Assignment of the evidential value of a fingermark general pattern using a Bayesian Network

Rudolf Haraksim, Didier Meuwly, Gina Doekhie, Peter Vergeer and Marjan Sjerps

WISK
Netherlands Forensic Institute
Laan van Ypenburg 6
2497 GB, The Hague
r.haraksim@nfi.minvenj.nl

Abstract: When visible on a fingermark, the general pattern maintains its importance in the fingerprint examination procedure, since the difference between the general pattern of a fingermark and a fingerprint is sufficient for exclusion. In the current work, the importance of the general pattern is extended by evaluating the strength of evidence of a match given corresponding general pattern. In current practice (due to the lack of statistical support for the general pattern evidence) the fingerprint examiners assign personal probabilities to the general pattern evidence based on their knowledge and experience, while in this work the probabilities are calculated using a Bayesian Network which is fed by empirical data.

1. Introduction

In this article, we aim to assign a value to the correspondence of the general patterns (GP) in terms of descriptive and inferential statistics. We have developed two Bayesian Networks (BN) – one at the level of finger and one at the level of person – to assist the fingerprint examiners in statistical quantification of probabilities they assign to the general pattern evidence. The main motivation for using BNs is their ability to model the dependencies between different types of evidence in a logically correct framework.

When a fingerprint examiner compares a fingermark retrieved from a crime-scene to a reference fingerprint of a suspected person, (s)he exploits all the available information to assign its evidential value: properties of the ridge flow (level 1), of the minutiae (level 2) and of the ridges themselves (level 3). Recently tools producing Likelihood Ratios (LR) have been developed, allowing the fingerprint examiners to quantify the evidential value of spatial configurations of minutiae [Ne11, ECM07, AJR13, NCJ12, FSS07]. According to [Ne11], the evidential value assigned to the spatial configuration of the minutiae present in a fingermark can be expressed using a likelihood ratio (LR) and a set of propositions at the level of the finger[1]:

Hp: the fingermark was left by a specific finger
Hd: the fingermark was left by an unknown finger

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[1] The factfinders phrase their questions at the level of the person, which is then investigated at the level of the finger.

or at the level of the person:

Hp: the fingermark was made by the person who made the set of fingerprints
Hd: the fingermark was made by some unknown person

In absence of realistic data, the numerator of the LR has been reduced by a factor of 10 in [Ne11] when the propositions are considered at the level of the person, to account for the uncertainty in relation to which of the ten fingers of a donor the fingermark originates. The aim of this article is to complement these approaches, using real forensic fingermark and fingerprint data as well as a BN to account for the probability from which of the 10 fingers of a donor the fingermarks retrieved from crime-scene originated and to quantify the evidential value of the shape of the ridge flow classified as a GP.

In the following sections of this article we will provide firstly an insight in the datasets used for constructing the networks, and secondly present each of the BNs proposed paired with a case example. Finally we will assign the evidential value in form of likelihood ratios. Such likelihood ratios can be combined with the evidential value assigned to the other corresponding features of the fingermark and fingerprint, for example the minutiae configuration.

2. Data used and descriptive statistics

2.1 Data labeling

By convention, the fingers are numbered from 1 to 10, starting from the right thumb (labeled finger 1) and ending to the left little finger (labeled finger 10). Numerous systems exist to assign GP to the shape of the ridge flow. In this work, the data are labeled according to the GP classification codes of the ANSI/NIST-ITL 1-2000 format [NIST11]: plain arch, tented arch, left loop, right loop and whorl. A 6th class labeled "unknown" merges the ANSI-NIST codes "unable to print" and "unable to classify".

