Fingerprint Recognition

Presentation By:

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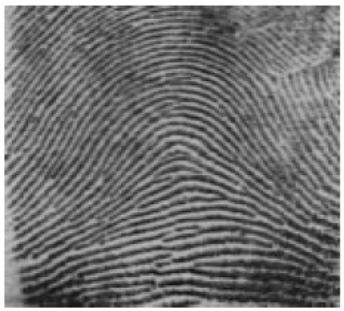
Background

- Each fingerprint can be classified into 1 of 6 classes.
- Size of database to be searched severely reduced by classifying into categories using class of all 10 fingers.

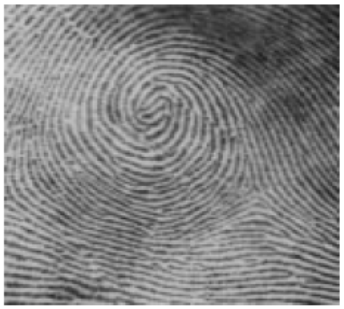


Arch

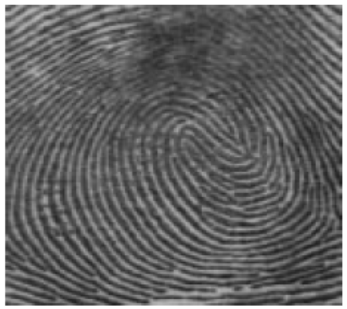
Tented Arch

Left Loop

Right Loop



Whorl



Twin-loop

Fingerprint Enhancement

- Need for enhancement

  Implications of poor quality image:

  - ✓ Spurious Minutiae detection
  - ✓ True Minutiae not detected
  - ✓ Large errors in localization of Minutiae

- Enhancement algorithm improves the clarity of ridge and valley structures in the fingerprint images.

