Fingerprints: Are They Your Own?

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Abstract

We will be investigating fingerprints and the accepted fact that everyone has a different set of fingerprints. We will look at the history of fingerprinting and see why it is the accepted form of identification. We will provide a background of the process of fingerprinting and the comparison process used in the criminal justice system. We will investigate the probability that two people could have the same set of fingerprints. We will then look at different mathematician's perspectives and how they proposed to solve this matter.

1 Introduction

Fingerprinting is the most widely accepted identification system in the world. Fingerprint examination in an art form that must be practiced and perfected, but is this science reliable? The main question we are trying to answer is whether or not two people could have the same set of fingerprints. If so, the use of fingerprinting as identification would cease to exist. We will look at the history of fingerprinting to develop a better understanding of where it came from. We were able to trace the origins of fingerprinting back to prehistoric Nova Scotia.

Fingerprints are used in a variety of ways, not just for identifying criminals. Fingerprints help identify deceased, namely soldiers killed in action. They also help prevent fraud and are used in hospitals to make sure mother and child do not get separated. Fingerprinting surpasses almost all other human identification systems, even DNA. Through many technological advances, fingerprinting has become an accepted form of identification not only the United States, but by the world.

2 Pre-History: The Bertillon System

Before fingerprinting, the Bertillon system was used. This system, developed by French anthropologist Alphonse Bertillon, measured certain bony parts on the body and recorded its dimensions. Some of these measurements involved the skull width, foot length, trunk, and left middle finger. He also took into account the person's eye color, hair color, and front and side view photographs. These measurements were then plugged into a formula that was supposed to be unique to the person and not change over time. He divided these measurements into groupings: small, medium, and large. He had 243 distinct categories that he placed an individual in. When he added eye and hair color to the measurement, he could separate into 1,701 groupings.

However, in 1903 it was discredited as an infallible system. Will West was sentenced to serve time in the US Penitentiary in Leavenworth, Kansas. When he arrived, there was already a prisoner booked with the name William West. These two men had almost identical measurements, and through an investigation were found to be unrelated. The men were only distinguished by their fingerprints.

As you can see, systems of the past have failed as a reliable source of identification. Even though out system has its flaws, it is still the best form of identification to date. It is much easier to obtain and compare fingerprints than measurements or DNA. Its mainstream acceptance and reputation has places it in a league of its own.

3 History of Fingerprinting

The history of fingerprinting dates back to prehistoric Nova Scotia, where a writing displayed a picture of a hand with ridge patterns was discovered. They next appeared in ancient Babylon where they appeared on clay tablets used for business transactions. In ancient China, thumbprints where discovered on clay seals. In 14th century Persia, fingerprint impressions were found on many official government papers. A government official had noted that no two prints were exactly alike, but took this thought no further and did not investigate their potential identification purposes.

From here, we see many individual findings that led to a better understanding of fingerprints and their use. In 1686, Marcello Malpighi, a professor of anatomy at the University of Bologna, wrote a treatise, or written discourse, that outlined three distinct patterns in a fingerprint: ridges, spirals, and loops. He did not see this as a way of identification, but merely noted their existence. He is mainly known for his contributions to the microscope, insects, and skin. He used the new technology of the microscope to observe plants and animals. Harvey's theory of circulation was completed by Malpighi with his observation of the movement of blood through capillaries. His studies of glands, the brain, spleen, liver, kidneys, the anatomy of the silkworm, the embryology of a chick, and of plant tissues facilitated in the widespread use of the microscope as a useful tool.

Many parts of the body bare his name, but one in particular is the Malpighi layer, which is 1.88 centimeters thick and is the deepest layer of the epidermis.

In 1823, John Evangelist Purkinji, an anatomy professor at the University of Breslau published his thesis. In it he identified nine different print patterns. He also made no mention of using this information as a way of identification.

In 1856, Sir William Hershel, the chief magistrate of the Hooghly district in Jungipoor, India, used fingerprints in an astonishing way. He had the natives place their palm print on the back of the contracts he had drawn up with them. This action of personal contact with the document played on the native's superstitious beliefs by frightening them out of renouncing the contract. At first, he had no mention of using the fingerprints as identification, but merely as a scare tactic. However, as his collection grew, he started to notice something. Through looking at his stacks and stacks of fingerprinted contracts, he found that the inked impressions could prove or disprove identity. He also hypothesized the prints to be unique to the individual and in fact permanent throughout the individual's life.