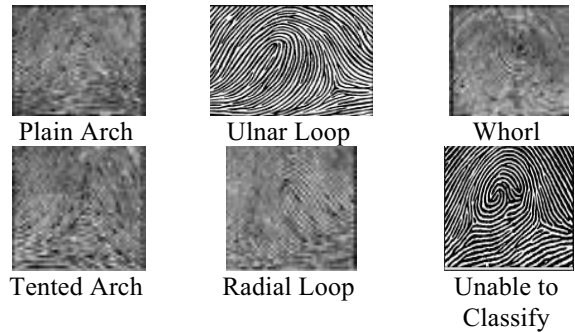| Plain Arch | Ulnar Loop | Whorl |
| Tented Arch | Radial Loop | Unable to Classify |

Figure 1 – General pattern classification

In 1975, A. J. Brooks conducted a study on the fingermarks identified in Chicago during the period from 1969 to 1973, to determine from which of the 10 fingers of a donor the

fingermarks retrieved from crime-scenes originated [Br75]. Since this time, too little attention has been paid to the study of datasets of identified fingermarks [RJM12]. More attention has been dedicated recently to the study of the distribution of the GP on the 10 fingers [Sw05, NBMM09, GARG08]. These studies use various GP classification codes and only the results presented in [GARG08] classify the shape of the ridge flows, with codes similar enough to the ANSI-NIST codes to be compared to the results of the present study.

Due to their age, rarity, diversity, or origin, we have replicated these studies independently in 2012 in our country using the most recent operational data, to ensure the applicability of the results in this country and at the present time.

2.2   Identified fingermarks – finger number

A total of 11555 identified fingermarks[2] from the years 2010 (4032 identifications) and 2011 (7523 identifications) was used to determine from which of the 10 fingers of a donor the fingermarks retrieved from crime-scenes originate. These data reflect the operational activity as processed by the national police force in the field of fingermark examination in these two years. For each identified fingermark, the finger number, the GP and the gender of the donor of the (corresponding) reference fingerprint general were provided. The results summarizing the distribution of fingers identified in the police investigations are presented in the Table 1.

Table 1 – Proportions of identified fingermarks (Brooks vs. Police identified fingermarks)

Finger Number	Brooks Identified Fingermarks	Police Identified Fingermarks
1	15.06	15.59
2	11.69	16.97
3	13.57	10.64
4	10	6.9
5	2.22	2.1
6	14.05	15.26
7	10.17	9.62
8	13.2	11.67
9	7.81	8.07
10	2.22	3.18

The proportions of identified fingermarks will be integrated into the "FingerNumber" node of both BNs (described in the following section). The results have also been compared to the results of the Brooks study.

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[2] We are aware that no ground truth exists for a decision regarding identification of a crime-scene fingermark and a corresponding reference fingerprint of a suspect. Due to the fact that 12-minutiae numerical standard is addopted in many countries (including ours) we consider the identifications carried out by fingerprint examiners based on this standard as an acceptable ground truth by proxy.

Despite the 35 years separating the two studies, the diversity of the populations studied and the fact that the quantity of data of the present study supersedes almost 4 times the dataset of Brooks, we observe similar results. The descriptive statistics presented indicate that differences smaller than 2% are observed between the two datasets. Our interpretation is that inferences made using these results are valid on the long term and are not sensitive to the diversity of the populations. We also observe fact that both hands are similarly represented in the criminal activity (47% left hand vs. 53% right hand), despite the fact that the majority of the human population is right-handed.
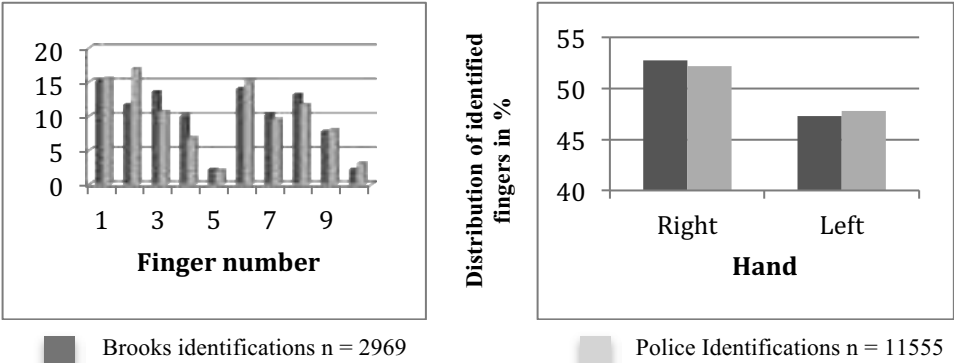