Fingerprint Enhancement

Input Image

Image Normalization

Orientation Image Estimation

Frequency Image Estimation

Region Mask Generation

Filtering

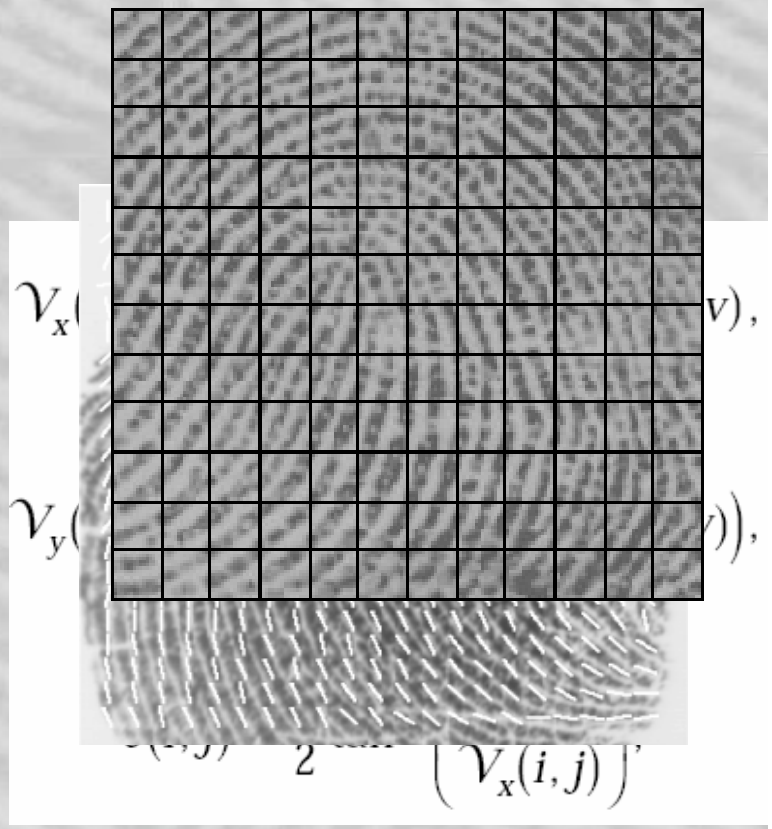
Enhanced Image

Image Normalization

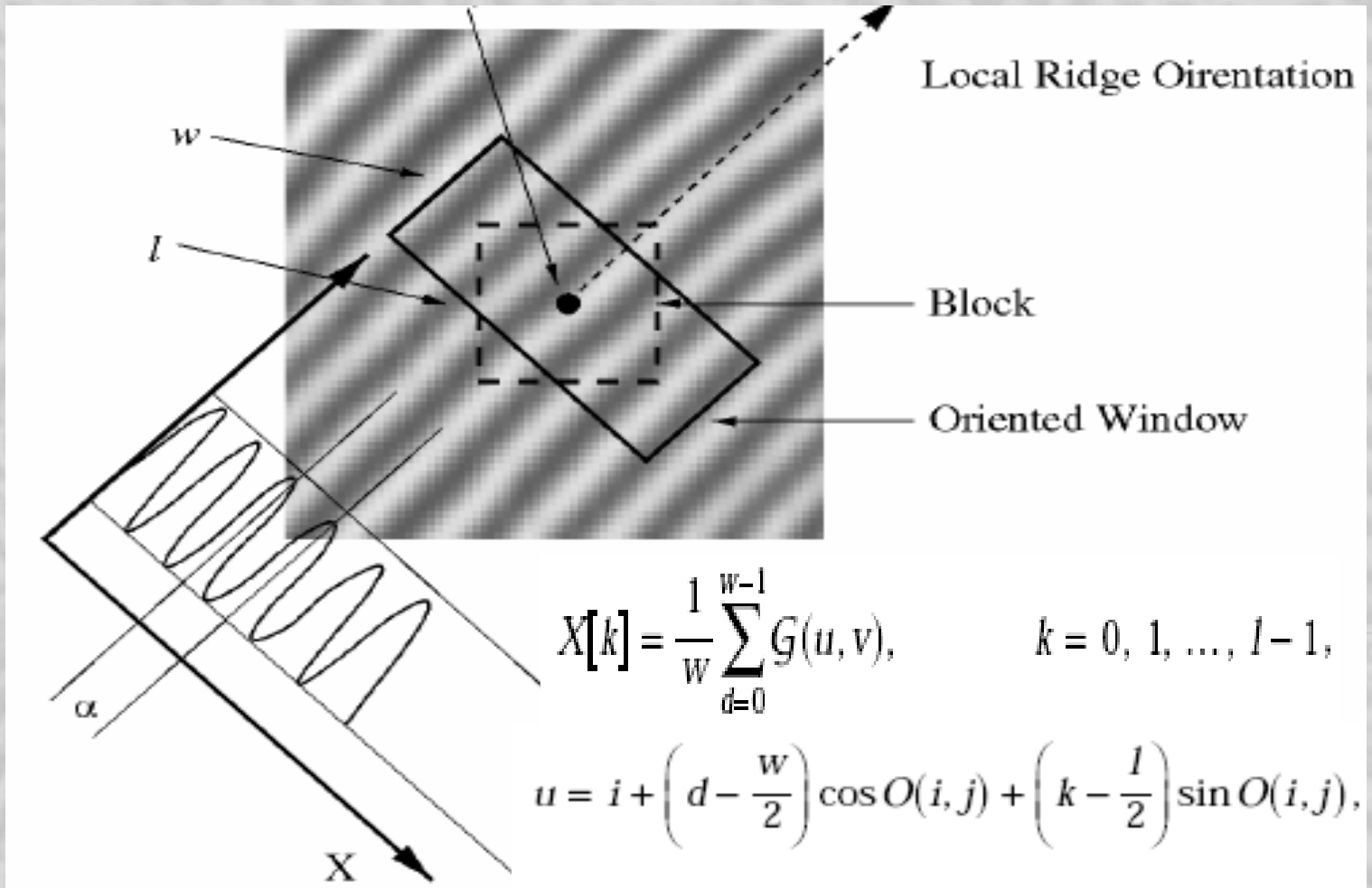
$$G(i,j) = \begin{cases} M_0 + \sqrt{\dfrac{VAR_0\left(I(i,j)-M\right)^2}{VAR}} & \text{if } I(i,j) > M \\ M_0 - \sqrt{\dfrac{VAR_0\left(I(i,j)-M\right)^2}{VAR}} & \text{if } I(i,j) \leq M \end{cases}$$

Local Orientation Estimation

- Normalized image is divided in blocks of size 16x16.
- Gradient $d_x(i,j)$ and $d_y(i,j)$ is calculated at every pixel.
- Least Square estimate of local ridge orientation is calculated at the block centered at pixel (i,j).
- Low pass filter is then used to modify the incorrect local ridge orientation.



Frequency Image Estimation



$$X[k] = \frac{1}{W}\sum_{d=0}^{W-1} G(u,v), \qquad k = 0, 1, \ldots, l-1,$$

$$u = i + \left(d - \frac{w}{2}\right)\cos O(i,j) + \left(k - \frac{l}{2}\right)\sin O(i,j),$$

$$v = j + \left(d - \frac{w}{2}\right)\sin O(i,j) + \left(\frac{l}{2} - k\right)\cos O(i,j).$$

Interpolate frequency for corrupted blocks from neighboring blocks having well defined frequency.

Region Mask Generation

- ***Amplitude*** α = (average height of the peaks - average depth of the valleys).
- ***Frequency*** $\beta = 1/T(i, j)$, where $T(i, j)$ is the average number of pixels between two consecutive peaks.
- ***Variance*** $$\gamma = \frac{1}{l}\sum_{i=1}^{l}\left(X[i] - \left(\frac{1}{l}\sum_{i=1}^{l}X[i]\right)\right)^2$$
- ***F (α, β, γ)*** ➡ Squared Error Clustering Algorithm

Recoverable Region

Non-recoverable Region

Image Filtering

- Gabor filters are used as bandpass filters to remove the noise and preserve true

$$h(x, y : \phi, f) = \exp\left\{-\frac{1}{2}\left[\frac{x_\phi^2}{\delta_x^2} + \frac{y_\phi^2}{\delta_y^2}\right]\right\}\cos(2\pi f x_\phi),$$

$$x_\phi = x\cos\phi + y\sin\phi,$$

$$y_\phi = -x\sin\phi + y\cos\phi,$$

enhanced image *E* is obtained as follows:

$$\mathcal{E}(i,j) = \begin{cases} 255 & \text{if } \mathcal{R}(i,j) = 0 \\ \sum_{u=-w_g/2}^{w_g/2} \sum_{v=-w_g/2}^{w_g/2} h(u, v : O(i,j), \mathcal{F}(i,j))\mathcal{G}(i-u, j-v) & \text{otherwise} \end{cases}$$

Thinning Methodologies

- Done before feature extraction
- All ridges should be one pixel thick
- Approaches
  - When a pixel detected as a boundary pixel it is …
    - deleted directly
      - Some thinning algorithms u… thinning iteration
    - Flagged and not deleted until t… entire image has been scanned
      - …