In 1880, a British surgeon-superintendent in Tokyo, Japan named Dr. Henry Faulds took up the study of skin furrows, or deep wrinkles in the skin. He noticed these marks on prehistoric pottery and began his research from there. He was one of the first to notice the identification power of fingerprints and actually developed his own classification system. He wrote his findings in an article titled *Nautre*, and handed the article to Sir Charles Darwin for scrutiny. Darwin, being in his later years, was too sick to critique the article and passed it to his cousin, Francis Galton. In this article, Faulds discussed fingerprints as an identification system and the use of printer's ink to obtain the prints. He was also credited with the first latent, or unseen, fingerprint identification of a greasy print left on an alcohol bottle.

To prevent forgery, Gilbert Thompson placed his own fingerprints on documents. This geological surveyor brought the identification factor of fingerprints to the United States in 1882. From there, we saw fingerprints start to become a widely accepted method of identification in the United States. Samuel L. Clemens, or better known as Mark Twain, used fingerprints in his two books titled *Life on the Mississippi* and *Pudd'n Head Wilson.* In *Life on the Mississippi*, fingerprints identified a murderer in a heated court case. In *Pudd'n Head Wilson*, there was a dramatic court trial involving fingerprints. These two books showed that fingerprinting was becoming mainstream and highly accepted by society as a reliable source for identification.

Sir Francis Galton, Sir Darwin's cousin, was a British anthropologist that began looking at the identification factors on fingerprints after reading Dr. Henry Faulds' article in 1892. He also published an article titled *Fingerprints* in which he outlined his own classification system and identified characteristics by which fingerprints can be compared by. These characteristics were named minutiae, or Galton's Details, and are line-like structures on the skin of the palm side of the finger past the distal, or last, joint, and are still used today. His main area of study was to determine racial background and heredity through fingerprints. Sadly, his inclinations on this subject matter did not materialize, but he did scientifically prove both Hershel and Faulds correct. He proved that fingerprints do not change over time and that no two people have the same fingerprints, getting a figure of a one in sixty-four billion chance of this phenomenon happening.

A follower of Galton's work, Juan Vucetich, an Argentine Police Official, began the first fingerprint files based on the patterns and classification system Galton had laid out. In the beginning, he had also kept Bertillon measurements with the fingerprint files, but later discarded them after the system was found to be flawed. In 1892, Vucetich made the first criminal fingerprint identification of a bloody print at a crime scene. He identified Francesca Rojas as the murderer in a double homicide. Rojas had killed her two sons and cut her own throat in an attempt to direct suspicion away from herself.

Dr. Henry DeForrest pioneered fingerprinting in the United States in 1902. He brought fingerprinting into the criminal justice system and pushed for its placement as an identification tool. In 1902 the first systematic use of fingerprints in the United States was implemented for testing by the New York Civil Service Commission. In 1903, the New York State Prison System began the first organized use of fingerprints for criminals in the United States. In 1914, Edmond Locard established the first rules of the minimum number of minutiae necessary for a positive identification. This student of Bertillon said that it would take a minimum of twelve matched points to conclude that two prints were the same. This is the rule of thumb we live by today. From here, fingerprints became the accepted means of identification all over the country and eventually made their way into every crevice of the criminal justice system.

4 Comparison

The comparing of fingerprints is an art form that is perfected through time and patience. To become an expert fingerprint technician, one has to go through extensive training to be certified, and maintain training throughout their career. Technology is evolving everyday that helps us compare fingerprints more efficiently and with the smallest percent of error as possible.

One first starts the comparison by looking at the core of the prints being compared. The core can be one of three patterns: arch, loop, or whorl. An arch pattern starts on one side of the print, moves laterally into a point, and falls back to the opposite side of the print, mimicking a parabola shape. An arch can either be plain (see Figure 1) or tented (see Figure 2). A tented arch is different than a plain arch in that it possesses either an angle, up thrust, or two of the three basic characteristics of a loop.

