Geometric Algorithms in Biometrics

Dr. Marina L. Gavrilova
Biometric goals

- Verify users
- Identify users
- Synthesis - recently
## Biometric identifiers

<table>
<thead>
<tr>
<th>Biometric Trait</th>
<th>Permanence over time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fingerprint (Minutia)</td>
<td>00000</td>
</tr>
<tr>
<td>Signature (dynamic)</td>
<td>0000</td>
</tr>
<tr>
<td>Facial structure</td>
<td>00000</td>
</tr>
<tr>
<td>Iris pattern</td>
<td>00000000000000000</td>
</tr>
<tr>
<td>Retina</td>
<td>00000000000000000</td>
</tr>
<tr>
<td>Hand geometry</td>
<td>00000000000000000</td>
</tr>
<tr>
<td>Finger geometry</td>
<td>00000000000000000</td>
</tr>
<tr>
<td>Vein structure of the back of the hand</td>
<td>00000000000000000</td>
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<tr>
<td>Ear form</td>
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<tr>
<td>Voice (Tone)</td>
<td>00000000000000000</td>
</tr>
<tr>
<td>DNA</td>
<td>00000000000000000</td>
</tr>
<tr>
<td>Odor</td>
<td>00000000000000000</td>
</tr>
<tr>
<td>Keyboard strokes</td>
<td>00000000000000000</td>
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<tr>
<td>Comparison: Password</td>
<td>00000000000000000</td>
</tr>
</tbody>
</table>

Courtesy of Bromba GmbH
Classification of identifiers

- **Physiological biometric identifiers**: fingerprints,
  - hand geometry,
  - eye patterns (iris and retina),
  - facial features
  - and other physical characteristics.

- **Behavioral identifiers**:
  - voice,
  - Signature
  - typing patterns
  - other.

Analyzers based on behavioral identifiers are often less conclusive because they are subject to limitations and can exhibit complex patterns.
Long-Term Goals

- Establish acceptable error rates
- Decrease possibility of error
- Improve methodology (new biometrics, combination)
- Make implementation more robust
Geometric proximity and topology

- Methods based on concepts of proximity of geometric sets and extracting and utilizing topological information on the data are:
  - Techniques for computing the medial axis transform
  - Distance distribution computation using weighted metric functions
  - Use of Voronoi diagram and Delaunay triangulation for data processing and matching
  - Topology-based approach for feature extractions along the boundary
  - Computational geometry methods for pre-processing and pattern matching
  - Topology-based approach for generation of biometric information
Outline

- Distance Distribution Computation
- Pattern matching
- Methods for identification and synthesis
- Feature extraction
Computational Geometry in Biometrics

Data Collection
- Data source
- Sensors

Processing
- Feature extraction
- Data pre-processing

Decision
- Pattern matching
- Reporting

Transmission

Storage

Data Base

Compression module

CG methods
Threshold distance

- A *threshold* distance: declare distances less than the threshold as a "match" and those greater to indicate "non-match".

- Genuine distribution
- Inter-template distribution
- Imposter distribution
Distance measures

Distance metrics

\[ d_p(x, P) = d(x, p)^2 - r_p^2 \]

**Power**

\[ d_e(x, P) = d(x, p) - r_p \]

**Additively weighted**

- **Euclidean**
  \[ d(x, P) = \sqrt{\sum_{i=1}^{d} (x_i - p_i)^2} - r_p \]

- **Manhattan**
  \[ d(x, P) = \sum_{i=1}^{d} |x_i - p_i| - r_p \]

- **supremum**
  \[ d(x, P) = \max_{i=1..d} |x_i - p_i| - r_p \]
Use of metrics

- Regularity of metric allows to measure the distances from some distinct features of the template more precisely, and ignore minor discrepancies originated from noise and imprecise measurement while obtaining the data.

- We presume that the behavioral identifiers, such as typing pattern, voice and handwriting styles will be less susceptible to improvement using the proposed weighted distance methodology than the physiological identifiers.
Pattern Matching

- Aside from a problem of measuring the distance, pattern matching between the template and the measured biometric characteristic is a very serious problem on its own.

- Some preliminary research, mainly in the area of image processing, should be utilized in order to approach the problem from the right angle.
Template comparison

- The most common methods are based on bit-map comparison techniques, scaling, rotating and modifying image to fit the template through the use of linear operators, and extracting template boundaries or skeleton (also called medial axis) for the comparison purposes.

- In addition, template comparison methods also differ, being based on either pixel to pixel, important features (such as minutae) positions, or boundary/skeleton comparison.
Template Matching approach to Symbol Recognition

Compare an image with each template and see which one gives the best match (courtesy of Prof. Jim Parker, U of C)
Most of the pixels overlap means a good match (courtesy of Prof. Jim Parker, U of C)
Distance transform

- **Definition 1.** Given an $n \times m$ binary image $I$ of white and black pixels, the *distance transform* of $I$ is a map that assigns to each pixel the distance to the nearest black pixel (a feature).

- The distance transform method introduced in [Gavrilova and Alsuwayel] is based on fast scans of image in the top-bottom and left-right directions using a fast polygonal chain maintenance algorithm.