Does not thin the object symmetrically

Each pass is to remove the boundary pixels from a given direction

More memory requirements and higher time complexity

Performance Evaluation

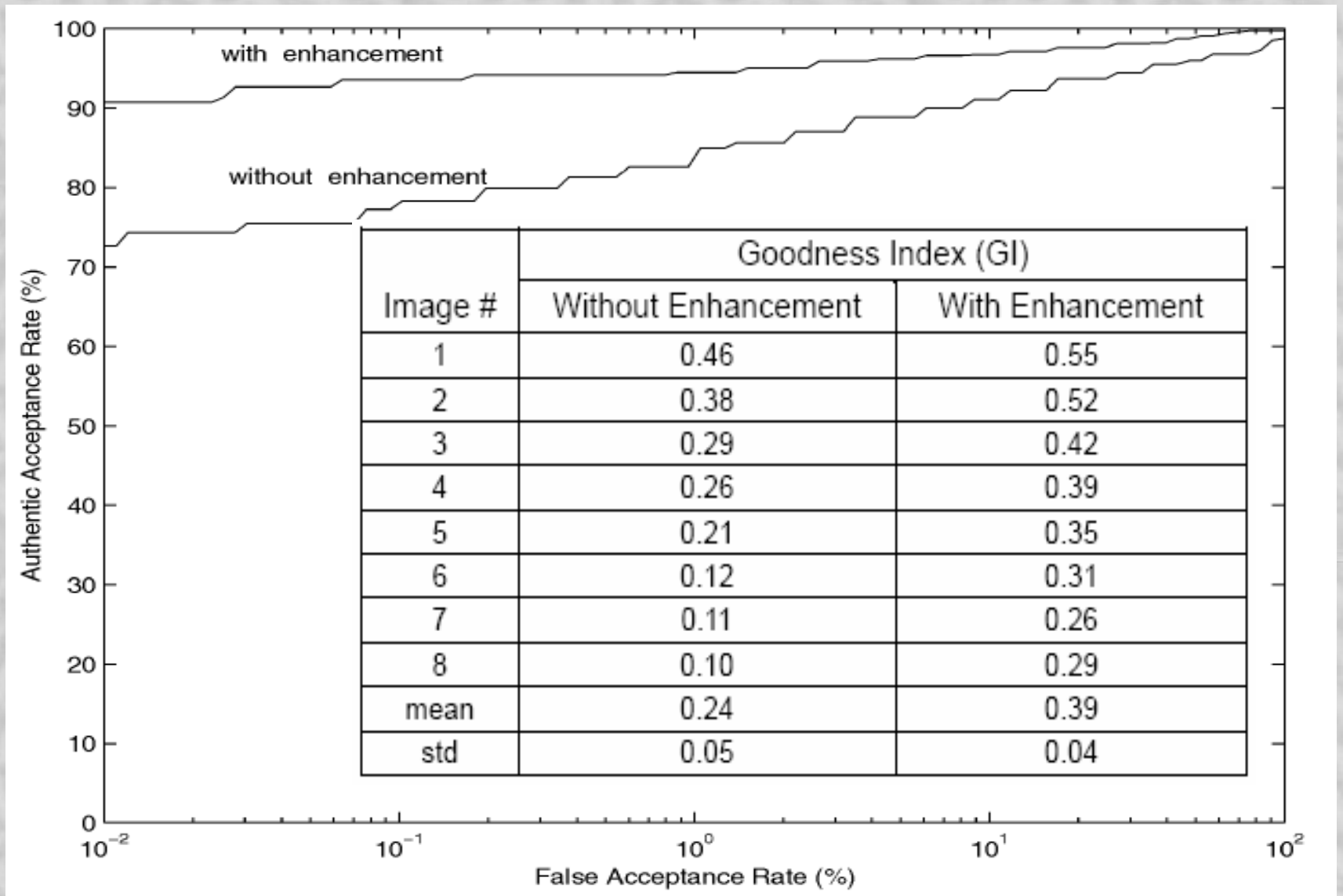
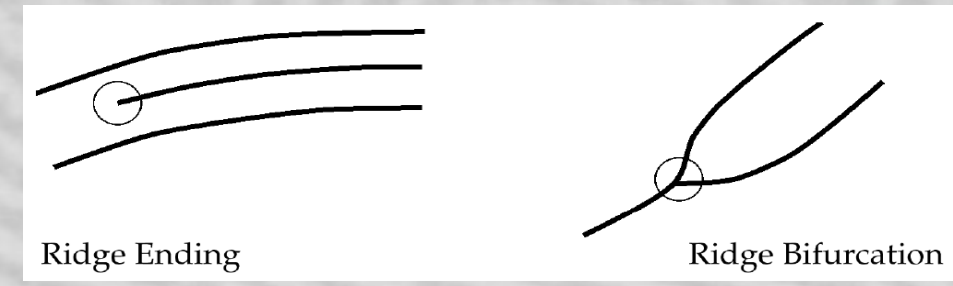