The loop pattern has more ridges that enter on one side, recurve, touch, or pass an imaginary line between the delta (to be described later) and the core and pass out on the same side they entered. A loop can be broken up into two sub-patterns: the ulnar or radial loops (see Figure 3). This distinction is made by looking at the side the loop enters and exits the print. This side will either be on the radial or ulna side of the hand. You must know the orientation of the print to make this distinction.

The last of the three patterns is the whorl. There are four different sub-patterns: plain, accidental, double loop whorl, and central pocket loop whorl. A plain whorl looks like a bulls-eye(see Figure 4). It starts at the relative middle of the print and makes concentric circles, curving around itself all through the print. All whorl patterns generally contain two deltas. The accidental whorl contains two different types of patterns, excluding the plain arch (see Figure 6). The double loop whorl pattern contains two separate loop formations with two distinct sets of deltas. The central pocket loop whorl contains at least one recurving ridge (see Figure 5).

Figure 1: Plain Arch

Figure 2: Tented Arch

Figure 3: Radial or Ulnar Loop

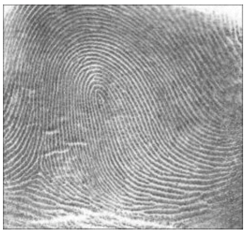


Figure 4: Plain Whorl

Figure 5: Central Pocket Whorl

Figure 6: Accidental Whorl

Once you have matched the core of the two prints, one must then compare minutiae points in the prints. There are many different minutiae points that one can compare: delta, ending, island, bifurcation, enclosure, dot, bridge, double bifurcation, trifurcation, spur, and crossover. These are not all the accepted minutiae characteristics that one can compare, but these are the most commonly used.

A delta is a collection of ridges that form a triangular shape. Delta is generally used to describe a triangular shape, and mimics the triangular alluvial deposit at the mouth of a river.

An ending ridge ends abruptly and never picks up again.

An island ridge has a starting and stopping point, almost like an ending ridge that starts again.

A bifurcation occurs where a single ridge divides into two ridges and never comes back together again.

An enclosure is where a single ridge splits into two ridges and comes back together again.

A dot is a short ridge that does not continue in any direction. This simply looks like a dot in the fingerprint and resembles a pore.

A bridge is where two ridges are connected by another ridge.

A double bifurcation is where a single ridge divides into two ridges and then divides once again. A trifurcation is where a double bifurcation divides once again.

A spur is a short ridge extending off a longer ridge. This bears a resemblance to the natural spur defined as a lateral ridge projecting from a mountain or mountain range.

A crossover is where two ridges cross each other.

Using these minutiae characteristics, one picks a point to start with on the known print and finds the same point on the unknown print. From there, one finds another point on the known print and counts ridge lines back to the original point. They then look at the unknown print and count from the original points the same number of ridges in the same direction to try to find the same point. One goes through this process over and over again until they have made enough point comparisons to say that the two points are the same. From Locard, we have accepted the minimum number of points to be twelve, but the Federal Bureau of Investigations (F.B.I.) uses ten points to make a positive identification.

5 Flaws

Despite our best efforts and many technological advances, fingerprint comparisons can still be flawed and errors can be made. Many factors can contribute to these mistakes. If a print is distorted when lifted, it is hard to accurately match some points that may be missing or stretched. If only a small segment of the print is found and is missing the core, then the orientation of the print cannot be determined. Also, the first step of identifying the core of the print cannot be completed. There is no place to start the comparison, thus a comparison is hard to make.

According to the Daubert versus Merrill Dow Pharmaceutical Supreme Court ruling, to be admissible in court as scientific, the evidence must possess five characteristics. The theory or technique has been or can be tested. The theory or technique has been subjected to peer review or publication. There must be existence and maintenance of standards controlling use of the technique. There must be a general acceptance of the technique in the scientific community. Lastly, a known potential rate of error must be established. The fifth characteristic has been used many times in court cases to make fingerprints inadmissible in court, because there is no potential rate of error known as of yet. Scientists are still working on developing the rate of error for fingerprinting.

5.1 Mistaken Identity Cases

Mistaken identity cases are numerable in the justice system. Brandon Mayfield, an Oregon lawyer, was arrested by the F.B.I for participating in the Madrid bombings. The Spanish National police compared the prints again and found the F.B.I. had made a false match.

