

Project Rational & Goals

EVIDENCE. An investigator has two pieces of evidence:

1. A digital image I_u involved in a crime where I_u is from an *unknown source (camera)*. The image I_u is called the *questioned image*.
2. A digital *camera fingerprint* F_k from a suspect's camera C_k . The camera C_k is called the *specific known device*.

KEY QUESTIONS. How likely is it that the questioned image originated from the specific known source? How likely is it that the questioned image did not originate from the specific known source?

HYPOTHESES. The key questions are often expressed as two competing, *specific-source* hypotheses [1]:

H_p : image I_u and camera fingerprint F_k both originated from camera C_k

H_d : camera fingerprint F_k originated from camera C_k but image I_u did not

GOAL. Implement three types of *score-base likelihood ratios* to evaluate the strength of the evidence with regard to the specific-source hypotheses and perform experiments on a wide range of camera models and devices.

Materials & Methods

TOOLS

- *Photo-response non-uniformity (PRNU)* [2] refers to slight variations in the pixels in a camera's sensor array caused during manufacturing. PRNU is an identifying characteristic, or *camera fingerprint*, and is estimated from *noise residuals*, images minus denoised versions.
- We measure the similarity between a noise residual X_u from questioned image I_u and a camera fingerprint F_k with a *similarity score* Δ , the *correlation distance* (1 minus the sample correlation):

$$\delta = \Delta(X_u, I_u F_k).$$

SCORE-BASED LIKELIHOOD RATIOS (SLR). Many forensic fields, including handwriting [3], glass fragments [4], and shoe impressions [4], have used SLRs, but SLRs have only been applied to small datasets for camera device identification and each research group focused on a single SLR type [5-7]. Building upon this previous work, we evaluate all three types of specific-source SLRs on a large dataset of 48 cameras representing 26 models.

What is the probability of obtaining δ if H_p is true? If H_d is true? An SLR is the ratio between these two probabilities and quantifies the strength of the evidence.

$$SLR_{source} = \frac{P(\delta | H_p)}{P(\delta | F_k, H_d)}, \quad SLR_{trace} = \frac{P(\delta | H_p)}{P(\delta | I_u, H_d)}, \quad SLR_{general} = \frac{P(\delta | H_p)}{P(\delta | H_d)}$$

