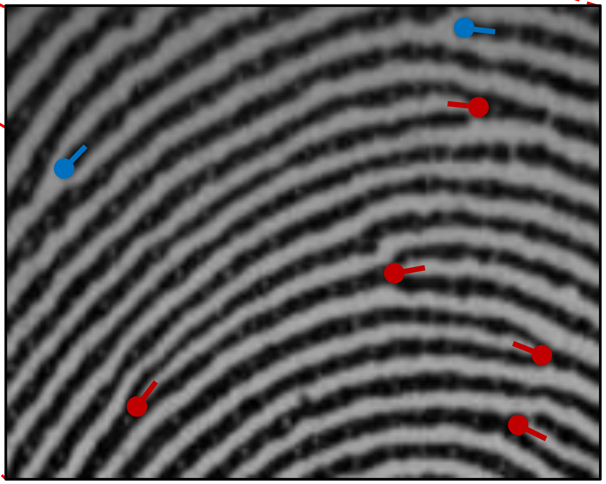
- Overview of fingerprint local matching methods
- The new local structures representation
- The local similarity measure
- A bit-based implementation
- Global score and consolidation
- Experimental evaluation
- Conclusions  and future works



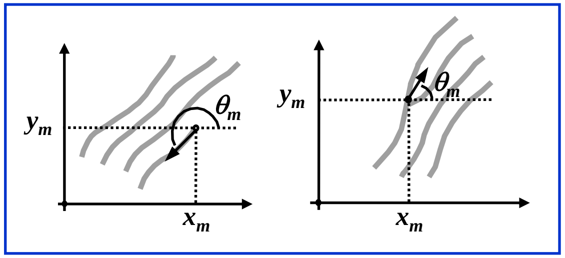
# Fingerprint anatomy

A fingerprint is composed of a set of lines (ridge lines), which mainly flow parallel, making a pattern (ridge pattern).

The minutiae, or Galton's characteristics, are determined by the termination or the bifurcation of the ridge lines.



$$m = \{x_m, y_m, \theta_m, t_m\}$$

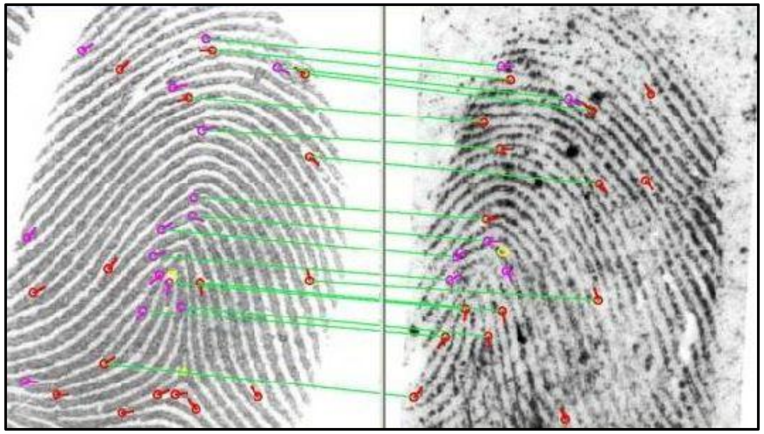


# Local minutiae-based matching methods

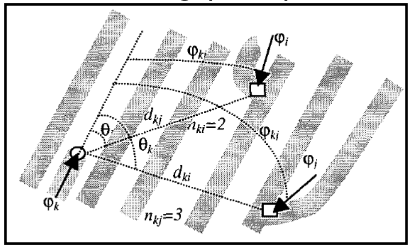
***Minutiae-based matching*** *consists in finding the alignment that results in the maximum number of minutiae pairings.*

***Local minutiae matching*** *consists of comparing two fingerprints according to local minutiae structures.*

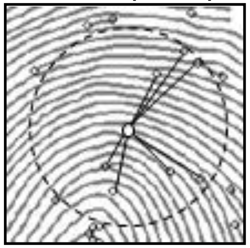
***Local structures*** *are characterized by attributes that are invariant with respect to global transformation (e.g., translation, rotation, etc.) and therefore are suitable for matching without any a priori global alignment.*



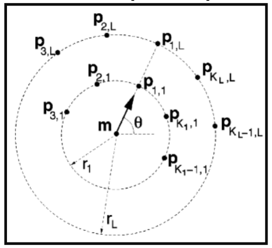
Jiang (2000)



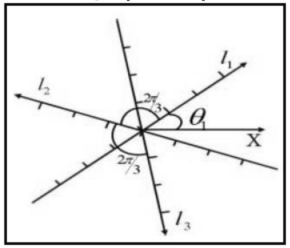
Ratha (2000)



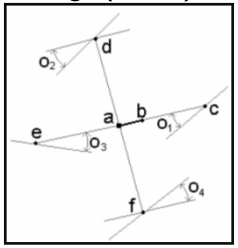
Tico (2003)



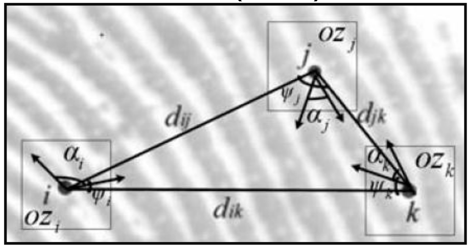
Qi (2004)



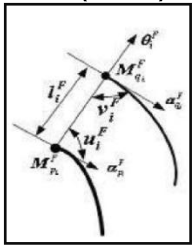
Ng (2004)



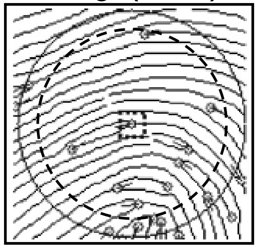

Chen (2005)

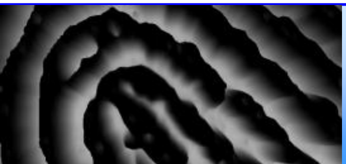


He (2006)



Feng (2008)



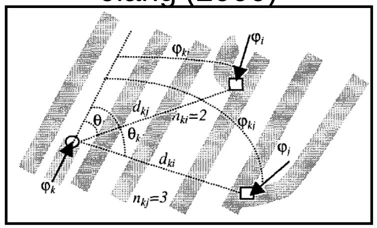


# Families of local structures

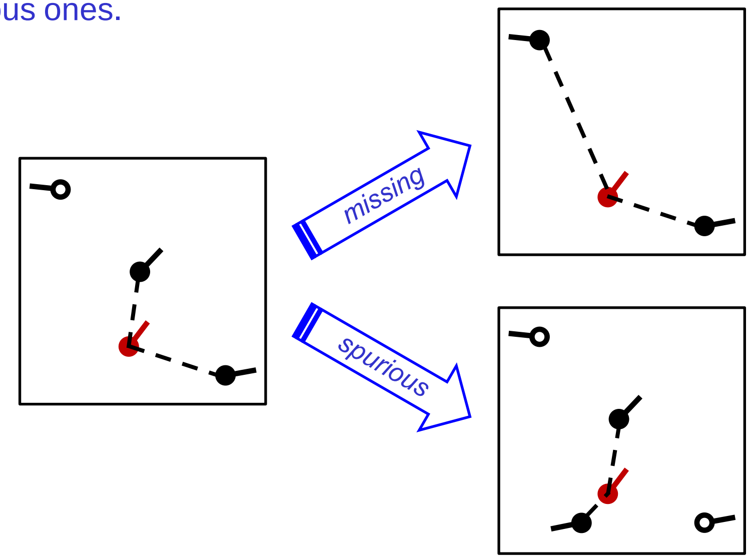
## Nearest neighbour-based structures:

the neighbors of the central minutia are formed by its *K* spatially closest minutiae. This leads to fixed-length descriptors that can be usually matched very efficiently.

Jiang (2000)



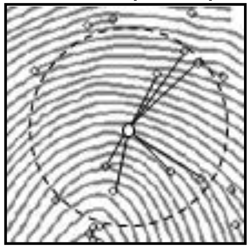
A critical point of these type of algorithms is the possibility of exchanging nearest neighbour minutiae due to missing or spurious ones.



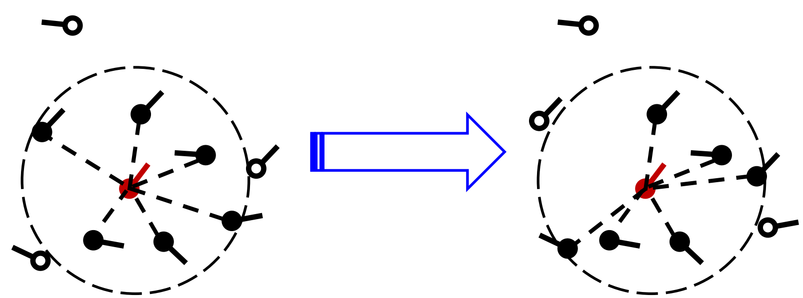

## Fixed radius-based structures:

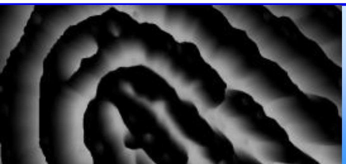
the neighbors are defined as all the minutiae that are closer than a given radius R from the central minutia. The descriptor length is variable and depends on the local minutiae density; this can lead to a more complex local matching; however, in principle, missing and spurious minutiae can be better tolerated.

Ratha (2000)



Matching fixed radius-based structures can lead to border errors: in particular, minutiae which are close to the local region border in one of the two fingerprints can be mismatched because of different local distortion or location inaccuracy that cause the same minutiae to move out of the local region in the second fingerprint.

