Covering the Basic Concepts Surrounding the Weight and Strength of Evidence

Danica Ommen

Iowa State University

February 4, 2019

csafe
Center for Statistics and Applications in Forensic Evidence
ForensicStats.org

Acknowledgements

- Chris Saunders, SDSU
- Cedric Neumann, SDSU
- JoAnn Buscaglia, FBI Lab Div. - CFSRU

Center for Statistics and Applications in Forensic Evidence
ForensicStats.org

Disclaimers

- Portions of this presentation have been supported in part by the National Institute of Justice, U.S. Department of Justice under Award No. 2014-IJ-CX-K088. The views expressed are those of the author and do not necessarily reflect the official policy or position of the National Institute of Justice or the U.S. Government.
- This research was supported in part by an appointment to the Visiting Scientist Program at the Federal Bureau of Investigation Laboratory Division, administered by the Oak Ridge Institute for Science and Education, through an interagency agreement between the US Department of Energy and the Federal Bureau of Investigation. The opinions and conclusions or recommendations expressed in this presentation are those of the author and do not necessarily represent those of the Federal Bureau of Investigation or the US Department of Energy.

csafe
Center for Statistics and Applications in Forensic Evidence
ForensicStats.org

Outline

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

Recent Developments

- Formalized structure for dealing with 2 common questions
  - Common source vs. Specific source frameworks
  - Explicit incorporation of evidence/data from relevant background population
  - More details can be found in the 2018 LPR paper[1]
- Exploration of rigorous VoE approximations
  - Relationship between BF and LR
  - Bernstein-von Mises approximation to the BF
  - Neyman-Pearson approximation to the LR

Motivating Example

FBI Copper Wire

- An improvised explosive device(s) (IED) is found.
- Can the copper wire in the two different IEDs be attributed to the same source?
- A roll of copper wire is found at a suspect's garage.
- Is the copper wire used in the IED indistinguishable from the wire found at the suspect's garage?

Motivating Example

At different points of this scenario, there are two different questions that are asked:

- **Q1:** Are the copper wire samples found at the crime scene from the same wire coil found on the suspect?
- **Q2:** Are the copper wire samples found at these two different crime scenes from the same wire coil?

Motivating Example

What is the difference between these two questions?

Q1: The source (the wire coil related to the suspect) is fixed!

Q2: There is not a specific source in mind- we are only concerned with whether or not the two samples share a common (but unknown) source.

Identification of Specific Source

Q1: Are the copper wire samples found at the crime scene from the same wire coil found on the suspect?

Forensic Evidence

$\mathbf{e_n} = \{\mathbf{e_s}, \mathbf{e_a}, \mathbf{e_u}\}$

- $\mathbf{e_s}$: The n_s control samples from the fixed specific source.
- $\mathbf{e_a}$: The samples from the n_a sources in the alternative source population.
- $\mathbf{e_u}$: The recovered samples with unknown source.

csafe
Center for Statistics and Applications in Forensic Evidence
ForensicStats.org

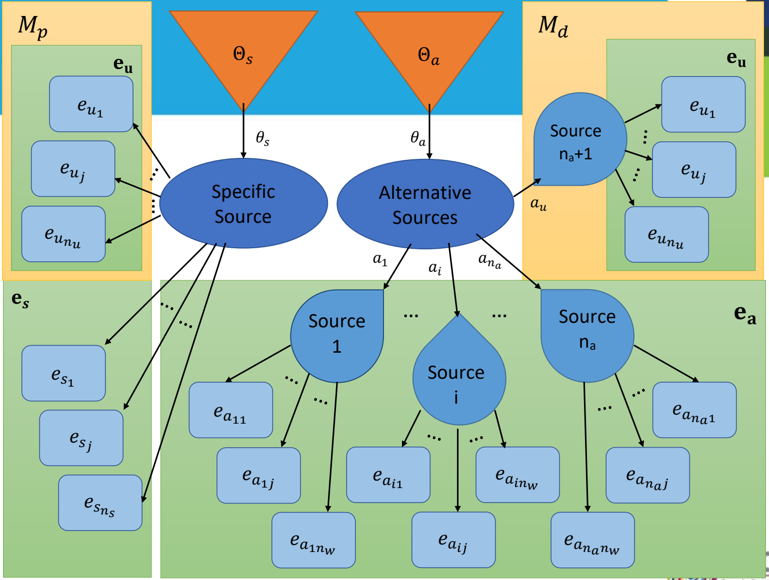
Identification of Specific Source

Q1: Are the copper wire samples found at the crime scene from the same wire coil found on the suspect?