Brooks identifications n = 2969   Police Identifications n = 11555

Figure 2 – Results of the comparison of the results of the present study with the results of the Brooks study [Br75]

2.3   Reference fingerprints – General pattern

The dataset consists of inked, digitized and encoded 10-print cards of the police fingerprint database. The GP of these prints has been assigned manually by fingerprint examiners. For each print, additional information regarding the finger number and the gender of the donor is available. 10-print cards from 312.484 individuals have been randomly selected from the original dataset to study the distribution of the GP over the 10 fingers. 72.5% of the data originates from male donors and 26.8% from female donors. For 0.7% of the data the gender was unknown.

Table 2 – GP distribution (%) on different fingers of the right hand (females and males)

Finger No.	1		2		3		4		5	
GP \ Gender	M	F	M	F	M	F	M	F	M	F
Plain arch	2.2	4.1	5.3	7.8	3.7	5	1	1.7	0.6	1.3
Tented arch	1.1	1.5	11.8	10.3	7.3	6.6	3	3.1	3	3.6
Right Loop	47.3	54.9	29.6	36.6	65.6	72.5	43.9	53.1	77.6	83.1
Left Loop	0.4	0.4	16.4	12	1.4	0.8	1	0.9	0.2	0.2
Whorl	48.7	39	36.3	32.9	21.5	14.9	50.8	41.1	18	11.4
Unknown	0.3	0.2	0.7	0.4	0.5	0.3	0.4	0.3	0.5	0.4

The information related to the GP, to the finger number, and to the gender have been exploited in combination in order to study the distribution of the GP on the 10 fingers. The results for the female and male donors are presented in the Tables 2 and 3. They will be integrated into the node variable "GeneralPattern" of the two BNs described in the next section.

Table 3 – GP distribution (%) on different fingers of the left hand (females and males)

Finger No.	6		7		8		9		10	
GP \ Gender	M	F	M	F	M	F	M	F	M	F
Plain arch	3.9	6.5	5.3	8.1	4.6	7.4	1.3	2.3	0.8	1.9
Tented arch	1.7	2	12	11.5	7.7	8.3	3.1	3.7	3.1	4.1
Right Loop	0.5	0.9	14.3	15.8	1.1	1.5	0.4	0.8	0.1	0.2
Left Loop	55.3	55	34.1	32.9	64.8	64.2	55.2	57.5	82	84.3
Whorl	38.3	35.4	33.8	31.3	21.4	18.3	39.6	35.4	13.5	11.2
Unknown	0.3	0.2	0.6	0.4	0.5	0.3	0.4	0.3	0.5	0.5

In the Figure 3 the results are compared to the results of the Gutierrez [GARG08] study. As the entries in the Tables 2 and 3 indicate minor differences of the order of 2% between the relative frequencies of GPs for females and males. The prints labeled as *Plain* and *Tented Arch* of our study have been merged into one class labeled *Arch* to fit the classification codes used in [GARG08].
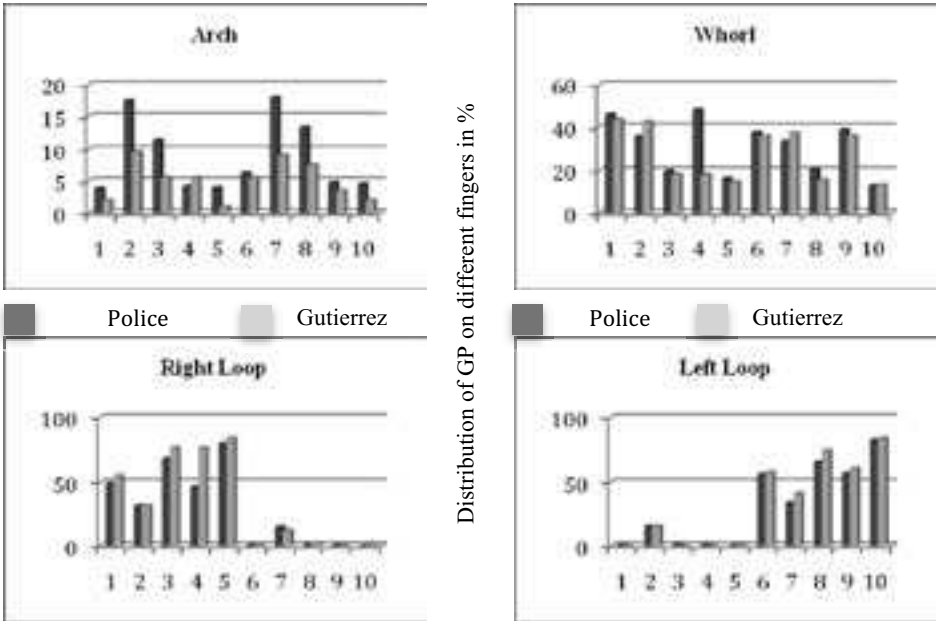