Shirley McKie was a policewoman in the United States. Her fingerprint was found at Marion Ross's home in Scotland where she was found murdered. United States experts compared the prints and testified on her behalf. She was later compensated for the mistake.

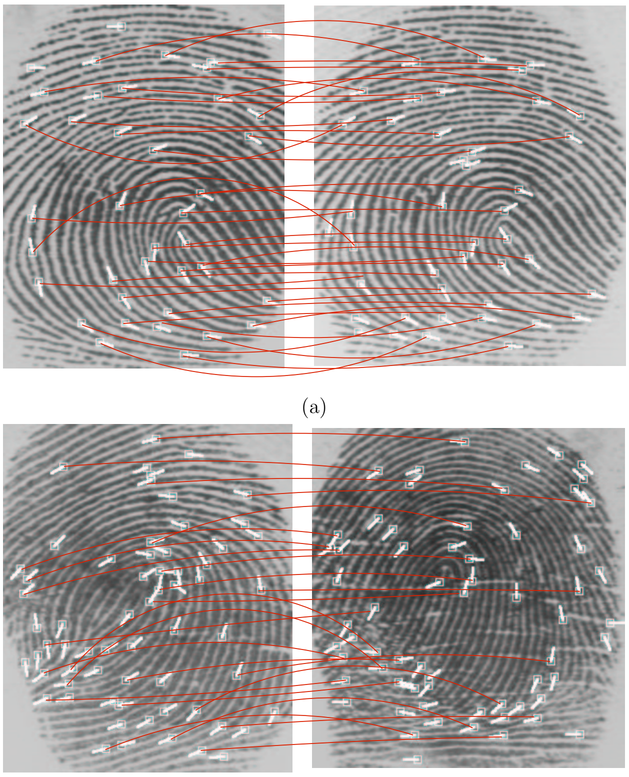
Stephan Cowens was convicted of attempted murder of a police officer in Massachusetts. He was sentenced to thirty-five years in prison on witness testimony and fingerprint evidence. While in jail, he earned money cleaning biohazards to have DNA tests run. He was later acquitted after serving six years in prison.

Rene Ramon Sanchez was arrested and fingerprinted for a minor offense. He was later arrested again for a minor crime, but his prints had been mislabeled and came back as a drug dealer. He was almost deported for the mix-up.

A big scandal with the New York State Police Troop C happened in 1993. Craig Harvey was charged with fabricating evidence when it was discovered that he had been lifting fingerprints from the examination room of the precinct and saying they were found at the crime scene. The news came out through a Central Intelligence Agency (C.I.A.) interview. David Harding, a colleague of Harvey's, was asked if he would be willing to break the law for the good of his country. He replied yes and explained how he had worked to convict guilty people by fabricating evidence. He thought this would please the C.I.A.

5.2 Federal Bureau of Investigations

The Federal Bureau of Investigations' Automated Fingerprint Identification System, or A.F.I.S, has been used for many years. In this system, an individual can copy a print into the database and run the program to compare the print to prints taken off of anyone that has gone through booking. This system had its flaws. A computer is not as smart as the human brain. It takes points and compares there relative position to one another. The human eye can look at a fingerprint and tell that even though a couple points might match up, it is clearly not the same print. There have been many instances where A.F.I.S. hits come back as a positive match and through investigation turned out to be incorrect.



(a)

(b)

Figure 3: Automatic minutiae matching. (a) Two impressions of the same finger are matched; 39 minutiae were detected in input (left), 42 in template (right), and 36 "true" correspondences were found. (b) Two different fingers are matched; 64 minutiae were detected in input (left), 65 in template (right), and 25 "false" correspondences were found.

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In the figure above, one can see a typical "hit" or positive match that had come back from A.F.I.S. The top two prints were found to be a positive match, both my A.F.I.S. and by expert fingerprint examiners. the bottom two prints were a positive match for A.F.I.S., but were determined to be two different fingerprints by a fingerprint examiner. As you can see, A.F.I.S. is flawed and does make false positive identifications.