Forensic Hypotheses

$\mathbf{H_p}$: The recovered and control samples both originate from the fixed specific source.

$\mathbf{H_d}$: The recovered samples originate from some other source in the alternative source population.


M_p
Θ_s
Θ_a
M_d
$\mathbf{e_u}$
e_{u_1}
e_{u_j}
$e_{u_{n_u}}$
θ_s
θ_a
Specific Source
Alternative Sources
Source n_a+1
a_u
a_1
a_i
a_{n_a}
$\mathbf{e}_s$
e_{s_1}
e_{s_j}
$e_{s_{n_s}}$
Source 1
Source i
Source n_a
$\mathbf{e_a}$
$e_{a_{11}}$
$e_{a_{1j}}$
$e_{a_{1n_w}}$
$e_{a_{i1}}$
$e_{a_{ij}}$
$e_{a_{in_w}}$
$e_{a_{n_a1}}$
$e_{a_{n_aj}}$
$e_{a_{n_an_w}}$
…

Identification of Common Source

Q2: Are the copper wire samples found at these two different crime scenes from the same wire coil?

Forensic Evidence

$\mathbf{e_n} = \{\mathbf{e_a}, \mathbf{e_{u_1}}, \mathbf{e_{u_2}}\}$

$\mathbf{e_a}$: The samples from the n_a sources in the alternative source population.

$\mathbf{e_{u_1}}$: The first set of recovered samples with unknown source.

$\mathbf{e_{u_2}}$: The second set of recovered samples with unknown source.

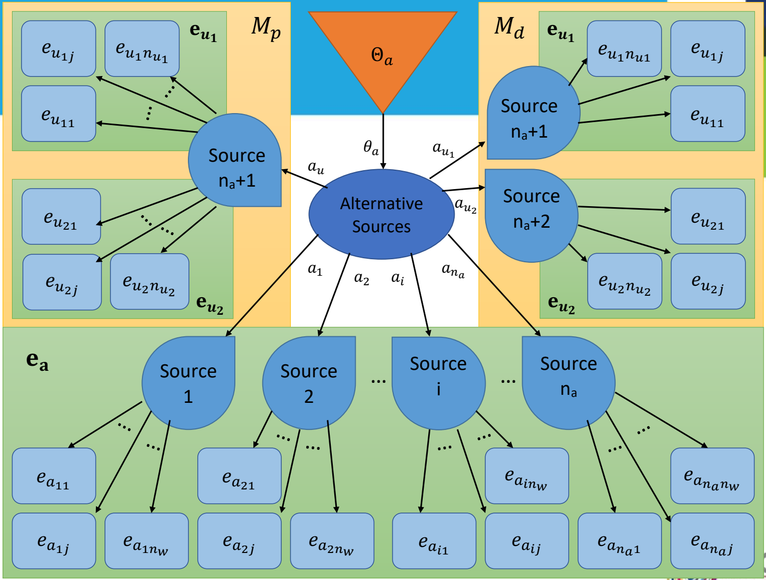
Identification of Common Source

Q2: Are the copper wire samples found at these two different crime scenes from the same wire coil?

Forensic Hypotheses

H_p: Both sets of recovered samples originate from the same source in the alternative source population.

H_d: The two sets of recovered samples originate from two different sources in the alternative source population.



M_p
M_d
Θ_a
θ_a
Alternative Sources
$\mathbf{e}_{u_1}$
$\mathbf{e}_{u_2}$
$\mathbf{e}_{\mathbf{a}}$
$e_{u_1 j}$
$e_{u_1 n_{u_1}}$
$e_{u_{11}}$
$e_{u_{21}}$
$e_{u_2 j}$
$e_{u_2 n_{u_2}}$
Source n_a+1
Source n_a+2
a_u
a_{u_1}
a_{u_2}
a_1
a_2
a_i
a_{n_a}
Source 1
Source 2
Source i
Source n_a
$e_{a_{11}}$
$e_{a_{1j}}$
$e_{a_{1n_w}}$
$e_{a_{21}}$
$e_{a_{2j}}$
$e_{a_{2n_w}}$
$e_{a_{i1}}$
$e_{a_{ij}}$
$e_{a_{in_w}}$
$e_{a_{n_a 1}}$
$e_{a_{n_a j}}$
$e_{a_{n_a n_w}}$

