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Mathematics in Forensic Science

Dr. Manish Kumar Sareen

Associate Professor, Department of Mathematics, SNDB Govt. PG College, Nohar, Hanumangarh, India

ABSTRACT: Forensic Mathematics is the best short description that I have found to describe the work that I do, which mostly pertains to DNA identification, and includes consulting, writing software – DNA•VIEW is DNA identification software used by some 100 laboratories, in every continent (except Antarctica) – academic activities in mathematics, biostatistics, and various aspects of population genetics.
Charles H. Brenner, Ph.D.

KEYWORDS: forensic, mathematics, software, DNA, genetics, population

I. INTRODUCTION

Forensic scientists analyze the evidence found in and around the crime scene,in search of clues pointing to a possible suspect, cause of death or other key piece of information.

Math is used to determine how crimes are committed, when they were committed, and even who committed them.
Whether it is bullet holes or blood splatters, crime-scene investigators are able to use mathematics (geometry) to determine the trajectory of a falling object.

Forensic scientists are able to use math in other forms of trajectory as well. For example, if a victim suffered a blow to the head, scientists are able to determine the height of the suspect based on the angle of the impact.[1,2]

Investigators analyze blood spatter by using trigonometry – the branch of math that measures triangles.
From here, they can deduce more information such as how hard the attacker hit the victim.
When examining foot prints in dirt or mud, investigators are able to determine how much a suspect weighs by comparing the depth of the print to a list of constants.

The length between foot prints can also be used to determine the height of the suspect.
Using time and distance, crime-scene investigators are able to create a radius in which the suspect could have traveled to and from.

Psycho-physical detection of deception exam are based on the scientific theory that when someone is telling a lie, their body responds differently.

Mathematically, a forensic scientist can tell if suspect is lying by measuring their pulse rate, blood pressure and breathing patterns.

DNA analysis is based on locating similar patterns from a human sample and samples located at the crime scene.
This is a process by which more patterns create a more positive match in the investigation.

Probability is used to determine if there is enough of a DNA match to convict of the crime.
Forensic scientists use the length of human bones to estimate the height of individuals. A person's height, h, in centimeters, can be determined from the length of the femur f , in centimeters, using the following formulas:

Man: $h = 69.089 + 2.238f$

Woman: $h= 61.412 + 2.317f$
Using the equation $v=\sqrt{d/k}$, where d is the length of the skid marks, k is a constant based on the car and the friction of the road, and v is the velocity in miles per hour, scientists are able to determine how fast a car was going at the time of impact.

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Compare fingerprints found at a crime scene to those of a potential suspect or to those they have on file.
Measure distances between grooves and look for pattern between the fingerprints.
Part of crime-scene investigations involves determining when a death occurred.
This time frame can be constructed by using measurements such as the temperature of the victim and the surrounding area.
The longer a body remains in an area, the closer to the environment's temperature it becomes.

II. DISCUSSION

Forensic science math requirements will vary based on concentration, but all forensic science degree programs will include math classes. With the continued popularity of forensics-based television shows, students pursuing forensic science degrees have grown rapidly.

The Bureau of Labor Statistics also predicts that employment opportunities within the forensic science field will experience 11% growth by the end of 2031, which is over double the rate predicted for all occupations.[2,3]

This growth can't occur without people enrolling in universities to work towards earning a degree in forensics science.
Degrees like forensics science are considered hard sciences, meaning that they need a lot of hands-on math and science.
Even in non-math-centric courses, there will be calculations needed in some of the other courses in the curriculum.
Forensic science as a career requires math daily.

To prepare students for the day-to-day requirements of this job, colleges have several math requirements for forensic science.

Most bachelor's degree programs, regardless of subject, include courses that are considered part of a general curriculum, which almost always includes some math class like algebra.

However, for degree paths like forensics science, math requirements will be higher.
Daily work involves chemistry and even ballistics calculations, depending on the job that a person has.
Because of these job requirements, forensic science curriculums usually include algebra, physics, and even calculus.
These classes aren't the only courses that you'll need to do math work in, though.

Any degree with a science focus will involve math in both dedicated math classes as well as the more general science classes.
More science-focused classes like biochemistry, physics, and others will include math-based work.
Although some careers can be performed at high levels without math, forensic science is not one of them.
Hard sciences require math to be used daily for a variety of tasks.
For forensic scientists, everything from calculating toxicology reports to analyzing bullet entry points and directions will require algebra, geometry, and, in many cases, physics and calculus.
These skills are too essential to the required work of a forensic scientist to not include math in the curriculum.
Every forensic science degree will have some math requirement.
However, the requirements will be different based on the level of degree that you earn.
Forensics science degrees, like most subjects, come in four primary levels:

- Associate's degree (one to two years to complete)
- Bachelor's degree (four years to complete)
- Master's degree (one to three years on average)
- Ph.D. (seven years on average)[3,4]

Master's level degrees in forensic science provide other classes involving more specialized learning that could increase some employment opportunities.

