# Topological Data Analysis and Fingerprint Classification

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# Purpose

Since classical methods of identifying fingerprints involve matching samples in an enormous database, to slightly decrease this time fingerprints are separated into classes. We want to further reduce the time it takes to identify fingerprints, by observing and analyzing their topological structures using persistence diagrams.

# Fingerprint Classification

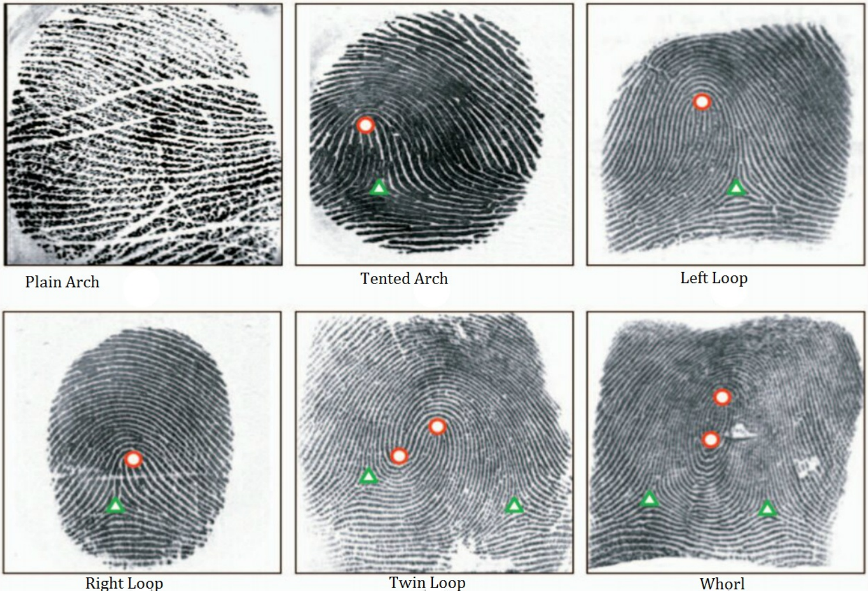
Fingerprints are classified in three ways:

1. Loops - the ridges will flow in one side, recurve, (loop around) touch or pass through an imaginary line drawn from the delta [1] to the core [2] , and exit the pattern on the same side from which it entered.
2. Whorl - consists of a series of almost concentric circles. A whorl pattern has two deltas.
3. Arch - ridges flow in one side and flow out the opposite side. There are no deltas in an arch pattern.

[1] The delta area is the triangular area where the ridges radiate outward in three directions.

[2] A center of a loop or whorl.

# Fingerprint Examples



# Current method for Analyzing Fingerprint Structures

A common technique currently involves singular points which detect and count the locations of core and delta points which were unique enough to use as unique identifiers in fingerprints

**Rule Based**

1. How it Works:
   - Rules are generated independent of a given data set.
   - Example, some rules may be: An Arch has no singular points. A tented arch, left loop, and right loop will consist of one loop and one delta. A whorl will have two loops and two deltas.
2. Cons
   - Has problems with inaccurately identifying deltas.
   - Dependent on comprehensive rules in order to deter inaccuracy of low quality fingerprint images.
   - Still have issues when faced with breaks, scars, too oily, or too dry in the fingerprint

# Current Meth. Cont.

## Poincaré Index

1. How it works:
   - By computing the orientation field, $O(m,n) \in [0, 2\pi)$, which represents the ridge orientation for each pixel, $(m.n)$, they can build a vector field $V = cos2O + i \cdot sin2O$.
   - The Poincaré Index is defined as the sum of the orientation differences along a closed circle:

Then, the Poincaré Index of $P$ can be computed by

$$\begin{aligned} I_P &= \frac{1}{\pi}\sum_{i=1}^{N-1} f(o_{i+1} - o_i) \\ &= \frac{1}{\pi}\sum_{i=1}^{N-1} f(\delta o_i), \end{aligned}$$

where $o_N = o_1$, and function $f$ is defined as

$$f(x) = \begin{cases} x, & |x| \leq \frac{\pi}{2}, \\ \pi - x, & x > \frac{\pi}{2}, \\ \pi + x, & x < -\frac{\pi}{2}. \end{cases}$$

# Poincaré Visually

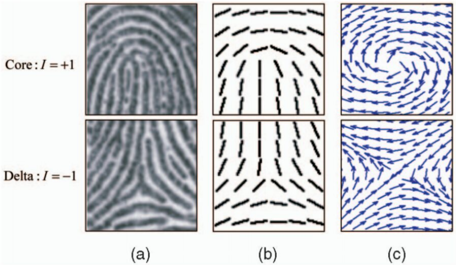



Fig. 4. (a) Singular points in fingerprints with the Poincaré Indices, (b) their local patterns in the orientation field $O$, and (c) the vector field $V$.

- Poincaré Index currently has the greatest accuracy detecting cores and deltas without false alarms.
- However,this method loses a lot of the ridges and other small details that could greatly improve fingerprint identifying.

# Goal/Why Persistent Homology

- Our goal is to see if we can apply persistent topology to fingerprints without losing valuable information.
- The reason we are using persistent homology is to test a relatively new tool in math against existing methods to see if we can find a viable approach and learn new ways of applying persistent homology to image analysis.

# Persistent Homology

A main purpose of persistent homology is the measurement of the scale or resolution of a topological feature.

- **Betti Numbers** - Denoted by "$\beta_0$ or $\beta_1$".
  1. $\beta_0$ - is the number of connected components in a topological space.
  2. $\beta_1$ - is the number of loops in a topological space.
- **Simplicial Complex** - A finite collection of simplices [3] K such that $\sigma \in K$ and $\tau \leq \sigma$ implies $\tau \in K$, and $\sigma, \sigma_0 \in K \Rightarrow \sigma \cap \sigma_0$ is either empty or a face of both.
- **Filtrations** - Let K be a simplicial complex. A filtration is a nested sequence of subcomplexes

$$\emptyset = K_0 \subset K_1 \subset \ldots \subset K_n = K.$$

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[3] Simplices are higher dimensional triangles

# Gif

# References


- Edelsbrunner, Herbert, and John Harer. Computational Topology: An Introduction. Providence, RI: American Mathematical Society, 2010. ebook.
- hou, Jie, Fanglin Chen, and Jinwei Gu. "A Novel Algorithm for Detecting Singular Points from Fingerprint Images." IEEE Transactions on Pattern Analysis and Machine Intelligence IEEE Trans. Pattern Anal. Mach. Intell. 31.7 (2009): 1239-250. ebook.
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