6 Mathematical Findings

Sir Francis Galton was the first to attack the problem of individuality and whether or not fingerprints are unique to the person. He devised a grid that fit over a fingerprint being compared that consisted of twenty-four squares. From this grid, he created a fingerprint configuration.

$$\frac{1}{16} \cdot \frac{1}{256} \cdot \left(\frac{1}{2}\right)^{24}$$

This made the probability of two people having the same fingerprints:

$$1.45 \cdot 10^{-11}$$

He estimated that any of the regions in the grid could be correctly reconstructed with a probability of $\frac{1}{2}$. Based on surrounding ridges, Galton added an exponent of twenty-four, giving us $\left(\frac{1}{2}\right)^{24}$. The number $\frac{1}{16}$ is the probability of occurrence of a specific fingerprint type, meaning an arch, loop, or whorl. The number $\frac{1}{256}$ is the probability of the correct number of ridges entering or exiting each of the twenty-four regions in the grid. The problem with this configuration is that it underestimates the individuality of a fingerprint and overestimates the probability of occurrence of minutiae in a grid. The grid system only looks at where a point enters and exits the square and pays no special attention to what is going on inside of the square.

Many later works were derived from Galton's initial fingerprint configuration. Pearson expanded on the grid theory and said there should be thirty-six squares in the grid. This then led to another configuration.

$$\frac{1}{16} \cdot \frac{1}{256} \cdot \left(\frac{1}{36}\right)^{24} = 1.09 \cdot 10^{-41}$$

Then, the N-minutiae fingerprint configuration was discovered, it being:

$$= p^N$$

For N, we used twelve, because that is the accepted value of minimum number of points required, set forth by Locard for positive identification. Many different values of p have been discovered in various studies conducted by different scientists and mathematicians. Starting with Henry, we see he chose $p = \frac{1}{4}$. He chose this value for p and added two to the number of minutiae, which is the value for N, if the fingerprint type and core-to-delta ridge count could be determined from the known print. His probability came out to be

$$p(\frac{1}{4}) = 5.9 \cdot 10^{-8}$$

Balthazard also set his p value at $p = \frac{1}{4}$ under the assumption that there are four types of equally likely minutiae events that could take place. The events he speaks of are a bifurcation to the right, bifurcation to the left, ending ridge to the right, and ending ridge to the left. We then move to Bose, who again used the same value for p, but under different circumstances. He believed there were four possibilities in each square region in the grid pattern of one-ridge interval width in a print. These four possibilities are a dot, bifurcation, ending ridge, and a continuous ridge, which is just a ridge that does not end.

We then see a shift in the value of p. Wentworth and Wilder hypothesized the value of $p = \frac{1}{50}$, making the probability

$$p(\frac{1}{50}) = 4.096 \cdot 10^{-21}$$

Cummins and Midlo also found the same value, but coupled it with a multiplicative constant of $\frac{1}{31}$. They said this constant accounted for the variation in fingerprint pattern type, such as arch, loop, or whorl.

Gupta estimated the values of p to be quite different. He found that $p = \frac{1}{10}$ for bifurcations and ending ridges. He then found $p = \frac{1}{100}$ for the less commononly occurring minutiae types, such as an enclosure or spur. He based his research on a thousand fingerprints that he tested. He also used a fingerprint-type-factor of $p = \frac{1}{10}$ and correspondence-in-ridge-count-factor of $p = \frac{1}{10}$. This made his probabilities:

$$p(\frac{1}{10}) = 1 \cdot 10^{-24}$$

$$p(\frac{1}{100}) = 1 \cdot 10^{-12}$$

7 Conclusion

As you can see, the question of whether or not two people could have the same fingerprint still remains unanswered. Many different scientists over many years have tried to answer this question, and all come up with a different answer. Further research on this topic will include modeling different statistical situations that may arise from this question. We want to try to investigate the carrying probabilities of error related to the number of points of comparison used. We would look at the percent error or probability of error of a match that used Locard's twelve point comparison compared with a fifteen point comparison, or even a twenty point comparison. Also, we would like to find more of the background of Galton and how he came up with the numbers he used in his fingerprint configuration.

The question of whether or not fingerprints are your own has not been solved yet, but hopefully sometime in the near future we can put our minds at ease and know that our fingerprints are uniquely our own.

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