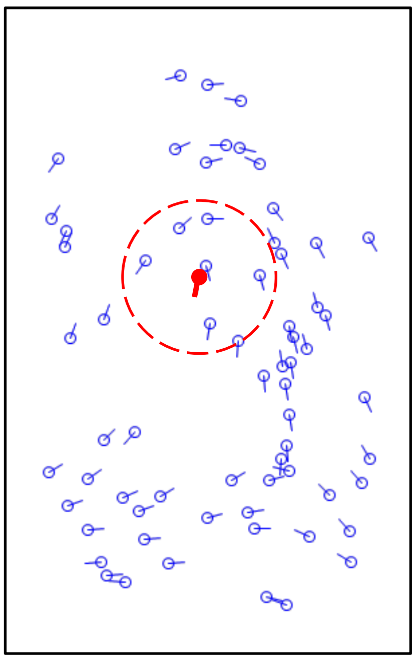




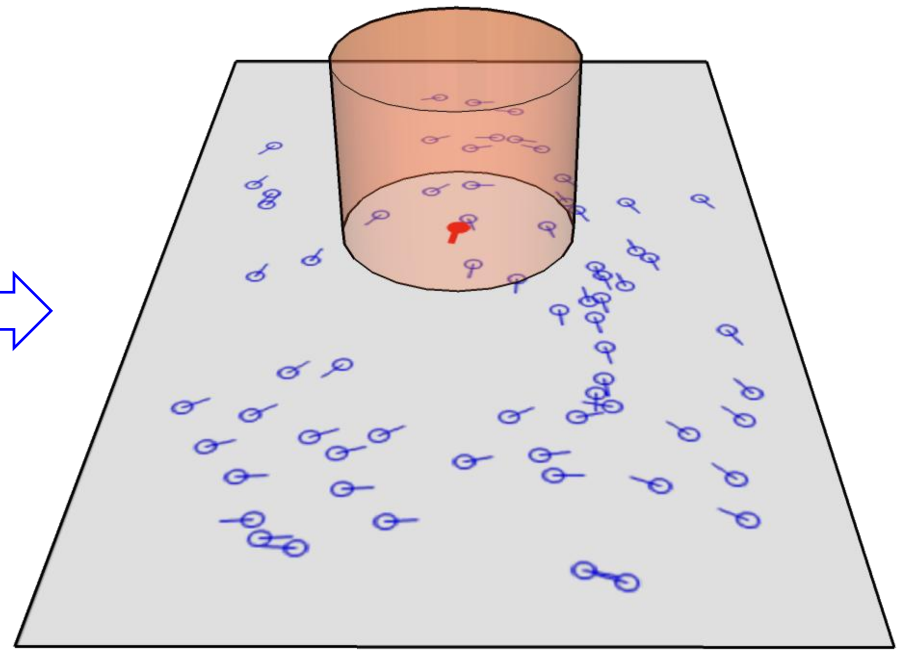
# The basic idea behind the new local method

- Fixed radius structure;
- Fixed-length descriptors;
- Fast and simple matching phase;
- Matching algorithm compliant to ISO/IEC 19794-2 (2005);
- Portable on inexpensive secure platforms.

