Covering the Basic Concepts Surrounding the Weight and Strength of Evidence

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Outline

- **Introduction**
- Timeline of Events
- Conclusion of Part 1
- Recent Developments
- Controversies
- Conclusion of Part 2

Introduction

- Interpreting forensic evidence is a task that requires collaboration from
  - Various scientific practitioners
  - Statisticians
  - Legal professionals and laypersons

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Introduction

A quote by famed criminalist Paul L. Kirk:[1]

The primary task of the criminalist is to assist the statistician toward enough understanding of the problems so that effective teamwork can be generated. Experience shows that our problems are sufficiently different from those in other areas involving probability, that an uninstructed statistician is unable to offer much useful assistance. It also shows that many statisticians share the great popular interest that attaches to our field, so that liaison may be readily established. The converse aspect of this educational process is the corresponding instruction of the criminalist in the mathematical and logical approach that is required to make the statistical analysis meaningful. The two educational processes appear to be subject to simultaneous achievement-a sort of cross fertilization of ideas.

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Introduction

I.J. Good in the 1950s:[2]

- Defines the "value of evidence" as the Bayes Factor
- Defines the "weight of evidence" as the logarithm of the Bayes Factor
- Later he goes on to say,[3]

  "I believe that the basic concepts of probability and of weight of evidence should be the same for all rational people and should not depend on whether you are a statistician."

The Bayes Factor

$$\underbrace{\frac{\mathbb{P}(H_p|e,I)}{\mathbb{P}(H_d|e,I)}}_{\text{Posterior Odds}} = \underbrace{\frac{\mathbb{P}(e|H_p,I)}{\mathbb{P}(e|H_d,I)}}_{\text{Bayes Factor}} \times \underbrace{\frac{\mathbb{P}(H_p,I)}{\mathbb{P}(H_d,I)}}_{\text{Prior Odds}}$$

where

P: Probability operator

e: Evidence

H_p: e generated according to prosecution model

H_d: e generated according to defense model

I: Background information common to H_p and H_d

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Interpretations

Several ways to interpret the value of evidence:

- From prior odds to posterior odds:
  - Bayes Factor greater than 1 increases the odds
  - Bayes Factor equal to 1 leaves the odds unchanged
  - Bayes Factor less than 1 decreases the odds
- Evidence in support of a hypothesis/proposition:
  - Bayes Factor greater than 1 indicates evidence in support of H_p
  - Bayes Factor equal to 1 indicates neutral evidence
  - Bayes Factor less than 1 indicates evidence in support of H_d

Interpretations

Several ways to interpret the value of evidence:

- Quantitative[4]
  - For a value of evidence greater than 1:

    It is [xx] times more likely to observe the evidence if H_p is true than if H_d is true

  - For a value of evidence less than 1:

    It is [xx] times more likely to observe the evidence if H_d is true than if H_p is true

Interpretations

Several ways to interpret the value of evidence:

- Verbal Scales[4]

Values* of likelihood ratio	Verbal equivalent (two options of phrasing are suggested)
1	The forensic findings do not support one proposition over the other. The forensic findings provide no assistance in addressing the issue.
2 - 10	The forensic findings provide weak support** for the first proposition relative to the alternative. The forensic findings are slightly more probable given one proposition relative to the other.
10 - 100	...provide moderate support for the first proposition rather than the alternative ...are more probable given...proposition...than proposition...
100 - 1000	...provide moderately strong suppor tfor the first proposition rather than the alternative ...are appreciably more probable given... proposition...than proposition...
1000 - 10,000	...provide strong support for the first proposition rather than the alternative ...are much more probable given... proposition...than proposition...
10,000 - 1,000,000	...provide very strong support for the first proposition rather than the alternative ...are far more probable given... proposition...than proposition...
1,000,000 and above	...provide extremely strong support for the first proposition rather than the alternative ...are exceedingly more probable given... proposition...than proposition...

Value of Evidence

Quantifying the value of evidence requires:

- Well thought out propositions/hypotheses
- Clear definition of what evidence/data to use
- Specification of relevant/appropriate background information

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Forensic Hypotheses

Hypotheses can be given at a variety of levels:[5]

- Offense Level
- Activity Level
- Source Level
- Sub-source Level

Evidence

Forensic evidence can be split into a variety of subsets:[5]

- The physical object
  - Unknown source vs. Known source
  - Crime scene vs. Laboratory samples
  - Recovered vs. Control
  - Databases?
- Measurements/features of the object
  - Class vs. subclass/individualizing characteristics
  - Categorical or Quantitative (Continuous or Discrete)
  - Number of dimensions

Background Information

The relevant background information is an important, and often overlooked, aspect:

- "The importance of distinguishing information from evidence/observations when formulating propositions" by Hicks et al. (2015)[6]
- Case dependent
- Can certain relevant background information be biasing?

