Diatoms, Retinal Hemorrhages and Other Forensic Tests
A Logical Appraisal Using Probability Theory

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Abstract:

The author applies probability theory and logic to forensic testing in the form of a thought experiment (*Gedankenexperiment*). The approach is largely Bayesian. Topics covered include: certainty and uncertainty, the Inferential Test for Expert Testimony, testing for identity, testing for the determination of "what happened," inference to a single explanation, experience, bias, manner of death determinations, differential diagnosis, syndromes, the determination of what caused a natural death, the determinations of time of death and injury, the determination of what caused a sudden and unexpected infant death, and the interpretation of forensic toxicology tests. A rule or conclusion is stated following each analysis. This exercise demonstrates that the evaluation of forensic testing in a credible and logical way is feasible and that Bayesian probability can form a foundation for model protocols in the future.

Abstract

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The List of Rules:

1. ***Facts* (items that can be directly observed) are more likely to be true than *beliefs* or *theories* (items that are not directly observed that may or may not be true). The clear distinction between what is fact and what is belief or theory is essential for determining what is probable for truth. Deductive or logical inferences using beliefs rather than facts are not dependable, even if the inferences are valid.** From Chapter 2: Certainty, Uncertainty and the Courtroom**.**

2. **Although nothing can be declared absolutely certain, evidence provided by scientific experts in the courtroom can be highly probable for truth if 1) the observations personally made by the scientist are truthful, 2) the scientific principles that form the basis of the testimony are fact-based and highly probable, and 3) the scientist reasons validly from such observations and principles.** From Chapter 2: Certainty, Uncertainty and the Courtroom**.**

3. **One can be reasonably certain if witness accounts of the past are consistent or not consistent with physical evidence in the present, but one cannot reliably surmise past events from physical evidence unless there is only one plausible explanation for that evidence (the Inferential Test for Expert Testimony).** From Chapter 3: The Inferential Test for Expert Testimony**.**

4. **If other evidentiary elements are coherent, then positive results for highly individuating tests of identity mean high probability of identity and negative results for <u>any</u> test of identity – even poorly individuating tests – mean non-identity.** From Chapter 5: Forensic Tests and the Identification of Human Remains**.**

5. **The use of a forensic test for surmising complex past events (more than one past event) is so unreliable that such testing should be considered "junk science" no matter how well the test performs.** From Chapter 6: Forensic Tests and the Determination of What Happened.

6. **Forensic tests used to test witness accounts can be highly reliable for the exclusion or the non-exclusion of the truth of the accounts.** From Chapter 6: Forensic Tests and the Determination of What Happened**.**

7. **As the data points for witness accounts and physical evidence increase, the odds of learning the truth also increase, indicating how important a thorough witness and physical evidence investigation is.** From Chapter 6: Forensic Tests and the Determination of What Happened**.**

8. **A scientist may infer a single explanation for physical evidence but only with great caution because it takes only one *other* plausible explanation to falsify the inference.** From Chapter 6: Forensic Tests and the Determination of What Happened**.**

9. **The experience of a scientist who affirms the consequent for complex past events is not reliable.** From Chapter 7: Forensic Tests and Experience**.**

10. **Experience based on comparing witness accounts to physical evidence – even very little experience – is reliable, provided that the forensic testing is reliable.** From Chapter 7: Forensic Tests and Experience**.**

11. **Forensic tests or scientific observations that are inaccurate, invalid, incomplete or unreliable are of *no* value to a forensic analysis. Additional testing or observation could hopefully aid in the discovery of mistakes.** From Chapter 7: Forensic Tests and Experience**.**

12. **Confirmation bias decreases the probability of learning the truth by a potentially calculable factor. For laboratory tests, it would be better if the examiner were blinded to the hypothesis.** From Chapter 8: Forensic Tests and Bias**.**

13. **Scientists who interpret evidence of what happened need consciously to avoid confirmation bias by focusing on eyewitness accounts and not on the theories of others who were not eyewitnesses. Focusing on witness accounts with the intent to verify them mitigates the bias that comes through surmising past events from physical evidence.** From Chapter 8: Forensic Tests and Bias**.**

14. **One should assign manner of death if only one manner remains as plausible after a thorough investigation; otherwise, the manner should be undetermined.** From Chapter 9: Forensic Tests and the Manner of Death**.**

15. **Forensic analysis and clinical diagnosis are two different processes. A diagnosis involves a condition in a patient evaluated in the present, but a forensic analysis involves past events. A forensic analysis offers more opportunities for valid deductive inference than diagnosis. Diagnosis is a complex probabilistic approach involving choices between conditions that are more probable and less probable given the evidence.** From Chapter 10: Forensic Tests and Diagnosis**.**

16. **The terms, "syndrome" and "differential diagnosis" are characteristic of the diagnostic process and are inappropriate for a forensic analysis. The application of such terms in a forensic analysis typically leads to surmising past events from physical evidence.** From Chapter 10: Forensic Tests and Diagnosis**.**

17. **The determination of the cause of a natural death must take into consideration both past events and physical evidence. The determination relies more on estimates of probability than other manners of death, making the analysis for the cause of a natural death less than certain. This is because the internal conditions that cause a natural death are not subject to witness observation.** From Chapter 11: Forensic Tests and the Cause of a Natural Death**.**

18. **In a natural death, more life-threatening conditions take precedence for cause over less life-threatening conditions, and common conditions that are life threatening take precedence for cause over rare conditions that are almost equally life-threatening. Rare and less life-threatening conditions are not considered when more common and more life-threatening conditions are present.** From Chapter 11: Forensic Tests and the Cause of a Natural Death**.**

19. **If two common and almost equally life-threatening conditions are both present at autopsy, both conditions should be listed in the death certificate separated by a disjunct ("or").** From Chapter 11: Forensic Tests and the Cause of a Natural Death**.**

20. **The use of forensic tests for timing events yields unreliable results not suitable for reasonable certainty, but one can**

compare such tests to witness accounts in a way that allows for reasonable certainty. From Chapter 12: Forensic Tests and Timing.

21. **Sudden unexpected infant deaths currently categorized as SIDS (Sudden Infant Death Syndrome) are undetermined for cause. In such cases, overlaying should not be surmised without positive witness or physical evidence for overlaying. Deaths due to co-sleeping and unsafe sleep environments are demonstrably improbable.** From Chapter 13: Forensic Tests and Sudden, Unexpected Infant Death**.**

22. **A drug reliably may be determined to be present or absent in a dead body by a test, but a drug level cannot be relied upon solely for a cause of death determination. A cause of death from drug overdose is only reliable when there is no other plausible explanation for the death after a sufficiently thorough investigation.** From Chapter 14: Forensic Toxicology Tests**.**

Introduction:

Recently, the National Academy of Sciences of the United States consulted with forensic and other scientists to see how the forensic sciences could be improved in their mission. One of their published recommendations, entitled Recommendation 5, states:

> The National Institute of Forensic Science (NIFS) should encourage research programs on human observer bias and sources of human error in forensic examinations. Such programs might include studies to determine the effects of contextual bias in forensic practice (e.g., studies to determine whether and to what extent the results of forensic analyses are influenced by knowledge regarding the background of the suspect and the investigator's theory of the case). In addition, research on sources of human error should be closely linked with research conducted to quantify and characterize the amount of error. Based on the results of these studies, and in consultation with its advisory board, NIFS should develop standard operating procedures (that will lay the foundation for model protocols) to minimize, to the greatest extent reasonably possible, potential bias and sources of human error in forensic practice. These standard operating procedures should apply to all forensic analyses that may be used in litigation[1].

To "lay the foundation for model protocols," I believe it would be useful to examine carefully the practices and the tests performed by forensic scientists and physicians in light of established tenets of logic and probability theory. To this end, I performed a thought experiment (*Gedankenexperiment*) approaching forensic testing through the perspective of logic and probability theory, hoping that such an exercise might aid toward a foundation for model protocols.

Chapter 1: Methods and Tables

Logic and probability theory are topics that have been approached by many authors in many different ways, and expressions of the principles of logic and probability are not standard. Terminology and symbols vary widely from source to source, so I relied upon a textbook in logic published in the United States for a source of terminology and symbols[2]. The textbook was recently published, so an up-to-date use of symbols and terminology is assumed. The notations for logic and probability operations (Table 1) and the stated rules of probability (Table 2) are the same as used in the textbook. The *Gedankenexperiment* that follows employs the application of these principles to forensic science testing. I recommend reading quickly through Tables 1 and 2 prior to proceeding and referring to the tables frequently as you read this treatise.

Table 1: Definitions of logic and probability operations used in this article and an explanation of notation[2,3]

Operation	Notation	English translation
Statement variables	**p**	Statement **p** is true, or Condition **p** is present.
	q	Statement **q** is true, or Condition **q** is present. From now on, "true" and "present" are logically equivalent, and the word, "statement" or "condition" is implied when variables are used.
Disjunction	$p \vee q$	**p** or **q** is true.
Conjunction	$p \bullet q$	**p** and **q** are true.
Negation	$\sim p$	**p** is not true, or **p** is false, or **p** is absent, or the opposite or negation of **p**.

Conditional statement	$\mathbf{p} \rightarrow \mathbf{q}$	If **p** is true, then **q** is true, or **p** being true is sufficient for **q** being true.
	$\mathbf{q} / \mathbf{p}$	**q** is true if **p** is true, or **q** is true given **p** is true, or **q** is true provided that **p** is true, or **q** is true on condition that **p** is true.
Biconditional statement	$\mathbf{p} \leftrightarrow \mathbf{q}$	If **p** is true, then **q** is true; and if **q** is true, then **p** is true, or **p** is true if and only if **q** is true, or **p** being true is sufficient and necessary for **q** being true, or **p** is logically equivalent to **q.**
Number	$n(\mathbf{p})$	The number of times **p** is true, or if **p** is complex (composed of more than one item), the number of items in **p** that are true.
Probability	$P(\mathbf{p})$	The probability of **p** being true.
Calculation of probability	$P(\mathbf{p}) = \frac{n(\mathbf{p})}{n(\mathbf{p}) + n(\sim \mathbf{p})}$	The probability of **p** being true is equal to the number of times **p** is true divided by the sum of the number of times **p** is true and the number of times **p** is not true.
Likelihood	$L(\mathbf{p} / \mathbf{q})$	The likelihood of **p** being true if **q** is true.
Calculation of likelihood	$L(\mathbf{p} / \mathbf{q}) = P(\mathbf{q} / \mathbf{p})$	The likelihood of **p** being true if **q** is true equals the probability of **q** being true if **p** is true.
Odds	$O(\mathbf{p})$	The odds of **p** being true.
Calculation of odds	$O(\mathbf{p}) = \frac{n(\mathbf{p})}{n(\sim \mathbf{p})}$	The odds of **p** being true equals the number of times **p** is true divided by the number of times **p** is not true.

Table 2: Rules of probability[2]

1. If a statement **p** is a **tautology** or **certainly true**, then $P(\mathbf{p}) = 1$.

2. If a statement **p** is a **contradiction** or **certainly false**, then $P(\mathbf{p}) = 0$.

3. **Restricted Disjunction Rule:** If **p** and **q** are mutually exclusive, then $P(\mathbf{p} \vee \mathbf{q}) = P(\mathbf{p}) + P(\mathbf{q})$.

4. **Negation Rule:** $P(\sim \mathbf{p}) = 1 - P(\mathbf{p})$.

5. **General Disjunction Rule:** $P(\mathbf{p} \vee \mathbf{q}) = P(\mathbf{p}) + P(\mathbf{q}) - P(\mathbf{p} \bullet \mathbf{q})$.

6. **Conditional Rule:** $P(\mathbf{q} / \mathbf{p}) = \dfrac{P(\mathbf{p} \bullet \mathbf{q})}{P(\mathbf{p})}$.

7. **General Conjunction Rule:** $P(\mathbf{p} \bullet \mathbf{q}) = P(\mathbf{p})P(\mathbf{q} / \mathbf{p})$.

8. **Restricted Conjunction Rule:** If **p** and **q** are independent, then $P(\mathbf{p} \bullet \mathbf{q}) = P(\mathbf{p})P(\mathbf{q})$.

