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Probability, Individualization, and Uniqueness in Forensic Science Evidence

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LISTENING TO THE ACADEMIES[*]

David H. Kaye[†]

INTRODUCTION

These are dark days for the forensic sciences. Newspaper and magazine articles, op-ed headlines, television news, and radio talk shows refer to the field as "seriously deficient,"[1] a "dismal science,"[2] "in disarray,"[3] even "clueless."[4] The stimulus for this negative publicity blitz is a report of a congressionally-mandated "independent forensic science committee at the National Academy of Sciences."[5] This belated report[6] calls for structural and cultural changes in the forensic science community ranging from the separation of laboratories and police departments, to a uniform, enforceable code of ethics[7] and standardized testimony.[8] The report found that:

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1 Pete Williams, *Crime Labs Are Seriously Deficient, Report Says: National Academy of Science Says Only DNA Evidence Is Dependable*, MSNBC, Feb. 18, 2002, http://www.msnbc.msn.com/id/29258576/.

2 *On Point: Crime Labs and Dismal Science*, (Nat'l Public Radio broadcast Feb. 19, 2009, *available at* http://www.onpointradio.org/shows/2009/02/dismal-science/.

3 Martha Neil, *Crime Labs in Disarray Nationally; Reform, Independence Needed, Report Says*, A.B.A.J. L. NEWS NOW, Feb. 18, 2009, http://abajournal.com/news/crime_labs_in_disarray_nationally_reform_needed_report_says/.

4 Jennifer L. Mnookin, Op-Ed., *Clueless 'Science'*, L.A. TIMES, Feb. 19, 2009, *available at* http://articles.latimes.com/2009/feb/19/opinion/oe-mnookin19.

5 The National Academies, Project: Identifying the Needs of the Forensic Science Community, http://www8.nationalacademies.org/cp/projectview.aspx?key=48741 (last visited Mar. 1, 2009).

6 The report originally was scheduled for January 2008. *See id.* (announcing a starting date of September 2006 for a project of 16 months duration).

7 NAT'L RESEARCH COUNCIL COMM. ON IDENTIFYING THE NEEDS OF THE FORENSIC SCI. CMTY. ET AL., STRENGTHENING FORENSIC SCIENCE IN THE UNITED

> The forensic science disciplines exhibit wide variability with regard to techniques, methodologies, reliability, level of error, research, general acceptability, and published material. . . . Many of the processes used in the forensic science disciplines are . . . not based on a body of knowledge that recognizes the underlying limitations of the scientific principles and methodologies for problem solving and discovery. . . . [S]ome of these activities [encompassed by the term "forensic science"] might not have a well developed research base, are not informed by scientific knowledge, or are not developed within the culture of science.[9]

These observations are hardly news to the *other* academy—the professoriate. For years, the authors of legal treatises and journals have complained bitterly about the lack of regulation of forensic laboratories, the absence of rigorous proficiency testing, and the dearth of basic research that would demonstrate the alleged ability of fingerprint, toolmark, and other analysts to identify traces from one person or object to the exclusion of all others in the world.[10] They have written dismissively of "nonscience forensic sciences" that "have little or no basis in actual science," and they have implored courts to exclude testimony, pending better research showing that analysts can live up to their claims.[11] With rare exceptions, however, the courts have failed to perceive the gap between

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STATES: A PATH FORWARD 26 (2009) [hereinafter NRC 2009], *available at* http://www.nap.edu/openbook.php?record_id=12589&page=R1.

[8] *Id.* at 21 ("The terminology used in reporting and testifying about the results of forensic science investigations must be standardized.").

[9] *Id.* at 38-39.

[10] A small sample of this literature includes D.H. KAYE ET AL., THE NEW WIGMORE, A TREATISE ON EVIDENCE: EXPERT EVIDENCE (2004); MODERN SCIENTIFIC EVIDENCE: THE LAW AND SCIENCE OF EXPERT TESTIMONY (David Faigman et al. eds., 2008-2009 edition); Simon A. Cole, *Is Fingerprint Identification Valid? Rhetorics of Reliability in Fingerprint Proponents' Discourse*, 28 L. & POL'Y 109 (2006); Craig M. Cooley, *Reforming the Forensic Community to Avert the Ultimate Injustice*, 15 STAN. L. & POL'Y REV. 381 (2004); Paul C. Giannelli, *Wrongful Convictions and Forensic Science: The Need to Regulate Crime Labs*, 86 N.C. L. REV. 163 (2007); Jennifer L. Mnookin, *The Validity of Latent Fingerprint Identification: Confessions of a Fingerprinting Moderate*, 7 L., PROBABILITY & RISK 127, 127 (2008); Michael J. Saks & Jonathan J. Koehler, *The Coming Paradigm Shift in Forensic Identification Science*, 309 SCIENCE 892 (2005).

[11] *E.g.*, Simon A. Cole, *Does "Yes" Really Mean Yes? The Attempt to Close Debate on the Admissibility of Fingerprint Testimony*, 45 JURIMETRICS J. 449 (2005); Lyn Haber & Ralph Norman Haber, *Experiential or Scientific Expertise*, 7 L., PROBABILITY & RISK 143 (2008); D. Michael Risinger & Michael J. Saks, *Science and Nonscience in the Courts:* Daubert *Meets Handwriting Identification Expertise*, 82 IOWA L. REV. 21 (1996); Adina Schwartz, *A Systemic Challenge to the Reliability and Admissibility of Firearms and Toolmark Identification*, 6 COLUM. SCI. & TECH. L. REV. 1, 1 (2005) ("[A]ll firearms and toolmark identifications should be excluded until adequate statistical empirical foundations and proficiency testing are developed for the field.").

optimistic theory and hard proof, and they have accepted remarkably weak forms of validation.[12]

With the imprimatur of the National Academy of Sciences behind recommendations for major change, the need for forensic scientists or analysts to retreat from the most extreme claims finally should be apparent to the judiciary as well as the forensic science community. But how far should this retreat go? Should forensic scientists be forever barred from giving an opinion that a DNA sample, a fingerprint, or a broken part of an object originated from a particular person, finger, or matching object? What does it take to justify such opinions? This essay seeks to clarify these questions by scrutinizing several statements and recommendations on how to present testimony offered in an essay by two of the legal academy's foremost critics of contemporary forensic science. In *The Individualization Fallacy in Forensic Science* ("*Fallacy*"),[13] Professors Michael Saks and Jay Koehler make the following statements:

> (1) The concept of "individualization," which lies at the core of numerous forensic science subfields, exists only in a metaphysical or rhetorical sense. It has no scientific validity, and it is sustained largely by the faulty logic that equates infrequency with uniqueness.[14]
>
> (2) [A]pplication of the product rule necessarily falls short of establishing unique individualization. The product of probabilities greater than zero always yields a value greater than zero. The probabilistic approach, therefore, always leads to the conclusion that a source other than the suspected individual or object might exist.[15]
>
> (3) The claim of unique individuality cannot be proven with samples . . . . "It is impossible to prove any human characteristic to be distinct in each individual without checking every individual . . . ." Anything less results in probability statements rather than conclusions of absolute specificity and absolute identification.[16]

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[12] *See, e.g.*, D.H. KAYE ET AL., *supra* note 10; 4 MODERN SCIENTIFIC EVIDENCE: THE LAW AND SCIENCE OF EXPERT TESTIMONY, *supra* note 10, at 276-77; Mnookin, *supra* note 10, at 127-29.