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Timeline of Events

Early versions of statistics and Bayesian reasoning in forensics date back to the late 19^{th} century[7]

- Bertillon used anthropometry to help identify habitual offenders
- Locard describes the role of probability in the court
- Probabilistic interpretations of handwriting evidence used in the Howland Will and Dreyfus cases
- Poincare demonstrates how to use Bayesian probabilities in a shoeprint example
- Balthazard assigns probabilities of finding n coincidentally corresponding minutiae for fingerprints

Timeline of Events

Methods using classical parametric statistics[1,8,9]

- 1965: Kingston developed methods for "identification" and "individualization" for transfer evidence
- 1966: Parker developed the Two-Stage Approach
- 1977: Evett applied the Two-Stage approach to a problem involving glass evidence
- Versions of the Two-Stage Approach remain popular methods of forensic evidence interpretation in the U.S.

The Two Stage Approach

Stage 1: Exclusion?

- Test H_p using an appropriate statistic and rejection region/p-value
- Answers: How atypical is the evidence under the H_p?
- Can the suspect/specific source be excluded as the source of the trace?
- Can the two traces be excluded as having come from the same source?

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The Two Stage Approach

Stage 2: Rarity?

- Compute (conditional?) random match probability using populations suggested by H_d
- What's the probability of observing a (conditional?) random match in the alternative source population/database given that the trace has come from the specific source?
- What's the probability of observing a random match in the alternative source population/database?

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The Two Stage Approach

Decision:

- Failing to reject in Stage 1 and small random match probability in Stage 2 is strong evidence supporting H_p
- Failing to reject in Stage 1 and large random match probability in Stage 2 is weak evidence supporting H_p
- Rejecting in Stage 1 is strong evidence supporting H_d

Note:

You do not get a value/weight of evidence from this approach

The Two Stage Approach

Interpretations:

- The glass fragments from the suspect and the crime scene are chemically indistinguishable (Stage 1)
- The suspect's firearm cannot be excluded as the weapon that fired the bullet (Stage 1)
- The probability of obtaining a matching DNA profile is 1 in a million if the specimen has come from a unknown person unrelated to the suspect (Stage 2)

Timeline of Events

Towards methods using Bayesian statistics[10,11,5,12]

- 1968: Kaplan discusses the use of Bayesian decision theory at the offense level in court
- 1970: Finkelstein and Fairley discuss using Bayesian decision theory to avoid the mistake of multiplying probabilities under non-independence (mostly offense and activity level)
- 1970s: De Bruin and others explore the use of Bayes Classification Rules for source level forensics
- 1977: Lindley formalized the Bayes Factor for forensic identification of source problems

The Bayes Factor

General Parametric Form

$$V_{BF}(e) = \frac{\int f(e|\theta_p, M_p)\ d\Pi(\theta_p)}{\int f(e|\theta_d, M_d)\ d\Pi(\theta_d)}$$

Timeline of Events

Confusion between the Likelihood Ratio and Bayes Factor[13,14]

- 1978: Seheult's commentary of Lindley's paper called his approach a "likelihood ratio"
- 1986: Evett's follow-up paper applied Lindley's "likelihood ratio" to the glass problem
- 1987: The DNA craze begins and furthers the confusion

The Likelihood Ratio

Likelihood Ratio Function

$$V_{LR}(\theta; e_u) = \frac{f(e_u|\theta_p, M_p)}{f(e_u|\theta_d, M_d)}$$

"True" Likelihood Ratio

$$V_{LR}(\theta_0; e_u) = \frac{f(e_u|\theta_{p_0}, M_p)}{f(e_u|\theta_{d_0}, M_d)}$$

Timeline of Events

Avoiding common pitfalls[15,3,16,17]

- 1982: Shafer reveals Lindley's paradox
- 1985: Good discusses the consequences of bad terminology
- 1987: Thompson & Schumann explore Prosecutor's Fallacy
- 1994: Dawid presents the Island Problem

Computational Methods

The value of evidence can be computed using one or more of the following techniques:

- Parameter Estimation
- Asymptotic Approximations
- Markov Chain Monte Carlo Methods
- Bayesian Computation
- Nonparametric approaches
- probably many others ...