In probability theory, numbers between 0 and 1 represent a degree of probability or improbability. The higher the number between 0 and 1, the more probable the statement, and the lower the number between 0 and 1, the more improbable the statement. Numbers greater than 0.5 indicate "more probable than not," numbers close to 1 represent highly probable, and numbers close to 0 represent highly improbable. For example, the probability of obtaining heads after repeated flipping of a coin is:

$$P(heads) = \frac{n(heads)}{n(heads) + n(tails)} = 0.5$$

Refer to Table 1 above for the calculation of probability.

A value of 0.5 indicates that the probability of heads equals the probability of tails (also 0.5). An outcome of heads is not probable, nor is an outcome of tails.

When inserting values into Bayes' Theorem (to be explained subsequently), I use the numbers 0 and 1 only if they are given in an assumption or if they have been derived logically (i.e. deductively – also to be explained subsequently); otherwise, I use a number between 0 and 1 for each substitution into Bayes' Theorem.

With each analysis, I propose a general "rule" to summarize each concept. The 22 rules are scattered throughout the treatise and listed above in order of presentation.

Chapter 2: Certainty, Uncertainty and the Courtroom

I believe the following statement is true (although I am not absolutely certain of this):

> We cannot be absolutely certain that we should be certain of anything.

In spite of the profound doubt expressed in this statement, many of us – if not most of us – live our lives with some sense of order most of the time. We make decisions, even important and critical decisions, and many of those decisions seem to work out well for us. How can we do this if we accept that nothing is certain?

It is because many of us – if not most of us – have learned to manage our uncertainty. Something may not be certain in an absolute sense, but it may be probable, even highly probable – perhaps even highly, highly, highly probable. Using a simple standard, such as a set of colored balls in a container, a pair of dice, or a pack of playing cards, we can demonstrate that probabilities can be added together, multiplied together, and asserted as a fraction between zero and one[3]. Without realizing it, we often make calculations for items other than balls, dice and cards – calculations of what is likely to happen or not happen, what is likely true or not true. From these, we make assessments that guide critical decision-making, including decisions made in a court of law. If those assessments are true most of the time, then they work out most of the time, though not all the time.

Furthermore, we cannot claim as humans to have knowledge of "all things" because our ability to observe "all things" is limited, but we might claim with good reason to be certain of those items we have directly learned and observed. We cannot observe all past events, but we can remember the past events that involved us personally. We cannot observe the future but we can predict that certain future events are highly probable (such as the sun rising tomorrow morning). Even in the present, there is a universe of events happening all around us that we cannot observe, but if we had the ability and capacity to observe them, then we could claim great knowledge about many, many things. Our knowledge base is limited, but as our knowledge base expands, a sense of probability that approaches but never reaches absolute certainty increases.

It is also granted that the knowledge base of judges and juries is limited because they are human, yet they are called upon to make critical decisions beyond their knowledge base. To do this, they need the assistance of some who have knowledge in certain matters that exceeds their own. They need to rely on learned persons – experts – who hopefully reason logically.

Logic in the form of deductive inference has been discussed for millennia, yet admittedly, deductive inference is limited – just as all things human are limited. Deductive inference means that in regard to a set of statements composing an argument, if the premises of an argument are true, then the conclusion of an argument is *guaranteed* or *certain* to be true. The limitation of such inference has to do with the nature of certainty: we cannot be absolutely certain that the premises in an argument are true.

For the expert in science, the premises relied upon are the expert's observations and the controlled observations of other scientists. The expert cannot be absolutely certain that his or her observations are truthful or that the controlled observations of other scientists are truthful. If the premises are not true or at least not highly probable given available knowledge, then we experience "garbage in, garbage out" such as has been described for computers. This is a major weakness of deduction: flawed premises can contaminate a conclusion.

There are certain premises, however, that are more likely to be true than other premises. If a premise is based on a direct observation – referred to in this treatise as a *fact* – then the premise is likely to be true. Furthermore, facts not tainted by suppositions or *beliefs* (items that are not directly observed that may or may not be true) are the most reliable of premises. A *theory* is a set of beliefs – consisting of items that are not directly observed that may or may not be true.

This leads to the first rule:

- ***Facts* (items that can be directly observed) are more likely to be true than *beliefs* or *theories* (items that are not directly observed that may or may not be true). The clear distinction between what is fact and what is belief or theory is essential for determining what is probable for truth. Deductive or logical inferences using beliefs rather than facts are not dependable, even if the inferences are valid.**

Consider, for example, the *circular argument* – where the conclusion of an argument is simply an obvious restatement of one or more premises. A circular argument is a valid deductive argument but not a useful one. Consider the following circular argument:

> Premise 1: I believe this child has abusive head injury in the form of the Shaken Baby Syndrome (SBS—a controversial

theory that a person who shakes a child violently can cause brain damage).

Premise 2: If the child has abusive head injury in the form of SBS, then the child will have retinal hemorrhages, subdural hemorrhages, and brain swelling.

Conclusion: Therefore, the child is found to have retinal hemorrhages, subdural hemorrhages, and brain swelling (What do you know? The findings confirm my belief about abusive head injury in this case!).

This deductive argument in the form of *modus ponens* is a valid argument because of its form (valid argument forms will be discussed subsequently) but it is not a useful argument. Applying a theory like SBS as a premise will simply cause us to conclude the same in a circular fashion, and we will not learn if it is the truth in this particular case even though we may conclude deductively that it is.

Consider another deductive argument, this time in the famous valid argument form of *modus tollens*:

Premise 1: If the suspect did not commit child abuse, then the non-abusive event that he said happened would be consistent with what was found in the child.

Premise 2: What he said happened is not consistent with what was found in the child.

Conclusion: Therefore, the suspect committed child abuse.

The argument is valid but it is not sound ("sound" means truthful). Premise 1 in this argument, like Premise 1 in the previous argument, is a belief and not a fact. Numerous people every day make untruthful statements for a host of reasons but very few of them abuse children. This makes Premise 1 unsound and the conclusion unsound.

Deduction is misleading if we use beliefs rather than facts as premises. The facts we observe and accept can also be distorted by our beliefs. As demonstrated above, our beliefs can be reinforced in a circular fashion and are subject to bias.

Deduction, however, can be useful if the distinction between facts and beliefs is made clear in the mind of the examiner. Facts exist outside the mind of the examiner, unlike beliefs. Even though facts can be misstated or mischaracterized, they are not subject to manipulation by the examiner in a real sense. Facts are capable of being observed by persons other than the examiner. Even though much of science is a collection of beliefs subject to human error, scientific statements that are based on direct and repeated observations in carefully controlled settings made previous to the case in question can also be useful as premises in a deductive argument. An examination of the "Materials and Methods" section of a published, peer-reviewed scientific study allows an assessment of its reliability for truth. This section of a study will disclose the logic behind the study and whether or not the facts in the study are misstated or mischaracterized.

If the conclusion of a deductive argument is not an obvious restatement of a premise (a circular argument) and if the premises of the argument contain facts rather than beliefs, then deduction can help those with a limited base of knowledge – judges and jurors –

make truthful assessments – or at least increase the probability that they will make truthful assessments.

The scientist in the courtroom is the explainer of scientific evidence to the jury and judge. The hope for the court is that the scientist uses premises that are fact-based and not belief or theory-based, thereby removing as much as possible the taint of contaminated conclusions. If the direct observations of the scientist and the scientific principles are fact-based, then the court also hopes that the scientist will reason logically so that the probability of the judge or jury reaching the *correct* conclusion is increased. The term "logically" in this sense means *deductively valid*, which means the conclusion is certain to be true if the premises are true. If such reasoning is not deductively valid, the conclusion is probably incorrect, as will be demonstrated subsequently.

This brings us to the term, "reasonable medical or scientific certainty" as introduced by the courts[4]. The courts agree that no scientist can claim absolute certainty; if a scientist makes such a claim, then the court is likely to exclude the testimony. The courts however do allow a scientist to ***reason*** – on the basis of the facts provided in the case, his personal observations of the physical evidence and his knowledge of well-established fact-based or "evidence-based" principles of medicine and science – to a conclusion that he ***can*** claim as ***certain*** according to his knowledge. Such a claim would be acceptable logically if the inferences from evidence and science are valid.

Therefore:

- **Although nothing can be declared absolutely certain, evidence provided by scientific experts in the courtroom can be highly**

probable for truth if 1) the observations personally made by the scientist are truthful, 2) the scientific principles that form the basis of the testimony are fact-based and highly probable, and 3) the scientist reasons validly from such observations and principles.

Chapter 3: The Inferential Test for Expert Testimony

How can we know when an expert reasons validly from scientific principles and from his observations? The way to know is to apply the **Inferential Test for Expert Testimony** (IT), to wit:

> One can be reasonably certain if witness accounts of the past are consistent or not consistent with physical evidence in the present, but one cannot reliably surmise past events from physical evidence unless there is only one plausible explanation for that evidence[5].

The test is a theorem – a tautology, a certain truth – in the same fashion as Bayes' Theorem is for probability and the Pythagorean Theorem is for right triangles. It has been proven through deductive inference just as all theorems are proven[6]. Although the theorem itself is as certain as anything can be certain, it makes provision for uncertainty, just like Bayes' Theorem. A careful analysis of the IT reveals four provisions for uncertainty:

1. ***…can be reasonably certain if…***: The claim is not that one "should" be reasonably certain, "has to be" reasonably certain, or "will be" reasonably certain. It means that it is possible and valid to be reasonably certain provided that one applies the appropriate conditions followed by "if."

2. ***…are consistent or not consistent with…***: The claim is not that "the witness accounts of the past" are certainly truthful. Using the term, consistent, only indicates that the witness accounts are sufficient for the physical evidence.

3. ***…cannot reliably surmise…***: Although the verb, "cannot surmise," implies "impossible," the adverb, "reliably," indicates the opposite. It means that the probability of determining the past events from physical evidence in most cases is so low that it is not reliable for truth. The word, "surmise," is another term for "speculate" or "guess" – an activity that the courts are supposed to forbid an expert witness to engage in during testimony.

4. ***…only one plausible explanation…***: The adjective, "plausible," is another way of stating "seemingly probable." The one exception to the statement about the improbability of determining past events from physical evidence is found here, yet the application of the adjective is in itself an expression of uncertainty.

Inference in the courtroom by a medical or scientific expert generally follows two famous valid argument forms and one famous invalid argument form. An argument form is the "scaffold" upon which an argument is constructed. A careful examination of the form of an argument indicates that the argument is deductively valid – therefore probable for truth – or deductively invalid – therefore improbable for truth. The soundness of the IT can be understood by explaining the two famous valid argument forms, the one famous invalid argument form, and one of the exceptions to the invalid form that makes it valid. The two famous valid argument forms are *modus ponens* (MP) and *modus tollens* (MT). The famous invalid argument form is *affirming the consequent* (AC). One of the exceptions that makes AC valid is the *if and only if* exception.

MP is composed of two premises and a conclusion:

$\mathbf{p}$

$\mathbf{p \rightarrow q}$

$\therefore \mathbf{q}$

The statement, **p** → **q** is translated into English as "if statement **p** is true, then statement **q** is true." This is a *conditional statement* composed of two atomic statements. In a conditional statement, the component to the left of the arrow (**p**) is the *antecedent* and the component to the right of the arrow (**q**) is the *consequent*. The conditional statement is applied typically in expert testimony as a "rule" – even a rule of science or mathematics.

One simple way to illustrate MP is with numbers. Consider the following equation; what number fills the blank?

$1 + 1 = \_\_$

The argument with MP would be

- **p:** One is added to one.
- **p** → **q:** If one is added to one, then the sum is two (a simple "rule" of arithmetic).
- **∴ q:** Therefore, the sum is two.

If the first premise is true (and it is true) and the second premise is true (and it is true), then one can be certain that the conclusion is true. An expression of certainty for the conclusion is a valid and logical expression.

MT also consists of two premises and a conclusion:

$$\mathbf{p} \rightarrow \mathbf{q}$$
$$\sim \mathbf{q}$$
$$\therefore \sim \mathbf{p}$$

The following is an example of MT using numbers:

$$1 + 2 = 3$$

- **p → q:** If one is added to one, then the sum is 2 (a simple "rule" of arithmetic).
- **~q:** The sum is three (not two).
- **∴ ~p:** Therefore, one is not added to one.