[13] Michael J. Saks & Jonathan J. Koehler, *The Individualization Fallacy in Forensic Science Evidence*, 61 VAND. L. REV. 199 (2008).

[14] *Id.* at 205.

[15] *Id.* at 209 (footnote omitted).

[16] *Id.* at 211 (footnote omitted). After asserting that sampling is incapable of proving uniqueness, the first sentence adds that this is "especially" so for "samples that are a tiny proportion of the relevant population." *Id.*

> (4) [A]s Karl Popper famously explained, it is logically impossible to prove a hypothesis by accumulating positive instances. The hypothesis, "all swans are white," remains unproven, even after a large number of sightings of white swans, because the sighting of a single black swan would disprove it. Similarly, the hypothesis that no two objects are indistinguishably alike cannot be proven true from an accumulation of observations in which different object sources produce distinctive markings.[17]
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> (5) Even a very large number of pairwise, case-by-case comparisons made by individual examiners would not provide a satisfactory method for testing the object uniqueness claim.[18]

Although I agree with the critique of a great deal of forensic science testimony, to the extent that these statements imply that, even in principle, science cannot establish the uniqueness of objects, I am dubious. In addition, individualization—the conclusion that "this trace came from this individual or this object"—is not the same as, and need not depend on, the belief in universal uniqueness.[19] Consequently, there are circumstances in which an analyst reasonably can testify to having determined the source of an object, whether or not uniqueness is demonstrable. Part I of this essay shows why the arguments for radical skepticism of uniqueness are not convincing. Part II explains the distinction between individualization and uniqueness. It explicates what I believe to be the real individualization fallacy—the putatively sharp dichotomy between class and individual characteristics. Part III applies these ideas to courtroom testimony and argues that a variety of courtroom explanations of the meaning of a match should be permissible.

I. PROVING UNIQUENESS

A. Metaphysics

If all that a criminalist can say is that, in some untestable ways, no two objects are the same, then the testimony should be excluded as irrelevant and as not constituting specialized "knowledge" within the meaning of

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17 *Id.* at 212 (footnotes omitted).

18 *Id.*

19 On a more restricted meaning of "individualization" in forensic science, see, for example, John I. Thornton & Joseph L. Peterson, *The General Assumptions and Rationale of Forensic Identification*, *in* 4 MODERN SCIENTIFIC EVIDENCE: THE LAW AND SCIENCE OF EXPERT TESTIMONY, *supra* note 10, at 1, 11.

Rule 702 of the Federal or Uniform Rules of Evidence.[20] Courtroom claims of individuality, however, necessarily have to do with measurable characteristics that can exhibit unequivocal differences and similarities.[21] For example, in 1992, a committee of the National Academy of Sciences (the "NAS") recommended that "[c]ourts should take judicial notice of [the] scientific underpinnings of DNA typing"—including the fact that "[e]ach person's DNA is unique (except that of identical twins) . . . ."[22] Although we lack the technology to generate error-free sequences of the more than six billion base pairs that constitute diploid human genomes, in principle, the claim of individuality can be refuted by a much improved sequencing experiment that establishes perfect congruence in two individual genomes. The NAS committee's individualization hypothesis—which is standard fare in human genetics—could be wrong, but it is not metaphysical.[23]

B. The Product Rule and Nonzero Probabilities

Saks and Koehler's second point is that uniqueness is beyond the realm of proof because "[t]he product of probabilities greater than zero always yields a value greater than zero. The probabilistic approach, therefore, always leads to the conclusion that a source other than the suspected individual or object might exist."[24]

This argument proves too much. If the problem is simply that another source *might* exist, then the fallacy infects all scientific research and testimony. There is always some nonzero probability of an erroneous conclusion. Ohm's law

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[20] *Cf.* D.H. Kaye, *On "Falsification" and "Falsifiability": The First* Daubert *Factor and the Philosophy of Science*, 45 JURIMETRICS J. 473 (2005) (discussing the importance and meaning of falsifiability for scientific knowledge).

[21] *See, e.g.*, Michael G. Koot et al., *Radiographic Human Identification Using Bones of the Hand: A Validation Study*, 50 J. FORENSIC SCI. 263, 263-64 (2005) (suggesting that "skeletal features formed in late childhood remain unique throughout life" on the basis, in part, of a previous analysis of 40 pairs of hand radiographs of same-sex, identical twins for which "there were, in every instance, some features which made it possible to distinguish the hand and wrist bones of one person from those of his or her own twin"). This limited study falls woefully short of demonstrating uniqueness, but the logic of looking at identical twins for differences is sound.

[22] NAT'L RESEARCH COUNCIL COMM. ON DNA TECH. IN FORENSIC SCI., DNA TECHNOLOGY IN FORENSIC SCIENCE 23 (1992) [hereinafter NRC 1992].

[23] In describing certain claims of uniqueness as "not metaphysical," I am responding to "the impression that metaphysics is a study that somehow 'goes beyond' physics." Peter van Inwagen, *Metaphysics*, *in* STANFORD ENCYCLOPEDIA OF PHILOSOPHY (2007), http://plato.stanford.edu/entries/metaphysics/.

[24] Saks & Koehler, *supra* note 13, at 209.

might not be exactly right, or it might break down tomorrow, but electrical engineers can safely assume that it is absolutely true.[25] Returning to forensic science, was it fallacious for the 1992 NAS committee to represent that an individual's full genome is unique? A researcher applying standard statistical reasoning would reject the hypothesis of duplication vis-à-vis the alternative hypothesis of uniqueness when the probability of duplication in the population is small enough. A second NAS committee suggested that "[w]ith an increasing number of loci available for forensic analysis, we are approaching the time when each person's profile will be unique (except for identical twins and other close relatives)."[26] Its 1996 report distinguished between specific and general claims of uniqueness. A specific profile might be unique: "Suppose that, in a population of *N* unrelated persons, a given DNA profile has probability *P*. The probability (before a suspect has been profiled) that the *particular* profile observed in the evidence sample is not unique is at most *NP*."[27] A small probability *NP* indicates that the one profile under consideration is likely to be unique within a population that contains as many as *N* unrelated people. This is uniqueness conditioned on a given genotype.

General uniqueness refers to all the profiles in the population. "A lower bound on the probability that *every* person is unique depends on the population size, the number of loci, and the heterozygosity of the individual loci."[28] With some simplifying assumptions, the probability of this event also can be estimated. "Neglecting population structure and close relatives, 10 loci with a geometric mean heterozygosity of 95%

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[25] In their rejoinder in this issue of the *Law Review*, Professors Koehler and Saks question whether Ohm's law (as opposed to say, the subsequent example of the laws of electromagnetism) is a good illustration of the common practice of expressing textbook knowledge as established scientific fact. Jonathan J. Koehler & Michael J. Saks, *Individualization Claims in Forensic Science: Still Unwarranted*, 75 BROOK. L. REV. 1187, 1203-04 (2010). They are correct in criticizing this first example. More dubious, however, is their insistence that "[t]he implication is that even if forensic examiners can't be 100% sure of their ability to individualize, they are safe in proceeding on the assumption that their individualization conclusions are absolutely true." *Id.* at 1203. Whether it is safe to accept any scientific statement obviously depends on its foundation. *See infra* note 45. As the next sentence in the text and the larger discussion plainly indicate, the only implication of these examples is that, in appropriate circumstances, statements of uniqueness (such as the textbook claims about human genomes) could be accepted as true despite a nonzero probability that they are false.