Figure 3 – Distribution of the GPs on the 10 fingers (*Police vs Gutierrez datasets*)

Despite the fact that 312.484 individuals were used in our study and only 200 individuals in the study of Gutierrez, we observe similar proportions of right and left loops distributed over different fingers. However, proportions of arches and whorls appears to be quite different for some fingers. Unfortunately, the difference in encoding standards used by Nithin [Sw05] and Swofford [NBMM09] prevent a direct comparison.

3. Inferential statistics using Bayesian Networks

From practice and experience the fingerprint examiners acquire an implicit knowledge of the distribution of the GP over the 10 fingers and of the relative contribution of the 10 fingers to the fingermarks retrieved from crime scenes. They make use of this knowledge when assigning evidential value to the correspondences and differences observed between a fingermark and a fingerprint.

Two BNs integrating the descriptive statistics described in Section 2 have been built to quantify the evidential value resulting from the combination of the GP and the relative contribution of the 10 fingers. The utility of these networks is to assist the fingerprint examiners to refine the numerator of the LR when they consider propositions at the finger and person level. In other words, the use of BNs allows the examiners to support their personal probabilities with statistical data. Concretely, we propose two BNs to assist the examiner, the first one for the finger level (3.1) and the second one for the person level (3.2). The BN models are „built for purpose" and their implicit validation and justification is subject to further research.

3.1 Finger level *(Distinctivness of the GP)*

At the finger level the BN informs about the rarity of a GP observed on each finger number of a random person (based on the population). The node "Finger Number" contains the distribution from which of the 10 fingers of a random donor the fingermark originated; the node "Hand" encapsulates the proportion of right / left handed in the identified fingermarks; the node general "General Pattern" contains the distribution of the GP over the 10 fingers and the node "Gender" contains the proportions of male / female / unknown donors of identified fingermarks. We express the dependency of the GP node on the finger number and the gender[3] by *P(GP|FN,G)*.

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[3] The gender dependency has been made explicit, despite the minor differences in the GP distribution between the male and female population (see Section 2.2 of this article)
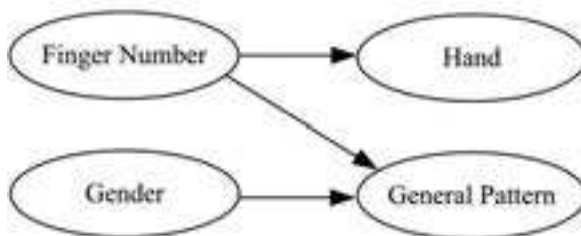
Figure 4 – the finger level BN

Case example

A fingermark containing a GP labeled as a whorl is recovered from the surface of a ceramic mug. The BN calculates the probability (posterior odds) for this whorl to have been left by each finger of a randomly selected donor. In this case the BN indicates that this mark has the highest probability to have been left by the finger number 1 and the lowest probability to have been left by the finger number 5. This result is useful for 2 purposes. Firstly, it allows for searching the database per finger number, starting from the most common finger. Secondly, the posterior odds indicate that the evidential value expected strongly depends on which finger of a donor it can be paired to.