If the first premise is true (and it is true) and the second premise is true (and it is true), then one can be certain that the conclusion is true. An expression of certainty for the conclusion is a valid and logical expression.

The invalid form AC also consists of two premises and a conclusion:

$$\mathbf{q}$$
$$\mathbf{p} \rightarrow \mathbf{q}$$
$$\therefore \mathbf{p}$$

Consider the following equation; what numbers fill the blanks?

$$\_\_ + \_\_ = 2$$

The argument using AC would be:

- $\mathbf{q}$: The sum is two.
- $\mathbf{p} \rightarrow \mathbf{q}$: If one is added to one, then the sum is two (simple arithmetic is used as a rule).
- $\therefore \mathbf{p}$: Therefore, one is added to one.

If the first premise is true (and it is true) and the second premise is true (and it is true), the conclusion that "one is added to one" is not reliably true. Consider all the pairs of numbers that could be added together to come up with a sum of two: 0.5 and 1.5, 0.9 and 1.1, 101 and –99, 1.99999 and 0.00001, to name a few. The possible combinations of two numbers that add up to two are endless. Consequently, an expression of certainty for the conclusion that "one is added to one" is not a valid and logical expression.

Note that the solution to the example above is *complex*. That means that the solution for **p** has more than one component and more than one plausible explanation. If there were only one solution or explanation for **p**, it would no longer be complex, such as in the example below:

$$1 + \_\_ = 2$$

- $\mathbf{q}$: The sum is two.
- $\mathbf{p} \leftrightarrow \mathbf{q}$: If the blank in "one plus blank" is one, then the sum is two; and if the sum is two, then the blank in "one plus blank" is one.

  <u>Or</u>

  The blank in "one plus blank" is one *if and only if* the sum is two.

- **∴ p** : Therefore, the blank in "one plus blank" is one.

Premise number two is not a conditional statement but a *biconditional* (*if and only if*) statement. It is valid to use the consequent to learn the antecedent if the relationship between antecedent and consequent is biconditional. A relationship between the antecedent and a given consequent is biconditional if and only if there is only one plausible explanation or solution for the antecedent (i.e. not complex).

I have often used the following example in public, using numbers to illustrate problems with complex antecedents. I ask the audience to fill in the final blank:

2, 4, 6, 8, 10, 12, ___

Invariably, the audience calls out "14." Without realizing it, they use the following deduction in the form of MP:

- **p:** The first six numbers are "2, 4, 6, 8, 10, 12"
- **p → q:** If the first six numbers are "2, 4, 6, 8, 10, 12," then the final number is 14 (ascending even numbers is perceived as a "rule" by the audience without so stating).
- **∴ q:** Therefore, the final number is 14.

Then I ask them to fill in the first six blanks when the final number is 13:

__, __, __, __, __, __, 13

When I have asked an audience to do this, I characteristically receive numerous blank stares. This is because any answer they might provide would be highly improbable. A few might provide me with ascending odd numbers, thinking as follows in the form of AC:

- **q:** The final number is 13.
- **p → q:** If the first six numbers are "1, 3, 5, 7, 9, 11," then the final number is 13 (ascending odd numbers is perceived as a pattern and used as a rule).
- **∴ p:** Therefore, the first six numbers are 1, 3, 5, 7, 9, 11.

Those few members of the audience may "surmise" the rule above, thinking that this rule is the most probable rule; however, this is a guess of low probability because the pattern formed by the antecedent is not known. The first six numbers may be ascending prime numbers, or ascending whole numbers, or descending odd numbers, or… The possibilities are endless, so selecting one possibility out of a set of endless possibilities makes the selection of the correct answer highly improbable as well as deductively invalid.

Not only do these thought experiments apply to numbers but they also apply to past events and physical evidence from past events. Past events are often complex, even highly complex (numerous components and possibilities), so determining multiple antecedent past events from consequent physical evidence is logically invalid. Scientists should never surmise past events from physical evidence, but unfortunately, many did and still do -- thanks to Charles Darwin, Arthur Conan Doyle ("Sherlock Holmes"), Bernard Spilsbury, C. Henry Kempe ("Battered Child Syndrome") and many others.

But if one knows the antecedent even if the antecedent is complex, then one can test the antecedent by the consequent because the appropriate rule is perceived from knowing the antecedent. This allows one to be "reasonably certain if witness accounts of the past (the preceding events or antecedent) are consistent (MP) or not consistent (MT) with physical evidence in the present (the subsequent evidence or consequent)." The witness accounts form the basis of the hypothesis or conditional statement to be applied. Witness accounts are alleged facts developed previous to the involvement of the scientist – facts that can be tested with another set of facts that also developed previous to the involvement of the scientist: the physical evidence. Witness accounts provide the pattern that allows a comparison of them with the physical evidence for consistency or inconsistency.

On the other hand, surmising complex past events from physical evidence is unreliable for certainty or probability because more than one plausible explanation – more than one rule or possible combination of events – can be applied when trying to determine past events. I demonstrate the great improbability of this approach for determining past events in Chapter 6.

Therefore:

- **One can be reasonably certain if witness accounts of the past are consistent or not consistent with physical evidence in the present, but one cannot reliably surmise past events from physical evidence unless there is only one plausible explanation for that evidence (the Inferential Test for Expert Testimony).**

Chapter 4: Forensic Tests and Probability Theory

What follows now is the application of probability theory to forensic testing. Forensic tests are procedures – often performed in a clinical setting, in a laboratory, or in a morgue – that are used to learn answers to the two critical questions posited by a court proceeding: "What happened?" and "Who is responsible for what happened?"

Deductive inference is useful for answering these questions but it is limited. Certainly, MT is capable of falsifying any hypothesis for "What happened?" and "Who is responsible for what happened?" with forensic scientific evidence, demonstrating that a hypothesis is certainly false given our knowledge. The hypothesis – symbolized by variable *h* – represents an answer or answers to the two critical questions or other questions in a forensic case. The problem with or limitation of deduction is that while MP applied to a forensic case can guarantee that the hypothesis may be true given our knowledge, it cannot guarantee that the hypothesis is the *truth*. Here is why:

That past events leave physical evidence is true. If variable, *e*, represents the physical evidence that results from hypothesis, *h*, then $h \rightarrow e$; nevertheless, perusal of the truth table for the conditional statement (see Table 3 below) indicates that the hypothesis may be true or false, even though the scientific principle of past events leading to physical evidence ($h \rightarrow e$) is true and the observation of forensic scientific evidence (*e*) is true (see lines 1 and 3 in Table 3 below).

Table 3: Truth Table for the Conditional Statement[2]

h	e	$h \rightarrow e$
T	T	T
T	F	F
F	T	T
F	F	T

In other words, both $\sim h$ and h may be true, and both $\sim h$ and $\sim h \rightarrow e$ may be the truth instead of h and $h \rightarrow e$.

For example, using MP may not be helpful when one is trying to identify human remains. Consider the following argument – two premises and the conclusion – in the form of MP (Note: the premises are in a different order than previous examples of MP, but premises may be listed in any order, as long as the conclusion is at the end):

- If the identity of this burned body is Mary Jones, then the body will have a uterus at autopsy ($h \rightarrow e$).
- The burned body is that of Mary Jones (h).
- Therefore, the burned body has a uterus (e).

But the following is also true:

- If the identify of this burned body is another woman, then the body will have a uterus at autopsy ($\sim h \rightarrow e$).
- The burned body is that of another woman (~*h*).
- Therefore, the burned body has a uterus (*e*).

If the premises of the first argument are true (and they can be determined to be true through an investigation), then the conclusion is true but the conclusion is not helpful for identifying Mary Jones. Mary Jones has a uterus, but so do many, many other women. We need to find out if indeed the burned body is that of Mary Jones. In order to do that, we have to affirm the consequent (AC). In other words, we need to reason from $e \rightarrow h$ (a simplified form of AC) in an identity question, using probability theory to see if the probability of *h* given *e* is sufficiently high for some form of reliability. We do this through forensic tests. In this treatise, the result of forensic tests is represented by the variable, *e*, which also represents physical evidence.

AC is not valid for certainty unless there is only one plausible explanation. A famous exception for AC is the *if and only if exception*, represented symbolically as $e \leftrightarrow h$. AC may be probable, even highly probable, depending on the nature of the forensic test – so highly probable, in fact, that it may represent the only plausible explanation. Establishing the identity of a human through his or her remains is an example of one situation that demonstrates the *if and only if* exception to AC.

Probability theory allows us to assess the probability of the results of forensic tests. The rules of probability – most of them derived deductively from standard observations of balls in a container, rolls of dice, and playing cards – are in Table 2, and the meaning of several logical operators used in this treatise are in Table 1 (please refer once again to Chapter 1). We will make ample use of both tables in the remainder of this treatise.

Although most of the rules of probability are derived deductively from standard observations, the standard observations themselves – such as observing that coin tosses have a probability of 0.5 for being heads – are *inductive*. Induction means that if the premises are true, then the conclusion is *probably* true: observations of multiple coin tosses will demonstrate that heads will *probably* come up half of the time. The probability can also be calculated using Bayes' Theorem. This will be demonstrated subsequently.

One final note for this chapter. Some states in the United States do not expect or require an expert to offer opinions to a "reasonable degree of medical certainty" but insist instead on a "reasonable degree of medical probability" or "more probable than not." As will be demonstrated subsequently, such distinctions are not important. This is because items that are deductively invalid score very, very low for probability and items that are deductively valid score very, very high for probability, so distinctions between certainty and probability in this context are not critical. The inductive approach using Bayesian calculations is simply another way to demonstrate the soundness of what I have been writing all along about this topic in previous treatises.

Chapter 5: Forensic Tests and the Identification of Human Remains

Regarding the identification of human remains, AC is required but identification is not complex. Assuming that MT does not falsify the hypothesis (h_i means "hypothesis for the identity of the human remains"):

$$[(e_1 \bullet e_2 \bullet e_3 \bullet \ldots \bullet e_n) \rightarrow h_i] \vee [(e_1 \bullet e_2 \bullet e_3 \bullet \ldots \bullet e_n) \rightarrow \sim h_i]$$

Varying forms of *e* such as multiple friction ridge patterns (fingerprints) or multiple sequences of deoxyribonucleic acid (DNA) are complex data points (the conjunct "and" is represented by a "dot") that can be used to learn the identify the decedent. The hypothesis for identity, from the example in Chapter 4, will either be Mary Jones (h_i) *or* (the disjunct "or" is represented by the "vee" in the logical operator notation above) not Mary Jones ($\sim h_i$). There are no other alternatives other than these two because $h_i \vee \sim h_i$ (it is Mary Jones or it is not Mary Jones) is a **tautology** or a certain truth according to the **Law of the Excluded Middle:**

$$P(\mathbf{p} \vee \sim \mathbf{p}) = P(\mathbf{p}) + P(\sim \mathbf{p}) = 1$$

Since we are affirming the consequent, the statement about complex physical evidence may be restated in probability notation. Since each data point in identification is considered *independent* of another, we can simply multiply probabilities, according to the **Restricted Conjunction Rule** applied to more than two items:

$$P(e) = P(e_1 \bullet e_2 \bullet e_3 \bullet \ldots \bullet e_n) = P(e_1)P(e_2)P(e_3)\ldots P(e_n)$$

For any forensic scientific observation, we will assume that an evidence of identification – a data point – is truly present or not present. If *any* of the data points are *not present*, then the entire *P(e)* will equal zero.

$$(0)(1)(1)\ldots(1) = 0$$

If *all* data points are *present*, then *P(e)* will equal 1.

$$(1)(1)(1)\ldots(1) = 1$$

For a test of identification, a higher number for $n(e)$ (see Table 1), means greater power for *individuating*. Individuating means selecting an individual from a population of individuals. High numbers of data points from variable regions of the human genome or high numbers of data points from variable friction ridge patterns allow the tests for DNA and fingerprints to be highly individuating. On the other hand, the "uterus" test for identity — a single data point only – is poorly individuating because most women have a uterus.

Below is the **Conditional Rule** applied to $e \rightarrow h_i$ or h_i / e (both are conditional statements that mean the same thing).

$$P(h_i / e) = \frac{P(e \bullet h_i)}{P(e)}$$

The term, h_i / e, means "hypothesis of identity given the evidence" or "h_i, if e."