The Bayes Factor

General Form

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

Common Source

$$BF_{cs}(e) = \frac{\int f(e_{u_1}, e_{u_2}|\theta_a, M_p)\ d\Pi(\theta_a|e_a)}{\int f(e_{u_1}|\theta_a, M_d) f(e_{u_2}|\theta_a, M_d)\ d\Pi(\theta_a|e_a)}$$

Specific Source

$$BF_{ss}(e) = \frac{\int f(e_u|\theta_s)\ d\Pi(\theta_s|e_s)}{\int f(e_u|\theta_a)\ d\Pi(\theta_a|e_a)}$$

The Likelihood Ratio Function

Likelihood Ratio Function

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

Common Source

$$LR_{cs}(\theta_a; e_u) = \frac{f(e_{u_1}, e_{u_2}|\theta_a, M_p)}{f(e_{u_1}|\theta_a, M_d)f(e_{u_2}|\theta_a, M_d)}$$

Specific Source

$$LR_{ss}(\theta; e_u) = \frac{f(e_u|\theta_s, M_p)}{f(e_u|\theta_a, M_d)}$$

The Likelihood Ratio

True Likelihood Ratio

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

Common Source

$$LR_{cs}(\theta_{a_0}; e_u) = \frac{f(e_{u_1}, e_{u_2}|\theta_{a_0}, M_p)}{f(e_{u_1}|\theta_{a_0}, M_d)f(e_{u_2}|\theta_{a_0}, M_d)}$$

Specific Source

$$LR_{ss}(\theta_0; e_u) = \frac{f(e_u|\theta_{s_0}, M_p)}{f(e_u|\theta_{a_0}, M_d)}$$

Comparing the BF and the LR

- The BF is a single number which contains in it all measures of uncertainty
- The true LR has no uncertainty
- Can often think of the BF as an integrated LR with respect to a special posterior

$$V_{BF}(e) = \int V_{LR}(\theta; e_u) \; d\Pi(\theta | e, M_d)$$

- They are both nearly impossible to obtain in real life!!

Comparing the BF and the LR

Theorem (1)[1]

Assumptions:

- *Fixed observation of* e_u
- *Suitable conditions on* $V_{LR}(\theta; e_u)$ *and* $\hat{\theta}_{n|M_d}$
- *Assumptions of Bernstein-von Mises Theorem*[2] *hold*

Result: The sequence of Bayes Factors converges in P_θ^n*-probability to the true likelihood ratio as* $n \to \infty$,

$$V_{BF}(e_n) \xrightarrow{P_\theta^n} V_{LR}(\theta_0; e_u).$$

[1]See the current arXiv paper[2] for details.

[2]Theorem 10.1 from van der Vaart[3]

Value of Evidence Approximation

The goal is to find an approximation of the value of evidence, $\tilde{V}$, which will lead to an *approximately admissible decision rule* [4]

$$\frac{P(H_p|e,I)}{P(H_d|e,I)} = \left[\tilde{V} \times \frac{P(H_p|I)}{P(H_d|I)}\right] + o_{P_{\theta_0}}(1).$$

Two approximations will be considered:

1. Bernstein-von Mises Approximation
2. Neyman-Pearson Approximation

The Bernstein-von Mises Approximation

- Approximate a posterior distribution with a Normal centered at MLE with variance of inverse observed Fisher Information Matrix
- $\hat{\theta}_d$ is the MLE for θ under M_d using the data e_n
- $I_{n_d}^{-1}(\hat{\theta}_d)$ is the observed Fisher's information matrix for e_n at $\hat{\theta}_d$ under M_d

$$V_{BVM}(e_n) = \int V_{LR}(\theta; e_u) \; d\mathcal{N}(\hat{\theta}_d, I_{n_d}^{-1}(\hat{\theta}_d))$$

csafe
Center for Statistics and Applications in Forensic Evidence
ForensicStats.org

Bernstein-von Mises Approximation

- **Specific Source**

$$BVM_{ss}(e_n) = \int LR_{ss}(\theta; e_u)\ d\mathcal{N}(\hat{\theta}_d, I_{n_d}^{-1}(\hat{\theta}_d))$$