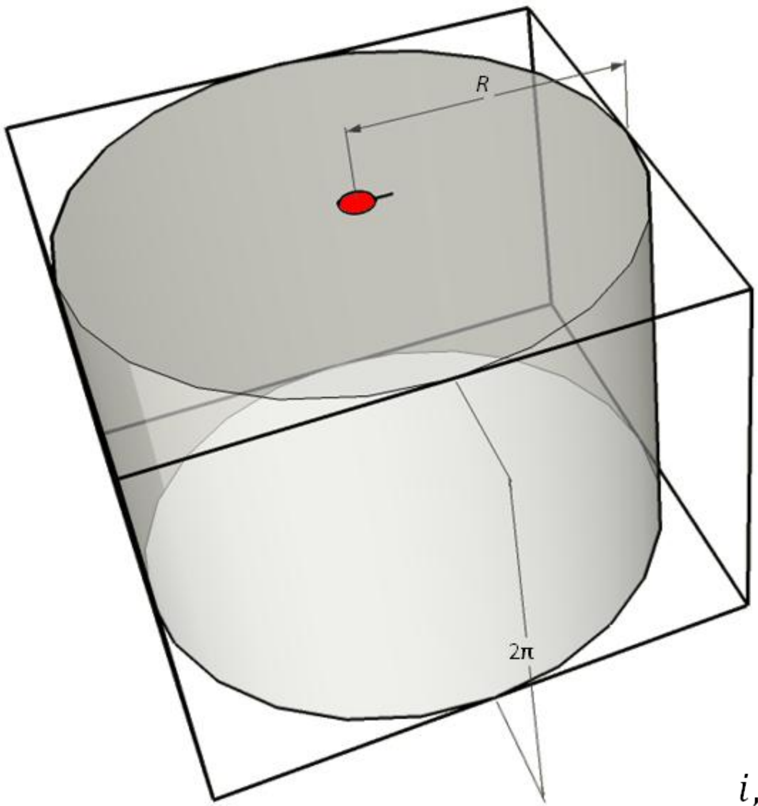
Common local structure



New 3D local structure

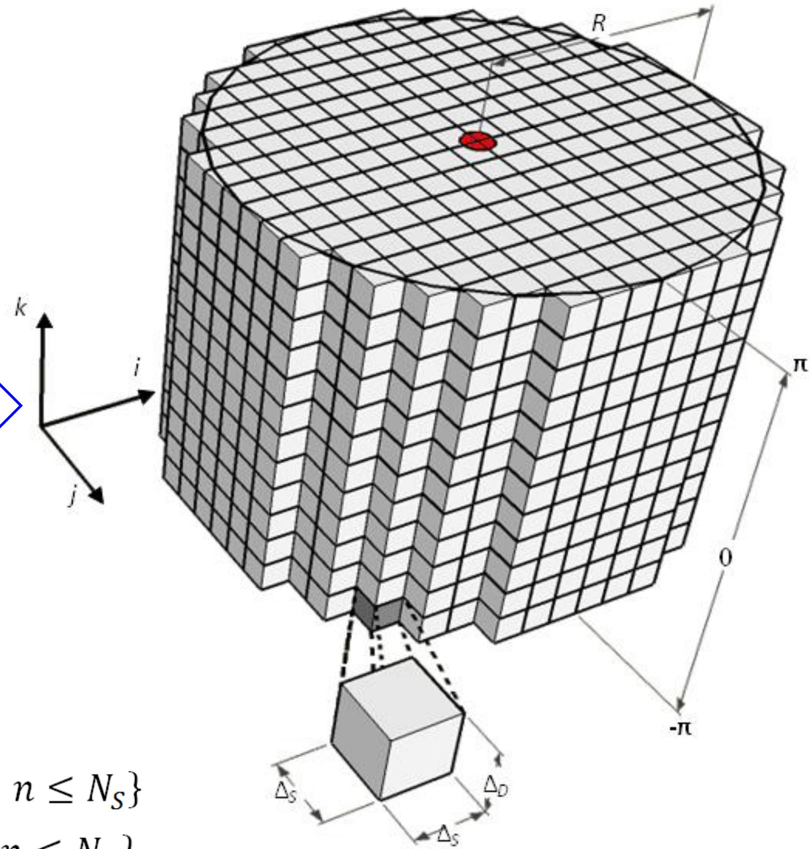


# The cylinder local structure



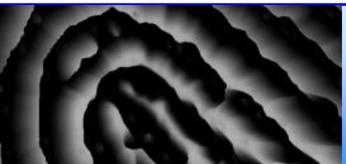

$$\Delta_S = \frac{2 \cdot R}{N_S}$$

$$\Delta_D = \frac{2\pi}{N_D}$$

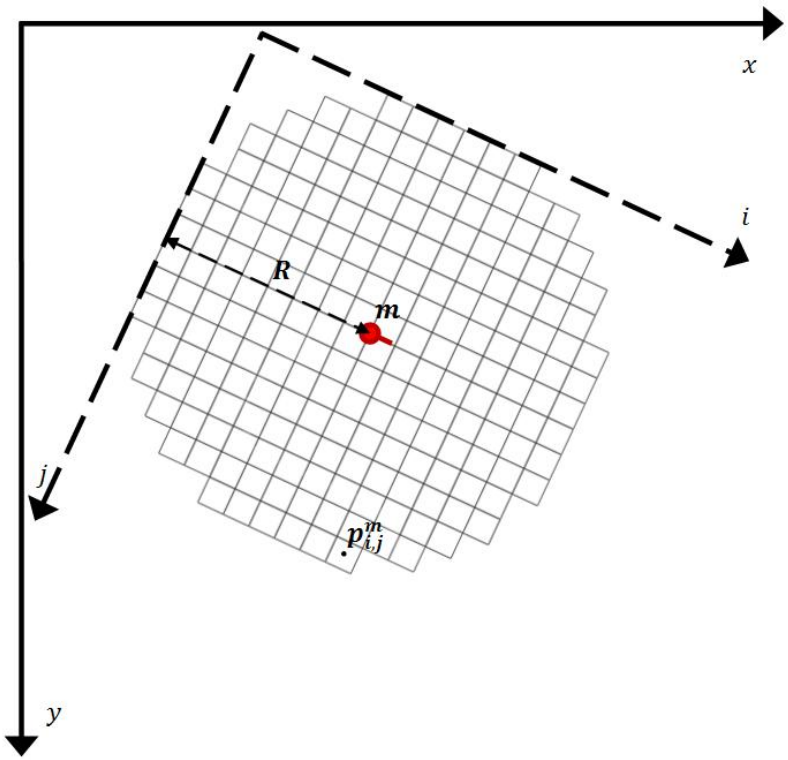



$$i, j \in I_S = \{n \in \mathbb{N}, 1 \leq n \leq N_S\}$$

$$k \in I_D = \{n \in \mathbb{N}, 1 \leq n \leq N_D\}$$

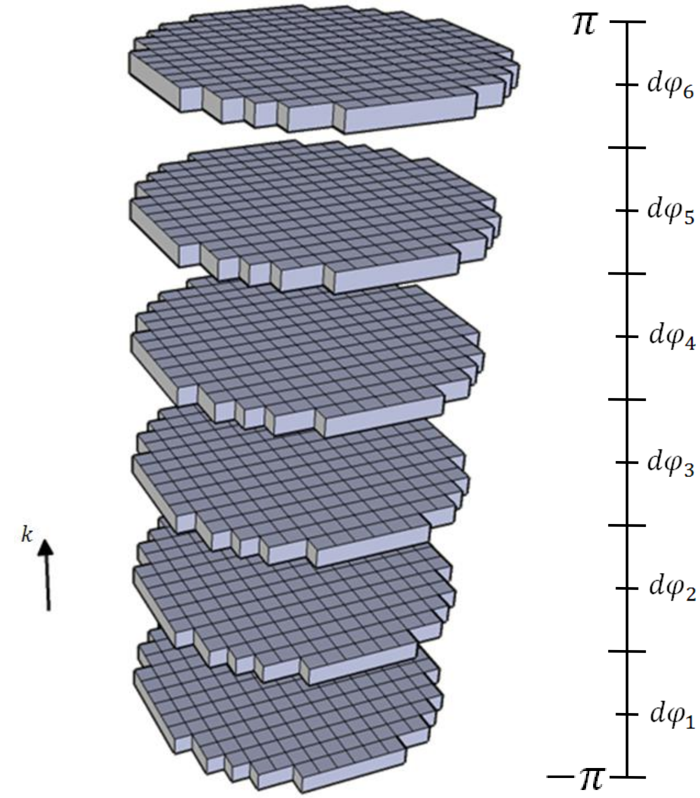


# The cell identification indices



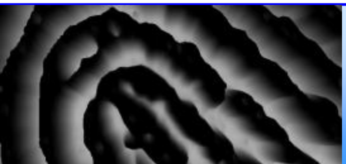

$$i, j \in I_S = \{n \in \mathbb{N}, 1 \le n \le N_S\}$$

$$p^m_{i,j} = \begin{bmatrix} x_m \\ y_m \end{bmatrix} + \Delta_S \cdot \begin{bmatrix} \cos(\theta_m) & \sin(\theta_m) \\ -\sin(\theta_m) & \cos(\theta_m) \end{bmatrix} \cdot \begin{bmatrix} i - \frac{N_S+1}{2} \\ j - \frac{N_S+1}{2} \end{bmatrix}$$

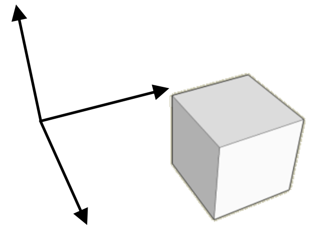



$$k \in I_D = \{n \in \mathbb{N}, 1 \le n \le N_D\}$$

$$d\varphi_k = -\pi + \left(k - \frac{1}{2}\right) \cdot \Delta_D$$



# The cell value

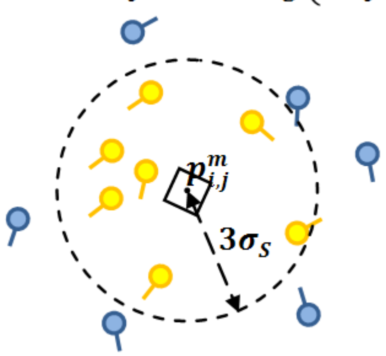


Limiting Function · Contributions Summatory · Spatial Contribution · Directional Contribution

$$C_m(i,j,k) = \begin{cases} \Psi\left(\sum_{m_t \in N_{p_{i,j}^m}} \left(C_m^S\left(m_t, p_{i,j}^m\right) \cdot C_m^D\left(m_t, d\varphi_k\right)\right)\right) & \text{if } \xi_m\left(p_{i,j}^m\right) = valid \\ invalid & \text{otherwise} \end{cases}$$

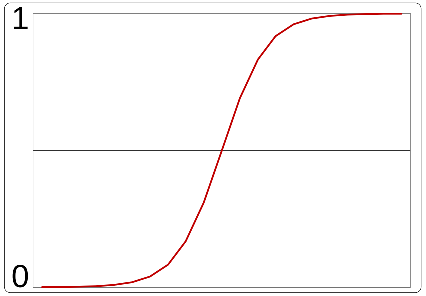
Validity Function

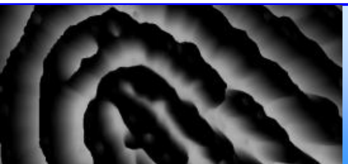
$$N_{p_{i,j}^m} = \left\{m_t \in T; m_t \neq m, d_S\left(m_t, p_{i,j}^m\right) \leq 3\sigma_S\right\}$$



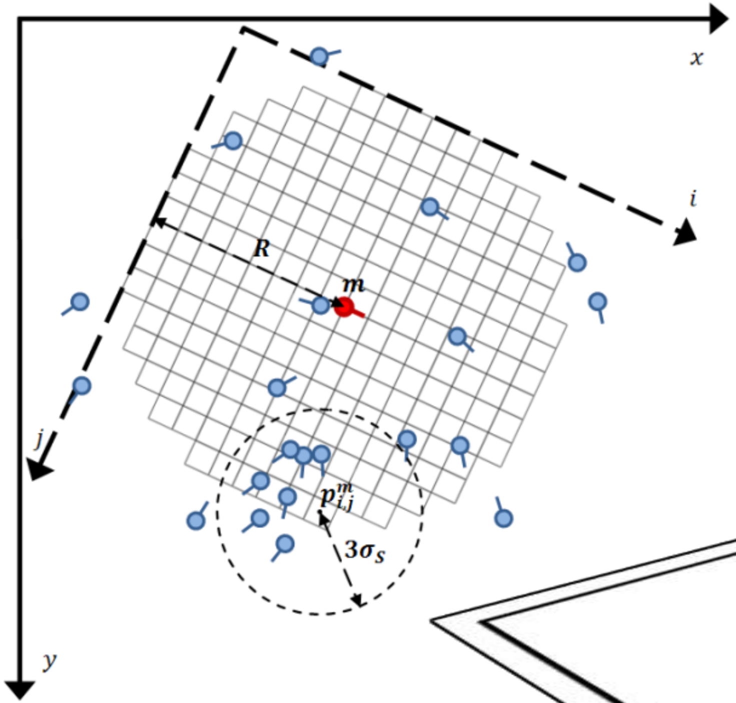

$$\Psi(v) = \mathrm{Z}(v, \mu_\Psi, \tau_\Psi)$$

$$\mathrm{Z}(v,\mu,\tau) = \frac{1}{1 + e^{-\tau\cdot(v-\mu)}}$$



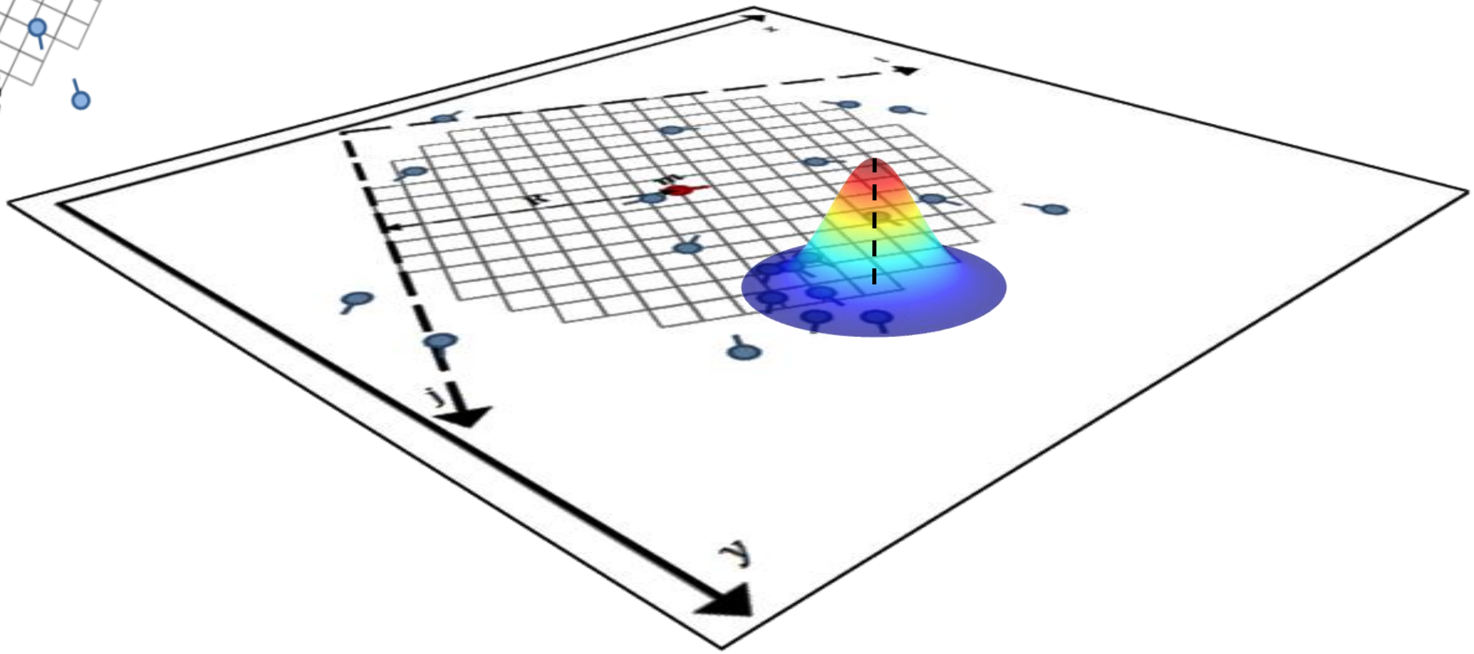



# The spatial contribution

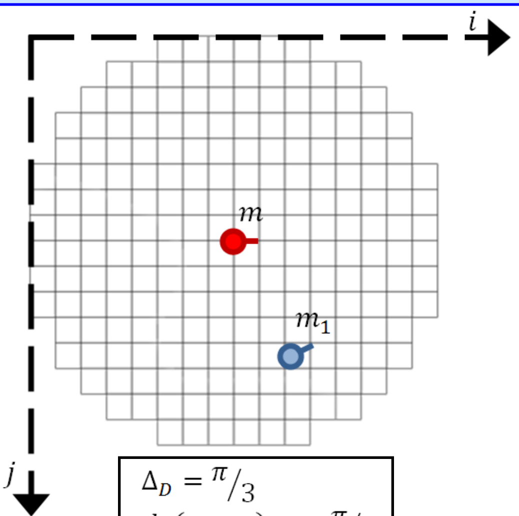



$$C_m^S(m_t, p_{i,j}^m) = G_S\left(d_S(m_t, p_{i,j}^m)\right)$$

$$G_S(t) = \frac{1}{\sigma_S\sqrt{2\pi}} e^{\left(-\frac{t^2}{2\sigma_S^2}\right)}$$