Using the **General Conjunction Rule** and making the appropriate substitution, we now have **Bayes' Theorem** applied to identification:

$$P(h_i / e) = \frac{P(e / h_i)P(h_i)}{P(e)}$$

Referring to the autopsy of the burned body discussed in the last chapter – the example of the female suspected to be Mary Jones – let us assume that the frequency of a tested DNA pattern of Mary Jones in a population is one in 1,000,000. Let us further assume that a DNA test of the tissue from the autopsy discloses a result consistent with Mary Jones.

In order to calculate the probability that the remains are those of Mary Jones given the evidence or $P(h_i / e)$, using the data above, we need to start with the "odds" form of Bayes' Theorem[3]. To convert it into this form, we need to start with the form of Bayes' Theorem listed above:

$$P(h_i / e) = \frac{P(e / h_i)P(h_i)}{P(e)}$$

The same calculation can be made for its complement, that this is not Mary Jones given the evidence or $\sim h_i / e$:

$$P(\sim h_i / e) = \frac{P(e / \sim h_i)P(\sim h_i)}{P(e)}$$

If we were then to divide $P(h_i / e)$ by $P(\sim h_i / e)$, we would cancel out $P(e)$ -- of course assuming $P(e)$ to be a truthful, non-zero number:

$$\frac{P(h_i / e)}{P(\sim h_i / e)} = \frac{P(e / h_i)P(h_i)}{P(e/ \sim h_i)P(\sim h_i)}$$

Furthermore, the fractions below can be converted to “odds” (refer to Table 1):

$$\frac{P(h_i / e)}{P(\sim h_i / e)} = \frac{\dfrac{n(h_i / e)}{n(h_i / e) + n(\sim h_i / e)}}{\dfrac{n(\sim h_i / e)}{n(h_i / e) + n(\sim h_i / e)}} = \frac{n(h_i / e)}{n(\sim h_i / e)} = O(h_i / e)$$

$$\frac{P(h_i)}{P(\sim h_i)} = \frac{\dfrac{n(h_i)}{n(h_i) + n(\sim h_i)}}{\dfrac{n(\sim h_i)}{n(h_i) + n(\sim h_i)}} = \frac{n(h_i)}{n(\sim h_i)} = O(h_i)$$

Allowing further appropriate substitutions:

$$O(h_i / e) = \frac{P(e / h_i)}{P(e/ \sim h_i)} O(h_i)$$

The idea behind all these substitutions is to eliminate all forms of $P(e)$, including the forms given each hypothesis. We do this by converting probabilities into likelihoods (see “Calculation of likelihood” in Table 1):

$$O(h_i / e) = \frac{L(h_i / e)}{L(\sim h_i / e)} O(h_i)$$

Although “probability” and “likelihood” appear to be the same in the English language, they are not the same in Probability Theory. $L(\sim h_i / e)$ in this case is equivalent to the estimated frequency (f) of the DNA result in a population – in other words, the theoretical number of people in a population who are not Mary Jones but have Mary Jones’ result[3]. This is a very, very small number – much less than 1 – because numerous “rocks would have to be turned over” to find another person with a result like Mary Jones – about one million rocks according to our assumption above. Of course, the number of people added together who are Mary Jones and have that result is 1 (There is only one Mary Jones with that DNA result). Consider how the odds for the hypothesis increase astronomically given the DNA evidence (odds can be much, much greater than 1, unlike probability):

$$O(h_i / e) = \frac{1}{f} \bullet O(h_i)$$

$$O(h_i / e) = \frac{1}{0.000001} \bullet O(h_i)$$

$$O(h_i / e) = 1{,}000{,}000 \bullet O(h_i)$$

DNA testing that discloses the same DNA result as Mary Jones increases the odds that the identity is that of Mary Jones by a factor of one million. If the prior odds for identity – before the test is performed – are one to one, the testing results would change the odds to one million to one. This makes the hypothesis given the evidence as close to a "sure bet" as anything possibly can be.

Now let us use a form of Bayes' Theorem that compares competing hypotheses. Let us start with the **Conditional Rule:**

$$P(h_i / e) = \frac{P(e \bullet h_i)}{P(e)}$$

$P(e)$ represents the probability of the test result being true prior to performing the test – a "prior" probability. This would mean that the hypothesis for identity would be h_i or $\sim h_i$. Using the Law of the Excluded Middle:

$$P(h_i / e) = \frac{P(e \bullet h_i)}{P[e \bullet (h_i \vee \sim h_i)]}$$

Using the Distributive Property:

$$P(h_i / e) = \frac{P(e \bullet h_i)}{P[(e \bullet h_i) \vee (e \bullet \sim h_i)]}$$

And the **Restricted Disjunction Rule** (h_i and $\sim h_i$ are mutually exclusive):

$$P(h_i / e) = \frac{P(e \bullet h_i)}{P(e \bullet h_i) + P(e \bullet \sim h_i)}$$

And finally the **General Conjunction Rule:**

$$P(h_i / e) = \frac{P(e / h_i)P(h_i)}{P(e / h_i)P(h_i) + P(e/ \sim h_i)P(\sim h_i)}$$

If $L(\sim h_i / e) = 0.000001$, then $P(e/ \sim h_i) = 0.000001$, and if $L(h_i / e) = 1$, then $P(e / h_i) = 1$ (refer to Table 1). $P(e/ \sim h_i)$ in this setting means the probability of obtaining a DNA result identical to Mary Jones if the remains are not those of Mary Jones. Also, for the sake of discussion, we could consider the prior probability of h_i or $\sim h_i$ to be 0.5 ("even odds," "one to one" or "fifty-fifty" – the same as obtaining a result of heads when tossing a coin). Using the appropriate substitutions:

$$P(h_i / e) = \frac{(1)(0.5)}{(1)(0.5) + (0.000001)(0.5)} = 0.999999$$

The probability of a DNA result indicating identity (as long as other factors do not exclude that identity) is nearly one. A positive DNA result in such a case represents the *only plausible explanation* for the identity (the biconditional exception in the second half of the IT):

Positive DNA results for Mary Jones ↔ Mary Jones

If DNA testing discloses a different DNA result than that of Mary Jones, then Mary Jones is excluded. $O(h_i / e)$ and $P(h_i / e)$ equal zero, as would be expected with MT:

- If the identify of this burned body is Mary Jones, then the body will have Mary Jones' DNA result ($h_i \rightarrow e$).
- The burned body does not have Mary Jones' DNA result *(~e*).

- Therefore, the identity of this burned body is *not* Mary Jones ($\sim h_i$).

If the pathologist finds a uterus at autopsy, what is the probability that the identity is Mary Jones? Using an approximation since males to females are roughly one to one in a population and all women do not have a uterus at the time of their death:

$$P(h_i / e) = \frac{(0.5)(0.5)}{(0.5)(0.5) + (0.5)(0.5)} = 0.5$$

The gender test is poorly individuating and does not give a probable result; however, if the pathologist discovers male genitalia at autopsy, then $P(h_i / e) = 0$. This is because $L(h_i / e)$ and $P(e / h_i)$ now equal zero (a contradiction) and $L(\sim h_i / e)$ and $P(\sim e / h_i)$ now equal 1 (a tautology). Consequently:

$$P(h_i / e) = \frac{(0)(0.5)}{(0)(0.5) + (1)(0.5)} = 0$$

Finding male genitalia instead of a uterus falsifies the hypothesis of Mary Jones with MT, even though the gender test itself is poorly individuating.

- If the identity of this burned body is Mary Jones, then the body will have a uterus at autopsy ($h_i \to e$).
- The burned body has male genitalia and not a uterus *(~e)*.
- Therefore, the identity of this burned body is *not* Mary Jones ($\sim h_i$).

Therefore:

- **If other evidentiary elements are coherent, then positive results for highly individuating tests of identity mean high probability of identity and negative results for *any* test of identity – even poorly individuating tests – mean non-identity.**

Chapter 6: Forensic Tests and the Determination of What Happened

The portion of the Inferential Test that states, "…but one cannot reliably surmise past events from physical evidence…" represents the fallacy of *affirming the consequent for complex past events* (ACCPE). ACCPE is not only deductively invalid but it also scores very, very low for probability.

Let h be the hypothesis for "what happened" and let e be the physical evidence resulting from what happened.

A hypothesis for past events consists of multiple events, and physical evidence from past events consists of multiple items. Both are complex (more than one item):

$$(h_1 \bullet h_2 \bullet h_3 \bullet \ldots \bullet h_{n(h)}) \rightarrow (e_1 \bullet e_2 \bullet e_3 \bullet \ldots \bullet e_{n(e)})$$

When a prosecutor, "crime scene reconstructionist" or errant forensic pathologist tries to surmise past events from physical evidence, he or she points to an item of physical evidence (such as e_1) and links it to a particular past event (such as h_1). After considering the items of physical evidence together, he or she comes up with an overall hypothesis for what happened:

$$[(e_1 \rightarrow h_1) \bullet (e_2 \rightarrow h_2) \bullet (e_3 \rightarrow h_3) \bullet \ldots \bullet (e_{n(e)} \rightarrow h_{n(h)})] \leftrightarrow [(e \rightarrow h)]$$

Expressing the above numerically with probability notation:

$$P[(h_1 / e_1) \bullet (h_2 / e_2) \bullet (h_3 / e_3) \bullet \ldots \bullet (h_{n(h)} / e_{n(e)})] = P(h / e)$$

Unlike data points of evidence, past events are not independent of each other. The second event will not occur until the first event occurs, and the third event will not occur until the first and second events occur, and so on. If one event does not occur, the next will not occur, thereby falsifying the entire statement. Using the **General Conjunction Rule** for more than two items:

$$P(h_1 / e_1)P(h_2 / h_1 e_2)P(h_3 / h_1 h_2 e_3)...P(h_n / h_1 h_2 h_3 .. h_{(n-1)(h)} e_{n(e)}) = P(h / e)$$

This is a highly complex situation. To clarify, $P(h_3 / h_1 h_2 e_3)$ for example means "The probability that h_3 is true if h_1 is true and h_2 is true and e_3 is true." It would seem even now that the probability of trying to surmise accurately such a complex chain of events from physical evidence would be low, but this becomes even more apparent when we assign numbers.

Since each past event given previous events and physical evidence has not been demonstrated to be certainly true nor can be assumed to be certainly true, then the probability for each portion of the hypothesis has to be less than 1. Each event may be probable – even highly probable – but not certain. Consider if the probability of hypothetical events given the evidence and previous events averages 0.7 and there are 10 hypothetical events.

$$P(h / e) = 0.7^{10} = 0.03$$

Because each item is multiplied, the probability of the hypothesis greatly decreases with a higher number of *n* events. Even if the probability for each event is more likely than not (greater than 0.5), the product of all probabilities greatly drops, even approaching zero. The result for the overall *P(h/e)* indicates strong improbability.

In other words, the probability for correctly surmising a complex succession of past events given the physical evidence by affirming the consequent is very, very low.

Also, if any of the probabilities for past events are not possible (equal to zero) after considering the universe of "facts" in a case – both physical evidence items and previous events – the probability for the hypothesis is then equal to zero because one false event falsifies the entire hypothesis.

Let us apply some of these concepts for a hypothesis supplied by a scientist who "surmises past events from physical evidence" (h_s):

$$P(h_s / e) = \frac{P(h_s)P(e / h_s)}{P(h_s)P(e / h_s) + P(\sim h_s)P(e / \sim h_s)}$$

We will assume that the testing for the evidence will yield the same result regardless of the hypothesis (no confirmation bias), making $P(e / h_s) = P(e / \sim h_s)$, allowing these factors to be cancelled out:

$$P(h_s / e) = \frac{P(h_s)}{P(h_s) + P(\sim h_s)}$$

Notice that the denominator follows the Law of the Excluded Middle, making the sum equal to 1. This leaves:

$$P(h_s / e) = P(h_s) = 0.03$$

And according to the **Negation Rule**:

$$P(\sim h_s) = 1 - P(h_s) = 0.97$$

making the probability of a hypothesis other than the one selected by the scientist to be highly likely.

The number, 0.03, is used in this example because the scientist affirms the consequent for complex past events, and that low number was the yield in an example above for ACCPE. Note that the prior probability before testing or $P(h_s)$ is equivalent to the probability after the testing or $P(h_s / e)$. Even before the first test is performed, the probability of a hypothesis surmised by a scientist is already doomed, regardless of the test results. This makes testing meaningless for a hypothesis for complex past events derived by a scientist.