The propositions to be tested are: the mark originates from donor's finger 1 vs. the mark originates from any other finger (2-10) of a the same donor. The posterior odds provided by the BN allow to calculate the posterior odds ratio P (F1|GP) / P (F$_{2\sim10}$|GP). The uninformed prior odds of 1/10 in absence of data are updated using the descriptive statistics of the Table 4. The evidential value for a whorl observed on a fingermark paired to the finger number 1 (vs. on any other finger) as calculated in the table 4 is 1.46. In other words, it is 1.46 times more likely to observe a whorl if it originates from the finger number 1 than if it originates from any other finger number of a donor randomly selected. The calculation for the highest and lowest evidential value has been added for illustration purposes.

Table 4 – LR values for the most rare, case example and most common GP

Evidence	Evidential Value	Prior Odds (in %)	Posterior Odds (in %)	LR
Whorl on Finger 1	Example given	15.59/84.51	21.26/78.74	1.46
Right loop on Finger 10	Highest	3.18/96.82	0.02/99.98	0.000609
Right loop on Finger 5	Lowest	2.10/97.90	6.22/93.78	3.09

$$\frac{P(F_1 \mid GP)}{P(F_{2-10} \mid GP)} = LR \times \frac{P(F_1)}{P(F_{2-10})}$$

$$\frac{21.26}{78.74} = LR \times \frac{15.89}{84.51}$$

Equation 1 – LR calculation from the prior and posterior odds

3.2 Person level

A few extra nodes need to be introduced in the previous BN to address the propositions at the person level. The node "Suspect Print GPs" contains the classification code of the 10 GPs for the donor of the 10-print card paired to the fingermark (GP code). The node "Source of the Mark" contains the pair of alternative propositions to be tested: the mark originates from the donor of the 10-print card vs. the mark originates from a donor randomly selected. For a practical reason the prior odds ratio for these 2 propositions is set to ½ (prior odds = 1). The choice for the prior of 1 is a conscious choice to force the posterior odds to be equal to LR. We do not mean to imply that equal prior odds are a good choice for any other purpose than extracting the LR from the BN.

The probabilities of the GP of the mark ("Mark General Pattern" node) diretly depend on the finger number, the gender and GP code of the donor of the 10-print card. In the case of correspondence between the GP code and finger number of the fingermark and fingerprint of the donor of the 10-print card, the numerator of the likelihood ratio is equal to 1; it is equal to 0 in the case of a difference. For the denominator of the LR, the probability of correspondence between the GP code and finger number of the fingermark and the fingerprint of another person is determined by the data of the Tables 1, 2 and 3.
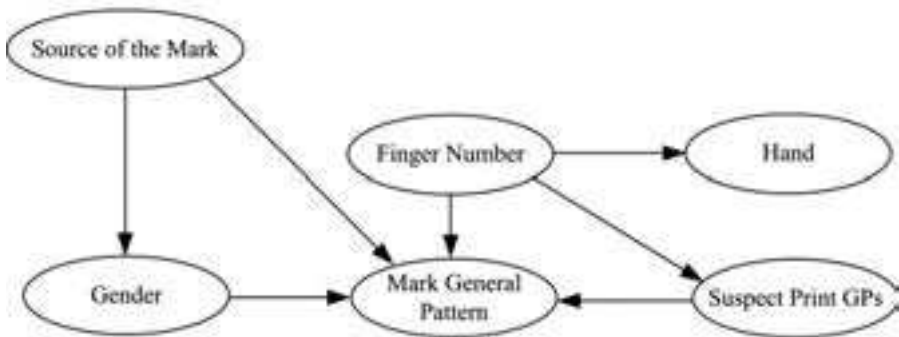

Figure 5 – *the person level BN*

Case example

At the person level we use the same fingermark as in the previous example: a whorl found on a ceramic mug on the crime-scene. Based on eyewitness testimony the police

arrest a person, from which a 10-print card is produced. The Table 5 summarizes the GP classification codes of this donor.