[26] NAT'L RESEARCH COUNCIL COMM. ON DNA FORENSIC SCI., AN UPDATE, THE EVALUATION OF DNA EVIDENCE 161 (1996) [hereinafter NRC 1996].

[27] *Id.*

[28] *Id.*

give a probability greater than about 0.999 that no two unrelated people in the world have the same profile."[29]

For Saks and Koehler, however, no probability of duplication is small enough to warrant an opinion that DNA or anything else is unique. Thus, they reject the reasoning that a "probability of two individuals having the same fingerprint is one out of 1×10^{60} . . . is so small as to exclude the possibility of any two individuals having the same fingerprints."[30] They are correct, but only in the trivial sense that every event with a nonzero probability is a "possibility." $P = 10^{-60}$ is supposed to be the probability that two randomly selected people will have matching fingerprints. Although I doubt the accuracy of the estimated match probability,[31] the allegedly "faulty logic"[32]—the move from $P = 10^{-60}$ for the probability of a match to a randomly selected pair to zero for the probability of a match for all possible pairs—is defensible. Suppose that the world's population (N) is seven billion. The number of distinct pairs of people is $N(N - 1)/2$, which is on the order of 10^{19}. Even for this many comparisons, when each has only a probability of 10^{-60} of being the same, the chance of one or more identical fingerprints in the world's population is about 10^{-41}.[33] Technically, this

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[29] *Id.* The computation, "an application of the 'birthday problem' with unequal probabilities," can be found in appendix 5C of the report. More STR loci (the type currently used in DNA identification) would be required to achieve the same probability of uniqueness. *See id.* at 165; *see also* KAYE ET AL., *supra* note 10, § 12.5.3.

[30] Saks & Koehler, *supra* note 13, at 203 (quoting RICHARD SAFERSTEIN, CRIMINALISTICS: AN INTRODUCTION TO FORENSIC SCIENCE 73 (9th ed. 2007)).

[31] If we truly could believe that the chance of the fingerprints of any two different people matching were 10^{-60}, we could—and should—believe in the uniqueness of fingerprints. Whether fingerprint examiners reliably can differentiate latent prints at the level of detail needed to give rise to probabilities such as 10^{-60} is obviously another story (and not a very believable one). *See generally* David H. Kaye, *From Snowflakes to Fingerprints: A Dubious Courtroom Proof of the Uniqueness of Fingerprints*, 71 INT'L STAT. REV. 521, 524 (2003) (criticizing an unpublished study by an FBI contractor introduced by the Department of Justice and relied on by federal courts to show "that the probability of finding two people with identical fingerprints was one in ten to the ninety-seventh power [and] that the probability of finding two different, partial fingerprints to be identical was one in ten to the twenty-seventh power."); *see also* Christophe Champod, *Fingerprint Examination: Towards More Transparency*, 7 L., PROBABILITY & RISK 111, 113 (2008) ("Systematic research on the selectivity of fingerprint features [indicates] that even very limited configurations of fingerprint minutiae can provide . . . match probabilities on the order of 1 in a billion, even without considering the statistical contribution of level 1 features (general pattern, ridge counts, etc.) or other fingerprint features if available.").

[32] Saks & Koehler, *supra* note 13, at 204.

[33] Intuitively, if each comparison has the same tiny probability P of producing a match and we have made n comparisons, then the probability of at least one match is close to nP. *See* Frederick Mosteller, *Understanding the Birthday Problem*, 55 MATH. TEACHER 322 (1962) (eqn. 7), *reprinted in* SELECTED PAPERS OF FREDERICK MOSTELLER

probability is greater than zero, but that mathematical truism hardly makes it fallacious to exclude as totally unrealistic the thought of a matching fingerprint from someone else. It is not a fallacy to infer uniqueness (both specific and general) when the match probability P is immensely smaller than the reciprocal of the size of a population of objects, every one of whose members has the small probability P of matching.[34]

Thus, the problem with using probability theory to demonstrate uniqueness is not that the probability of duplication always exceeds zero. The difference might be too small to matter. Such demonstrations are generally unconvincing because it is so hard to establish that the models are sufficiently realistic and accurate to trust the computed probabilities. But sometimes probabilities *are* negligible. Just think about the chance that you would suffocate because all the nearby molecules of oxygen in the room would happen to move to the other half of the room. A few simple assumptions and a bit of statistical mechanics demonstrate that the possibility need not worry us.

C. Direct Testing (Sampling)

Saks and Koehler's remaining arguments (3 through 5) boil down to the claim that sample data cannot establish the *exact* proportion of an entire population that shares a given characteristic. Uniqueness means that the proportion of objects with the given feature in the whole population of size N is exactly $1/N$. Yet, no matter how close the sample proportion comes to $1/N$, the next sample datum could establish that the population proportion is $2/N$ or more.

Again, this is true but not indicative of faulty reasoning. Certainly, there are reasons to distrust the "it hasn't happened yet" theory of uniqueness. *Fallacy* cogently explains the limitations of unsystematic, "pairwise, case-by-case comparisons made by individual examiners,"[35] and it points to

349, 351 (Stephen E. Fienberg & David Caster Hoaglin eds., 2006). For $n = 10^{19}$ and $P = 10^{-60}$, this gives 10^{-41}. (A more precise calculation gives a value with the same order of magnitude.) Since the probability of the world's population having distinct fingerprints differs from 1 by a mere 10^{-41}, for all practical (and impractical) purposes, fingerprints are globally unique—that is, if people are assigned fingerprint patterns by a process that is equivalent to randomly sampling an infinite population in which the 10^{60} distinct patterns are uniformly distributed.

[34] *See* DAVID J. BALDING, WEIGHT-OF-EVIDENCE FOR FORENSIC DNA PROFILES 148 (2005).

[35] *Id.*

contradictory reports of matches in trace evidence coming from different individuals.[36] These are reasons enough for skepticism, but the white swans and the insistence that only a census will do the job makes it look as if the examiners are pursuing a line of proof that is *logically* incapable of supporting the desired inference. The flaw is not with the logic. It is with the data.[37] The number of comparisons required to prove uniqueness by brute empirical force (that is, to make the normal statistical inference from a sample to a population) is surprisingly larger than one might think.[38] It takes a random-match probability whose reciprocal is orders of magnitude larger than the population of objects to make uniqueness almost certain.[39]

But this difficulty with a direct empirical proof is not tantamount to Popper's realization that universal laws cannot be proved to a logical certainty by simple induction.[40] Modern science is full of universal laws. The laws of electromagnetism, for instance, remain unproven and unprovable in Popper's logical sense.[41] The only universal propositions that can be proven to a certainty are deductively valid ones, such as the theorem that all whole numbers that end in an even digit are divisible by two. No experimentation is required to test this law. In contrast, no matter how many times scientists observe that a change in the magnetic flux in a coil or wire induces a voltage, they cannot be certain that it will happen the next time. In principle, a single experiment with no change in voltage would disprove Faraday's Law.[42]

In Popper's framework, the repeated failure of forensic examiners to find "two sets of markings produced by different

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[36] *Id.* at 213.

[37] *Fallacy* can be read this way as well. *See id.* ("As the size of a comparison database becomes larger, the object uniqueness hypothesis is subjected to an increasingly tough empirical test. If, under these circumstances, scientists still do not find indistinguishably similar matches produced by different objects, then object uniqueness becomes a more credible theory.").

[38] *Id.* at 203-04 (describing a version of the "birthday problem" in probability theory).

[39] *Id.* at 148.

[40] Saks & Koehler, *supra* note 13, at 212.