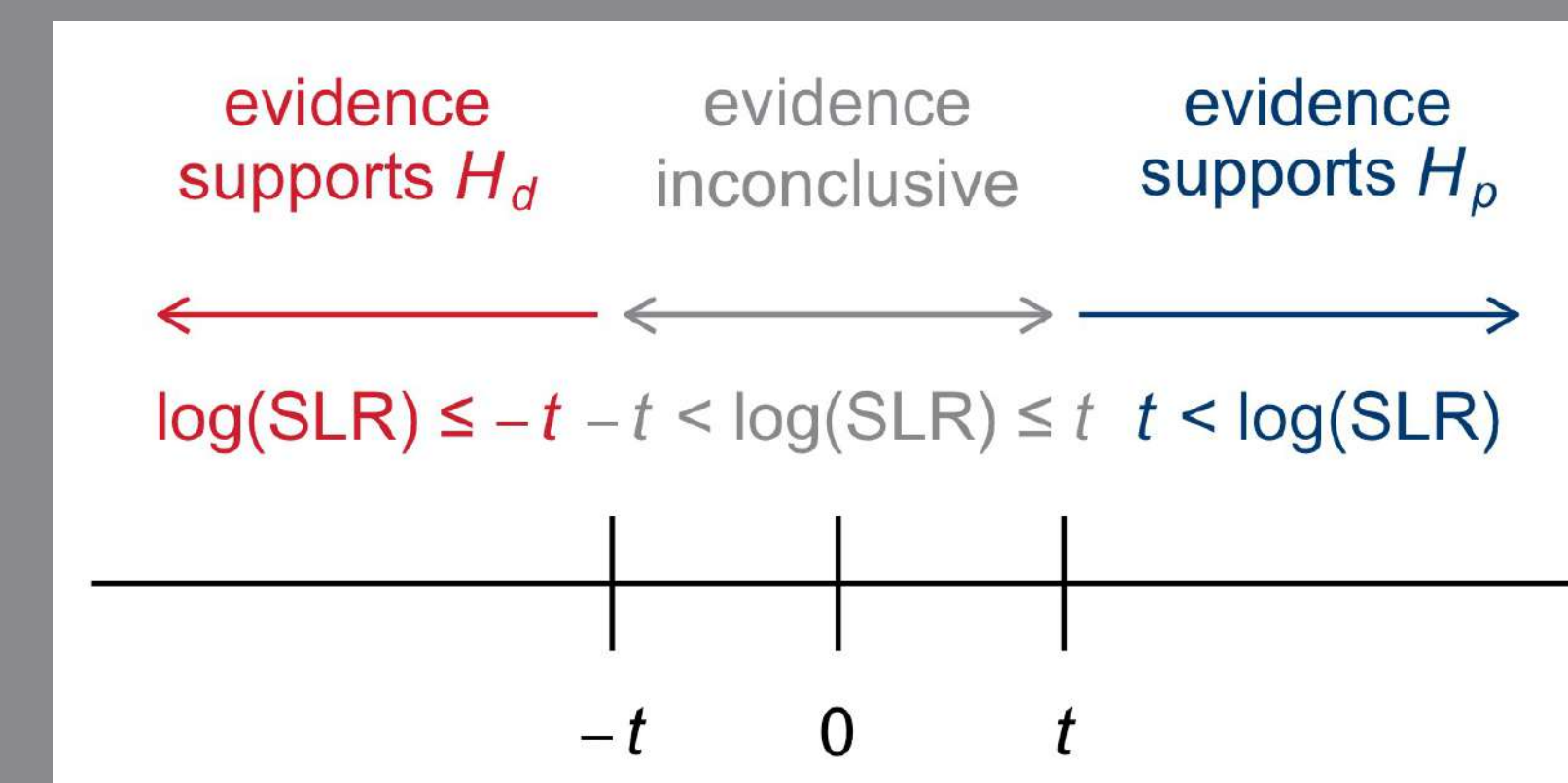
$P(\cdot)$ is a joint probability density function estimated from reference sets of *matching* (same specific source) or *non-matching scores* (different source) using kernel density estimation.

DATASET. We use 4,800 images (100 images from each camera) from 48 cameras, representing 26 camera models, from 4 image databases [8-11]. 80 images from each camera are used to estimate camera fingerprints and build reference sets of scores. 20 images from each camera are questioned images. For each questioned image, we set each of the 48 cameras as the specific known device (suspect's camera) in turn, and calculate the general match, source-anchored, and trace-anchored SLRs.

Results

Interpreting SLR values

FIGURE 1. An SLR value supports H_p if $\log_{10}(SLR)$ is greater than an inconclusive threshold $t \geq 0$. If $\log_{10}(SLR)$ is less than or equal to $-t$ it supports H_d . Otherwise, the SLR is inconclusive.

