Fingerprints

- The inside surfaces of hands and feet of humans (and, in fact, all primates) contain minute ridges of skin with furrows between each ridge.
- The purpose of this skin structure is to:
  - Facilitate excretion of perspiration
  - Enhance sense of touch
  - Providing a gripping surface

Friction skin

- Friction skin differs significantly in structure and function from the skin covering the rest of the body:
  - It is hairless
  - It contains no sebaceous (oil glands)
  - It has a much higher concentration of nerve endings
  - It has a much higher concentration of sweat glands
  - There is a lack of pigmentation

Fingerprint images

- Optical scanner
- Capacitive scanner
- Piezoelectric scanner
- Thermal scanner
- Inked impression
- Latent fingerprint

Fingerprints

- Fingerprint images are "permanent" in that they are formed in the fetal stage, prior to birth, and remain the same throughout lifetime.
- The changes can be made by: flexibility from the skin, growing, a dirty finger, scarring, a wound, or a disease of the skin.
- They are only weakly determined by genetics, e.g., identical (monozygotic, one egg) twins (the same DNA) have fingerprints that are quite different.
- Fingerprints of an individual are "unique"; they indeed are distinctive to a person.
- The right definition of a fingerprint is strictly speaking the print (stamp) that a finger left on an object.

Description:

- Graphical flow like ridges present in human fingers

Formal:

- During embryonic development

Permanence:

- Minute details do not change over time

Uniqueness:

- Believed to be unique to each finger

History:

- Used in forensics and has been extensively studied
Biological Principles of Fingerprints

- Individual epidermal ridges and valleys have different characteristics for different fingerprints.
- Configurations and minute details of individual ridges and valleys are permanent and unchanging (except for enlargement in the course of bodily growth).
- Configuration types are individually variable, but they vary within limits which allow for systematic classification.

History of Fingerprints

- Many impressions of fingers have been found on ancient pottery.
- Grew (1684): first scientific paper on ridges, valleys & pore structures.
- Bewick (1809): used his fingerprint as his trademark.
- Purkinje (1823): classified fingerprints into 9 categories based on ridges.
- Herschel (1858): used fingerprints on legal contracts in Bengal.
- Vucetich (1888): first known user of dactylograms (inked fingerprints).
- Scotland Yard (1900): adopted Henry/Galton system of classification.
- FBI (1924) set up a fingerprint identification division with a database of 810,000 fingerprints.
- FBI (1965): installed AFIS with a database of 810,000 fingerprints.
- FBI (2000): installed IAFIS with a database of 47 million prints; conducts an average of 50,000 searches/day; ~15% of searches are in lights out mode. Response time: 2 hours for criminal search and 24 hours for civilian search.

Fingerprint Matching

- Find the similarity between two fingerprints.

Fingerprint Sensors

- Optical, capacitive, ultrasound, pressure, thermal, electric field.
Fingerprint Classification

- Assign fingerprints into one of pre-specified types

Plain Arch  |  Tented Arch  |  Right Loop  |  Left Loop

Accidental  |  Pocket Whorl  |  Plain Whorl  |  Double Loop

Terminology

- **Fingerprint** – Impression of a finger
- **Minutiae** – Ridge bifurcations, endings and many other features (52 types listed, 7 are usually used by human experts and two by automated systems)
- **Core** – uppermost point on the innermost ridge
- **Delta** – separating point between pattern area and non-pattern area

**Feature Levels**
- Level 1: pattern
- Level 2: minutiae points
- Level 3: pores and ridge shape

Level 1 features – singularities (core points)

- Left loop
- Right loop
- Whorl

Level 3 features

- Sweat pores
Orientation Field Flow Curves

- Study the topology of the curves formed by ridges
- OFFC is a curve inside a fingerprint image whose tangent direction is parallel to the direction of the orientation field
- Starting points of OFFCs are chosen along the vertical and horizontal lines passing through the midsection of the image

Fingerprint Representation

- Local ridge characteristics (minutiae): ridge ending and ridge bifurcation
- Singular points: Discontinuity in ridge orientation

Minutiae-based Representation

- Orientation field estimation
- Fingerprint area location
- Ridge extraction
- Thinning
- Minutia extraction
Minutiae Extraction Algorithm

Minutiae Type Detection
- A ridge pixel is a ridge ending, if the number of ridge pixels in the 8-neighborhood is 1
- A ridge pixel is a ridge bifurcation, if the number of ridge pixels in the 8-neighborhood is greater than or equal to 3
- A ridge pixel is an intermediate ridge pixel, if the number of ridge pixels in the 8-neighborhood is 2

[x, y, θ, associated ridge] are stored for each minutia

Minutiae Correspondences

Minutiae Matching
- Point pattern matching problem
- Let $P = \{(x_1, y_1, \theta_1), \ldots, (x_M, y_M, \theta_M)\}$ be the set of $M$ minutiae in the template image
- Let $Q = \{(x_1', y_1', \theta_1'), \ldots, (x_N', y_N', \theta_N')\}$ be the set of $N$ minutiae in the input image
- Find the number of corresponding minutia pairs between $P$ and $Q$ and compare it against a threshold

Stages of Minutiae-based Verification
- Extract Minutiae using corner detection
- Characterize (label) Minutiae
- Transformations between fingerprint images
- RANSAC

Corner Detection
Finding Corners

Intuition:
- Right at corner, gradient is ill-defined.
- Near corner, gradient has two different values.