[41] *See id.*

[42] *Id.* In practice, a single experiment would not suffice. Effects that cannot be replicated are likely to be the result of experimental error. Because data gathering is fallible, a single sighting of a black swan might not be enough to disprove the hypothesis that all swans are white. The observer might have been mistaken about the bird (it was not really a swan) or its true color (it had flown through a cloud of soot).

sources that are indistinguishable from each other"[43] lends some support to the generalization that all different sources produce distinguishable markings. His swan example merely shows that we never can be absolutely certain of any generalization. If that is all that the individualization fallacy consists of, then all induction is fallacious. "[T]he faulty logic that equates infrequency with uniqueness" is not a *logical* fallacy.[44]

The threshold issue for the law, therefore, is not the impossibility of falsifying universal propositions. It is whether criminalists are warranted in believing, as a practical matter, that certain universals (everyone has different fingerprints, everyone other than identical twins have different genomes, every face is unique, and so on) are true.[45] If these beliefs are warranted, and if criminalists can measure the features that give rise to these differences with sufficient accuracy, then their claims to be able to individualize are sound. If these beliefs outstrip available theory and knowledge, as Saks and Koehler claim and as the NAS committee agrees (except, it

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[43] *Id.*

[44] *Id.* at 205. A fallacy in logic is a faulty *form* of reasoning, not merely a conclusion that might be faulty. In a system of *inductive* logic, there is no formal fallacy in generalizing from repeated observations. Sample data permit inferences about population parameters—including the parameter that a characteristic occurs only once in the population. Naturally, there is a nonzero risk of error in accepting any inference about any population parameter. "The gap between the sample and the population will always require a leap of faith." PHILLIP I. GOOD & JAMES W. HARDIN, COMMON ERRORS IN STATISTICS (AND HOW TO AVOID THEM) 74 (2003). The only issue worth debating is the length of the leap.

[45] Koehler and Saks read this sentence and personal correspondence not intended for publication as indicating that I use the words "establish the truth" to mean, in their words, "something . . . akin to a strong personal belief that has a solid foundation in data." Koehler & Saks, *supra* note 25, at 1196 n.35. In contrast, they define "establish the truth" to mean "that all point predictions other than the target prediction have been ruled out by the data," and they "simply do not accept [my] weakened definitional form of 'establish the truth.'" *Id.* This characterization prompts a brief clarification. Clearly, the warrant for a scientific belief or statement is not the strength of the conviction of the scientist who holds it. Neither does the warrant lie in vague allusions to "training and experience." *Id.* at 1197. Rather the question is whether the proposition has a secure foundation in data and theory. For most (and arguably all) forensic identification techniques, this foundation for strong claims of global uniqueness is missing. However, I do not embrace the rigid "definitional" view that a census is required to establish the likely truth (and what other kind of truth is there in science?) with respect to "all point predictions other than the target prediction." *Id.* at 1196 n.35. For example, if the probability of duplication really were as small as 10^{-41}, *see supra* note 33, then the competing hypotheses effectively would have been ruled out, and the belief in the "target prediction" would be warranted.

seems, for DNA evidence),[46] then the beliefs are either premature or false.

II. INDIVIDUALIZATION WITHOUT UNIQUENESS

Part I distinguished between claims of general uniqueness (no two pairs anywhere match) and specific uniqueness (no other object matches the particular trace seen in the case at bar). I argued that although general uniqueness is much more difficult to establish, an inductive proof of it is not beyond the capacity of science.[47]

That said, the fact that general uniqueness is so hard to prove makes the traditional reasoning of many forensic-identification practitioners suspect, if not dogmatic. Rather than conduct the difficult empirical research that would be needed to establish that these objects or impressions are all uniquely identifiable, they postulate general uniqueness and use it to infer that a match then proves that a hair, a fiber, or the mark must have originated from the source that it matches. In the absence of proof of the premise of general uniqueness, however, this reasoning is insecure and might well be denominated an individualization fallacy.

Furthermore, the widely used distinction between "class" and "individual" characteristics[48] encourages this individualization fallacy. The theory is that a large number of objects share class characteristics (such as shoe size), while other features (such as the scratches on the sole of a shoe) are individual characteristics. This definitional system promotes such tautologies as "[t]he uniqueness of an object may be established by an ensemble of individual [as opposed to class] characteristics."[49] Blithely postulating uniqueness in this manner, forensic science textbooks contain advice such as the following: "A positive identification is a conclusion that a

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[46] NRC 2009, *supra* note 7, at 87 ("[N]o forensic method other than nuclear DNA analysis has been rigorously shown to have the capacity to consistently and with a high degree of certainty support conclusions about 'individualization' . . . .").

[47] Additional analysis of conceptions of uniqueness and their relationship to individualization can be found in David H. Kaye, *Identification, Individualization, and Uniqueness: What's the Difference?*, 8 L., PROBABILITY & RISK 85 (2009) (distinguishing between "universal individualization" and "local individualization," between "general uniqueness" and "special uniqueness," and between "universal uniqueness" and "local uniqueness").

[48] *See, e.g.*, Thornton & Peterson, *supra* note 19, § 29:7, at 8 (describing the distinction and its use in the process of comparison).

[49] *Id.*

particular shoe, and no other shoe, made the crime scene impression. No minimum number of individual identifying characteristics is needed to establish a positive identification."[50] It would be better to eschew the class-individual distinction in favor of the realization that all characteristics are class ones. What matters is the size of the class. Some features are more discriminating than others. Shoe size, for example, is *known* to be shared by many objects. It can be extremely valuable and easily used in excluding a given individual or object from further investigation.[51] (If the shoe does not fit, you must acquit.) It also has rather modest probative value in showing that a specific individual or object is the source of the trace evidence. (Even if the shoe fits, you need not convict.) Other characteristics are far more variable. These supposedly "individual" characteristics pertain to a much smaller class (a class of one in the limit). As such, they have much greater probative value in establishing an association between two items than do the "class" characteristics that define a larger class.[52]

But even if the traditional class-individual distinction begs the question of global uniqueness, a scientifically defensible opinion as to individualization is still attainable in some situations.[53] This is the case for two reasons. First, testimony that a particular item is unique is a much weaker claim than testimony that all items are unique. Second, contrary to the loose or elliptical statements of many forensic scientists,[54] individualization does not presuppose or imply even conditional uniqueness in a finite set. Suppose that a man suspected of stealing a jewel on a cruise ship has a fingerprint pattern that matches the latent print on the drawer from which the jewel was stolen and that there were 2500 people on board the ship at the time. Two thousand of them are fingerprinted, and only one is found to match. The other 500 people cannot be located. If the quality of the prints is high, the probability of a match to any of the 500 missing people could be

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[50] William J. Bodziak, *Forensic Footwear Evidence*, *in* FORENSIC SCIENCE: AN INTRODUCTION TO SCIENTIFIC AND INVESTIGATIVE TECHNIQUES 297, 309 (Stuart H. James & Jon J. Nordby eds., 2003); *see also id.* at 298.

[51] *See e.g.*, Thornton & Peterson, *supra* note 19, § 29:7, at 8.

[52] This perspective is congruent with Saks and Koehler's emphasis on probability statements. *See* Saks & Koehler, *supra* note 13, at 211.

[53] For a more detailed discussion, see generally Kaye, *supra* note 47.