- **Common Source**

$$BVM_{cs}(e_n) = \int LR_{cs}(\theta_a; e_u)\ d\mathcal{N}(\hat{\theta}_a^d, I_{n_d}^{-1}(\hat{\theta}_a^d))$$

Bernstein-von Mises Approximation

Theorem (2)

Assumptions:

- *Fixed observation of* e_u
- *Suitable conditions on* $V_{LR}(\theta; e_u)$ *and* $\hat{\theta}_{n|M_d}$
- *Assumptions of Bernstein-von Mises Theorem*[3] *hold*

Result:

$$\left| V_{BVM}(e_n) - V_{BF}(e_n) \right| \xrightarrow{P_\theta^n} 0, \qquad n \to \infty$$

[3] Theorem 10.1 from van der Vaart[3]

The Neyman-Pearson Approximation

- Estimate unknown parameters with MLEs under each model independently
- Let Θ_p and Θ_d represent the restricted parameter spaces under M_p and M_d, respectively

$$V_{NP}(e_n) = \frac{\max\limits_{\theta_p \in \Theta_p} f\left(e_n \left| \theta_p \right.\right)}{\max\limits_{\theta_d \in \Theta_d} f\left(e_n \left| \theta_d \right.\right)}.$$

Neyman-Pearson Approximation

- **Specific Source**

$$NP_{ss}(e_n) = \frac{f(e_s|\hat{\theta}_s^*)f(e_u|\hat{\theta}_s^*)f(e_a|\hat{\theta}_a)}{f(e_s|\hat{\theta}_s)f(e_u|\hat{\theta}_a^*)f(e_a|\hat{\theta}_a^*)}$$

  - $\hat{\theta}_s^*$ and $\hat{\theta}_a$ are the MLEs of θ_s and θ_a under M_p
  - $\hat{\theta}_s$ and $\hat{\theta}_a^*$ are the MLEs of θ_s and θ_a under M_d

- **Common Source**

$$NP_{cs}(e_n) = \frac{f(e_{u_1}, e_{u_2}|\hat{\theta}_a^p, M_p)f(e_a|\hat{\theta}_a^p)}{f(e_{u_1}|\hat{\theta}_a^d, M_d)f(e_{u_2}|\hat{\theta}_a^d, M_d)f(e_a|\hat{\theta}_a^d)}$$

  - $\hat{\theta}_a^p$ is the MLE of θ_a under M_p
  - $\hat{\theta}_a^d$ is the MLE of θ_a under M_d

csafe
Center for Statistics and Applications in Forensic Evidence
ForensicStats.org

Neyman-Pearson Approximation

Theorem (3)

Assumptions:

- *Fixed observation of* e_u
- *Likelihood functions are bounded, continuous*
- *Assumptions of the Consistency of M-Estimators theorem*[4] *hold*
- *Assumptions of the Linearization of M-Estimators theorem*[5] *hold*

Result:

$$V_{NP}(e_n) \xrightarrow{P_\theta} V_{LR}(\theta_0; e_u), \qquad n \to \infty$$

[4] Corollary 3.2.3 on p. 287 from van der Vaart and Wellner[5]

[5] Theorem 3.3.1 on p. 310 from van der Vaart and Wellner[5]

Neyman-Pearson Approximation

Corollary (3.1)

Suppose that the likelihood ratio function is bounded in P_{θ_0}-probability in a neighborhood of θ_0. The Neyman-Pearson approximation is an approximate value of evidence for the forensic identification of source problems:

$$\frac{\mathbb{P}\left(H_p|e,I\right)}{\mathbb{P}\left(H_d|e,I\right)} = \left[V_{NP}(e_n) \times \frac{\mathbb{P}\left(H_p|I\right)}{\mathbb{P}\left(H_d|I\right)}\right] + o_{P_{\theta_0}}(1).$$

csafe
Center for Statistics and Applications in Forensic Evidence
ForensicStats.org

Outline

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

Controversies

- Quantifying uncertainty in Likelihood Ratios
- PCAST and commentary

Debates about Quantifying Uncertainty

Round 1: Law, Probability, and Risk

- Dismissal of the Illusion of Uncertainty in the Assessment of a LR [14]
- Uncertainty and LR: to integrate or not to integrate, that's the question [15]
- Comment from a practitioner's point of view [16]

csafe
Center for Statistics and Applications in Forensic Evidence
ForensicStats.org

Debates about Quantifying Uncertainty

Dismissal of the Illusion of Uncertainty ...