What is image filtering?
- Modify the pixels in an image based on some function of a local neighborhood of the pixels.

Convolution: $R = K \ast I$

Kernel size is $m+1$ by $m+1$

\[
R(i, j) = \sum_{h=-m}^{m} \sum_{k=-m}^{m} K(h,k) I(i-h, j-k)
\]
Convolution: $R = K \ast I$

Kernel size is $m+1$ by $m+1$

$R(i, j) = \sum_{k=-2}^{2} \sum_{l=-2}^{2} K(h, k)I(i-h, j-k)$
Convolution: $R = K*I$

Kernel size is $m+1$ by $m+1$

$$R(i,j) = \sum_{h=-m/2}^{m/2} \sum_{k=-m/2}^{m/2} K(h,k)I(i-h,j-k)$$

Average Filter
- Mask with positive entries, that sum 1.
- Replaces each pixel with an average of its neighborhood.
- If all weights are equal, it is called a BOX filter.

(Camps)

Image Noise
- Gaussian Noise: $\sigma=1$
- Gaussian Noise: $\sigma=16$

Smoothing by Averaging
An Isotropic Gaussian

- The picture shows a smoothing kernel proportional to
  \[ \exp \left( -\frac{x^2 + y^2}{2\sigma^2} \right) \]
  (which is a reasonable model of a circularly symmetric fuzzy blob)

Smoothing with a Gaussian

Kernel:

Numerical Derivatives

Take Taylor series expansion of \( f(x) \) about \( x_0 \):

\[
f(x) = f(x_0) + f'(x_0)(x-x_0) + \frac{1}{2} f''(x_0)(x-x_0)^2 + \ldots
\]

Consider Samples taken at increments of \( h \) and first two terms, we have

\[
f(x_0+h) = f(x_0)+f'(x_0)h + \frac{1}{2} f''(x_0)h^2
\]
\[
f(x_0-h) = f(x_0)-f'(x_0)h + \frac{1}{2} f''(x_0)h^2
\]

Subtracting and adding \( f(x_0+h) \) and \( f(x_0-h) \) respectively yields

\[
f'(x_0) = \frac{f(x_0+h) - f(x_0-h)}{2h}
\]
\[
f''(x_0) = \frac{2f(x_0+h) + 2f(x_0) - f(x_0-h)}{2h^2}
\]

Smoothing and Differentiation

- Need two derivatives, in \( x \) and \( y \) direction.
- Filter with Gaussian and then compute gradient, or
- Use a derivative of Gaussian filter
  - because differentiation is convolution, and convolution is associative

Formula for Finding Corners

Let \( I_x = \frac{\partial I}{\partial x} \) and \( I_y = \frac{\partial I}{\partial y} \)

Sum over a small region, the hypothetical corner

\[
C = \sum I_x^2 + \sum I_x I_y + \sum I_y^2
\]

Matrix is symmetric

WHY THIS?
First, consider the case where:

\[ C = \begin{bmatrix} \sum I_x^2 & \sum I_x I_y \\ \sum I_x I_y & \sum I_y^2 \end{bmatrix} = \begin{bmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{bmatrix} \]

This means all gradients in the neighborhood are:

- \((k,0)\) or \((0,c)\) or \((0,0)\) (or off-diagonals cancel).

What is the region like if:
1. \(\lambda_1 = 0\)?
2. \(\lambda_2 = 0\)?
3. \(\lambda_1 = 0\) and \(\lambda_2 = 0\)?
4. \(\lambda_1 > 0\) and \(\lambda_2 > 0\)?

General Case:

From Linear Algebra, it follows that

\[ C = R^{-1} \begin{bmatrix} \lambda_1 & 0 \\ 0 & \lambda_2 \end{bmatrix} R \]

since \(C\) is symmetric. So every case is like the one on the last slide.

So, to detect corners:
- Filter image.
- Compute the gradient everywhere.
- We construct \(C\) in a window of some size.
- Use linear algebra to find \(\lambda_1\) and \(\lambda_2\).
- If \(\lambda_1\) and \(\lambda_2\) are both big, we have a corner.
  1. Let \(e(u,v) = \min(\lambda_1(u,v), \lambda_2(u,v))\)
  2. \((u,v)\) is a corner local maximum of \(e(u,v)\)
     and \(e(u,v) > \tau\)

Corner Detection Sample Results:
- Threshold=25,000
- Threshold=10,000
- Threshold=5,000