# The directional contribution

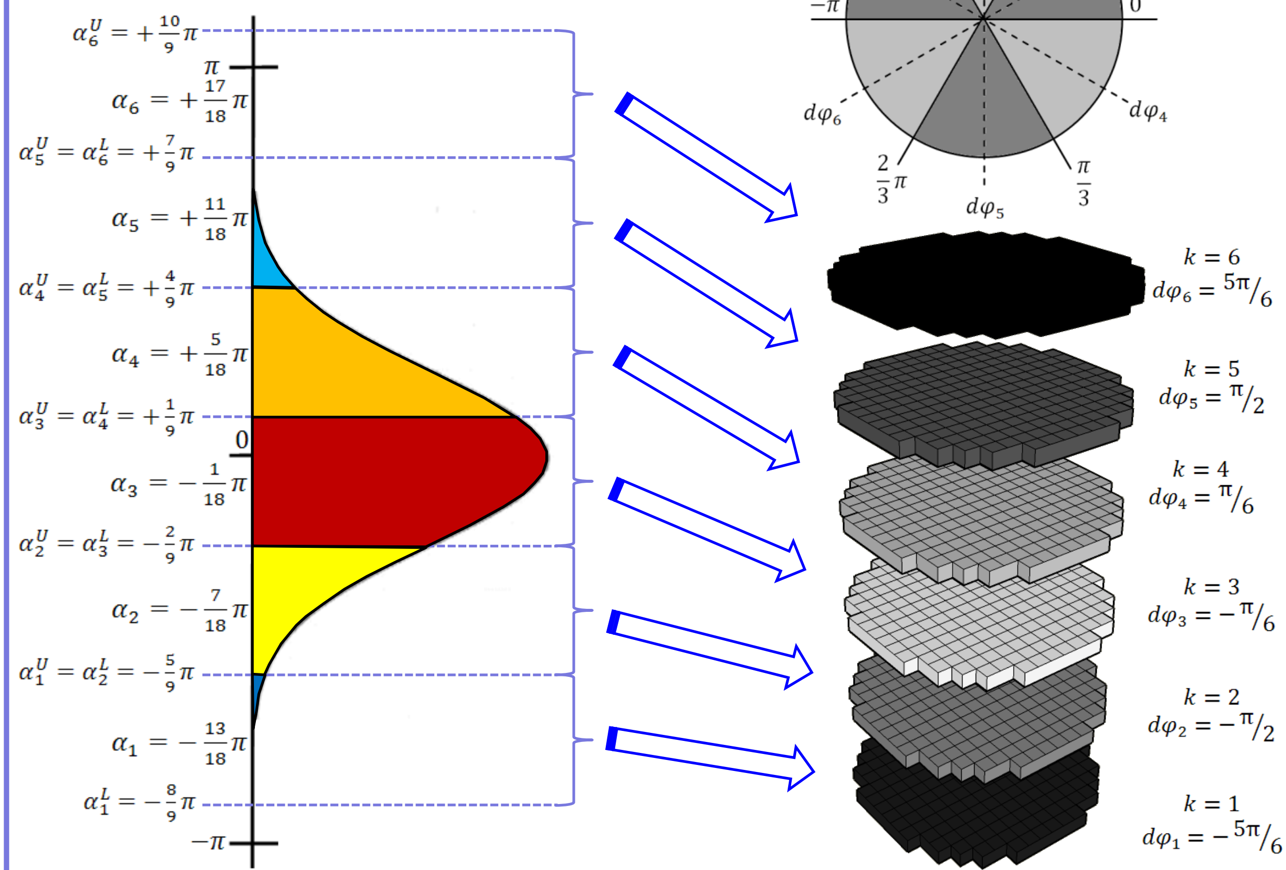


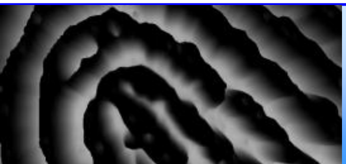

$$\Delta_D = \pi/3$$
$$d_\theta(m, m_1) = -\pi/9$$

$$C_m^D(m_t, d\varphi_k) = G_D\left(d\phi\left(d\varphi_k, d_\theta(m, m_t)\right)\right)$$

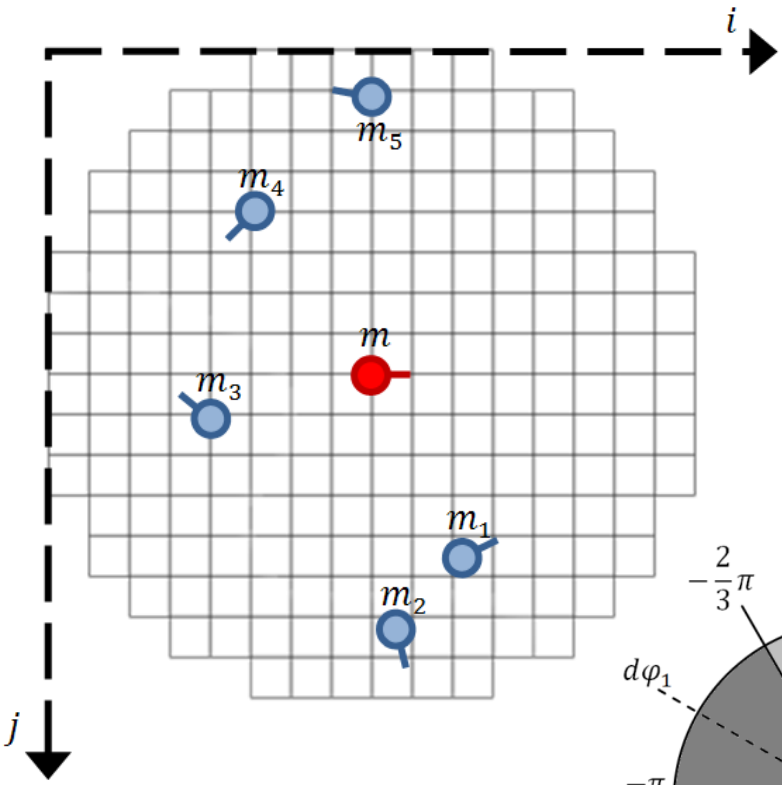
$$\alpha_k = d\phi(d\varphi_k, -\pi/9)$$
$$\alpha_k^L = \alpha_k - \pi/6$$
$$\alpha_k^U = \alpha_k + \pi/6$$

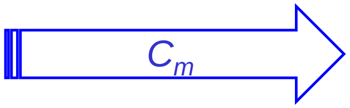
$$G_D(\alpha) = \frac{1}{\sigma_D\sqrt{2\pi}}\int_{\alpha-\frac{\Delta_D}{2}}^{\alpha+\frac{\Delta_D}{2}} e^{-\frac{t^2}{2\sigma_D^2}}\,dt$$