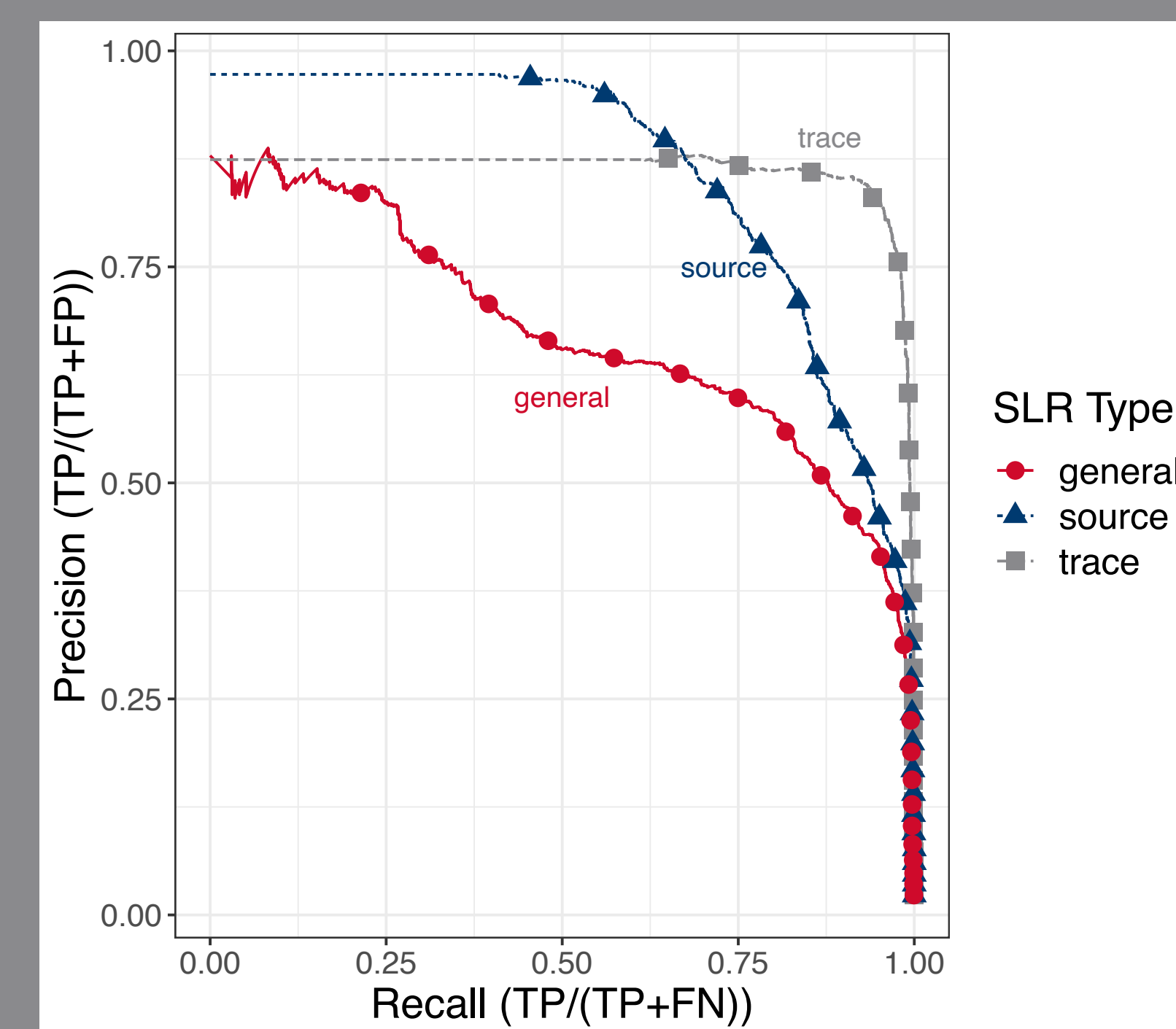


Evaluation measures

- *True Positives (TP)* = the number of SLRs that correctly support H_p
- *True Negatives (TN)* = the number of SLRs that correctly supports H_d
- *False Positives (FP)* = the number of SLRs that incorrectly support H_p when H_d is true
- *False Negatives (FN)* = the number of SLRs that incorrectly support H_d when H_p is true