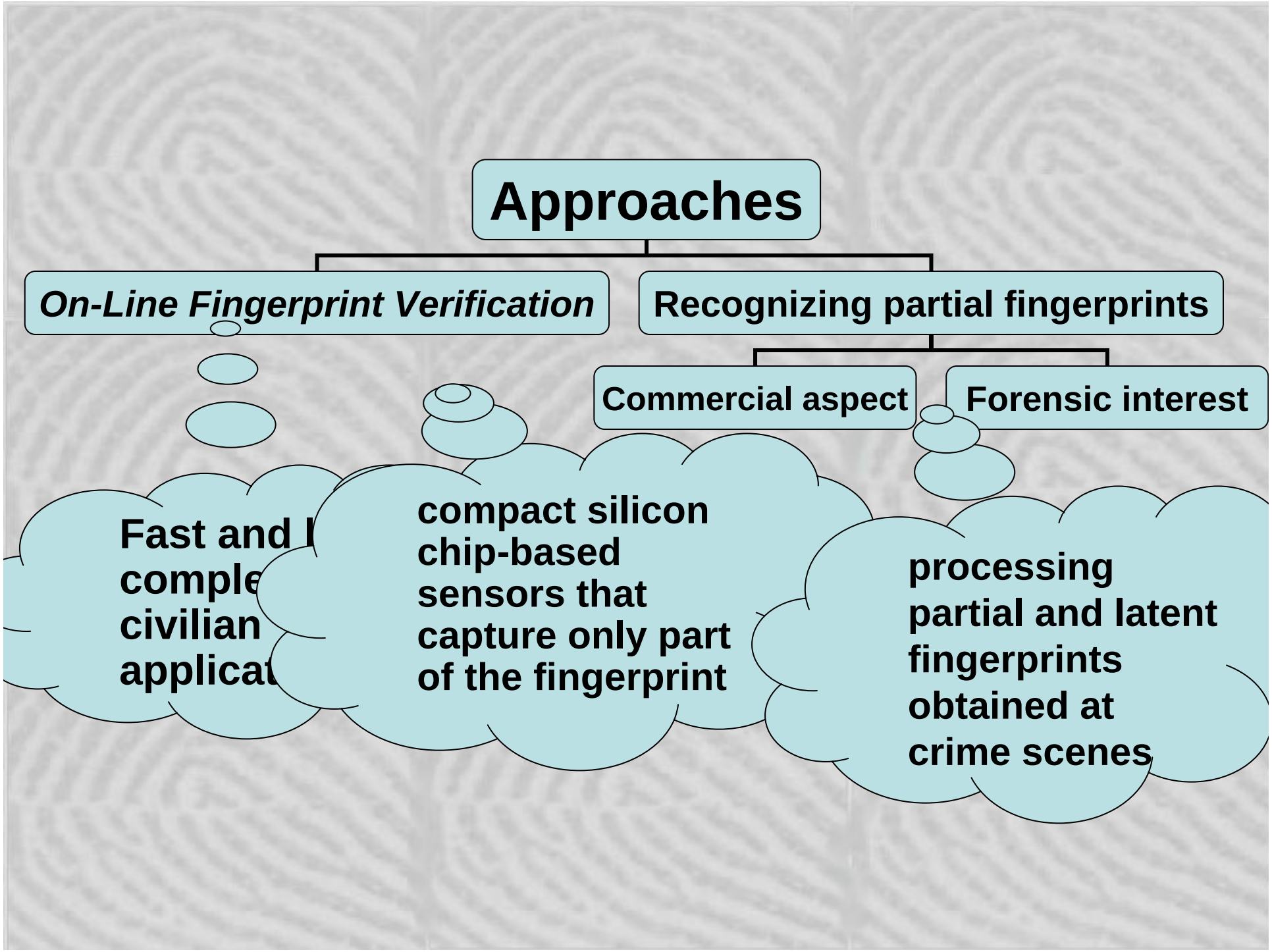
Image #	Goodness Index (GI)	
	Without Enhancement	With Enhancement
1	0.46	0.55
2	0.38	0.52
3	0.29	0.42
4	0.26	0.39
5	0.21	0.35
6	0.12	0.31
7	0.11	0.26
8	0.10	0.29
mean	0.24	0.39
std	0.05	0.04

Paper Critique: ***On-Line Fingerprint Verification***

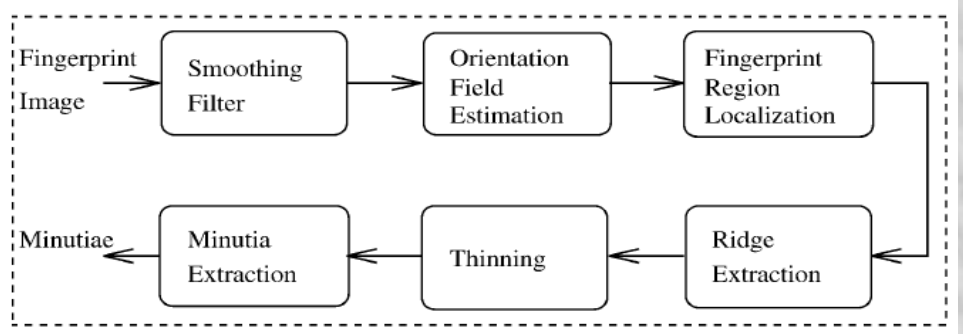
by Anil Jain, Lin Hong, Ruud Bolle

- On-line system requirements: Low Response time (feature retrieval speed) and High Accuracy
- Fingerprint verification made difficult by
  - ✓ No correspondence is known beforehand
  - ✓ Relative translation, rotation, nonlinear deformation
  - ✓ Spurious minutiae
  - ✓ Minutiae missed
- Minutiae based matching algorithm used: Minutiae are the most prominent ridge features