- After the distance transform is build, it can be used to visualize proximity information in a form of *temperature map*.

- As the distance from the black pixels (*features*) increases, the color intensity changes.
Distance Transform

Given an $n \times m$ binary image $I$ of white and black pixels, the distance transform of $I$ is a map that assigns to each pixel the distance to the nearest black pixel (a feature).
Thermogram vs. distance transform

Thermogram of an ear (Brent Griffith, Infrared Thermography Laboratory, Lawrence Berkeley National Laboratory)
What is a Distance Transform?

Given an $n \times m$ binary image $I$ of white and black pixels, the distance transform of $I$ is a map that assigns to each pixel the distance to the nearest black pixel (a feature).
What is a Feature Transform?

The feature transform of I is a map that assigns to each pixel the feature that is nearest to it.
$L_1$ Distance Transform
Algorithm
$L_\infty$ Distance Transform Algorithm
A Fast Algorithm for Computing Euclidean Distance Transform

- Works in Euclidean Metric
- Optimal – linear in the number of pixels
- Proceed in two passes over the image, top down and bottom up
- For each row
  - Maintain a polygonal chain - a set of pixels in which the nearest feature may lies
  - Updates the chain for next row by pruning - it becomes the *minimal* set of pixels
    - Prune Endpoints and Internal Vertices
What is a Chain?

- One Chain for the row
- Contains at most one pixel per column
- Contains the lowest pixel in the column
- After pruning, it contains only those points that will be nearest features to some points in the row
- Dynamically updated from row to row
Example of a Chain
Pruning Endpoints

- Identifying superfluous endpoints
Pruning Internal Points

- Point $q$ is removed

(a)
Point q remains
Algorithm Walkthrough
Experimental results

Algm 1 – pruning
Algm 2 – no pruning

Graph shows running time in sec. (OY axis) vs. number of pixels in image (OX axis)

Results:
Significant improvement in running time
Linear function grows slowly
Algm 1 with pruning was tested

Saturation levels: 5%, 15%, 30%

Results:

Linear Running Time, Regardless of Saturation (% of black pixels in image)
Experimental results
Generalized Voronoi diagram

A *generalized Voronoi diagram* for a set of objects in the space is the set of generalized Voronoi regions according to some proximity rule.

A *generalized Delaunay triangulation* is the dual of the generalized Voronoi diagram obtained by joining all pairs of sites whose Voronoi regions share a common Voronoi edge.
Example: VD and DT in power metric
Voronoi methods in biometrics

- The methodology is making its way to the core methods of biometrics, such as fingerprint identification, iris and retina matching, face analysis, ear geometry and others (see recent works by [Xiao, Zhang, Burge]).

- The methods are using Voronoi diagram to partition the area of a studies image and compute some important features (such as areas of Voronoi region, boundary simplification etc.) and compare with similarly obtained characteristics of other biometric data.
Definition 2. The *medial axis*, or *skeleton* of the set $D$, denoted $M(D)$, is defined as the locus of points inside $D$ which lie at the centers of all closed discs (or spheres) which are maximal in $D$, together with the limit points of this locus.
Medial axis transform
Singular-point detection

- In many biometric problems, such as detecting singular points in fingerprint images, the quality of the result and false detection rates depend directly on the quality of the data (image, print, recording etc).
- To improve the result, pre-processing can be used. In some cases, it is not enough to simply enhance the image properties.
- Many cases of false detection happen at the boundary of an image or at places where lines are of irregular shape.
- A method based on extending the lines of the image beyond the boundary in the projected direction so that the singular point can be computed more precisely. For the second case, topology-based method are traditionally used to smooth the irregularity (including the interpolation techniques) [Maltony, Jain, Zhan]
Singular point detection (top to bottom): singular point close to boundary (lower); regular pattern.
DT for minutiae point extraction

(a) Thinned Image  
(b) Minutia Extracted
DT for minutiae point extraction

(a) Purified minutia
(b) DT constructed based (a)
Delaunay Triangulation can be used for Matching

For each Delaunay triangle, the length of three edges, the three angles and the ridge numbers between each edge are recorded to construct a 9 dimensional local vector to find the best-matched local structure in two fingerprints.
Triangle edge comparison in minutiae matching
Finally, one of the most challenging areas is a recently emerged problem of generating biometric information, or so-called *inverse* problem in biometrics.

In order to verify the validity of algorithms being developed, and to ensure that the methods work efficiently and with low error rates in real-life applications, a number of biometric data can be artificially created, resembling samples taken from live subjects.

In order to perform this procedure, a variety of methods should be used, but the idea that we explore is based on the extraction of important topological information from the relatively small set of samples (such as boundary, skeleton, important features etc), applying variety of computational geometry methods, and then using these geometric samples to generate the adequate set of test data.
Conclusions

- Geometric data structures and methodology based on proximity and topology prove to be useful for emerging field of biometric technologies.

- The overview discussed existing computational geometry methods and their recently developed applications in biometrics.

- We suggest a number of new approaches for investigation of specific biometric problems, including those of synthesis of biometric information.