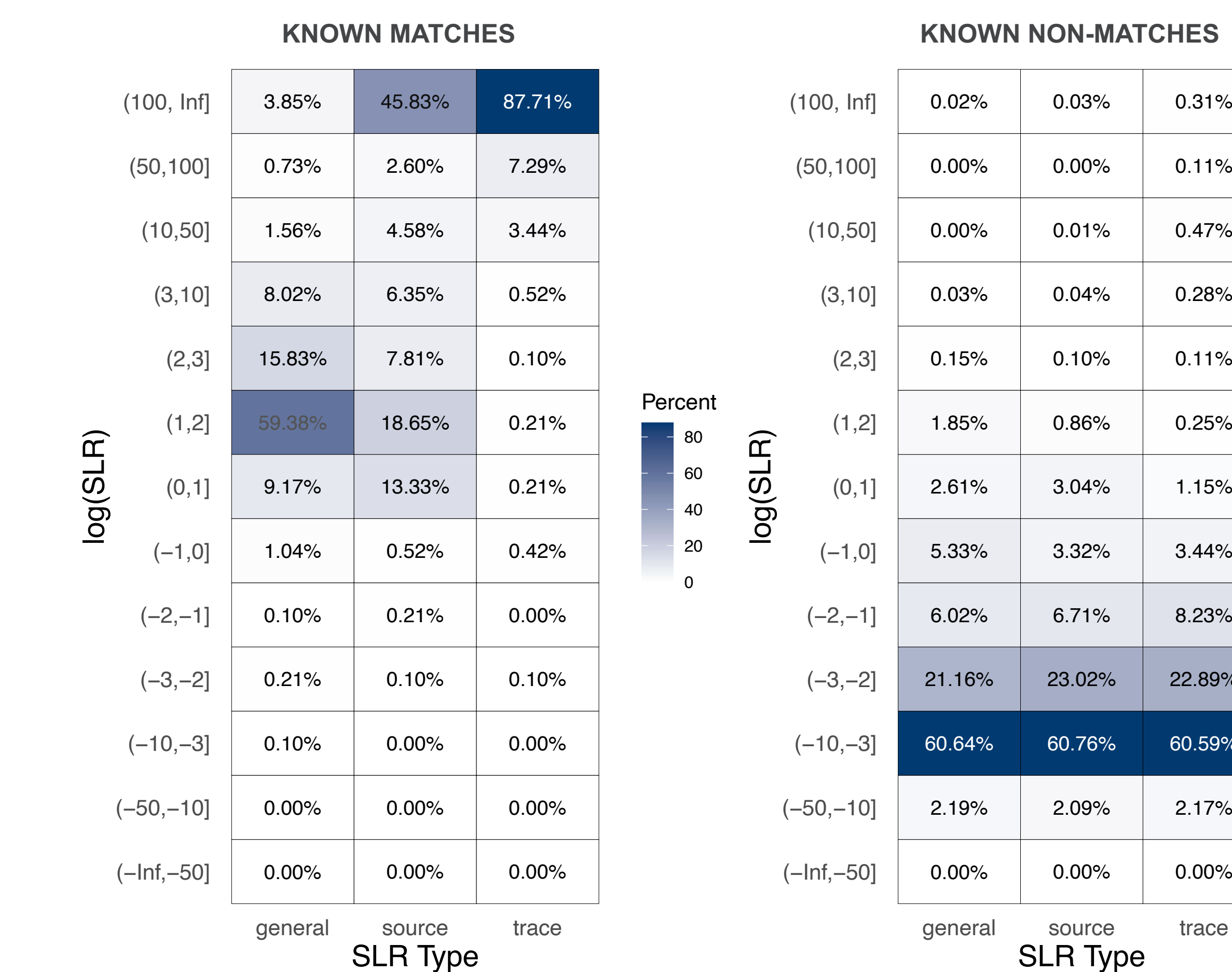
Overall performance

FIGURE 2. The precision-recall (PR) curves compare overall performance of the general match, source-anchored, and trace-anchored SLRs. The closer a model gets to precision and recall equal to 1, the better it performs. (These PR curves were constructed with an inconclusive threshold of $t = 0$.)