Approaches
On-Line Fingerprint Verification
Recognizing partial fingerprints
Commercial aspect
Forensic interest
Fast and l
comple
civilian
applicat
compact silicon chip-based sensors that capture only part of the fingerprint
processing partial and latent fingerprints obtained at crime scenes

Minutiae Extraction



Orientation field estimation

- G_x and G_y gradients in a block WxW used

$$\theta_o = \frac{1}{2}\tan^{-1}\left(\frac{\sum_{i=1}^{W}\sum_{j=1}^{W} 2G_x(i,j)G_y(i,j)}{\sum_{i=1}^{W}\sum_{j=1}^{W}\left(G_x^2(i,j) - G_y^2(i,j)\right)}\right)$$

- Improvement: *Consistency level* check of computational field wrt neighborhood W

$$C_o = \frac{1}{N}\sqrt{\sum_{(i',j')\in D}\left|\theta(i',j') - \theta(i,j)\right|^2}$$

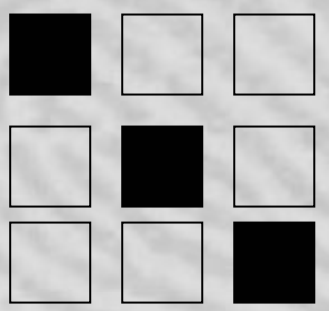
$$|\theta' - \theta| = \begin{cases} d & \text{if } \left(d = (\theta' - \theta + 360) \bmod 360\right) < 180 \\ d - 180 & \text{otherwise} \end{cases}$$

- Balances effect of noise, smudges, cuts, breaks

Minutiae Extraction

- Ridge Detection
  - ✓ Gray level values on ridges attain local maxima along normal directions of local ridges
  - ✓ 2 masks used to adaptively accentuate gray level values in normal direction
  - ✓ Output is binarized ridge map
- Thinning (whole class of algorithms)
- Minutiae Detection
- Ridge also stored with minutiae

$$\left(\sum_{i=0}^{8} N_i\right)$$



Minutiae Extraction

- Improvement: Refinement with Modified Rules
  - ✓ If several minutiae form a cluster in a small region, then remove all of them except for the nearest to the cluster centre.
  - ✓ If 2 minutiae are located close enough, facing each other, but no ridge lies between them, remove both.
- **Minutiae Matching**
  - ✓ Step1: Alignment Stage
  - ✓ Step2: Matching Stage

Minutiae Matching

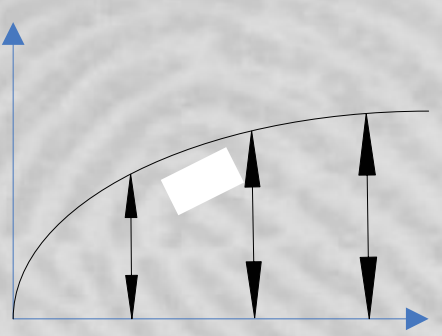
- Curve sections (ridges) used to align 2 point patterns
  - ✓ Works well in presence of noise, deformation
- Find best-match ridge pair
  - ✓ S(0≤ S ≤1)
- Find translation, rotation parameters

$$S = \frac{\sum_{i=0}^{L} d_i D_i}{\sqrt{\sum_{i=0}^{L} d_i^2 D_i^2}}$$

$$\begin{pmatrix} \Delta x \\ \Delta y \end{pmatrix} = \begin{pmatrix} x^d \\ y^d \end{pmatrix} - \begin{pmatrix} x^D \\ y^D \end{pmatrix}$$

$$\Delta\theta = \frac{1}{L}\sum_{i=0}^{L}(\gamma_i - \Gamma_i)$$

$$\begin{pmatrix} x_i^A \\ y_i^A \\ \theta_i^A \end{pmatrix} = \begin{pmatrix} \Delta x \\ \Delta y \\ \Delta\theta \end{pmatrix} + \begin{pmatrix} \cos\Delta\theta & \sin\Delta\theta & 0 \\ \sin\Delta\theta & -\cos\Delta\theta & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} x_i - x^d \\ y_i - y^d \\ \theta_i - \theta^d \end{pmatrix}$$



Minutiae Matching

- Convert aligned minutiae sets to polar coordinates
- Elastic matching carried out to model nonlinear plastic deformations of skin
- Polar coordinates are much more convenient while allowing for elastic matching
- Matching score calculated for input image
- If matching score greater than threshold, successful match !!

Recent Developments

- Spurious Minutiae: Without any spurious minutiae removal algorithms, more than 1000 minutiae can be detected.
- Actual minutiae: <100
- Several new algorithms for
  - ✓ *Elimination of close minutiae*
  - ✓ *Topological Validation*
  - ✓ *Island Elimination*
  - ✓ *Bifurcation Validation*

Challenges in Partial Fingerprint Matching

- The number of minutia points available in such prints is few
  - ✓ **Reducing its discriminating power**
- Loss of singular points (core and delta) is likely
  - **A robust algorithm independent of these singularities is required**
- Unspecified orientations of partial fingerprints, and distortions like elasticity and humidity are introduced
- Not reasonable to use an absolute number of matched minutiae alone in case of partial fingerprints
  - **Must also consider the overlapped areas on both prints and the total distance between all the matched minutiae**