[54] *E.g.*, Thornton & Peterson, *supra* note 19, § 29:10, at 11 ("Individualization implies uniqueness.").

miniscule. It then would be reasonable to conclude that the fingerprint examiner has identified the one individual who left the print. This is an individualization even though it does not imply that no one else on the earth has the same prints.[55]

It might be thought that the cruise-ship example is contrived, but the point is more general. Following the invitation of the 1996 NRC report, FBI examiners, focusing on conditional uniqueness, have testified to source identifications in cases for which they consider the duplication probability for a particular profile in the United States population to be quite small.[56] The 2009 report also seems comfortable with such testimony.[57] Yet, the Saks-and-Koehler argument that any nonzero probability makes an assertion fallacious applies to DNA,[58] and *Fallacy* brands an opinion that a defendant is the source of a DNA sample as "an evasion" of science.[59]

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[55] *Cf.* IAN W. EVETT & BRUCE S. WEIR, INTERPRETING DNA EVIDENCE: STATISTICAL GENETICS FOR FORENSIC SCIENTISTS 239 (1998) ("The issue for the forensic scientist is not 'Is this profile unique' . . . but 'Is there sufficient evidence to demonstrate that they originate from the identical source.'"). Koehler and Saks object to using the word "individualization" to denote such testimony. They write that

> The definition that Professor Kaye relies on reduces individualization to a subjective belief that is bolstered by evidence that falls far short of sufficient proof for this extreme claim. The difference between individualization as it is commonly understood and the definition offered by Professor Kaye is the difference between claiming that Alberto is the tallest man in the world because his measured height is greater than every other person in the world, and claiming that Alberto is the tallest man in the world either because an insufficiently tested theory assumes he is or because we have not seen anyone taller among those we have looked at.

Koehler & Saks, *supra* note 25, at 1201. This seems exactly backwards. Most critics maintain that it is the current definition of "individualization"—the "commonly understood" one described by Koehler and Saks—that produces testimony of identification based on subjective determinations that lack rigorous support. Relying on "subjective belief" and studies that fall "far short" is not a consequence of defining "an individualization" as a determination that one and only one individual is the source of the trace evidence in the case at bar. Similarly, this easily understood definition does not commit one to unsubstantiated claims about Alberto's height or to "personal feelings or hunches." *Id.* Neither Professors Koehler and Saks nor the last generation of forensic scientists can, by definitional fiat, confine the words "individualize" or "identify" to assertions based on the postulate of global uniqueness.

[56] Roberto Suro, *DNA Now Used to Make Specific Identification; FBI Calls Lab Match "Major Breakthrough"*, WASH. POST, Nov. 13, 1997, at A4. Courts have upheld these source attributions despite defense arguments that untested relatives might match or that the laboratory could have erred. United States v. Davis, 602 F. Supp. 2d 658, 683-85 (D. Md. 2009); Young v. State, 879 A.2d 44, 56 (Md. 2005).

[57] *See supra* note 46.

[58] They also describe a different fallacy with regard to DNA evidence, exemplified by the prosecutor's closing argument in *People v. Simpson* that if the random-match probability is one in 57 billion, the population must exceed 57 billion for a duplicate to exist. Saks & Koehler, *supra* note 13, at 203. As they cogently explain,

In sum, a well founded and extremely tiny random-match probability indicates that, even if some other pairs of objects do match, the match at issue is not merely a coincidence; rather, it is a true association to a single source.[60] In appropriate cases, therefore, it is ethical and scientifically sound for an expert witness to offer an opinion as to the source of the trace evidence. Of course, it would be more precise to present the random-match probability instead of the qualitative statement, but scientists speak of many propositions that are merely highly likely as if they have been proved. They are practicing rather than evading science when they round off in this fashion.

This is not to say that such testimony is the best method of communicating the test results to a lay jury. There is a cogent argument that such opinions are not helpful when more precise indications of probative value are available to permit the jury to reach its own conclusion about the source of the trace evidence.[61] At this point, however, we are moving from what is scientifically acceptable to what is legally optimal. This

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the mere fact that the expected number of individuals on Earth with a specific DNA type is less than the world's population does not mean that there can be no duplication. *Id.* At some point, however, the probability of duplication becomes so small that it is fair to dismiss this hypothesis as implausible. *Id.* Existing random-match probabilities for DNA evidence may have reached the point where an expert can opine that a profile is unique to an individual (and any identical twins). *See, e.g.*, People v. Nelson, 185 P.3d 49, 52 (Cal. 2008) ("The prosecution presented evidence that the odds that a random person unrelated to defendant . . . could have fit the profile of some of the crime scene evidence are one in 930 sextillion (93 followed by 22 zeros)."); State v. Bloom, 516 N.W.2d 159, 160 n.2 (Minn. 1994) ("Dr. [Daniel] Hartl, if permitted, would further testify at trial that in fact there was a nine-loci match and that in his opinion the nine-loci match constituted 'overwhelming evidence that, to a reasonable degree of scientific certainty, the DNA from the victim's vaginal swab came from [defendant], to the exclusion of all others.'"). However, one should take all the zeroes in the estimates like those in *Nelson* with a proverbial grain of salt. *See, e.g.*, Peter J. Bickel, *Discussion of "The Evaluation of Forensic DNA Evidence"*, 94 PROC. NAT'L ACAD. SCI. 5497 (1997) ("[M]any scientists would not agree that the modeling assumptions . . . can be verified to hold so precisely that the match probabilities can be ascertained to an order of 1 in one billion.").

[59] Saks & Koehler, *supra* note 13, at 218 n.94. In doing so, they part company with the statistician whose exposition of "the uniqueness fallacy" motivates their putative fallacy. *See* BALDING, *supra* note 34, at 148 (describing as "reasonable" the judgment that a characteristic is unique when it is "several orders of magnitude smaller" than the random match probability).

[60] This inference assumes that other hypotheses (handling error, fraud, etc.) also have been eliminated. *See* KAYE ET AL., *supra* note 10, § 12.3.1.

[61] *See, e.g.*, EVETT & WEIR, *supra* note 55, at 241 ("Once we assign a [probability] then we must recognize that we have given the court something that they may choose to work with or without our assistance. Certainly, the idea that the scientist has some particular power to take that number and take a step equivalent to the Stoney 'leap of faith' is misconceived.").

argument should be addressed on its merits and not foreclosed as an unscientific option.

III. PRESENTING LIMITED KNOWLEDGE IN COURT

The NAS committee recommends that "[f]orensic reports, and any courtroom testimony stemming from them, must include clear characterizations of the limitations of the analyses, including measures of uncertainty in reported results and associated estimated probabilities where possible."[62] Saks and Koehler likewise implore criminalists to present "humbler, scientifically justifiable, and probabilistic conclusions."[63] But neither group presents any serious analysis of whether numerical presentations are preferable to arguably more comprehensible qualitative ones, and what to do when probabilities are not at hand is open to debate. Inasmuch as there is a growing literature on these matters, I shall content myself with commenting on a few specifics, mentioning a variety of approaches, and pleading for eclecticism.

A. *"Consistent-with" Testimony*

Fallacy calls on criminalists who report that two samples are "a match" or "consistent" to add that this "does not require a conclusion that the patterns share a common source."[64] To hammer home the point that other people or objects might match, *Fallacy* asks the witnesses to state that "in finding that two patterns match, they have placed the suspect object or person in a pool of *one or more* objects that match the evidentiary marks."[65] The take-home message would be, "we have a match, but we cannot say how many other people or things would match."

This "appropriate clarity and restraint" seems comparable to the weak presentation recommended by an NAS committee that reviewed the foundations for testimony about

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[62] NRC 2009, *supra* note 7, at 21-22.