- "probabilities are not states of nature, but states of mind"
- it only makes sense to estimate a state of nature
- "probability is given by a single number" (it's not logical to have two different numbers)
- "nothing will be gained if a particular expression for uncertainty, in terms of a probability, is itself obscured or blurred by an additional level of uncertainty."
- **Conclusion:** "for a particular case, forensic scientists ought to offer to the court a single value for the BF, rather than a range of values."

csafe
Center for Statistics and Applications in Forensic Evidence
ForensicStats.org

Debates about Quantifying Uncertainty

... To integrate or not to integrate ...

- If you choose to present a Bayes Factor then there is no disagreement
- If you choose to present a "plug-in" likelihood ratio based on available data, then it seems reasonable to attach uncertainty to that estimate in the form of a credible interval
- Outside of the fully Bayesian approach, "estimating" the likelihood ratio makes sense
- **Conclusion:** It is more informative to the courts to present a "plug-in LR" with corresponding uncertainty quantification

csafe
Center for Statistics and Applications in Forensic Evidence
ForensicStats.org

Debates about Quantifying Uncertainty

Comment from a practitioner's point of view

- There is a gap between the sophistication of methods statisticians propose and the statistical knowledge of a forensic practitioner
- "There is obviously some kind of clash here between quality assurance and probabilistic reasoning."
- **Conclusion:** "I think we should admit that at a beginning stage it is better that a forensic expert reports a range of likelihood ratios than that she returns to the classical way of expressing posterior probabilities by using vague verbal expressions."

Debates about Quantifying Uncertainty

Round 2: Science and Justice

- Virtual Special Issue on Measuring and Reporting the Precision of Forensic Likelihood Ratios [17]
- 7 position papers [18–24]
- 3 response papers [25–28]
- 3 reply papers [29–31]

Debates about Quantifying Uncertainty

Round 3:

- Oct 12, 2017 Press Release:

  NIST Experts Urge Caution in Use of Courtroom Evidence Presentation Method: Use of 'Likelihood Ratio' not consistently supported by scientific reasoning approach, authors state.

- Authors: Steven Lund and Hari Iyer
- Likelihood Ratio as Weight of Forensic Evidence: A Closer Look [32]
- Responses: 4

csafe
Center for Statistics and Applications in Forensic Evidence
ForensicStats.org

Debates about Quantifying Uncertainty

Lund & Iyer

- There has been a lot of talk about BF & LR ...
  Should we even be using them in court?
- "We find the likelihood ratio paradigm to be unsupported by arguments of Bayesian decision theory"
- "Nevertheless, a likelihood ratio may be viewed as a potential tool for experts in their communications to triers of fact."
- **Conclusion:** "We propose the concept of a lattice of assumptions leading to an uncertainty pyramid as a framework for assessing the uncertainty in an evaluation of a likelihood ratio."

Debates about Quantifying Uncertainty

Responses

- "We conclude that L&I argue against a practice that does not exist and which no one advocates." [33]
- Provides suggestions for how to properly use BF in court [34]
- Reviews an argument (originally discussed by IJ Good) that the BF/LR "is the only logically admissible form of evaluation." [35]
- "A press release from NIST could potentially impede progress toward improving the analysis of forensic evidence and the presentation of forensic analysis results in courts in the US and around the world." [36]

csafe
Center for Statistics and Applications in Forensic Evidence
ForensicStats.org

PCAST Controversy

Which evidence interpretation paradigm to use?

- Many interpreted the PCAST report[37] as advocating the use of the Two-Stage Approach
- Responses: 2
  - Both advocate use of the Bayesian (Likelihood Ratio) paradigm
  - Letter to Editor in FSI by Morrison et al.[38]
  - Commentary in FSI by Evett, Berger, Buckleton, Champod, and Jackson[39]

Outline

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

Conclusion

Thank you!

- There has been a LOT of progress towards better ways of finding the value of evidence
- This progress has sparked a lot of controversy as researchers move in "opposing" directions
- There's still a lot of work to be done
- We should attempt to reconcile the arguments if we have any hope for change in practice

csafe
Center for Statistics and Applications in Forensic Evidence
ForensicStats.org

References

Too many to list in this one slide ...

dmommen@iastate.edu