Approach

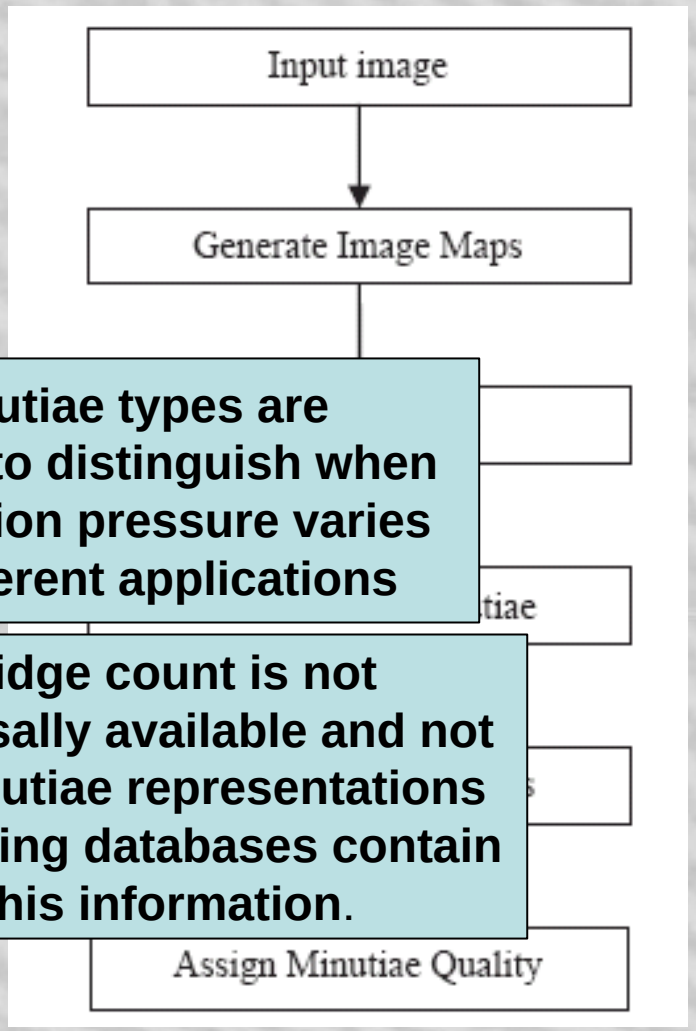
Two main features

- Local
  - ✓ **minutiae information (and secondary features), contain the information that is in a local area only and invariant with respect to global transformation**
  - ✓ **geometric deformations on local areas can be more easily controlled than global deformations**
- Global
  - ✓ **number, type, and position of singularities,**
  - ✓ **spatial relationship and geometrical attributes of ridge lines, size and shape of the fingerings, are characterized by the attributes that capture the global spatial relationships of a fingerprint**

Paper Critique: A minutia-based partial fingerprint recognition system

(Tsai-Yang Jea & Venu Govindaraju)

- Local Feature Extraction
  - ✓ Minutiae
- Relative distance, ra… angle & minutia orien… along with the ridge c… minutiae type to gen… the features for l… matching.

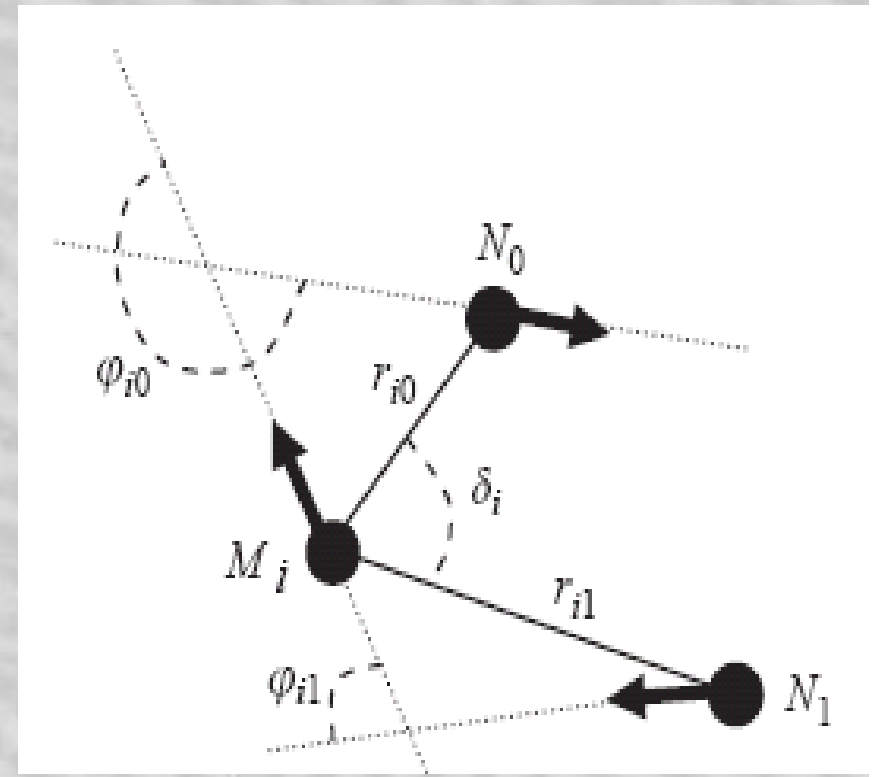


Minutiae types are difficult to distinguish when impression pressure varies different applications

Ridge count is not universally available and not all minutiae representations in existing databases contain this information.