[63] Saks & Koehler, *supra* note 13, at 219.

[64] *Id.* at 216; *cf.* NAT'L RESEARCH COUNCIL COMM. ON SCIENTIFIC ASSESSMENT OF BULLET LEAD ELEMENTAL COMPOSITION COMPARISON, FORENSIC ANALYSIS: WEIGHING BULLET LEAD EVIDENCE 110 (2004) [hereinafter NRC 2004] ("The conclusions in laboratory reports should be expanded to include the limitations of compositional analysis of bullet lead evidence. In particular, a further explanatory comment should accompany the laboratory conclusions to readily portray the limitations of the evidence.").

[65] Saks & Koehler, *supra* note 13, at 216 (emphasis added).

the concentrations of various elements in bullet lead.[66] The committee's findings brought to a halt this use of analytical chemistry to associate bullet fragments with boxes of ammunition.[67] The committee had proposed limiting the formerly exuberant statements of analysts to

> testimony that bullets from the same compositionally indistinguishable volume of lead (CIVL) are more likely to be analytically indistinguishable than bullets from different CIVLs. An examiner may also testify that having . . . evidence that two bullets are analytically indistinguishable increases the probability that two bullets come from the same CIVL, versus no evidence of match status.[68]

In colloquial terms, the committee recommended testimony to the effect that it is more likely to find a match when bullets come from the same blob of molten lead than when they come from different blobs. Such statements might reasonably be made with respect to other forms of trace evidence. A cautious analyst could report that similarities in head hairs are more likely when the hairs come from the same scalp than when they come from different scalps.[69]

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[66] *See* NRC 2004, *supra* note 64.

[67] Press Release, FBI Nat'l Press Office, FBI Laboratory Announces Discontinuation of Bullet Lead Examinations (Sept. 1, 2005), *available at* http://www.fbi.gov/pressrel/pressrel05/bullet_lead_analysis.htm (last visited Mar. 2, 2009).

[68] NRC 2004, *supra* note 64, at 112.

[69] In statistical jargon, this is a statement that the likelihood ratio or Bayes' factor for the evidence exceeds one. *See* KAYE ET AL., *supra* note 10, §§ 12.4.2, 12.4.3. The 2009 NRC report implicitly endorses the use of more sharply defined likelihood ratios, at least for written reports. The report states that:

> Although some disciplines have developed vocabulary and scales to be used in reporting results, they have not become standard practice. This imprecision in vocabulary stems in part from the paucity of research in forensic science and the corresponding limitations in interpreting the results of forensic analyses. Publications such as Evett et al., Aitken and Taroni, and Evett provide the essential building blocks for the proper assessment and communication of forensic findings.

NRC 2009, *supra* note 7, at 186 (citations omitted). The three authorities cited propose verbal scales for characterizing likelihood ratios. Two of them offer the following table for "reporting the value of the support of the evidence" (where V is the applicable likelihood ratio):

$1 < V \leq 10$	Limited evidence to support
$10 < V \leq 100$	Moderate evidence to support
$100 < V \leq 1000$	Moderately strong evidence to support
$1000 < V \leq 10000$	Strong evidence to support
$10000 < V$	Very strong evidence to support

Neither of these approaches—the one-or-more-out-there statement nor the makes-it-more-likely assertion—clarifies *how* probative the evidence is. With bullet-lead comparisons, the jury might well be unduly impressed even with the modest statements of the results of inductively coupled plasma optical emission spectroscopy, which is the technique that gives the concentrations of the elements. This danger seems less when it comes to more mundane matters like the visual appearance of toolmarks and hairs. Thus, even though there is some risk of prejudice, this risk seems worth running with most forms of trace evidence, at least when compared with the alternative of entirely depriving the jury of a fair description of a relevant scientific finding.[70]

The proposals to scale back forensic science testimony reflect the view that an expert testifies not as an advocate, but as the representative of a learned profession, conveying its knowledge, along with its limitations, to the jury. A neutral expert not seeking to overawe the jury would express the important limitations up front. This is an attractive ideal but difficult to realize in practice. Attorneys often urge expert witnesses to suppress all qualifications and reservations—the joke about the desirability of the "one-handed economist," the one who won't say "on the other hand . . . ," comes to mind.[71] Whether criminalists can stake out and preserve the independence to use both hands is far from obvious. Perhaps the NAS recommendation for an enforceable code of ethics would provide the requisite backbone. Although I am not sure that the law needs to require the expert to express every caveat in direct examination, much would be gained if the legal system or the forensic science profession insisted on written laboratory reports containing all the cautions. An analyst who holds these back on direct examination should be easy to impeach with his or her own report. In addition, a cautionary instruction from the judge might be of assistance.[72]

COLIN AITKEN & FRANCO TARONI, STATISTICS AND THE EVALUATION OF EVIDENCE FOR FORENSIC SCIENTISTS 107 tbl.3.10 (2d ed. 2004) (citing IW Evett, G Jackson, JA Lambert & S McCrossan, *The Impact of the Principles of Evidence Interpretation on the Structure and Content of Statements*, 40 SCI. & JUSTICE 233, 236 (2000)).

[70] *See* KAYE ET AL., *supra* note 10, § 12.5.1.

[71] *Bartlett's* tentatively attributes the remark to President Truman. CLIFTON FADIMAN, & ANDRÉ BERNARD, BARTLETT'S BOOK OF ANECDOTES 542 (2000).

[72] *See, e.g.*, NRC 1996, *supra* note 26, at 197.

B. Rarity and Numerical Testimony

Let us assume that the jury gets the message—a match is not an absolute identification. Can the criminalist do something more to explain its probative value? Obviously, this depends on what is known about the frequency of the identifying trait in the relevant population. Are the features very common, rarely seen, or somewhere in between? There will be occasions when such qualitative testimony is reasonable.[73] When no duplicates have been seen after systematic, careful, and (one hopes) representative studies, a criminalist determined to refer to uniqueness might even assert that a trait is either unique or very rare in a population.

Numerical estimates should generally be possible, but not necessarily from the kind of research and modeling that Saks and Koehler describe. *Fallacy* suggests that forensic scientists can devise probability models for complex patterns of trace-evidence characteristics, sample the frequency of each characteristic in relevant populations, verify the independence of the characteristics, and multiply to arrive at random-match probabilities for consumption by juries.[74] This will not be easy. Unlike nuclear DNA evidence, which both the 2009 report and *Fallacy* present as a model for all of forensic science, other patterns can be more complex, can vary substantially by locale, or can change over time.[75]

Perhaps a more useful paradigm will turn out to be mitochondrial DNA sequences. These are used in cases where sample quantities are minute or the DNA is highly degraded.[76] Mitochondrial DNA, which is found only in cytoplasm, reproduces asexually. Therefore, it is inherited from mother to child as a single unit.[77] To give a numerical indication of the frequency of a lineage, the FBI maintains a collection of

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[73] *See* KAYE ET AL., *supra* note 10, § 12.5.2. A related proposal is to describe the strength of the evidence (the likelihood ratio) with phrases such as those listed *supra* note 69. Indeed, an expert witness with adequate information could give qualitative characterizations of both rarity and the likelihood ratio.

[74] Saks & Koehler, *supra* note 13, at 217-18.

[75] Robert D. Koons & JoAnn Buscaglia, *Forensic Significance of Bullet Lead Compositions*, 50 J. FORENSIC SCI. 1 (2005); Saks & Koehler, *supra* note 13, at 217-18.