Therefore:

- **The use of a forensic test for surmising complex past events (more than one past event) is so unreliable that such testing should be considered “junk science” no matter how well the test performs.**

What if the hypothesis for past events is supplied by a witness account, perhaps given by a defendant (h_w)? Since there would be no competing hypothesis with such an account (only one series of events is stated and no alternates are proposed), the simpler form of Bayes’ Theorem can be used:

$$P(h_w / e) = \frac{P(e / h_w) P(h_w)}{P(e)}$$

If the observation of evidence is accurate and free of confirmation bias, then $P(e)$ and $P(e / h_w)$ are equal to one and cancelled out, leaving:

$$P(h_w / e) = P(h_w)$$

If the witness told the truth ($P(h_w) = 1$), then the hypothesis for what happened given the testing would so indicate ($P(h_w / e) = 1$). If the witness did not tell the truth ($P(h_w) = 0$), then the hypothesis for what happened given the testing would so indicate ($P(h_w / e) = 0$).

When a hypothesis provided by a witness is tested, the probability value for that hypothesis, by necessity, has to be zero or one and not a fraction between zero and one. This is because the witness is either giving a truthful account in its entirety or speaking falsely in at least one portion of it. Remember that every past event data point given the evidence and previous past events has to be true in order for the overall hypothesis for what happened to be true…

$$(1)(1)(1)\ldots(1) = 1$$

$$(0)(1)(1)\ldots(1) = 0$$

…just like with fingerprints and DNA. As daunting as this may seem, a witness or witnesses who simply tell the truth will satisfy such conditions easily. Consequently, the greater number of past events given the evidence and previous past events that are true (the higher that *n(h)* is), the more likely it is that the witness account is actually the truth. This is because a higher *n(h)* means that a higher number of opportunities to falsify the hypothesis have failed. Also, greater numbers of witness data points individuate the physical evidence, explaining more comprehensively the unique combination of evidence data points.

Also, the greater number of evidence items, *n(e)*, the more likely the witness account is the truth when *h/e* is true, not only because more opportunities for falsification have failed but also because numerous evidence data points are highly individuating for past events just as they are for identity.

This "individuation" can be illustrated by using the odds form of Bayes' Theorem:

$$O(h/e) = \frac{L(h/e)}{L(\sim h/e)} O(h)$$

If data points for *h* or *e* fail to falsify either hypothesis given the evidence, then either hypothesis is equally likely (remember that the probability forms of the likelihoods above, $P(e/h)$ and $P(e/\sim h)$, were canceled out in the examples above because they were equivalent to each other). If one hypothesis however has 2 past event and 2 physical evidence data points that fail to be falsified and the other hypothesis has only one past event and one physical evidence data point that fail to be falsified, consider the effect on the odds equation:

$$O(h/e) = \frac{L(h_1/e_1) + L(h_2/h_1e_1) + L(h_1/e_2) + L(h_2/h_1e_2)}{L(\sim h_1/e_1)} O(h)$$

All component hypotheses in their varying combinations given the evidence are equally likely, but more data points – past event or physical evidence data points – have the same effect as frequency in the odds equation for identity. More data points for a hypothesis increase the odds that it is true.

Consequently, with the example above…

$$O(h/e) = 4 \bullet O(h)$$

…because there are four addends in the numerator and only one in the denominator. The odds of obtaining the correct hypothesis given the evidence are now expanded 4 fold. The relationship overall can be described as follows:

$$O(h/e) = n(h) \bullet n(e) \bullet O(h)$$

with *n(h)* representing the number of data points for *h* and *n(e)* representing the number of data points for *e*. If there are 100 past event data points and 100 physical evidence data points that are not falsified, the odds for obtaining the true hypothesis given the evidence would increase 10,000 fold.

Essentially, forensic testing has no effect on a hypothesis derived by a scientist through ACCPE – the hypothesis remains highly improbable regardless of the testing. On the other hand, forensic testing allows a demonstration of whether or not witness accounts given the evidence are either false or not excluded for truth – simply two outcomes, just like a test for identity. Remember that non-exclusion does not mean necessarily mean that the witness account is the truth, but the odds of it being the truth are increased with the number of data points. This allows us to draw the next two conclusions:

- **Forensic tests used to test witness accounts can be highly reliable for the exclusion or the non-exclusion of the truth of the accounts.**

- **As the data points for witness accounts and physical evidence increase, the odds of learning the truth also increase, indicating how important a thorough witness and physical evidence investigation is.**

Comparing test results to witness accounts is clearly reliable and a good basis for the evaluation and quality control of tests, particularly when there are numerous past event and physical evidence data points in the comparison. This is a conclusion that one can reach intuitively, but it is helpful to see how this kind of data relationship asserts itself through probability theory. The high number of past events dooms ACCPE but greatly supports a determination of truth or falsehood through comparing witness accounts with physical evidence.

What if we were to surmise only one past event from the physical evidence? For example, what if we were to look at a defect pattern in the face of a dead person and determine that there was animal depredation or if we were to look at a bullet in a body at the end of a wound track and determine that the person was shot? If the past event is perceived as the only plausible explanation, then the situation approaches 1 in a fashion similar to identification with DNA testing:

$$P(h_1 / e) = P(h_1) \approx 1$$

This is simply a restatement of the *if and only if* exception to affirming the consequent ($e \leftrightarrow h_1$), allowed in the IT when there is only one plausible explanation – a relationship between past event and physical evidence that is not only sufficient but also necessary. This allows a pathologist to look at a lesion or a pattern of lesions and infer its cause, such as with animal depredation, gunshot wounds, sharp force "defense" wounds, or even a diagnosis of cancer from a histopathology examination (looking at stained tissues mounted on glass slides). This also allows a scientist to infer a past event from evidence after all witness accounts and all items of physical evidence have been considered and there is only one plausible explanation for a final piece of physical evidence that has no witness account; nevertheless, the scientist must be careful. All it takes is only one *other* plausible explanation for the evidence to falsify the use of the *if and only if* exception. Surgical pathologists who surmise the nature of a disease from its appearance under a microscope should understand this: one does not diagnose a malignant melanoma when the lesion could be a benign Spitz nevus.

Therefore:

- **A scientist may infer a single explanation for physical evidence but only with great caution because it takes only one *other* plausible explanation to falsify the inference.**

One more thought experiment question. Many states, such as Missouri, require a standard of "reasonable degree of medical certainty" for experts, but not all states have this requirement. Some states, like Ohio, require only "reasonable degree of medical probability," and some states, like Indiana, require only that the inference is "more probable than not." What if there were only *two* plausible explanations for the physical evidence? Would choosing one or the other explanation pass the tests of "reasonable medical probability" or "more probable than not"?

The answer is no. Although inferring to a single past event would allow for certainty ($h_1 = 1$), inferring to one of two past events (h_1 or h_2) would drop the probability of each to 0.5 if each event is equally probable: $P(h_1) = P(h_2)$.

$$\frac{P(h_1)}{P(h_1) + P(h_2)} = 0.5$$

Just like flipping a coin. This is not even "more probable than not."

The expert may then argue that in his or her experience, one event is more probable than the other. I discuss the reliability and the value of such experience in the next chapter.

Chapter 7: Forensic Tests and Experience

When the courts qualify an expert, they often look carefully at experience. "How many autopsies have you performed in career?" is an example of a question designed to learn the expert's experience. Frequently, an expert will rely on his or her experience for asserting opinions.

Furthermore, a doctor with long experience seems impressive. Along with that long experience comes the veneer of reliability – a reliability that may impress juries. How reliable is experience?

Let us say a doctor claims, "I have seen abusive head injury in 90 out of 100 cases when retinal hemorrhages have been present in the eyes of a child," or "I have made firm determinations of drowning in 90 out of 100 cases when diatoms have been present in the viscera of a dead body." How reliable are these opinions?

In all 100 cases, if the doctor used tests without reference to freely offered witness accounts to infer these past events, then the doctor used ACCPE to make his determinations. Not only is ACCPE not valid, it is also not reliable for probability, as demonstrated previously. In truth, the doctor never saw the abusive head injuries or the drowning events take place – only the evidence from the cases – yet he speaks as if he witnessed these events in all cases. Such is the power of a circular argument applied to experience. The doctor after ACCPE too often speaks as if he is certain that all of his "diagnoses" are true ($h_s = 1$).

Consider this equation using Bayes' Theorem for competing hypotheses to represent the experience above:

$$P(h_s / e) = \frac{90P(h_s)P(e / h_s)}{90P(h_s)P(e / h_s) + 10P(\sim h_s)P(e/ \sim h_s)}$$

If *e* is assumed to be accurate ($P(e) = 1$) and free of bias ($P(e) = P(e / h_s) = P(e/ \sim h_s)$, see Chapter 8) and if the doctor considers the prior probability of h_s to be equal to 1 and $\sim h_s$ to be equal to zero because he is certain from experience, then:

$$P(h_s / e) = \frac{90(1)(1)}{90(1)(1) + 10(0)(1)} = 1$$

$P(h_s)$ and $P(h_s / e)$ are equal to 1. The evidence from this form of experience reflects certainty in a circular fashion.

But if using ACCPE means that – as in the previous example – each h_s has an average of 10 events with each event having an average probability of 0.7, then:

$$P(h_s / e) = \frac{90(0.03)(1)}{90(0.03)(1) + 10(0.97)(1)} = 0.22$$

$$P(\sim h_s / e) = 1 - P(h_s / e) = 1 - 0.22 = 0.78$$

The equations indicate that experience does not turn improbability into probability.

Or try this: “There are retinal hemorrhages in 90% of all abusive head injury cases according to the literature” or “There are diatoms in 90% of all drowning cases according to the literature.”

In these cases, the doctor uses the experience with retinal hemorrhages and diatoms published in the literature, much of that experience determined through both ACCPE and confessions of the accused (witness accounts obtained through police interrogation that are *not* freely offered). For this, $P(e/h_s)$ -- the probability of the evidence given the scientist's hypothesis or 90% -- and $P(e/\sim h_s)$ -- the probability of the evidence given other hypotheses or 10% -- is reflected in Bayes' Theorem below. If the doctor considers the prior probability of h_s to equal 1 (because he trusts the literature with all those confessions), then:

$$P(h_s/e) = \frac{P(h_s)P(e/h_s)}{P(h_s)P(e/h_s) + P(\sim h_s)P(e/\sim h_s)}$$

$$P(h_s/e) = \frac{(1)(0.9)}{(1)(0.9) + (0)(0.1)} = 1$$

The evidence from this "experience" also reflects certainty in a circular fashion.

Now, let us substitute 0.03 for the probability of $P(h_s)$. Remember that $P(\sim h_s) = 1 - P(h_s)$.

$$P(h_s/e) = \frac{(0.03)(0.9)}{(0.03)(0.9) + (0.97)(0.1)} = 0.22$$

$$P(\sim h_s/e) = 1 - P(h_s/e) = 1 - 0.22 = 0.78$$

Experience does not make the hypothesis probable in these cases either.

Therefore:

- **The experience of a scientist who affirms the consequent for complex past events is not reliable.**

On the other hand, MP and MT works every time it is tried. Using summation notation (symbolized by the upper case Greek letter, sigma) to indicate the summing of experience with every case from the first witness account ($w = 1$) to the final account ($w = n$).

$$\sum_{w=1}^{n} P(h_w / e) = \sum_{w=1}^{n} P(h_w)$$

With each successive combination of $P(h_w / e)$ and $P(h_w)$ that are added together, both variables that equal each other are either both zero or one depending on the witness or witnesses; however, there is one caveat. If the lack of experience of the doctor does not allow him to observe physical evidence accurately (poor observational skills), then *P(e)* in Bayes' Theorem will not equal 1. Also, if a forensic test is not reliable or is not properly quality controlled, then *P(e)* will not equal 1. In fact, if any physical evidence finding pertinent to the hypothesis is incorrect (or 0), then the examination is not reliable at all for determining anything.

$$P(e_1)P(e_2)P(e_3)...P(e_{n(e)}) = P(e)$$

$$(0)(1)(1)...(1) = 0$$

I mention the phrase, "…pertinent to the hypothesis" because, for example, mistaking a child's hair color at autopsy may not have anything to do with the reason why the child died suddenly and unexpectedly. It is the *e* that is pertinent to the hypothesis that will affect *h/e*.