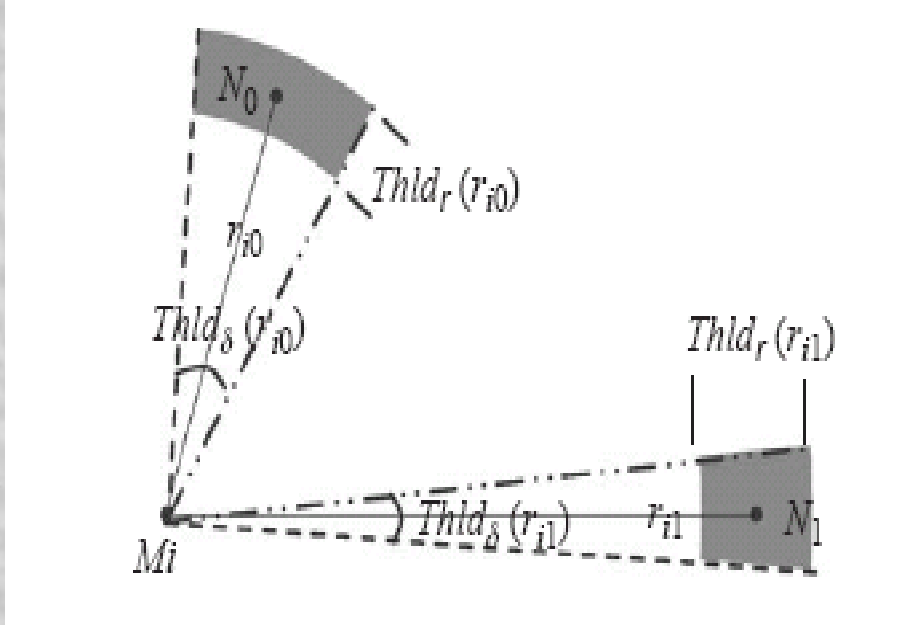
Secondary Feature

- Five element vector
- $S_i\ (r_{i0}, r_{i1}, \varphi_{i0}, \varphi_{i1}, \delta_i)$
- N_0 and N_1 are the two nearest neighbors of the central minutia M_i



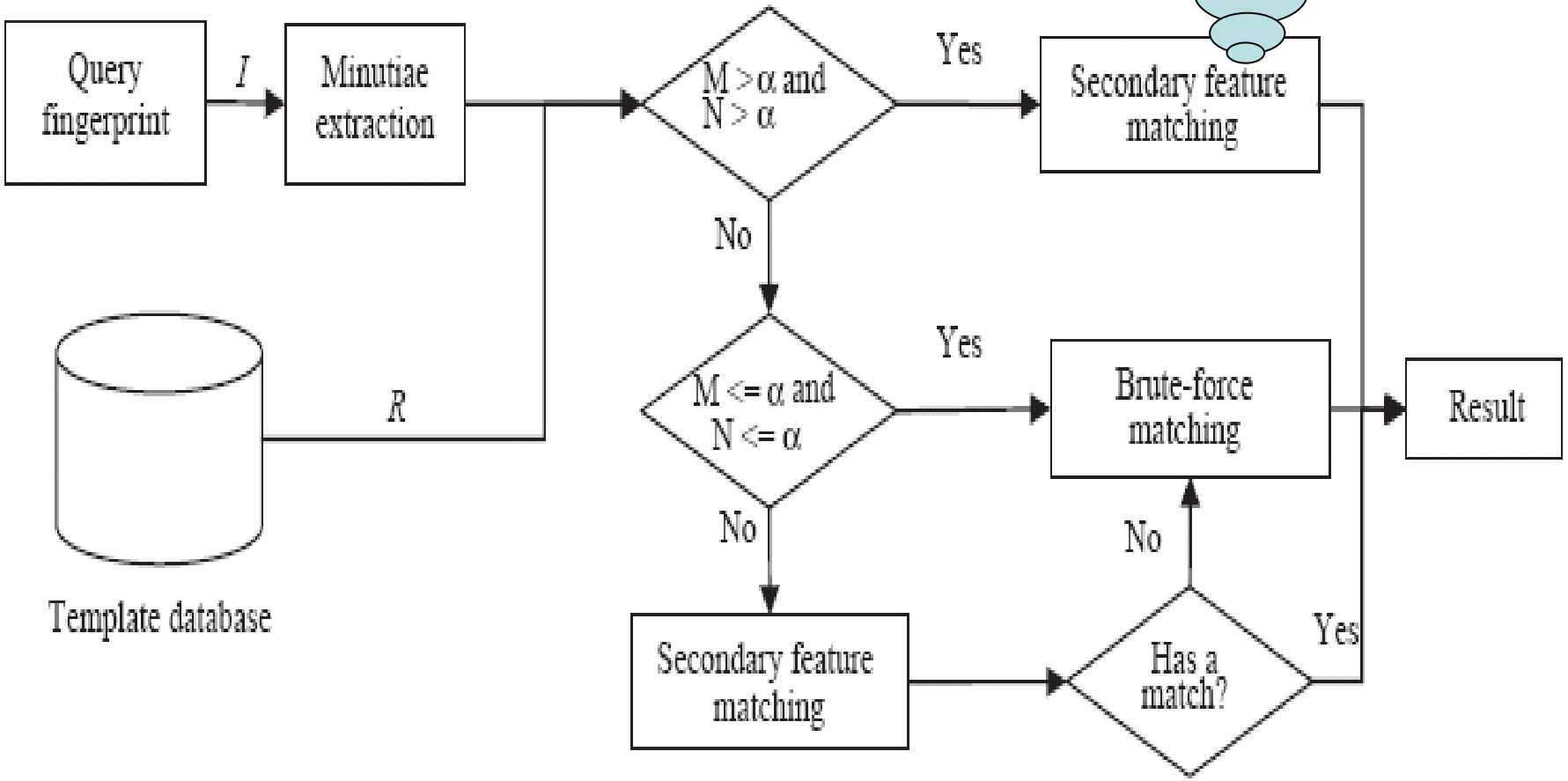
Tolerance Areas

- Distortions are inevitable when mapping a three dimensional fingertip onto a two-dimensional plane
- The distance thresholds should be more restrictive when r_{i0} and r_{i1} are smaller and more flexible when r_{i0} and r_{i1} are larger.
- The thresholds on angles should be larger in order to allow large distortions when r_{i0} and r_{i1} are small, but smaller when r_{i0} and r_{i1} are large