[76] A small number of human hairs often contain enough mitochondrial DNA for sequencing to succeed. DAVID H. KAYE, THE DOUBLE HELIX AND THE LAW OF EVIDENCE 227-28 (2010).

[77] The father merely contributes half of the nuclear DNA to the fertilized egg cell. *Id.* at 215. The cytoplasm is part of the mother's egg cell. *Id.*

sequences from thousands of cases.[78] It typically reports that the matching sequence in the case at bar has not been seen in this sample.[79] For concreteness, suppose that the sample consists of 7000 sequences. When a defendant's sequence is not in the database (which is the usual situation), one could say that so far it has been encountered one out of 7001 times.[80] There is ample room to argue that this number should not be taken too seriously. It does not come from a random sample, and it might not be representative of the population in the vicinity of the crime.[81] Still, it gives the jury some sense of how rare the sequence is, and jurors should be able to appreciate the limitations of the number, especially when there is discussion of how many other people in the vicinity of the crime might share the sequence.[82]

With a mitochondrial-DNA-sequence database, each new sample is compared to all the previous ones to estimate the match frequency, and we know how many distinct sequences have been observed to date. Estimating the probability of a rare event from case work is trickier, but

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78 *See* State v. Pappas, 776 A.2d 1091, 1104, 1110 n.9 (Conn. 2001); Wagner v. State, 864 A.2d 1037, 1045 n.9 (Md. Ct. Spec. App. 2005); Keith L. Monson et al., *The mtDNA Population Database: An Integrated Software and Database Resource for Forensic Comparison*, 4 FORENSIC SCI. COMMC'NS, Apr. 2002, http://www.fbi.gov/hq/lab/fsc/backissu/april2002/miller1.htm; Deborah Polanskey & Bruce Budowle, *Summary of the Findings of a Quality Review of the Scientific Working Group on DNA Analysis Methods Mitochondrial DNA Database*, 7 FORENSIC SCI. COMMC'NS, Jan. 2005, http://www.fbi.gov/hq/lab/fsc/backissu/jan2005/research/2005research.htm.

79 *See Pappas*, 776 A.2d at 1104.

80 The upper confidence limit of the estimate also could be provided. The FBI does not do this. It quotes the upper bound of a 95% confidence interval above the proportion (0%) of the cases in which the sequence was previously seen. *Id.* at 1110 & n.11 (Conn. 2001). This is the "counting method" recommended in NRC 1992, *supra* note 22, at 75, to avoid any argument over the accuracy of multiplying individual probabilities with nuclear DNA.

81 *See, e.g.*, Frederika A. Kaestle et al., *Database Limitations on the Evidentiary Value of Forensic Mitochondrial DNA Evidence*, 43 AM. CRIM. L. REV. 53, 74-75 (2006).

82 Previous research by Koehler shows that when the expected number of matching individuals in a population is substantial, the "pool" formulation benefits defendants relative to the match-probability method. Jonathan J. Koehler, *The Psychology of Numbers in the Courtroom: How to Make DNA-Match Statistics Seem Impressive or Insufficient*, 74 S. CAL. L. REV. 1275, 1280-81 (2001). But the "pool" method also can lead to disputes over the size of the relevant population, *see* David H. Kaye, *Rounding Up the Usual Suspects: A Legal and Logical Analysis of DNA Database Trawls*, 87 N. CAR. L. REV. 425, 431 (2009) [hereinafter *Trawls*], and to fractional numbers of people, which could be difficult for jurors to understand. KAYE ET AL., *supra* note 10, § 12.4.1(2). When presented with both "pool" numbers and the match frequency, mock jurors were not overwhelmed by the mitochondrial DNA evidence. David H. Kaye et al., *Statistics in the Jury Box: Do Jurors Understand Mitochondrial DNA Match Probabilities?*, 4 J. EMPIRICAL LEGAL STUD. 797 (2007).

similar reasoning applies—and shows that failing to find any matches in a large number of comparisons of different objects can be quite informative.[83] There are various methods for estimating the probability of an event that has occurred zero times in a sample of n observations—the "zero-numerator" problem.[84] Applying the simplest of these, if a laboratory documented a zero numerator in 30,000 tests, it could infer a random-match probability of no more than 0.0001.[85]

Naturally, there is a risk that the jury will draw too strong a conclusion from such a probability. This problem can be handled by cautioning the jury against inferring uniqueness or misconstruing the probability as a source probability. In addition, the quality of the estimate depends on the accuracy of the reported fraction of matching comparisons, the conditions under which the matches were made, and the analogy between a random sample and the casework or research sample.

C. Source Testimony

Experts in other fields routinely provide categorical statements. Pathologists opine as to the manner of death, psychologists to competence, and engineers to the cause of product failures. The law of evidence generally allows expert opinion testimony when it is well founded, but under normal relevance rules, existing theory and data on the discernible uniqueness of trace evidence typically are too weak to justify admission of an opinion that a pattern is unique.[86] Contrary to

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[83] In assessing the probative value of a match, the sensitivity needs to be considered as well: How often do matches arise when the objects being compared are one and the same? *See, e.g.*, V.L. Phillips et al., *The Application of Signal Detection Theory to Decision-making in Forensic Science*, 46 J. FORENSIC SCI. 294 (2001).

[84] *E.g.*, J.A. Hanley & A. Lipp-Hand, *If Nothing Goes Wrong, Is Everything All Right? Interpreting Zero Numerators*, 249 J. AM. MED. ASS'N 1743, 1743 (1983); Thomas A. Louis, *Confidence Intervals for a Binomial Parameter After Observing No Successes*, 35 AM. STAT., 154, 154 (1981); Allan R. Sampson & Robert L. Smith, *Assessing Risks Through the Determination of Rare Event Probabilities*, 30 OPERATIONS RES. 839, 840-41 (1982); Robert L. Winkler et al., *The Role of Informative Priors in Zero-Numerator Problems: Being Conservative Versus Being Candid*, 56 AM. STATISTICIAN 1, 1 (2002).

[85] This estimate uses $3/n$ as an approximate upper bound on the probability. B. D. Jovanovic & P. S. Levy, *A Look at the Rule of Three*, AM. STATISTICIAN, May 1997, at 137. The "counting method" proposed for DNA typing, with a confidence coefficient of 0.95, *see supra* note 80, is equivalent to this simple rule.

[86] An expert might still be justified in reporting the reasons for thinking that the match is probative of identity. Statements such as "In my experience, different guns always give rise to different striations on the bullets" could be used in lieu of more precise studies, but unless the expert has meaningful experience in studying

recent federal district court opinions, experts should not be permitted to avoid the limitations in their knowledge simply by qualifying assertions of uniqueness with a fig leaf such as "to a reasonable degree of ballistic certainty."[87]

But what if the record were stronger? As long as there is a nonzero probability of duplication or another swan to consider—as there always will be—such testimony apparently fails *Fallacy*'s exacting standard for statistical proof. As we have seen, however, this austere standard does not comport with normal scientific practice. In the DNA field, scientists have indicated that opinions of general uniqueness[88] or uniqueness of a particular DNA type within some smaller region[89] are or will soon become scientifically acceptable.[90]

To be sure, there is disagreement over how and whether to ascertain a precise value of a probability of uniqueness,[91] and

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mismatches for guns that did not actually produce the striations, undocumented references to "experience" may reveal more about the analyst's state of mind than they do about the state of the world. When testimony is of the "I know it, but neither I nor anyone else has studied it systematically" variety, a strong argument can be made that juries will overvalue the testimony and that exclusion is appropriate to encourage more extensive research.