Consider Bayes' Theorem for witness accounts:

$$P(h_w / e) = \frac{P(e / h_w)P(h_w)}{P(e)} = \frac{(0)P(h_w)}{0}$$

If the test is completely flawed or false, then the test has no value for the purpose of a truthful and valid investigation – it becomes meaningless because zero in the denominator of a fraction is meaningless. Hopefully, additional tests would allow the mistake to be discovered, but if there are few data points for a comparison of tests, then there is greater danger of an errant test derailing an investigation.

Therefore:

- **Experience based on comparing witness accounts to physical evidence – even very little experience – is reliable, provided that the forensic testing is reliable.**

- **Forensic tests or scientific observations that are inaccurate, invalid, incomplete or unreliable are of *no* value to a forensic analysis. Additional testing or observation could hopefully aid in the discovery of mistakes.**

Chapter 8: Forensic Tests and Bias

What would be the effect of confirmation bias (learning the hypothesis derived by ACCPE and letting the hypothesis influence the examiner)?

If the examiner gave a wrong result when she otherwise might have given the correct result had she not been aware of the hypothesis, then the hypothesis given the evidence would be incorrect:

$$P(h/e) = \frac{P(e/h)P(h)}{P(e)} = \frac{(0)P(h)}{1} = 0$$

Or if she has a tendency to be influenced in a negative way in one out of five cases (one out of five times she is wrong because she became aware of the hypothesis for past events in five cases), then the probability of getting the correct hypothesis would decrease accordingly:

$$P(h/e) = \frac{P(e/h)P(h)}{P(e)} = \frac{(4)P(h)}{5} = 0.8$$

Theoretically, confirmation bias could be measured for an examiner or a group of examiners by allowing her or them to test multiple samples from cases with known, well-witnessed events and known results. Bias would be detected if false hypotheses for past events lead to incorrect results. By necessity, the supplied hypotheses would need to be false because true hypotheses should have no effect on results, regardless of the presence or absence of bias. With such testing, a **bias factor** symbolized by the lower case Greek letter, beta, could be calculated following the summation of each test result:

$$\beta = \frac{\sum_{i=1}^{n} P(e_i / h)}{\sum_{i=1}^{n} P(e_i)}$$

The factor would have the following effect:

$$P(h / e) = \beta \bullet P(h)$$

This would assume that *P(e)* is not zero and $0 \leq \beta \leq 1$. If *P(e)* were zero or beta greater than one, both would indicate a problem with the accuracy of the test itself. A result of zero for beta would indicate complete bias (the examiner is completely misled by all false accounts) and a result of one for beta would indicate no bias (the examiner is not affected by false accounts).

Therefore:

- **Confirmation bias decreases the probability of learning the truth by a potentially calculable factor. For laboratory tests, it would be better if the examiner were blinded to the hypothesis.**

Regarding the rule above, some important points need to be made.

If the one examining the evidence is also the one comparing the past event hypothesis provided by witnesses to the physical evidence in a forensic analysis (such as a forensic pathologist), this person is *required* to know the past events prior to the analysis. Knowing the past events allows the pathologist to assess if sufficient data has been collected and if the evidence investigation is sufficient to answer future questions. This makes it more critical that the pathologist chooses not to rely on second-hand accounts for an analysis before making determinations. The pathologist needs to pay attention to primary witness accounts if the cause and manner of death are not obvious.

Furthermore, for the sake of accuracy, the pathologist and well-trained investigators need to focus on *verifying* witness accounts rather than falsifying them. To prevent a deadly error, the courts are supposed to consider a person innocent until proven guilty; consequently, the most reasonable approach for the scientist or investigator is to verify a witness account and not to falsify it. If the account is false, then it is easily determined to be false because it is easily falsified – only one zero is required for one event to falsify the entire account. On the other hand, if the truth is told, the probability of it being the truth is great when complex events sufficiently explain numerous evidence data points without falsification. If there is a discrepancy in the witness account, it is wise to interview the witness again – multiple times if necessary – giving him or her every opportunity to provide a truthful account. In order to learn the truth, an interview style that is not coercive would be more likely to be successful then a style that is coercive and manipulative. One does not need to obtain a "confession" to learn the truth because 1) false accounts are easy to spot most of the time if one knows the proper inferential techniques, and 2) the witness might not know the truth or underlying cause of what happened, even though the witness might know what he or she did.

Therefore:

- **Scientists who interpret evidence of what happened need consciously to avoid confirmation bias by focusing on eyewitness accounts and not on the theories of others who were not eyewitnesses. Focusing on witness accounts with the intent to verify them mitigates the bias that comes through surmising past events from physical evidence.**

Chapter 9: Forensic Tests and the Manner of Death

Not uncommonly, at the outset of an investigation or even at its conclusion, witness accounts are sparse, non-existent or insufficient. Still, members of law enforcement and the community require guidance as to what a case might entail. In such a situation, AC may be needed for **hypothetical categorization**.

Hypothetical categorization is not the same as surmising complex past events. It is instead an attempt to determine 1) the nature of the events given the evidence and 2) the future implications of the events given the evidence. Hypothetical categorization can be simple – unlike ACCPE.

For death investigation, the hypothetical categorization is known as the manner of death. This is a one-word description of the death written on a death certificate. It is designed to describe the nature of the death and its future implications.

A death may occur because of internal causes due to disease. This death falls under the manner of **natural**. A natural death often has no legal implications – at least criminally. A **violent** death is a death brought about by an external cause. Such a death may not look violent at all, such as in the case of a drug overdose; nevertheless, a death due to an external cause (its nature) may result in a criminal indictment or there may be other forms of litigation and due process (its future legal implications).

A violent death may be a suicide (a death caused by the decedent with variable degrees of intent), a homicide (a death caused by another or others with variable degrees of intent), or an accident (a death from external cause with no apparent intent from anyone).

These manners of death – natural, suicide, homicide, and accident – are not intended to have any overlap of cases with each other. They are all *mutually exclusive* (no two manners can both be true) and *jointly exhaustive* (one of the statements must be true).

$$h_{nat} \vee h_{sui} \vee h_{ho} \vee h_{acc}$$

As such, they allow the **Restricted Disjunction Rule** to be applied as follows:

$$P(h_{nat}) + P(h_{sui}) + P(h_{ho}) + P(h_{acc}) = 1$$

If nothing is known about a case, then one might consider each manner as equally probable:

$$0.25 + 0.25 + 0.25 + 0.25 = 1$$

This, of course, is unacceptable because selecting any one of these manners for the death certificate would make the determination improbable (less than 0.5). What is needed is investigation, both for witness accounts and for evidence.

$$(h_1 \bullet h_2 \bullet h_3 \bullet \ldots \bullet h_{n(h)}) \rightarrow (e_1 \bullet e_2 \bullet e_3 \bullet \ldots \bullet e_{n(e)})$$

Each side of the conditional arrow hopefully has a sufficiently high *n*. Once the information is studied, the hypothesis for each manner is considered given the witness and physical evidence:

$$P(h_{nat} / he) + P(h_{sui} / he) + P(h_{ho} / he) + P(h_{acc} / he) = 1$$

Substituting the results of an investigation for 1 using the law of the excluded middle ($P(\mathbf{p} \vee \sim \mathbf{p}) = P(\mathbf{p}) + P(\sim \mathbf{p}) = 1$) and the law of identity ($a = b \leftrightarrow b = a$):

$$P(h / e) + P(\sim h / e) = P(h_{nat} / he) + P(h_{sui} / he) + P(h_{ho} / he) + P(h_{acc} / he)$$

The variable, *h*, without a subscript is simply the hypothesis for what happened as provided by witness accounts.

The equation above implies several scenarios:

- If MT does not falsify the hypothesis and there is a sufficiently high n on either side of the $h \rightarrow e$ conditional arrow (a thorough investigation), then $P(h / e) \approx 1$ can be stated with confidence. Often, this allows one of the manners on the right side of the equation to be selected with confidence (confidence meaning almost certainty) because the other manners are ruled out (equal to zero). So, for example:

  $$P(h / e) \approx P(h_{ho} / he) \approx 1$$

  If there is a disagreement in how to apply manner of death classifications among pathologists, then theoretically there may be more than one manner that could apply to a succession of past events. For the rest of this discussion, we will assume that there are no disagreements about how to apply mutually exclusive and jointly exhaustive manner of death classifications.

- If there are gaps in the witness evidence because the witness accounts are insufficient or false, then h / e and $\sim h / e$ are uncertain, making the probability values of each between 0 and 1; nevertheless, if the evidence indicates only one manner of death and the other manners are ruled out, then the manner of death can still be stated with confidence:

$$P(h/e)+P(\sim h/e)\approx P[h_{ho}/(h\vee\sim h)e]\approx 1$$

For example, if a person is found in the street with an indeterminate range gunshot wound to the head (no soot or gunpowder stippling) and no gun near the body, it could be determined that there is no other plausible explanation for manner but homicide even though all of the past events are not known.

- If there is more than one plausible manner of death in an uncertain case after the implausible manners have been ruled out, then:

$$P(h/e)+P(\sim h/e)\approx P[h_{ho}/(h\vee\sim h)e]+P[h_{sui}/(h\vee\sim h)e]$$

For example, let us say we cannot determine if a gunshot case is a homicide or a suicide and we know that each hypothesis is plausible. We accept that the manner is either homicide or suicide. Then:

$$(h_{ho}\rightarrow e)\vee(h_{sui}\rightarrow e)$$

Each disjunct (each side of the vee) can lead to the observed evidence, so when e/h_{ho} or e/h_{sui} is used in Bayes' Theorem, the value for each will equal each other (equally likely) and can be canceled out. Here is Bayes' Theorem for a selection of homicide:

$$P(h_{ho}/e) = \frac{P(h_{ho})P(e/h_{ho})}{P(h_{ho})P(e/h_{ho}) + P(h_{sui})P(e/h_{sui})}$$

This can now be simplified to:

$$P(h_{ho}/e) = \frac{P(h_{ho})}{P(h_{ho}) + P(h_{sui})}$$

So which one is it? Homicide or suicide?

We cannot use physical evidence to help in distinguishing one manner from the other because the equation leaves out *e*. Each hypothesis for manner leads to the same physical evidence, allowing the evidence for each given the hypothesis to be cancelled out. We cannot use experience because, as we have seen above, the experience is circular and not reliable when used to affirm the consequent in a past event case. The only thing left to do is to assign equal probability to homicide and suicide:

$$P(h_{ho}) + P(h_{sui}) = 1$$
$$P(h_{ho}) = P(h_{sui}) = 0.5$$

Since both are equally probable and the probability for each is poor, it would not make sense to choose one or the other. The best choice then would be to declare the manner as **undetermined** after putting a comment in the report that neither homicide nor suicide can be ruled in or ruled out in this case; however, if one category or the other is ruled out in the future after new information is learned, then one or the other – either homicide or suicide – can be selected for manner and the death certificate amended accordingly. This allows the following dictum to apply:

- **One should assign manner of death if only one manner remains as plausible after a thorough investigation; otherwise, the manner should be undetermined.**

The word, "plausible" – which means "seemingly probable" – is used instead of "possible" because it recognizes that when affirming the consequent, new information may change the opinion from seemingly impossible to now seemingly probable. Plausible indicates that the opinion could change if further information (witness or physical evidence) were to be discovered.

Pathologists may disagree on what is plausible, adding complexity to a manner determination. Some may claim that a hypothesis for manner can lead to observed evidence:

$$h_{ho} \to e$$

Some may claim that it cannot:

$$\sim (h_{ho} \to e)$$

For example, let us say that a person is found with a gaping intraoral shotgun wound that devastates the head but there is no physical evidence of a struggle. Let us say the shotgun is with the decedent at the scene. Some may say that homicide in such a situation is implausible because no decedent would allow the insertion of a shotgun muzzle into his or her mouth without offering a struggle and that the presence of the shotgun at the scene supports a self-inflicted wound as a more likely scenario. Others may disagree and claim that a homicide is plausible. Note that implausible is not the same as impossible – only highly, highly unlikely. Disagreements of this nature add to the complexity of what might ordinarily seem to be a simple decision.