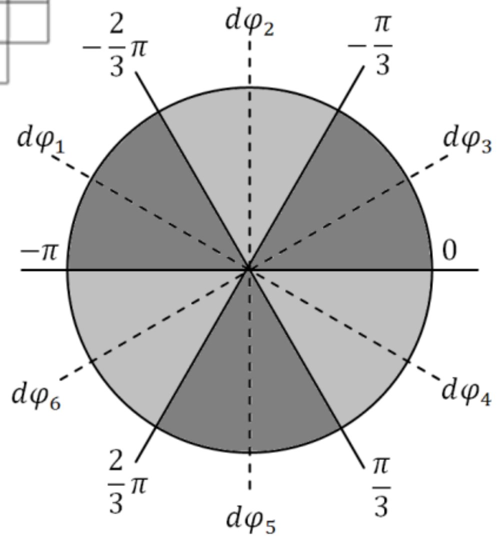


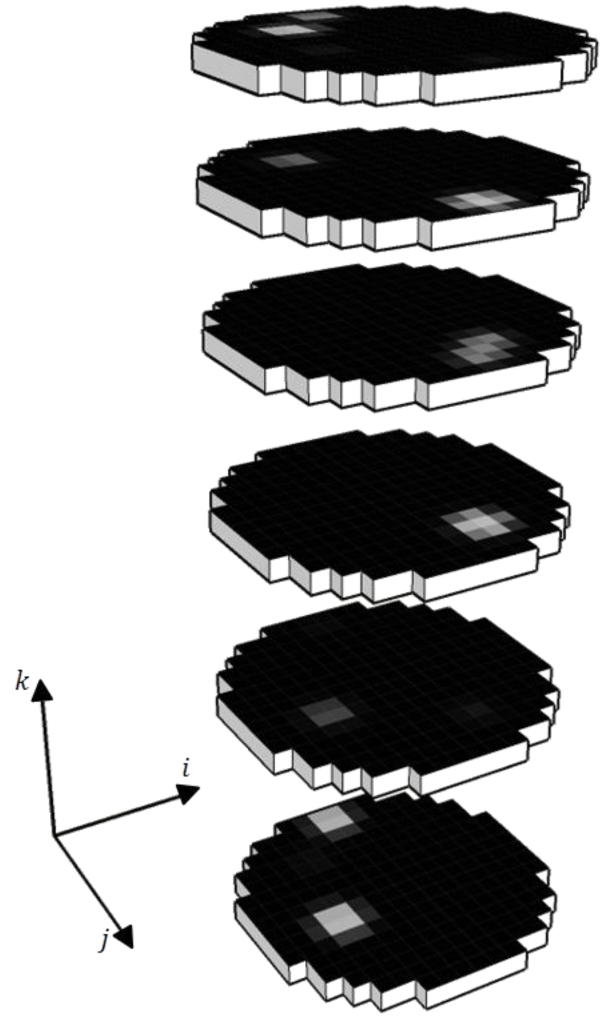



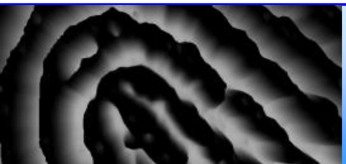
# Example of a cylinder



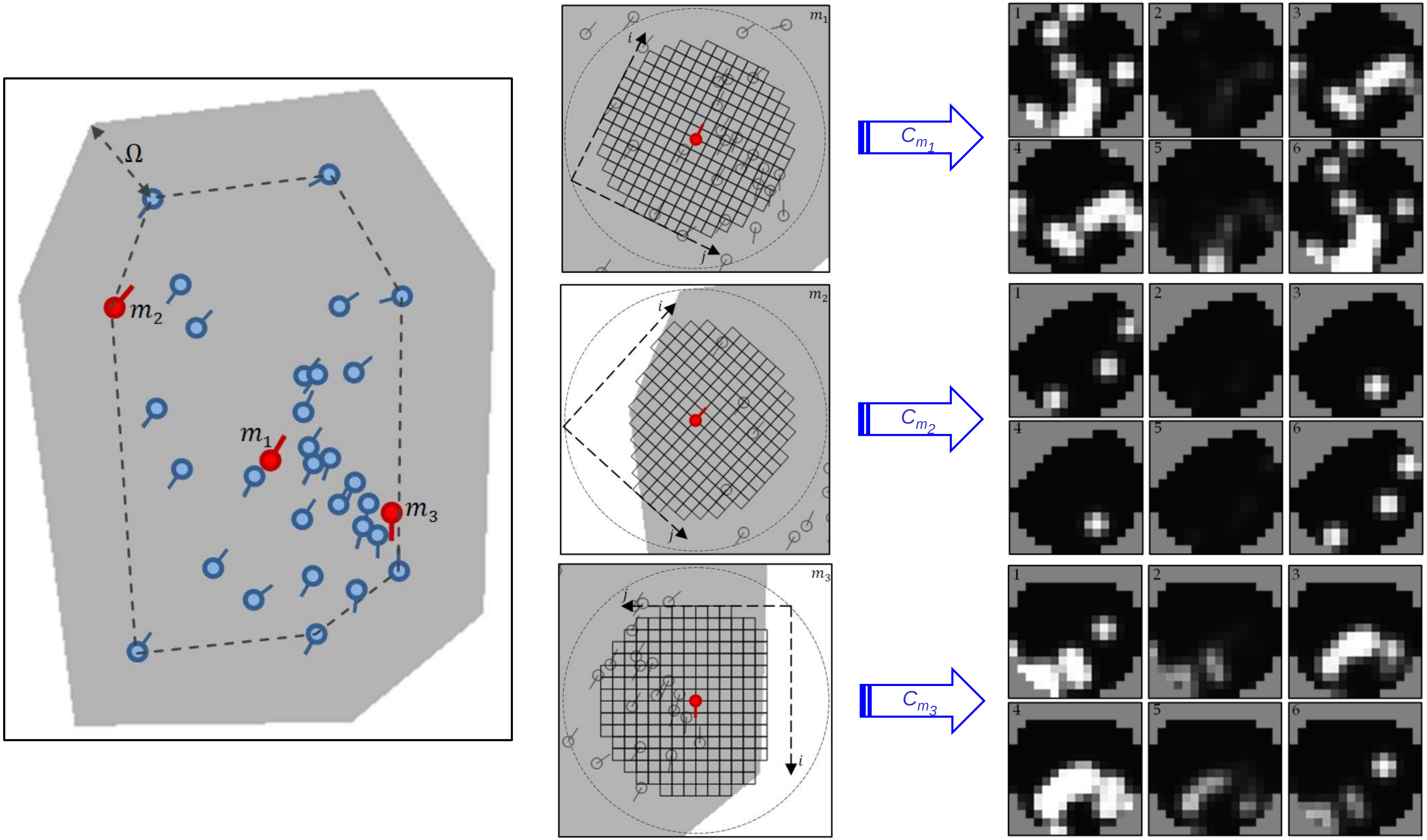



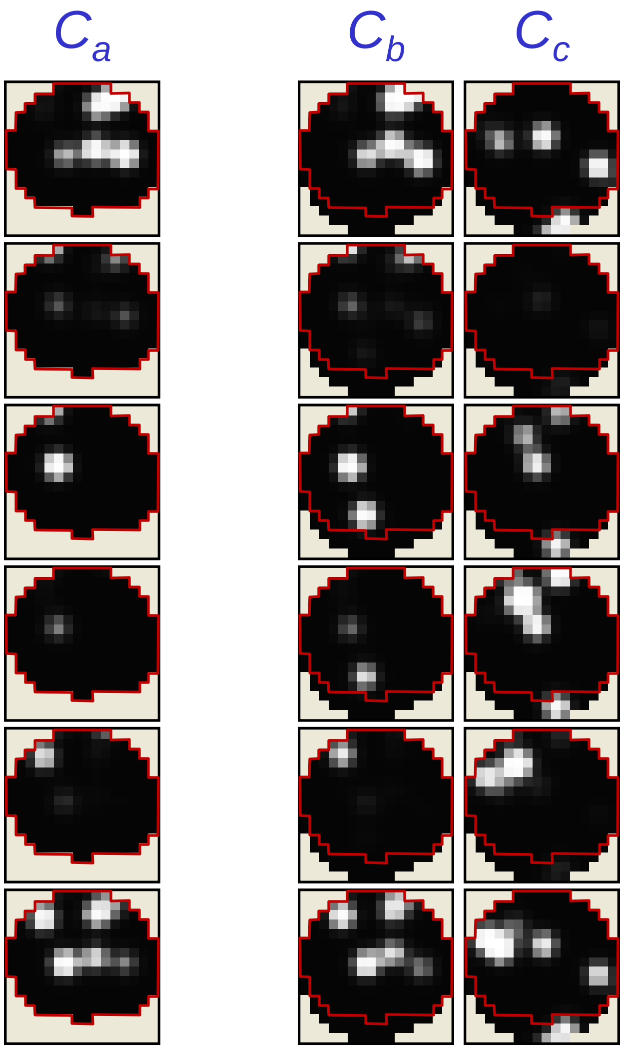
Minutia Cylinder-Code: A new representation and matching technique for fingerprint recognition

# Cylinder template




Minutia Cylinder-Code: A new representation and matching technique for fingerprint recognition

# The similarity between two cylinders




$$\mathbf{c}_m[lin(i,j,k)] = C_m(i,j,k)$$

$$lin(i,j,k) = (k-1)\cdot(N_S)^2 + (j-1)\cdot N_S + i$$

$$\mathbf{c}_{a|b}[t] = \begin{cases} \mathbf{c}_a[t] & \text{if } \mathbf{c}_a[t] \text{ and } \mathbf{c}_b[t] \text{ are } \textit{matchable} \\ 0 & \text{otherwise} \end{cases}$$

$$\mathbf{c}_{b|a}[t] = \begin{cases} \mathbf{c}_b[t] & \text{if } \mathbf{c}_b[t] \text{ and } \mathbf{c}_a[t] \text{ are } \textit{matchable} \\ 0 & \text{otherwise} \end{cases}$$

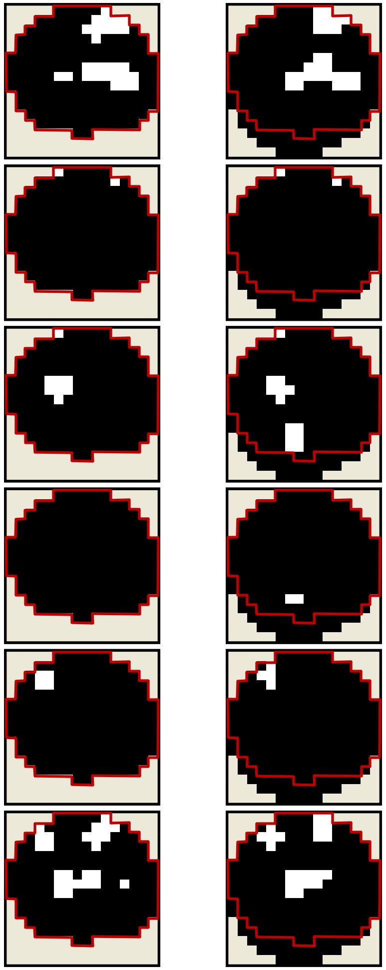
$$\gamma(a,b) = \begin{cases} 1 - \frac{\|\mathbf{c}_{a|b} - \mathbf{c}_{b|a}\|}{\|\mathbf{c}_{a|b}\| + \|\mathbf{c}_{b|a}\|} & \text{if } C_a \text{ and } C_b \text{ are } \textit{matchable} \\ 0 & \text{otherwise} \end{cases}$$

*γ(a,b)=0.75*

*γ(a,c)=0.38*

# Bit-based implementation

$C_a$ $C_b$



## The cell value:

$$\Psi_{Bit}(v) = \begin{cases} 1 & \text{if } v \geq \mu_\Psi \\ 0 & \text{otherwise} \end{cases}$$


## The similarity between two cylinders:

$$\mathbf{c}_m[lin(i,j,k)] = \begin{cases} 1 & \text{if } C_m(i,j,k) = 1 \\ 0 & \text{otherwise} \end{cases}$$