[87] United States v. Monteiro, 407 F. Supp. 2d 351, 375 (D. Mass. 2006) (holding that "the expert may testify that the cartridge cases were fired from a particular firearm to a reasonable degree of ballistic certainty" even though the accuracy of these judgments is unclear and "the expert may not testify that there is a match to an exact statistical certainty"); *see also* United States v. Mouzone, No. WDQ-08-086, 2009 WL 3617748, at *19-20 (D. Md. Oct. 29, 2009) (recommendations in magistrate's report); United States v. Taylor, 663 F.Supp.2d 1170 (D.N.M. 2009); United States v. Diaz, No. CR 05-00167 WHA, 2007 WL 485967, at *14 (N.D. Cal. Feb. 12, 2007) (firearms toolmarks identification is admissible under *Daubert*, but "[t]he experts may not . . . testify to their conclusions 'to the exclusion of all other firearms in the world.' They may only testify that a particular bullet or cartridge case was fired from a particular firearm to a 'reasonable degree of certainty in the ballistics field.'").

[88] *See* NRC 1996, *supra* note 26; NRC 1992, *supra* note 22; DANIEL L. HARTL & ANDREW G. CLARK, PRINCIPLES OF POPULATION GENETICS 131 (3d ed. 1997) ("Matches at 7 to 9 [VNTR] loci are virtually definitive of identity—barring technical errors in the DNA typing itself (such as mislabeling of blood samples) and except for identical twins."); B.S. Weir, *Discussion of "Inference in Forensic Identification"*, 158 J. ROYAL STAT. SOC'Y A 49 (1995) ("[T]he chance that two unrelated individuals in a population share the same 16-allele [VNTR] profile is vanishingly small, and even for full sibs the chance is only 1 in very many thousands.").

[89] Bruce Budowle et al., *Source Attribution of a Forensic DNA Profile*, FORENSIC SCI. COMMC'NS, July 2000, http://www.fbi.gov/hq/lab/fsc/backissu/july2000/source.htm.

[90] After reviewing this literature, one court agreed that "when a DNA method analyzes genetic markers at sufficient locations to arrive at an infinitesimal random match probability, expert opinion testimony of a match and of the source of the DNA evidence is admissible." Young v. State, 879 A.2d 44, 45 (Md. 2005).

[91] *See* David J. Balding, *When Can a DNA Profile Be Regarded as Unique?*, 39 SCI. & JUSTICE 257, 257 (1999) ("The probability that a defendant's DNA profile is unique in a population of untyped individuals is . . . bounded below by one minus twice the sum of the match probabilities over the population . . . . However, because of the problem of the non-DNA evidence, there seems to be no satisfactory way for an expert

no canon of scientific reasoning demands that experts focus directly on the question of uniqueness.[92] DNA experts can continue with the present regime of giving the incredibly small random-match probabilities that imply uniqueness. They can multiply these numbers by some arbitrary population size and report that in the "pool," some number of people (even a fractional number) would be expected to have the defendant's genotype. But the numbers could be a hair's breadth away from the statement that no unrelated person would be expected to share this profile. Why not, as one astute statistician asks, give "a 'plain English' statement . . . ? For example, perhaps an expert witness could assert that, excluding identical twins and laboratory/handling errors, in his/her opinion the defendant's

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witness to address the question of uniqueness in court."); Bruce Weir, *Are DNA Profiles Unique?*, PROCEEDINGS OF THE NINTH INT'L SYMPOSIUM ON HUMAN IDENTIFICATION 114, 116 (1998), *available at* http://www.promega.com/geneticidproc/ussymp9proc/ ("It is very difficult to arrive at a satisfactory probabilistic or statistical genetic theory which will give the probability that a second person in a population has the same DNA profile as the one featuring in a criminal trial" because of "possible dependencies between loci and between individuals."). *But see* BALDING, *supra* note 34, at 138 ("A calculation of the probability of 'uniqueness' may also provide useful information for courts, proved that a satisfactory way is found to explain the underlying assumptions.").

[92] *Cf.* Saks & Koehler, *supra* note 13, at 218 n.94 ("[O]ffering source identifications at trial for sufficiently low probabilities would not be an implication of the science . . . ."). A scientific working group of the National Commission on the Future of DNA Evidence expressed the idea as follows:

> The statistical basis for individualization is discussed by Evett and Weir (1998, pp. 243-244). The concept of individualization has been supported by Balding (1999). The FBI procedure has been criticized by Weir (1999) and supported by Budowle, Chakraborty, et al. (2000). Whether this, or in fact any statistical procedure for defining individualization is defensible continues to be debated. The procedure provides one way to interpret discriminatory power (a scientific question) in terms of "a reasonable degree of scientific certainty" (a subjective question). It is quite possible that within 5 years or less some such criterion will be accepted by the legal and forensic community, not as a scientifically appropriate statement, but as a practical definition for forensic purposes.

NAT'L COMM'N ON THE FUTURE OF DNA EVIDENCE, RESEARCH & DEV. WORKING GROUP, THE FUTURE OF FORENSIC DNA TESTING: PREDICTIONS OF THE RESEARCH AND DEVELOPMENT WORKING GROUP 25-26 (2000). The committee was explaining that there is no strictly scientific criterion for deciding how small the random-match probability must be to warrant an opinion that a particular genotype is "effectively unique." It stated that:

> Eventually, the probability becomes so small that the profile is effectively unique. The basis for concern would then be whether the techniques are adequate, the chain of custody is intact, the statistical treatment is appropriate, and no errors were made. But how small must such a probability be for a profile to be individualized?

Id.

DNA profile is almost certainly unique in some appropriate population."[93]

Still other modes of presentation have been proposed.[94] My objective is not to argue for any one of them, but only to ask that the issue be decided by examining the ease of presentation, comprehensibility, and scientific defensibility of all of them.

CONCLUSION

Radical skepticism of all possible assertions of uniqueness is not justified. Absolute certainty (in the sense of zero probability of a future contradicting observation) is unattainable in any science. But this fact does not make otherwise well-founded opinions unscientific or inadmissible. Furthermore, whether or not global uniqueness is demonstrable, there are circumstances in which an analyst can testify to scientific knowledge of the likely source of an object or impression. The admissibility of particular source attributions thus should turn on the actual state of this knowledge as applied to the task at hand, and to the helpfulness to the judge or jury of this testimony as contrasted with alternative presentations of forensically valuable findings. The optimal format for explaining the logical impact of a match is not self-evident. But it is clear that if forensic scientists are to contribute fully to the just resolution of criminal cases, they need a less absolutist and more nuanced theory of identification than the traditional presumption of characteristics that are intuitively judged to be individualizing.[95] This is a fundamental—and fundamentally sound—message of the National Academy and of the broader academy.

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[93] BALDING, *supra* note 34, at 136. In "the minority of cases in which uniqueness cannot reasonably be asserted," Balding proposes "a probability of uniqueness." *Id. But see supra* note 91. A rough probability for uniqueness among unrelated individuals of the particular genotype in question could be provided in all cases. *See* KAYE ET AL., *supra* note 10, § 12.4.1(2).

[94] *See, e.g.*, KAYE ET AL., *supra* note 10, § 12; *Trawls*, *supra* note 81.

[95] *See, e.g.*, Christophe Champod & Ian W. Evett, *A Probabilistic Approach to Fingerprint Evidence*, 51 J. FORENSIC IDENTIFICATION 101 (2001); Saks & Kohler, *supra* note 13.