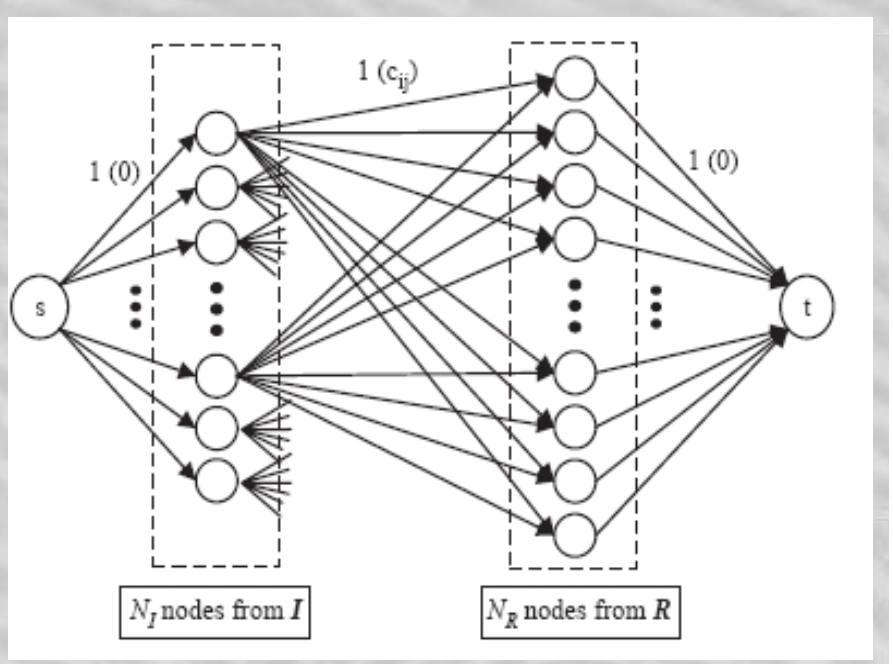
Feature Matc

Find one to one correspondence between the secondary features using MCF



Minimum Cost Flow (MCF)

- To find optimal pairing
  - ✓ **Maximum number of matches and minimum cost**
- Cost matrix $c(i, j)=dist(m_i,m_j)$
  - ✓ **For efficiency purposes, we remove the edge between *mi* and *mj* if *mi* is not in the tolerance area of *mj***
- Total of $NI + NT + 2$ (with the source *s* and sink *t* nodes) nodes in the network
- The capacity on every edge is set to 1



MCF Solution

- Solving the MCF problem is equivalent to finding the maximum number of matched feature points (maximum flow) with the minimum total feature distance (minimum cost)
- MCF and its applications are extensively discussed in the publications of Ford and Fulkerson, Edmonds and Karp
- Algorithms
  - ✓ **Out-Of Kilter**
  - ✓ **minimum-cost augmentation method,**
  - ✓ **methods of network simplex, cost-scaling, relaxation, and push-relabel**.
- The “Scaling & Canceling” algorithm by Orlin solves the problem in polynomial-time ($O(m(m + n\log n) \log(nU))$), where n is the no. of nodes in network, m is no. of edges and U is the upper bound of the value of capacity

Smart Access Systems

Fingerlock 250

- Speedy fingerprint verification within 0.5-1 seconds
- Each unit can recognize up to 50 different fingerprints
- Operates on 5AA sized batteries or can be hardwired into home power supply
- Front loading sensor mechanism offers protection against vandalism
- Password can be set in order to access the fingerprint sensor.
- Sleek ergonomic design suitable for most doors

Honeywell Access Systems

- Administration options include roaming (a laptop PC temporarily connected to the V-Pass RJ11 port) or network (RS-485, RS-232)
- Works with multiple types of fingerprint imaging devices while maintaining original enrollments
- Field upgradeable internal processor
- LED user feedback provided by red, green and amber signals
- Audible feedback
- Fake finger detection (rubber and latex)

Mitsubishi Electric
Fingerprint Verification

References

- L. Hong, Y. Wand, and A.K. Jain. "*Fingerprint image enhancement: algorithm and performance evaluation*." IEEE-PAMI Transactions on Pattern Analysis and Machine Intelligence, 20(8):777--789, 1998.
- Jain, A., Hong, L., Bolle, R.: "On-*line fingerprint verification*". IEEE-PAMI 19 (1997) 302—314
- Jea, T., Govindaraju, V.: "*A minutia-based partial fingerprint recognition system*." The Journal of Pattern Recognition (2005)
- http://global.mitsubishielectric.com/it/public/applications/security_systems.html
- http://www.honeywellaccess.com/products/readers/bio/18593.html
- http://www.aje.com.au/featured/fingerlock/250.htm