Furthermore, the logic above points out the importance of not declaring a manner until sufficient points of evidence – witness accounts and physical evidence – are discovered. Changing an opinion of a manner declared prematurely is not only professionally embarrassing but can also alter the outcome of an investigation. For example, once a case is declared a homicide, witnesses and suspects "lawyer up" and nothing further can be learned from them. Without these witness accounts, the truth behind the death will not be learned.

Using AC at all, even for surmising a single past item or category such as manner, needs to be done very carefully and not thoughtlessly, prematurely or dogmatically.

Chapter 10: Forensic Tests and Diagnosis

At this point, now that we have introduced the concept of hypothetical categorization, we need to discuss diagnosis.

A diagnosis is an inferential process where one tries to discover the answer to the question, "What is wrong with…?" "What is wrong with this patient?" or "What is wrong with this automobile?" involves diagnosis conducted by a physician or a mechanic. The importance of the diagnosis lies with the treatment or repair. If the physician or the mechanic can discover what is wrong, that discovery can lead to a treatment or a repair.

The important issue to understand is that a forensic analysis – where *past events* are evaluated and compared to physical evidence – is not the same as a diagnostic analysis – involving a *present concern*. Forensic science accepts that it is true that past events lead to physical evidence – even past events from a hypothesis other than the preferred hypothesis can lead to the same physical evidence:

$$(h \rightarrow e) \vee (\sim h \rightarrow e)$$

In diagnostic medicine, the issues concern present events and whether or not an underlying disease process or condition currently exists within a patient and causes his or her signs and symptoms. As such, a hypothesis for "what is wrong with this patient" does not always logically and characteristically lead to signs and symptoms or other evidence of what is wrong with the patient. Some conditions may be asymptomatic yet require screening procedures to detect. The same disease may manifest itself in some ways but not in other ways. Some forms of a disease may show up on imaging and some in screening laboratory tests. Some may not show up at all with tests yet still be present. Also, false positive results on tests may imply the presence of a disease when none exists. All of this could be characterized as follows:

$$(h_d \rightarrow e) \vee (h_d \rightarrow \sim e) \vee (\sim h_d \rightarrow e) \vee (\sim h_d \rightarrow \sim e)$$

h_d represents the hypothesis for "what is wrong with the patient" or the diagnosis. $h_d \rightarrow e$ indicates a true positive (the diagnosis is true and the evidence by testing so indicates), $h_d \rightarrow \sim e$ a false negative (the diagnosis is true but the evidence for it is false or not detected), $\sim h_d \rightarrow e$ a false positive (the diagnosis is false in spite of positive evidence for it – a positive test result), and $\sim h_d \rightarrow \sim e$ a true negative result (the diagnosis is not true and the evidence by testing so indicates). Both h_d and e are complex, so the same disease in the same case may yield varying evidentiary results.

Now consider the following:

$$\begin{aligned}
&P(h_d / e) + P(\sim h_d / e) + P(h_d / \sim e) + P(\sim h_d / \sim e) \approx \\
&P[h_{1d} / (h_d \vee \sim h_d)(e \vee \sim e)] + P[h_{2d} / (h_d \vee \sim h_d)(e \vee \sim e)] + \\
&P[h_{3d} / (h_d \vee \sim h_d)(e \vee \sim e)] + \ldots + P[h_{nd} / (h_d \vee \sim h_d)(e \vee \sim e)] - P(overlap)
\end{aligned}$$

This illustrates the complexity of the diagnostic approach used to determine the hypothesis of "what is wrong with this patient." The use of a hypothetical categorization known as a differential diagnosis (a list of possible diagnoses) may entail numerous diagnoses (labeled by subscripts *1d, 2d, 3d…nd*). The combinations of hypothesis and evidence on the left side of the "almost equal" sign are discrete and therefore mutually exclusive, i.e. there is no overlap, so the **Restricted Disjunction Rule** is required. The categories for the differential diagnosis on the right side of the "almost equal" sign are not mutually exclusive (two categories may be true or present at the same time), so the **General Disjunction Rule** for more than two terms is required. The term, *P*(*overlap*) describes a situation that is too complex to express numerically. All differential diagnosis hypotheses are uncertain, making each value less than 1 and greater than zero. Also, the human brain does not have the capacity to consider all possible diagnoses. A treating physician instead considers the categories that are the most common, the most potentially treatable, and the most potentially life-threatening. This is why the "approximately equal" symbol (≈) is used in the formula above, considering that the most common, treatable, and potentially life-threatening diagnoses leave only an uncertain number of unevaluated conditions of low probability. A diagnostic approach using trial and error in a living patient eventually uncovers a "treatable" answer in many cases but not in all cases. Although one can assign a treatment plan that may work, the answers themselves are less than certain, although they may be probable.

Diagnostic medicine practiced in a clinical setting is essentially educated guesswork and trial-and-error.

The diagnostic process is remarkably different from a forensic analysis, yet physicians characteristically confuse them with one another. Physicians believe that they can diagnose entities that occurred in the past without understanding that diagnosis is a process that occurs for a presently functioning organism.

For example, what happens when a physician makes a diagnosis of "abusive head injury"?

$$P(h_d / e) + P(\sim h_d / e) + P(h_d / \sim e) + P(\sim h_d / \sim e) \approx$$
$$P[h_{AHI} / (h_d \vee \sim h_d)(e \vee \sim e)] + P[h_{2d} / (h_d \vee \sim h_d)(e \vee \sim e)] +$$
$$P[h_{3d} / (h_d \vee \sim h_d)(e \vee \sim e)] + ... + P[h_{nd} / (h_d \vee \sim h_d)(e \vee \sim e)] - P(overlap)$$

Note that the first of a long line of conditions in the differential diagnosis indicates a diagnosis of "abusive head injury" (AHI). The human mind is limited in the number of diagnoses that are considered other than AHI: this limitation of the mind leads to a form of bias known as "availability"[7]. A few categories may be "ruled out" with a few tests, supposedly making the probability of those conditions equal to zero, but there is no way to be certain in the assignment of probability values for the categories that remain. Furthermore, clinical physicians do not typically consider primary witness accounts – secondary or hearsay accounts are the items that often end up in a clinical history obtained by a physician. This introduces further misinformation that can lead to false premises. The physicians declare that "abusive head injury" is the only plausible explanation if a history that may be based on false premises is not consistent with the evidence. Diagnoses are beliefs, theories, and even hunches – not facts – but out of ignorance, these doctors believe that they are using valid inference with sound premises for a diagnosis of "abusive head injury."

In the end, none of the inferences made by clinical physicians can be tested in the typical clinical medicine fashion because abusive head injury is a past event and not a present condition. A past event cannot be manipulated by trial-and-error testing like a present condition because the past event no longer exists. Confusing diagnosis with forensic inference has thrown many physicians who testify in court down a rabbit hole of confusion. Still, their expert testimonies in court are filled with dogmatic certainty, confusing jurors who are impressed by credentials and experience – particularly diagnostic experience in a clinical setting.

Diagnostic terms such as "syndrome" and "differential diagnosis" are used inappropriately for past event matters, and this terminology characteristically leads to an inference from theories and beliefs rather than facts. A syndrome is a theory, a belief, that a set of signs, symptoms, and other disease manifestations – when occurring together – has the same underlying cause. When used for past events, it essentially represents ACCPE because it selects a single underlying past event cause from numerous potential past event causes. This represents a hunch or a guess but not a determination made with certainty or even probability. Doctors who use the terms, "syndrome" and "differential diagnosis" in a past event analysis confuse complex past events with a possible underlying cause of an illness.

Therefore:

- **Forensic analysis and clinical diagnosis are two different processes. A diagnosis involves a condition in a patient evaluated in the present, but a forensic analysis involves past events. A forensic analysis offers more opportunities for valid deductive inference than diagnosis. Diagnosis is a complex probabilistic approach involving choices between conditions that are more probable and less probable given the evidence.**

- **The terms, "syndrome" and "differential diagnosis" are characteristic of the diagnostic process and are inappropriate for a forensic analysis. The application of such terms in a forensic analysis typically leads to surmising past events from physical evidence.**

Chapter 11: Forensic Tests and the Cause of a Natural Death

Determining the specific cause of death in a natural death is more problematic than in violent deaths because witnesses are not able to observe what goes on inside of a person. A person who dies may exhibit signs and symptoms prior to her passing, but these signs and symptoms are not unique for the specific cause of a natural death. Once violent manners of death have been excluded, AC is required to determine the cause of a natural death.

Consider the following formula.

$$P(h_c / h_{nat}e) \approx$$
$$P(h_{1c} / h_{nat}e) + P(h_{2c} / h_{nat}e) + P(h_{3c} / h_{nat}e) + ... + P(h_{nc} / h_{nat}e) - P(overlap)$$

The focus is "what happened" to cause the death, given that the cause is natural and given the evidence. Possible causes (*1c, 2c, 3c, nc*) are categories listed in "differential diagnosis" fashion, although they are not "diagnoses" in a functioning, living patient. The list of possible causes is not jointly exhaustive because of availability, hence the "approximately equal" symbol. All considerations for cause require an understanding of both the past events (which indicate a form of natural death) and physical evidence. A *complete* autopsy is often critically important for an accurate determination of the cause of a natural death. A partial autopsy confined to a particular portion of the body or an evaluation with imaging alone increases the likelihood of committing the *fallacy of incomplete evidence*.

Consider the following for a hypothesis of what natural condition caused the death given the autopsy evidence. Common conditions will have a higher probability than rare conditions if both conditions are life-threatening, so the probability of common conditions will be closer to 1 than rare conditions. Using **R** to represent "rare" and **C** to represent "common":

$$0 < P(\mathbf{R}) < P(\mathbf{C}) < 1$$

The more life threatening conditions will have a higher probability than the less life threatening conditions. Using **L** to represent "less life-threatening" and **M** to represent "more life-threatening":

$$0 < P(\mathbf{L}) < P(\mathbf{M}) < 1$$

The life-threatening element of the disease takes precedence over how common the disease is in a population. For example, someone is noted suddenly and unexpectedly to lose consciousness and die and there is a history of a seizure disorder. If the individual were to have severe coronary artery atherosclerosis at autopsy, this would be considered more probable as a cause of death than if the person had his last seizure 10 years ago. The former condition is more common and more life-threatening than the latter. On the other hand, if a witness noted the decedent to be in status epilepticus (recurrent seizures without regaining consciousness between seizures) prior to his death, the seizure disorder would be more probable for the death. Although seizures are less common than coronary atherosclerosis, recurrent and non-stop seizures are more life-threatening than coronary atherosclerosis.

What if a person who dies suddenly and unexpectedly has evidence of both hypertensive heart disease and severe coronary atherosclerosis, conditions that are both common and life threatening in the setting of a sudden and unexpected death:

$$0 < P[(\mathbf{C} \bullet \mathbf{M})_1 \vee (\mathbf{C} \bullet \mathbf{M})_2] < 1$$

Which condition should be chosen? Rather than choose, why not select both? The cause of death could be listed as "coronary atherosclerosis *or* hypertensive cardiovascular disease." Note the use of the disjunct *or*, rather than the conjunct *and*. It might make little difference if one should choose the English term, "and," over the term, "or"; however, logically speaking, the disjunctive *or* is more appropriate than the conjunctive *and*, considering the equation above. Logic uses the "inclusive *or*" which means "either **p** or **q** *or both*." When both common and life threatening conditions are added together as they are with a disjunction, the probability of both together closely approaches 1.

Since the determination of a natural cause of death requires AC, the only valid use of AC for this determination is the *if and only if* exception. Determining the *single plausible explanation* for the death involves the use of the exception for surmising past events from physical evidence in the IT. All of the procedures above are intended to do just that. If there are two plausible explanations discovered after an autopsy, combining the two conditions with a disjunct essentially turns the cause of a natural death into a single plausible explanation.

If the pathologist finds evidence of severe coronary artery atherosclerosis, it would not make sense to obtain histological sections of the conduction system or pay for testing for a cardiac channelopathy. Both are life-threatening, so the common condition is the more probable of the two; hence, the single plausible explanation. Rare conditions should not be considered unless there is no other plausible explanation.