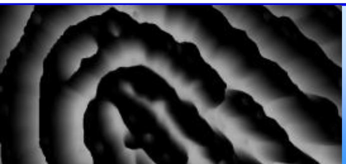
$$\hat{\mathbf{c}}_m[lin(i,j,k)] = \begin{cases} 1 & \text{if } C_m(i,j,k) \neq invalid \\ 0 & \text{otherwise} \end{cases}$$

$$\hat{\mathbf{c}}_{ab} = \hat{\mathbf{c}}_a \text{AND } \hat{\mathbf{c}}_b$$

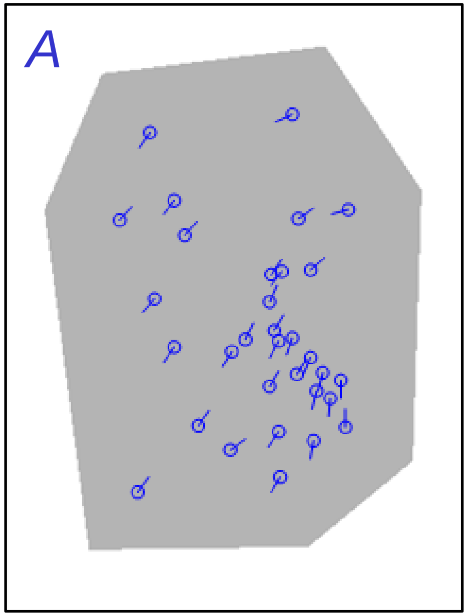
$$\mathbf{c}_{a|b} = \mathbf{c}_a \text{ AND } \hat{\mathbf{c}}_{ab} \text{ , } \mathbf{c}_{b|a} = \mathbf{c}_b \text{ AND } \hat{\mathbf{c}}_{ab}$$

$$\gamma_{Bit}(a,b) = \begin{cases} 1 - \frac{\|\mathbf{c}_{a|b} \text{ XOR } \mathbf{c}_{b|a}\|}{\|\mathbf{c}_{a|b}\| + \|\mathbf{c}_{b|a}\|} & \text{if } C_a \text{ and } C_b \text{ are } matchable \\ 0 & \text{otherwise} \end{cases}$$

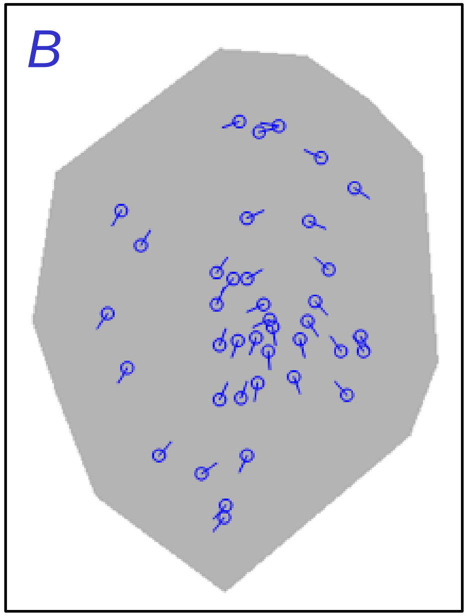
$\gamma_{Bit}(a,b)=0.63$



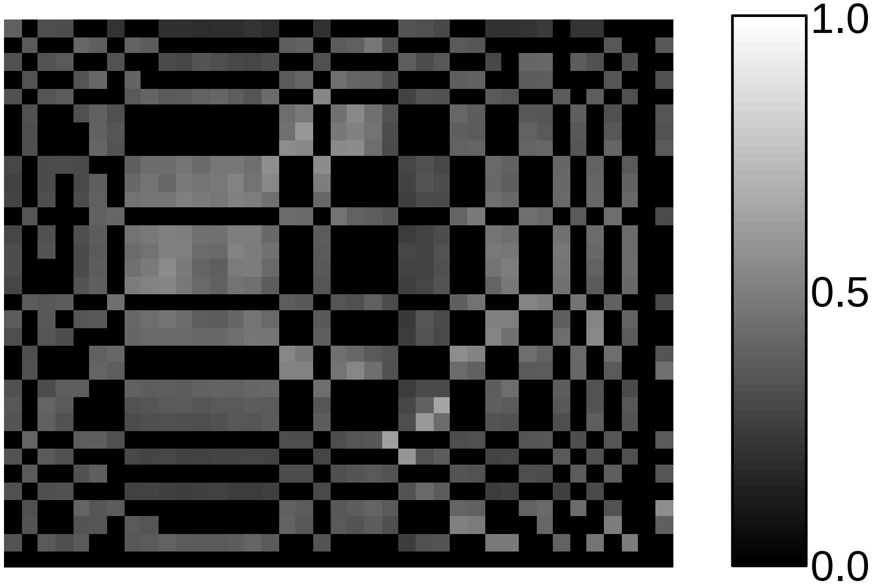
# Global score and consolidation




$A=\{a_1,a_2,\ldots,a_{n_A}\}$




$B=\{b_1,b_2,\ldots,b_{n_B}\}$

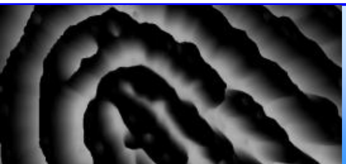



$$\Gamma \in [0,1]^{n_A \times n_B}$$

$$\Gamma[r,c] = \gamma(a_r, b_c)$$

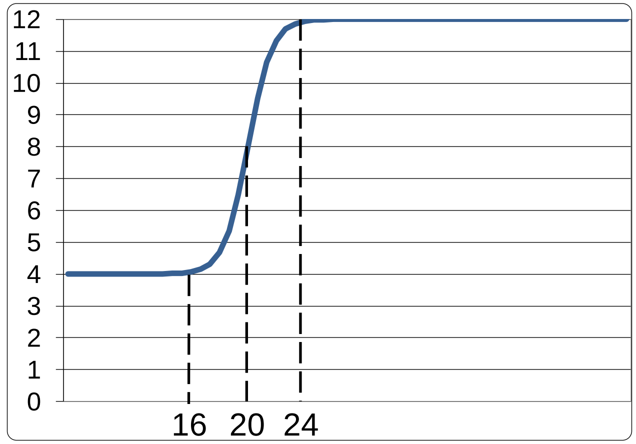
$$P = \{(r_t, c_t)\}, t = 1, \ldots, n_P, 1 \le r_t \le n_A, 1 \le c_t \le n_B$$

$$S(A,B) = \frac{\sum_{(r,c)\in P} \Gamma[r,c]}{n_P}$$

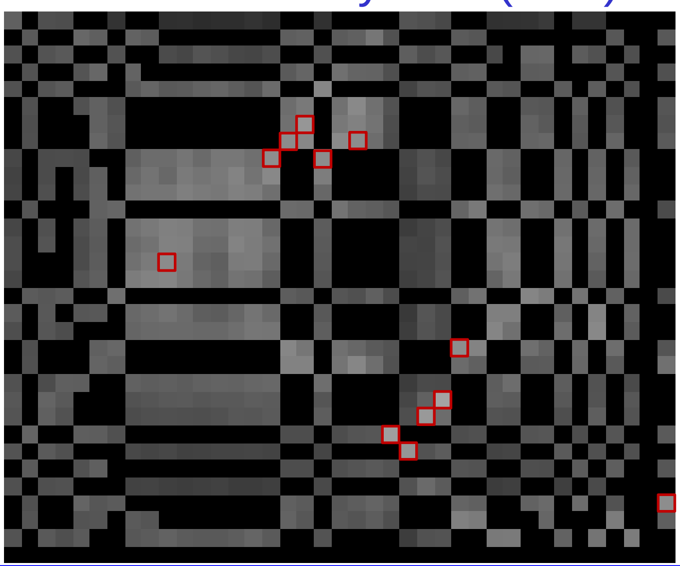


# Pure local techniques

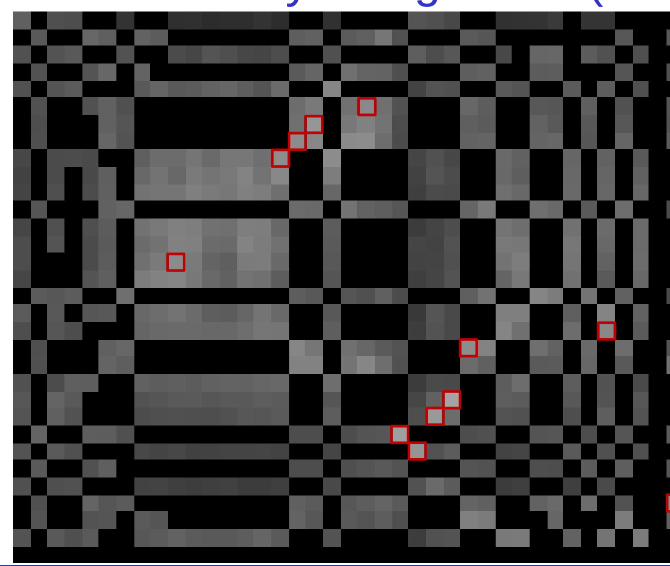
$n_P = ?(\min\{n_A, n_B\})$




## Local Similarity Sort (LSS)



## Local Similarity Assignment (LSA)



# Relaxation approach

The basic idea is to iteratively modify the local similarities based on the compatibility among minutiae relationships.