Table 5 – Description of the general pattern code the donor of the 10-print card
(A – Arch, W – Whorl, R – Right loop, L – Left loop)

Finger Numer	1	2	3	4	5	6	7	8	9	10
General Pattern	R	A	R	W	R	L	L	W	L	L

In the BN shown in Figure 5, the GP of the fingermark is given in the node "Mark General Pattern" and the GP code of the donor is given in the node "Suspect Print GPs". The probability that the fingermark originates from the donor of the GP code given the finger number and the correspondence of the GP divided by the probability that the fingermark originates from another person given the same evidence: $P(Hp|GP)$ / $P(Hd|GP)$ is calculated in the node "Source of the Mark". This posterior odds ratio is equivalent to the LR , since the prior odds for the 2 propositions have been set to 0.5 (odds 1/1).

The BN at the level of the person uses the general pattern code of the donor (distribution of the GPs over all 10 fingers) together with the whorl found on the crime-scene information to calculate the LR at the person level directly. This information is quantified for the two sets of propositions in the node "Source of the Mark": $P(Hp|GP) = 30.73$ and $P(Hd|GP) = 69.27$ (as shown in Figure 5). The value calculated as presented in Table 6 is 0.44 *(30.73/69.27)*. It means that it is slightly less probable to observe a whorl if it originates from the donor of the 10-print card than if originates from a donor randomly selected. For illustration purposes, the LR has also been calculated for the other available GPs: arch, right loop and left loop.

Table 6 – LR values for the most rare, case example and most common GP

Data from the BN	P(GP|Hp) in %	P(GP|Hd) in %	LR
Arch (given suspects GP)	80.73	19.27	4.19
Whorl given suspects GP (case example)	30.73	69.27	0.44
Right loop (given suspects GP)	51.43	48.57	1.06
Left Loop (given suspects GP)	57.64	42.36	1.36

Tables 2 and 3 show that the arch is the most rare classification code for a GP. Similarly, as in the previous example, we can attempt to evaluate the smallest and largest LR. Unlike in previous example however, we now operate at the level of the person, hence the LR depends not only on the GP found on the crime scene but also on distribution of the GPs in the population. It is directly dependent on the general pattern of the suspect as well. Given the general patterns of the suspect in this case the smallest LR corresponds to the whorl found on the crime-scene and the biggest LR corresponds to the arch. These

LR values remain modest, but the strategy consists in measuring and combining the evidential value of each characteristic available in the fingermark that can be paired with a reference fingerprint. Clearly, the LRs obtained for the first level information are calculated with the intention to combine them with the LRs calculated for the second level of information, based on the spatial arrangement of the minutiae.

4. Conclusions

When no prior information is available it is reasonable to assume the refinement of 1/10 when moving from the finger to person level as proposed by Neumann et al [Ne11].

The two BNs developed in this article combine the statistical information regarding the GP distribution over different fingers contained within the fingermarks (police identifications) and fingerprints (police database). The main motivation for using the BNs is their ability to model the dependencies between different types of evidence. They also provide a practical solution when quantifying the rarity of the GP found on the crime-scene fingermark and a finger of a random donor (level of the finger) or when quantifying the weight of the GP evidence found on the crime-scene fingermark and GP code of a donor (level of the person).

The choice between the two BNs proposed depends on the needs of the fingerprint examiner and/or operational conditions of the systems used to assign the evidential value of the second level details. Our aim in both cases was to quantify the evidential value contained in the first level detail fingermark/fingerprint comparison in meaningful LR values, which could be further combined with LR values obtained from the second level detail fingerprint evidence evaluation process or any other case related evidence.

5. Future work

Future work will include validation of the BN models developed in terms of enhanced application scenarios, sensitivity analysis and further improvement of the BN to support any finger combination. Also, further investigation is needed when utilizing the tools developed in combination with other fingerprint/case related evidence.

Acknowledgements

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