However, master's degrees are less most employers only require a bachelor's degree.
Even if you're trying to earn an associate-level degree, you will still be required to take some math courses and at least some of the same science classes that are required for higher degrees.

The math requirements will expand as the degree level increases, especially with certain concentrations.

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III. RESULTS

Beyond degrees, some people earn certifications in forensic science.
These certifications are specialized and can help scientists advance their careers.
These certificates are usually completed in a much shorter time than a degree, as many can be completed in less than six months, depending on the topic.
These continuing education courses will have their math requirements, but they will often be an essential topic of the certificate program.

Forensic science is a changing field as new technologies are invented and implemented.
New training and certifications will be needed, meaning that math-based education for forensic scientists will continue even after a degree has been earned.
Forensic science is a vast field, meaning that there is high potential for specialization in both education and future job opportunities.
Earning a degree in forensic science usually involves selecting from a high number of concentrations, including:

- Ballistics
- Toxicology
- Crime scene investigation
- Chemistry
- Medical examination

Each of these concentrations will have differing math requirements, with some including more advanced math when it applies to the subject.[4,5]

For example, a degree with a concentration in ballistics will have added physics and calculus requirements compared to a degree with a concentration in chemistry.

This isn't to say that chemistry won't include math, it just won't require the same math.
If you're looking to join the rapidly growing field of forensic science, you'll need to earn your degree.
However, finding the best degree program for your career goals isn't always easy.
Make your search easier with the tools available through Learn.
Our database includes resources and thousands of articles about forensic science and any other degree that you can think of.

Forensic statistics is the application of probability models and statistical techniques to scientific evidence, such as DNA evidence,[1] and the law. In contrast to "everyday" statistics, to not engender bias or unduly draw conclusions, forensic statisticians report likelihoods as likelihood ratios (LR). This ratio of probabilities is then used by juries or judges to draw inferences or conclusions and decide legal matters.[1] Jurors and judges rely on the strength of a DNA match, given by statistics, to make conclusions and determine guilt or innocence in legal matters.[2]

In forensic science, the DNA evidence received for DNA profiling often contains a mixture of more than one person's DNA. DNA profiles are generated using a set procedure, however, the interpretation of a DNA profile becomes more complicated when the sample contains a mixture of DNA. Regardless of the number of contributors to the forensic sample, statistics and probabilities must be used to provide weight to the evidence and to describe what the results of the DNA evidence mean. In a single-source DNA profile, the statistic used is termed a random match probability (RMP). RMPs can also be used in certain situations to describe the results of the interpretation of a DNA mixture.[3] Other statistical tools to describe DNA mixture profiles include likelihood ratios (LR) and combined probability of inclusion (CPI), also known as random man not excluded (RMNE).[4]

Computer programs have been implemented with forensic DNA statistics for assessing the biological relationships between two or more people. Forensic science uses several approaches for DNA statistics with computer programs such as; match probability, exclusion probability, likelihood ratios, Bayesian approaches, and paternity and kinship testing.[5] Although the precise origin of this term remains unclear, it is apparent that the term was used in the 1980s and 1990s.[6] Among the first forensic statistics conferences were two held in 1991 and 1993.[7]

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Random match possibilities (RMP) are used to estimate and express the rarity of a DNA profile. RMP can be defined as the probability that someone else in the population, chosen at random, would have the same genotype as the genotype of the contributor of the forensic evidence. RMP is calculated using the genotype frequencies at all the loci, or how common or rare the alleles of a genotype are. The genotype frequencies are multiplied across all loci, using the product rule, to calculate the RMP. This statistic gives weight to the evidence either for or against a particular suspect being a contributor to the DNA mixture sample.[4]

RMP can only be used as a statistic to describe the DNA profile if it is from a single source or if the analyst is able to differentiate between the peaks on the electropherogram from the major and minor contributors of a mixture.[3] Since the interpretation of DNA mixtures with more than two contributors is very difficult for analysts to do without computer software, RMP becomes difficult to calculate with a mixture of more than two people.[4] If the major and minor contributor peaks can not be differentiated, there are other statistical methods that may be used.

If the DNA mixture contains a ratio of 4:1 of major to minor contributors, a modified random match probability (mRMP) may be able to be used as a statistical tool. For calculation of mRMP, the analyst must first deduce a major and minor contributor and their genotypes based on the peak heights given in the electropherogram. Computer software is often used in labs conducting DNA analysis in order to more accurately calculate the mRMP, since calculations for each of the most probable genotypes at each locus become tedious and inefficient for the analyst to do by hand.[2]
Sometimes it can be very difficult to determine the number of contributors in a DNA mixture. If the peaks are easily distinguished and the number of contributors is able to be determined, a likelihood ratio (LR) is used. LRs consider probabilities of events happening and rely on alternative pairs of hypotheses against which the evidence is assessed.[8] These alternative pairs of hypotheses in forensic cases are the prosecutor's hypothesis and the defense hypothesis. In forensic biology cases, the hypotheses often state that the DNA came from a particular person or the DNA came from an unknown person.[2] For example, the prosecution may hypothesize the DNA sample contains DNA from the victim and the suspect, while the defense may hypothesize that the sample contains DNA from the victim and an unknown person. The probabilities of the hypotheses are expressed as a ratio, with the prosecutor's hypothesis being in the numerator.[3] The ratio then expresses the likelihood of both of the events in relation to each other. For the hypotheses where the mixture contains the suspect, the probability is 1, because one can distinguish the peaks and easily tell if the suspect can be excluded as a contributor at each locus based on his/her genotype. The probability of 1 assumes the suspect can not be excluded as a contributor. To determine the probabilities of the unknowns, all genotype possibilities must be determined for that locus.[3]