1. Preliminary step:

$$P_R = \{(r_t, c_t)\}, t = 1, \dots, n_R, 1 \le r_t \le n_A, 1 \le c_t \le n_B$$

$$n_R = \min\{n_A, n_B\} \quad n_R \gg n_P$$

$$\lambda_t^0 = \Gamma[r_t, c_t]$$

2. Relaxation step:

$$\lambda_t^i = w_R \cdot \lambda_t^{i-1} + (1 - w_R) \cdot \frac{\sum_{\substack{k=1 \\ k \neq t}}^{n_R} \rho(t,k) \cdot \lambda_k^{i-1}}{n_R - 1}$$

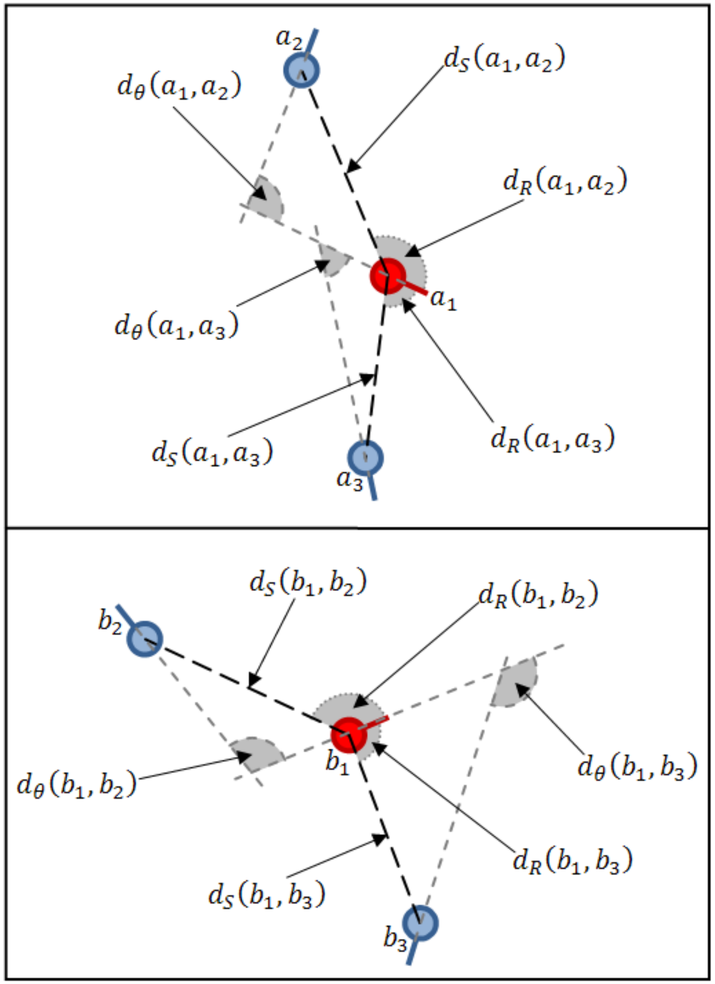
$$\rho(t,k) = \prod_{i=1}^{3} \mathrm{Z}(d_i, \mu_i^\rho, \tau_i^\rho),$$

$$d_1 = \left| d_S(a_{r_t}, a_{r_k}) - d_S(b_{c_t}, b_{c_k}) \right|$$

$$d_2 = \left| d\phi\left(d_\theta(a_{r_t}, a_{r_k}), d_\theta(b_{c_t}, b_{c_k})\right) \right|$$

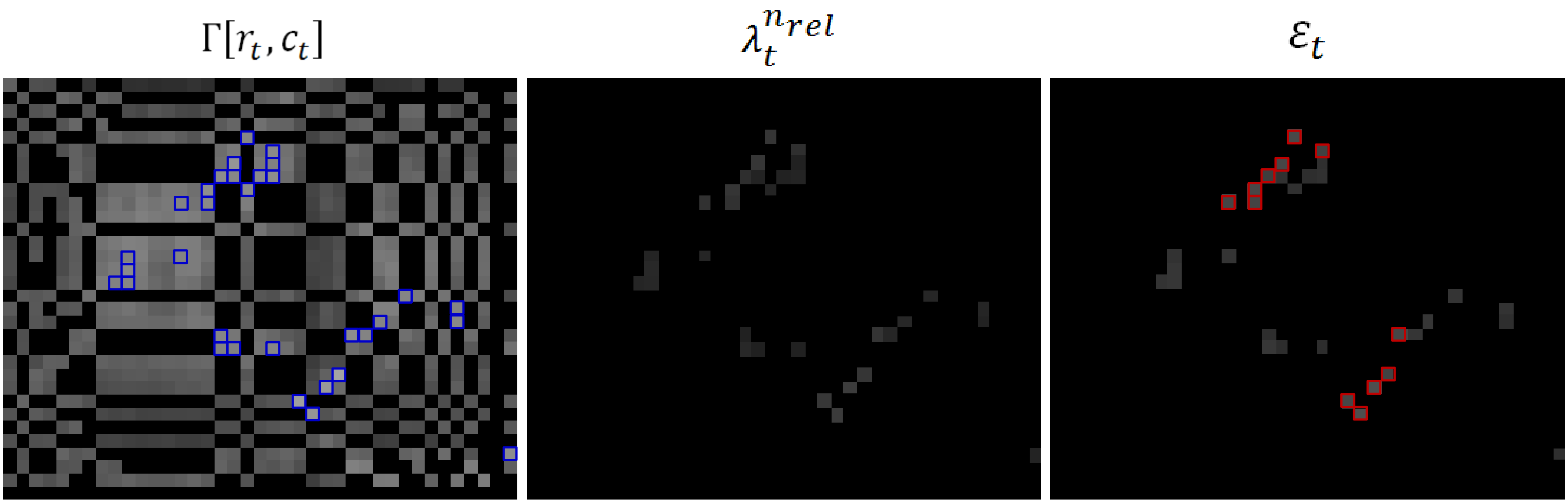
$$d_3 = \left| d\phi\left(d_R(a_{r_t}, a_{r_k}), d_R(b_{c_t}, b_{c_k})\right) \right|$$

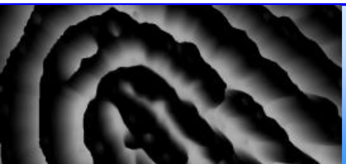
$$\varepsilon_t = \frac{\lambda_t^{n_{rel}}}{\lambda_t^0}$$



# Local similarity sort with relaxation (LSS-R)

*In the preliminary step, the $n_R$* pairs are selected using the LSS technique.

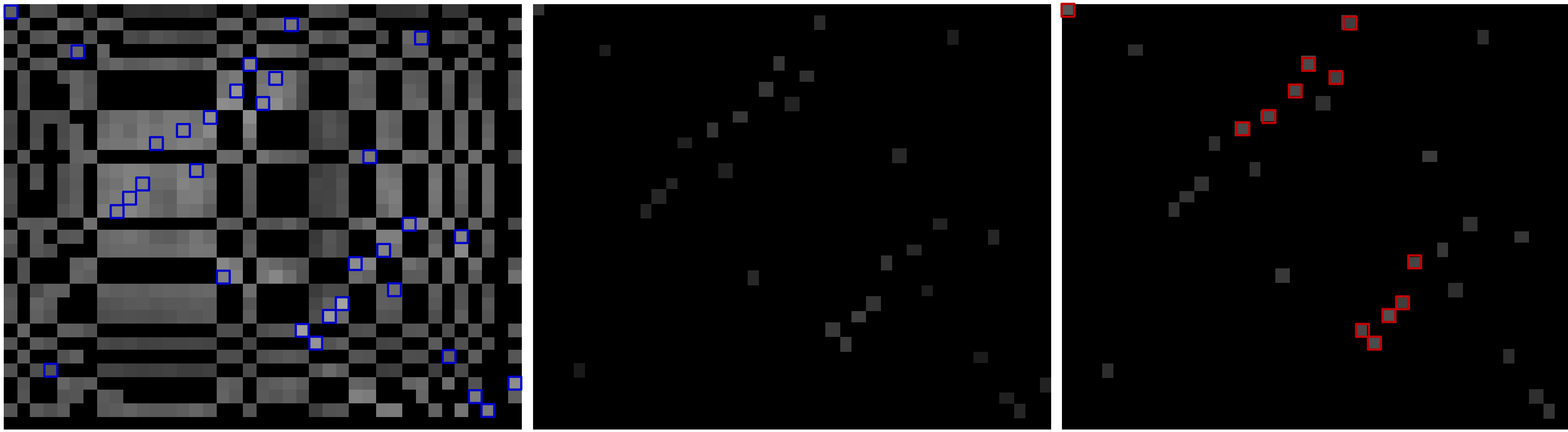


# Local similarity assignment with relaxation (LSA-R)

*In the preliminary step, the $n_R$* pairs are selected using the LSA technique.

$\Gamma[r_t, c_t]$ $\lambda_t^{n_{rel}}$ $\varepsilon_t$

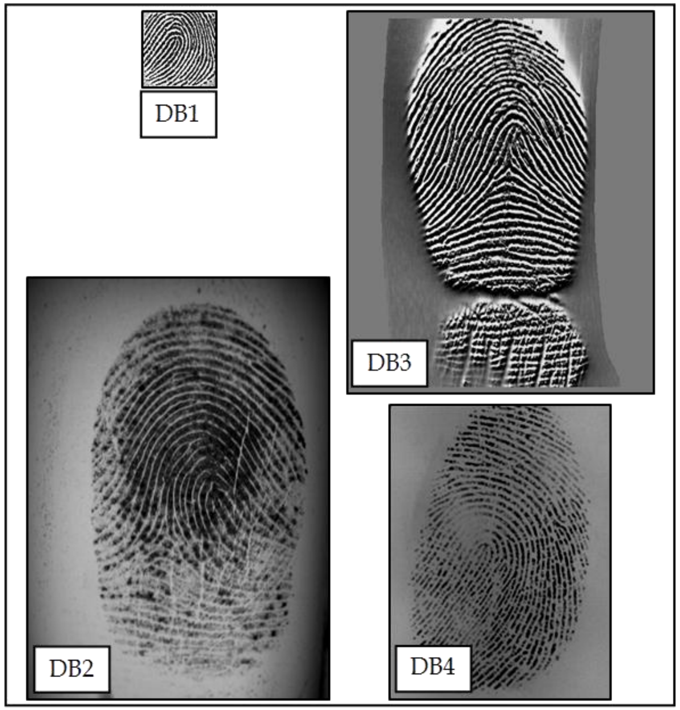


# Experimental evaluation (1)

Benchmark datasets:

– four *FVC2006* fingerprint databases (*DB1, DB2, DB3, DB4*);

– the datasets have been obtained using five ISO-compliant minutiae extractors (called *a, b, c, d, e*) provided by five of the best performing *FVC2006* participants.