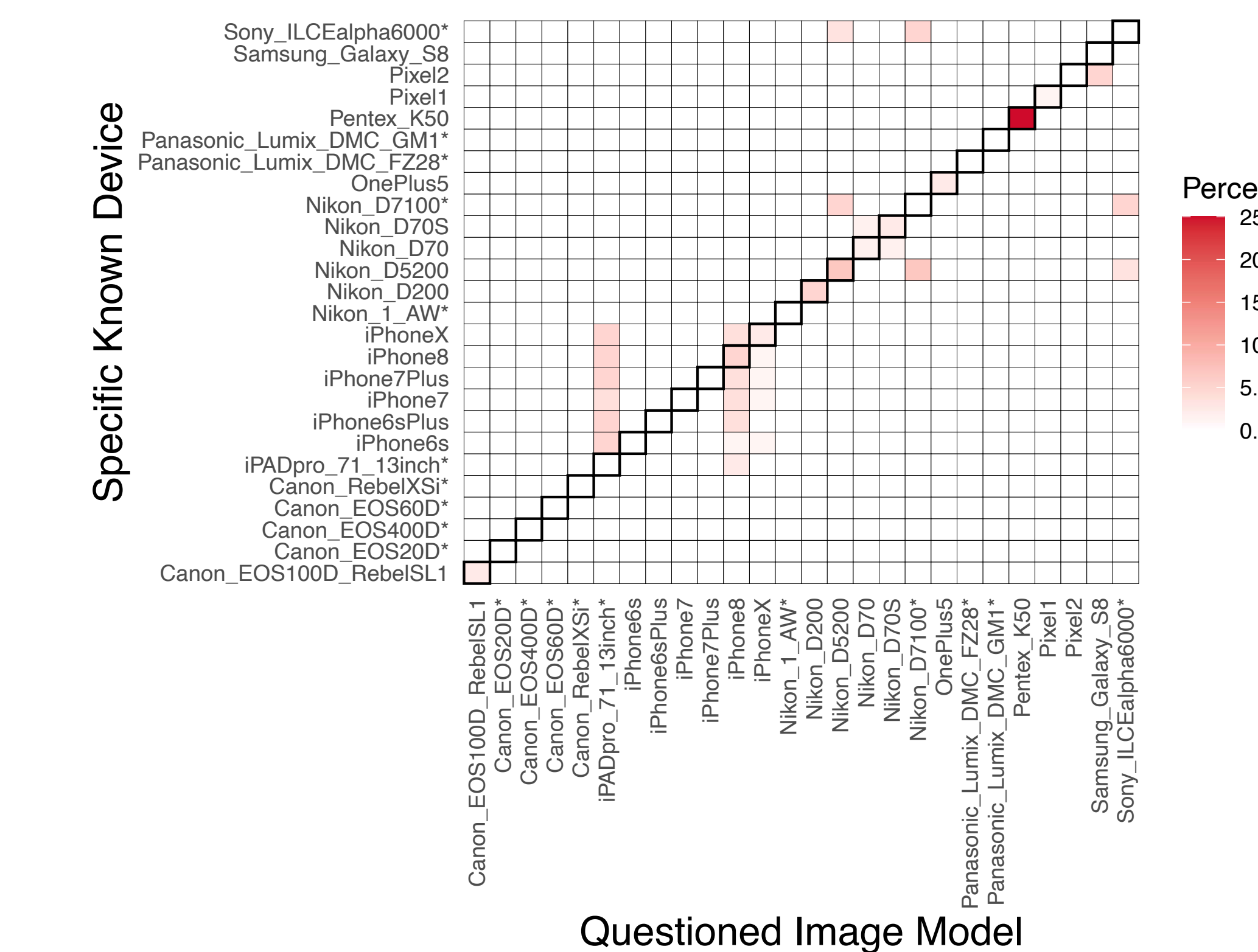
What is the strength of the evidence in favor of H_p or H_d ?

FIGURE 3. The plots display the percentages of $\log_{10}(SLR)$ values for each SLR type that belong to each interval. [Left] The $\log_{10}(SLR)$ values from known matches (H_p is true). [Right] The $\log_{10}(SLR)$ values from known non-matches (H_d is true).



Are false positive rates high among cameras of the same model?

FIGURE 5. The plot displays percentages of false positives by camera model for source-anchored SLRs and inconclusive threshold $t = 2$. Models that only have a single camera are denoted with an asterisk at the end of their name. All other models have 2, 3, or 4 cameras. Single camera models are included in this plot because they may produce false positives with devices of different models.



Can we decrease the false positive rate by increasing the inconclusive threshold t ? What is the trade-off?

FIGURE 4. Each column of plots shows results for a different inconclusive threshold $t = 0, 1, 2, 3, 4$. The plots on the top display the percentages of known matches (H_p is true) whose $\log_{10}(SLR)$ values are true positives, inconclusive, and false negatives. The plots on the bottom display the percentages of known non-matches (H_d is true) whose $\log_{10}(SLR)$ values are false positives, inconclusive, and true negatives.



Discussion & Future Work

- In cases where the questioned document originated from the specific known device (H_p is true), 87.71% of the trace-anchored SLRs provide *extremely strong* [12] support for H_p rather than H_d while only 45.83% of the source-anchored and 3.85% of the general match SLRs provide the same level of support. [See Figure 3]
- In cases where the questioned document did not originate from the specific known device (H_d is true), around 80% of all three types of SLRs provide *strong*, *very strong*, or *extremely strong* [12] support for H_d rather than H_p . [See Figure 3]
- Incorporating an inconclusive threshold t lowers the false positive rates for all three SLR types, but as a trade-off the true positive and true negative rates also decrease. [See Figure 4]
- The false positive rates are low between cameras of the same model, expect the Pentax K50, for the source-anchored SLRs and inconclusive threshold $t = 2$. [See Figure 5]
- In future work, we plan to further investigate *close non-matches*, where cameras belong to the same model, with a minimum of 10 cameras per model.

References

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