Once the calculation of the likelihood ratio is made, the number calculated is turned into a statement to provide meaning to the statistic. For the previous example, if the LR calculated is x, then the LR means that the probability of the evidence is x times more likely if the sample contains the victim and the suspect than if it contains the victim and an unknown person.[8] Likelihood ratio can also be defined as 1/RMP.[3]

Combined probability of inclusion (CPI) is a common statistic used when the analyst can not differentiate between the peaks from a major and minor contributor to a sample and the number of contributors can not be determined.[3] CPI is also commonly known as random man not excluded (RMNE).[3] This statistical calculation is done by adding all the frequencies of observed alleles and then squaring the value, which yields the value for probability of inclusion (PI). These values are then multiplied across all loci, resulting in the value for CPI.[2] The value is squared so that all the possible combinations of genotypes are included in the calculation[5,6]

Once the calculation is done, a statement is made about the meaning of this calculation and what it means. For example, if the CPI calculated is 0.5, this means that the probability of someone chosen at random in the population not being excluded as a contributor to the DNA mixture is 0.5.

CPI relates to the evidence (the DNA mixture) and it is not dependent on the profile of any suspect. Therefore, CPI is a statistical tool that can be used to provide weight or strength to evidence when no other information about the crime is known.[3] This is advantageous in situations where the genotypes in the DNA mixture can not be distinguished from one another. However, this statistic is not very discriminating and is not as powerful of a tool as likelihood ratios and random match probabilities can be when some information about the DNA mixture, such as the number of contributors or the genotypes of each contributor, can be distinguished. Another limitation to CPI is that it is not usable as a tool for the interpretation of a DNA mixture.[4]

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Blood stains are an important part of forensic statistics, as the analysis of blood drop collisions may help to picture the event that had previously gone on. Commonly blood stains are an elliptical shape, because of this blood stains are usually easy to determine the blood droplets angle through the formula "$\alpha = \arcsin d/a$". In this formula 'a' and 'd' are simply estimations of the axis of the ellipse. From these calculations, a visualization of the event causing the stains is able to be drawn, and alongside further information such as the velocity of the entity that caused such stains.[9]

IV. CONCLUSION

One of the many benefits of learning digital forensics is that we walk through the door eager to learn how to solve crimes. We find much of the information investigated in forensics is always new information. To successfully produce evidence, one needs to have a strong background in mathematics, statistics, science, technology and writing. Digital forensics is a fascinating field requiring a multi-disciplinary approach. The science of digital forensics is rooted in computer science, and the computer science is rooted in mathematics, which is fast becoming one of the most important techniques in crime detection.

Mathematics helps us think analytically and have better reasoning abilities. Analytical thinking refers to the ability to think critically about the crime. Reasoning is our ability to think logically about a situation. Analytical and reasoning skills are important because they help us solve problems and look for solutions in the investigation. Mathematics not only helps in framing a problem, also helps in identifying the knowns and unknowns, and taking steps to solve the problem. It is essential for digital forensic researchers to have good understanding of the relevant mathematical concepts, directly and/or indirectly.

- What is a statistically significant number of appearances of a search string in your results?
- What is a Message Digest 5 (MD5) hash or Secure Hash Algorithm 1 (SHA1) and how are they calculated?
- What is the hex representation[6,7] of a string and what is its significant?
- What happens when you use OR in a search term rather than use AND? - search results of different search constructions
- Regular expressions are all about sets (unions/disjoints/intersections), functions and logical operators. How to effectively use it?
- Discrete mathematics is a logic math that helps to deduct certain outcomes or situations and how it all makes sense – learning about algorithms and Boolean algebra.
- Binary, octal and hexadecimal maths are invaluable.
- Knowledge of computational complexity is good, as it gives an idea of how long we have to wait.
- Pascal's Triangle is helpful as well.[7,8]
- Knowledge of cryptography, statistics, error-checking and correcting are important as well.
- Statistics can be a precious tool when identifying the patterns behind confusing or misleading phenomena.
- Hash algorithms are a mathematical formula that provide verification of evidence accuracy, ensuring two data sets are the exact same content. Technically, a hash function takes binary data, called the message, and produces a condensed representation, called the "message digest". The mathematical certitude is higher than DNA. MD5 and SHA-1 are two of the most widely used.[8,9]

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