Algorithms evaluated:

– *MCC16* ($N_S$=16, $N_D$=6);

– *MCC16b* ($N_S$=16, $N_D$=6, bit-based implementation);

– *MCC8b* ($N_S$=8, $N_D$=6, bit-based implementation);

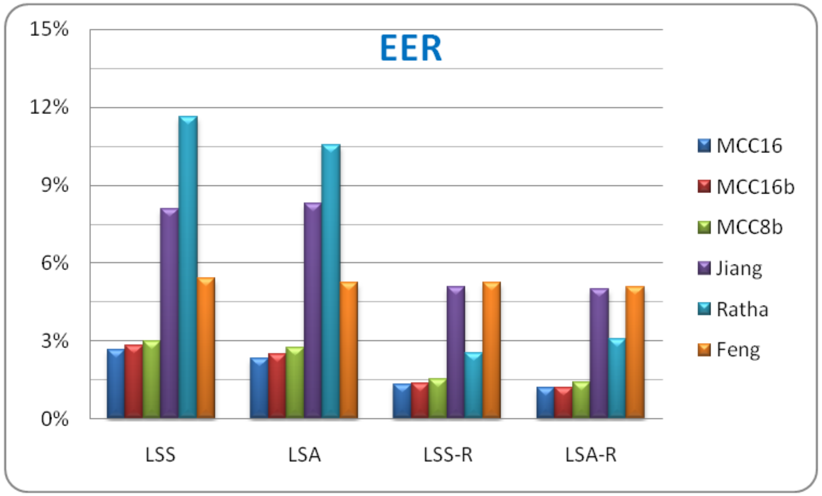
– *Jiang*;

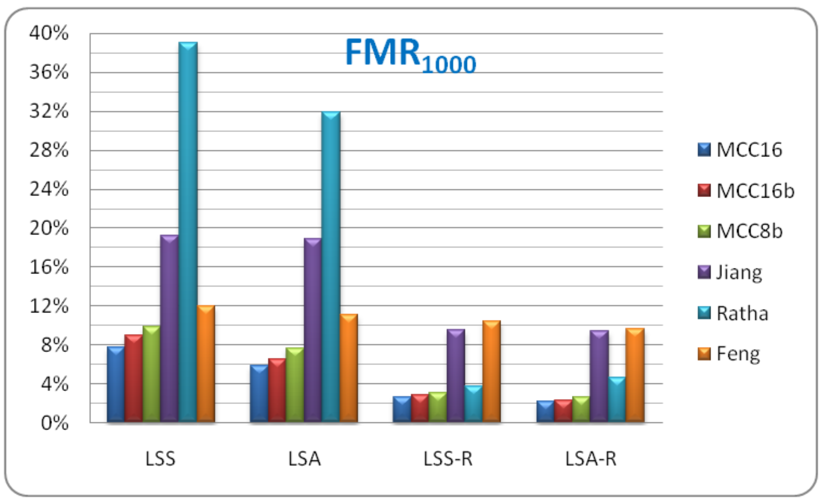
– *Ratha*;

– *Feng*.

# Experimental evaluation (2)

## Accuracy on *DB2*




## Efficiency

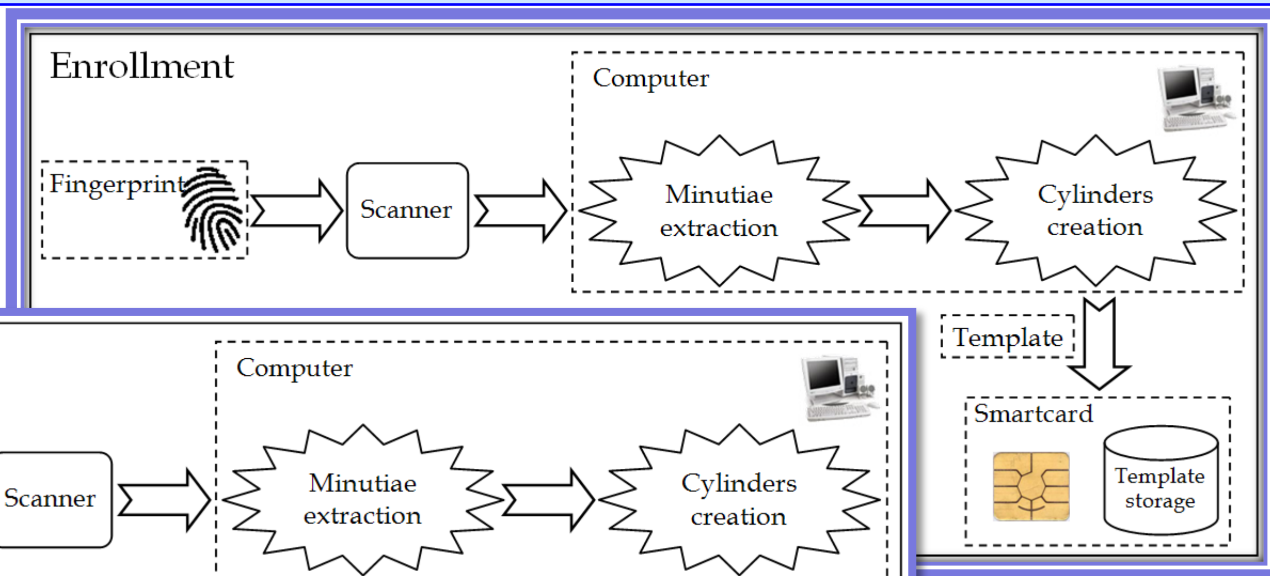
AVERAGE MATCHING TIMES OVER ALL DATASETS (MILLISECONDS)

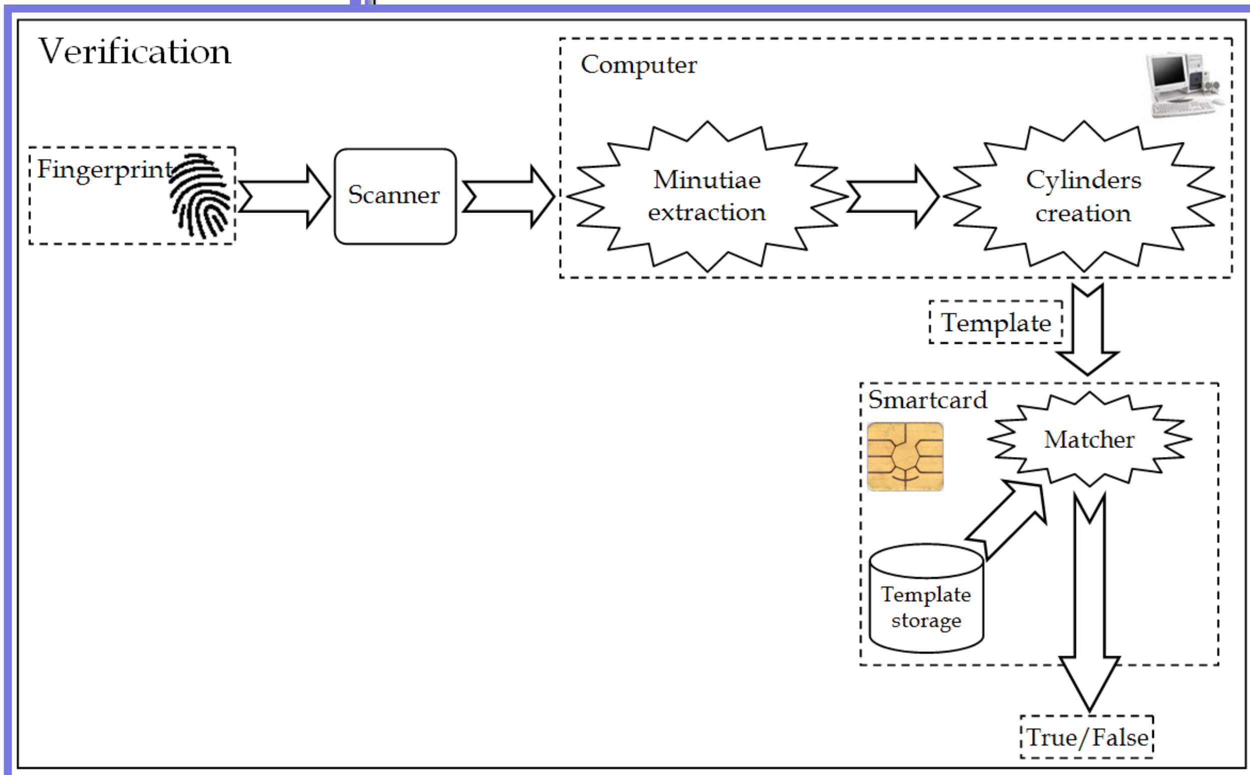
| | $T_{cs}$ | $T_{ls}$ | $T_{gs}$ | | | |
|---|---|---|---|---|---|---|
| | | | LSS | LSA | LSS-R | LSA-R |
| *MCC16* | 21.0 | 21.0 | 0.5 | 4.3 | 2.7 | 4.7 |
| *MCC16b* | 17.3 | 1.2 | 0.5 | 4.3 | 2.8 | 4.7 |
| *MCC8b* | 4.2 | 0.3 | 0.5 | 4.2 | 2.9 | 4.8 |
| *Jiang* | 1.0 | 0.8 | 0.4 | 4.3 | 2.6 | 4.1 |
| *Ratha* | 1.0 | 250.7 | 0.5 | 4.3 | 2.8 | 4.4 |
| *Feng* | 0.2 | 12.3 | 0.5 | 2.4 | 2.8 | 3.1 |

AVERAGE MEMORY SIZE OF THE LOCAL STRUCTURES, OVER ALL DATASETS, MEASURED IN BYTES

| | Raw format | Compressed format (rar) | | Compressed format (zip) | |
|---|---|---|---|---|---|
| | *Size* | *Size* | *Ratio* | *Size* | *Ratio* |
| *MCC16* | 209253 | 103766 | 202% | 104595 | 200% |
| *MCC16b* | 7630 | 1457 | 524% | 1642 | 465% |
| *MCC8b* | 1913 | 605 | 316% | 655 | 292% |
| *Jiang* | 1068 | 608 | 176% | 647 | 165% |
| *Ratha* | 26543 | 19487 | 136% | 20046 | 132% |
| *Feng* | 1428 | 567 | 252% | 614 | 233% |

# Patent pending n° ITBO2009A000149




# Conclusions and future works

- Conclusions:
  - Local structure characteristics:
    - fixed radius structure;
    - fixed-length descriptors
    - bit-oriented representation;
  - Matching algorithm characteristics:
    - high accuracy;
    - simple and fast;
    - suitable to be used on embedded systems/smart cards;
  - Patent pending;

- Future researches:
  - Fingerprint indexing;
  - Template protection.