Therefore:

- **The determination of the cause of a natural death must take into consideration both past events and physical evidence. The determination relies more on estimates of probability than other manners of death, making the analysis for the cause of a natural death less than certain. This is because the internal conditions that cause a natural death are not subject to witness observation.**

- **In a natural death, more life-threatening conditions take precedence for cause over less life-threatening conditions, and common conditions that are life threatening take precedence for cause over rare conditions that are almost equally life-threatening. Rare and less life-threatening conditions are not considered when more common and more life-threatening conditions are present.**

- **If two common and almost equally life-threatening conditions are both present at autopsy, both conditions should be listed in the death certificate separated by a disjunct ("or").**

Chapter 12: Forensic Tests and Timing

What follows in the next three chapters is an application of the principles above to situations commonly encountered by physicians in a forensic setting. First, the elusive issues of "time of death" and "time of injury."

- **The use of forensic tests for timing events yields unreliable results not suitable for reasonable certainty, but one can compare such tests to witness accounts in a way that allows for reasonable certainty.**

Although assessing the "time of death" by examining the body at a death scene is popular in detective fiction, it is a form of "junk science." It is ACCPE. There are variables that are too numerous to count associated with complex past events that were not witnessed, making the probability of obtaining a truthful determination very, very low. The same can apply for the timing of injuries – by histology or imaging – and applying other crude estimates of past events that involve timing, such as the Widmark formula for blood alcohol. Testimony relying on such assessments should never be allowed in the courtroom in the form of AC (using the evidence to surmise a hypothesis for time of injury).

On the other hand, such testing can be compared to witness accounts with reasonable certainty in the form of MP or MT as indicated in the first part of the IT. For example, the babysitter who took care of an infant for an hour and a half prior to the child's seizure cannot be implicated for abusive head injury if there is a chronic subdural hematoma noted on imaging. The long age of the subdural hematoma negates a hypothesis of abusive head injury perpetrated by the babysitter.

Chapter 13: Forensic Tests and Sudden, Unexpected Infant Death

Secondly, let us consider the issues of sudden and unexpected infant death.

The developing human organism is complex, and the potential for one of a vast number of complex systems in the body to develop abnormally is a plausible consequence. It is a wonder that more children do not die in infancy, considering the complexity of the developing human. Sudden unexpected infant deaths and "apparent life-threatening events" (ALTE) that later lead to death are relatively rare in the population. ALTE is a condition of often-unknown cause where an infant suddenly stops breathing, changes color, gags or chokes[8]. The number of potential causes for these conditions is legion, yet a potential cause by itself may be rare – so rare that the cause may not yet be discovered by medical science. Newborn screening methods only test for the more common metabolic errors that have been discovered; yet they may represent only the exposed tip of a very large iceberg that includes numerous conditions not yet described in the medical literature.

The same could be said of the causes of miscarriages and stillbirths. A witness cannot observe what happens to cause a sudden and unexpected death in an infant or stillborn, and affirming the consequent for a rare condition among a legion of potential conditions would be ludicrous. Consequently and by necessity, sudden unexpected infant deaths that are classically characterized as SIDS (Sudden Infant Death Syndrome) are best categorized as undetermined.

The problem with calling a sudden and unexpected death in an infant a "syndrome" is that such a condition does not have only one plausible explanation but plausible explanations that are potentially too numerous to count, so the term, "syndrome" – implying only one cause for a set of clinical effects – is neither useful nor accurate. In fact, it is misleading because it impels scientists to surmise causes they cannot and will not determine. The history of SIDS research is replete with examples of such surmised causes that are considered at one period of time and then discarded when additional evidence comes to light.

What about foul play? What about the chance that someone smothered an infant without admitting it and without leaving any evidence? There are only a limited number of ways that one can kill an infant and leave no witness or physical evidence, and the number of these possibilities pales in comparison to the vast number of ways an infant can die naturally. The probability for foul play further decreases when the witnesses describe a sudden and unexpected death, and the autopsy and other evidence support that account. The more data points gathered in an investigation, the more likely that account is truthful if it resists falsification. If witness accounts and physical evidence line up for a sudden and unexpected infant death, not only should the medical examiner call the cause undetermined, she should also call the manner of death natural.

Many as a result of experience believe that co-sleeping (bed sharing) and unsafe sleeping environments should be implicated as the cause of death instead of SIDS. Should co-sleeping and an unsafe sleeping environment be considered a cause of death?

Co-sleeping is a relatively common sleeping arrangement, and many children living today have grown up and survived – perhaps even thrived – in co-sleeping arrangements. Co-sleeping as a cause for a sudden infant death is not probable as illustrated by Bayes' Theorem:

$$P(d/c) = \frac{P(d)P(c/d)}{P(d)P(c/d) + P(\sim d)P(c/\sim d)}$$

The hypothesis is that if the child was in a co-sleeping arrangement, *c*, then this arrangement caused the death, *d*. In logical operator notation, this is $c \rightarrow d$ or d/c. Let us then say that for every 10 infant deaths we investigated, 9 were found in a co-sleeping arrangement (likely less in reality), and let us also say that only one out of 10 living infants in society sleep in a co-sleeping arrangement (likely more in reality). Also, let us consider that sudden unexpected infant deaths make up 2% (actually less) of live births. We then calculate the probability of dying while co-sleeping as follows:

$$\frac{(0.02)(0.9)}{(0.02)(0.9) + (0.98)(0.1)} = 0.16$$

Co-sleeping as a cause of death remains improbable, even though the prevalence of co-sleeping is probably much higher than 1 in 10 live infants and much lower than 9 in 10 dead infants. This is because co-sleeping is relatively common and sudden unexpected infant deaths are relatively rare.

What about an unsafe sleeping environment? Substitute the same numbers as for co-sleeping. The result will be just as improbable.

What about overlaying? That could be a different story, but in order to make that determination, one needs a positive witness account for overlaying and/or compelling physical evidence for the event. If the parent denies overlaying, and the physical evidence from the autopsy is consistent with that denial, then one should believe the parent and call the manner natural. If there is a suspicious element sufficient to raise doubt – suggesting that the death may be accidental or from foul play – the selection for manner should then be undetermined.

Therefore:

- **Sudden unexpected infant deaths currently categorized as SIDS (Sudden Infant Death Syndrome) are undetermined for cause. In such cases, overlaying should not be surmised without positive witness or physical evidence for overlaying. Deaths due to co-sleeping and unsafe sleep environments are demonstrably improbable.**

Chapter 14: Forensic Toxicology Tests

What about forensic toxicology?

- **A drug reliably may be determined to be present or absent in a dead body by a test, but a drug level cannot be relied upon solely for a cause of death determination. A cause of death from drug overdose is only reliable when there is no other plausible explanation for the death after a sufficiently thorough investigation.**

This is not a call to eliminate quantitative drug levels. Far from it. Learning as much information as one can is important for any death investigation; however, using reference or lethal ranges for a drug to determine the cause of death is essentially ACCPE.

There may be many explanations for a particular level of drug in a postmortem specimen. The site where the blood was drawn may affect the level of a drug in the blood of a dead person due to a phenomenon known as "postmortem redistribution"[9]. Variable patterns of drug metabolism or the presence or absence of certain disease processes may affect drug levels. Contamination of specimens from fermentation by bacteria or mold or the contamination of a blood specimen from exposure to gastro-intestinal contents may affect alcohol and drug levels[10]. Tolerance to a drug due to chronic use or misuse may lead to a level that would ordinarily be toxic to someone not previously exposed to the drug. The list goes on[11].

Toxicology data must be evaluated in the total context of the case. Data points from witness accounts and from testing other toxicology specimens may need to be increased. In a drug death, once all other factors have been evaluated, a pathologist may use the biconditional exception at the end of the IT to determine that drug overdose is the cause of death if and only if there is no other plausible explanation for the death.

This points out the importance of performing complete autopsies in suspected drug overdose deaths. An underlying disease not discovered until autopsy might not only be the cause of death but the disease also may have affected the drug level. Also, an autopsy finding like marked urinary bladder distension may indicate a comatose state for a period of time brought about by intoxication because a comatose person is insensible to the urge to urinate. Such a finding at autopsy is useful as an indication of drug intoxication. Although a doctor may remove a blood specimen from a dead person with a needle and syringe without performing an autopsy, determining a cause of death using a drug level from that specimen is unreliable.

Epilogue: A Few Parting Shots Across the Bow

I am done – not only with this treatise but also with the topic of forensic inference. All I need and care to say about this topic is now on this website, so I am happy to move on to something else.

It is impossible to persuade people who do not want to be persuaded. I have tried to call out to thought leaders in my profession, asking them to consider the topics I have covered. They have refused to do so, in spite of the critical nature of these topics. Without an understanding of how we should reason, we will aid and abet the false accusations and convictions of innocent people. As important as it is that we do not allow ourselves to do this, I cannot do any more then what I have already done.

Before I move on, I would like to impart the wisdom of four learned persons who came before us. Two of these were philosophers of science and two were physicians. I will deal with them in reverse chronological order.

In his book first published in 1975, entitled "Against Method," philosopher Paul Feyerabend advocated that scientists should throw out all methodology for conducting science[12]. He wrote – and rightly so, in my opinion – that building new theories from old ones does not work because we may very well be building upon tainted conclusions and creating a monster. No theory is ever consistent with all the relevant facts. Forensic and other scientists who testify in court have created and supported monsters. Several of these monsters end with the word, "syndrome," and contain the word, "abuse."

In his book first published in 1962, entitled "The Structure of Scientific Revolutions," philosopher Thomas Kuhn disclosed how the enterprise of science really works[13]. To use a simple analogy (and I apologize to the late Dr. Kuhn for the simple analogy), imagine a dog in the room of a house. The dog is chasing his tail, going round and round and never advancing. Someone comes along and kicks the dog. The dog is disoriented at first, so he looks around to get his bearings. He then proceeds to another room in the house where he once again chases his tail. As the history of science demonstrated to Dr. Kuhn, scientists operate "normally" by studying ways to uphold a theory or "paradigm." When a crisis appears that seriously challenges the paradigm, scientists end up having to reconsider and change old ways of thinking. Eventually, a new paradigm emerges, and scientists get back to their "normal" work. Forensic and other scientists who testify in court prefer "business as usual" and become nervous when a governmental body such as the National Academy of Sciences points out that there is a crisis. How hard of a kick will it take for the dog to stop chasing his tail?

In his lecture delivered in 1956, entitled "Classical Mistakes in Forensic Pathology," physician Alan R. Moritz disclosed the "mistake of substituting intuition for scientifically defensible interpretation"[14]. He described this mistake as "one of the most dangerous mistakes in forensic pathology, and one that is particularly prevalent among experienced forensic pathologists who, for one reason or another, acquire a propensity for what might be called 'categorical intuitive deduction.'" Dr. Moritz continued: "This Sherlock Holmes type of expert may see certain bruises in the skin of the neck and conclude without doubt that they were produced by the thumb and forefinger of the right hand of the stranger. He may see an excoriation of the anus and maintain unequivocally and without benefit of other elements of scientific proof that the assailant was a sodomist." Dr. Moritz concludes the section with, "The stakes are too high to play hunches in forensic pathology." A careful reading of what I have written points out what Dr. Moritz presciently described in 1956.

These three doctors all had one thing in common: their writings had a foundation in and an appreciation for logic. The appeal and persuasiveness of what they wrote and said comes from logic. Although Dr. Feyerabend in particular might criticize the human application of logic to science and although he might rightly criticize what falls under the rubric of "Logic," his arguments would have no appeal or persuasiveness without logic. Logic is the basis of rationality and an antidote to foolishness.

Finally, a physician named Luke – a man who seems no less logical than the three men mentioned above – wrote the biblical book entitled Acts of the Apostles. Luke tells the story of a religious leader named Gamaliel who said to his fellows in response to the early preaching of the gospel, "And now I say to you, keep away from these men (the preachers) and let them alone; for if this plan or this work is of men, it will come to nothing; but if it is of God, you cannot overthrow it – lest you even be found to fight against God"[15]. If the ideas expressed in this treatise and my other treatises are false, they will also come to nothing. They will simply be the unfounded opinions of a doctor who lives in the Heartland of the United States. On the other hand, if these ideas are true, then the implications are horrendous and those implications could very well haunt many scientists who glibly and authoritatively testify in courtrooms.

Time will tell.

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