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Computational Methods

$$V_{LR}(\theta; e_u) = \frac{f(e_u|\theta_p, M_p)}{f(e_u|\theta_d, M_d)}$$

Parameter Estimation

- Maximum likelihood
- Method of Moments
- Maximum a Posteriori (posterior mode)
- Posterior Mean/Expected Value
- Note: What collection of data should we base the estimate on?[18]

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Computational Methods

Asymptotic Approximations[19]

- Laplace (using traditional estimates)
- Variation of Laplace using MLEs
- BIC or Schwarz criterion (for the weight of evidence)

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Computational Methods

Markov Chain Monte Carlo Methods[19,20,21]

- Monte Carlo Integration
- Hamiltonian Monte Carlo
- Product Space Search
- Metropolized Product Space Search
- Reversible Jump MCMC
- Marginal Likelihood Estimation

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Computational Methods

Bayesian Computation[22–25]

- Approximate Bayesian Computation for Model Selection
- Partial Bayes Factor
- Intrinsic Bayes Factor
- Fractional Bayes Factor
- Variational Bayes ??
- INLA ??
- Empirical Likelihood ??

Computational Methods

Nonparametric Approaches

- There are MANY ...
- Kernel Density Estimation
  - [26] Chan and Aitken, Estimation of the Bayes' Factor in a forensic science problem, *Journal of Statistical Computation and Simulation*, 33 (1989), pp.249-264.
  - [27] Aitken and Lucy, Evaluation of trace evidence in the form of multivariate data, *Journal of the Royal Statistical Society. Series C (AppliedStatistics)*, 53 (2004), pp. 109-122.

Computational Methods

NOTE:

- Methods are NOT created equally ...
- Some methods are not directly applicable to forensics
- Some methods are highly sensitive to choice of prior distribution
- Some methods are highly variable due to simulation methods
- Some methods are computationally inefficient
- etc.

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Timeline of Events

A shift in methods

- 2000s: Score-based likelihood ratios become popular methods
  - Voice
  - Fingerprints
  - Handwriting
  - Shoeprints
  - Bullets
  - Glass
  - and many others ...

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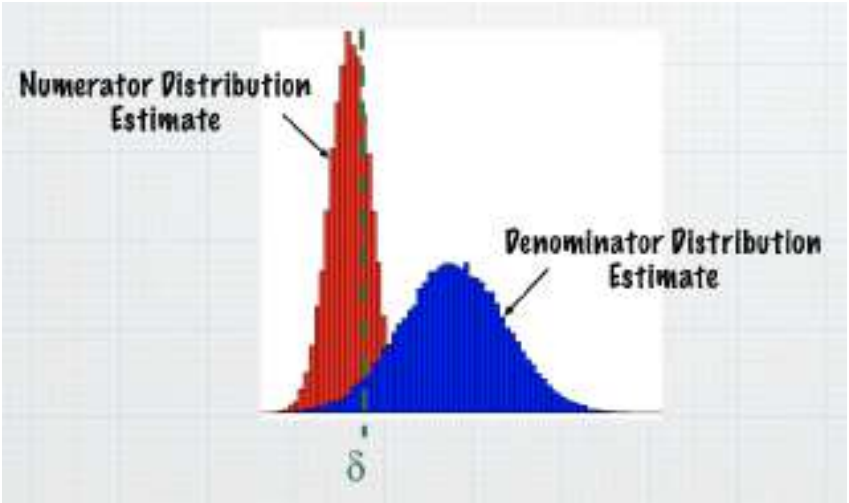
Score-based Likelihood Ratios

- Score: a measure of similarity/dissimilarity between two items of interest (denoted by δ)
- Easier to model distribution of univariate scores than multivariate evidence forms
- SLR: the ratio of the probabilities of observing the score under the two competing propositions



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Timeline of Events

Criticisms[28–30]

- 2009: NRC Report
  - Expressed need for more research and publishing
  - Called for improved methods of reporting forensic conclusions
  - Desire for "error rate" studies
- 2015: Score-based likelihood ratios
  - Cannot be substituted for the value of evidence
  - Not logical or coherent
- 2016: PCAST report
  - Need better standards for determining validity and reliability
  - Need evaluation of scientific validity for impression and pattern evidence

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Conclusion

Thank you!

- Forensic evidence interpretation is a complicated and collaborative effort
- The value of evidence has been defined as the Bayes Factor for over 50 years
- There is still a lot of confusion between Bayes Factors and likelihood ratios
- Come back for Part 2 if you want more details!

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References

Too many to list in this one slide ...

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