A Likelihood Ratio Approach for Detecting Behavioral Changes in Device Usage Over Time

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Background

Evidence: categorical sequence of user-generated event data on a device

Ex: sending texts or emails, making calls, using apps

Forensic question: is there evidence of a change in event patterns, or changepoint, during this sequence?

Is there evidence of a changepoint here specifically? Old method (1)

Is there evidence of a changepoint anytime in this time window? This method

A changepoint in the sequence may indicate that the sequence of events was generated by two different individuals rather than a single individual.

Hypotheses: one source vs. two source

H_1	H_2
: there is no changepoint in the sequence; it was generated by a single individual	: there is one changepoint in the sequence; it was generated by two different individuals

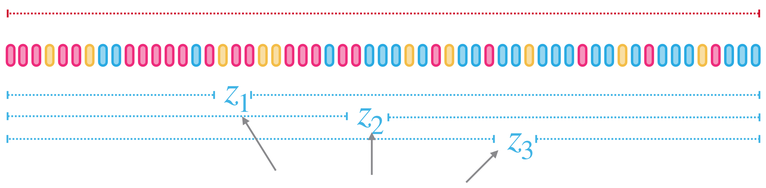
Methods

Likelihood ratio (Bayes factor):

$$\frac{P(H_1)}{P(H_2)} \times \frac{P(E \mid H_1)}{P(E \mid H_2)} = \frac{P(H_1 \mid E)}{P(H_2 \mid E)}$$

Model:

$X_{1:N} \mid H_1, \theta_1 \overset{iid}{\sim} Categ(\theta_1)$ → Count events per category → $C_{1:N}$

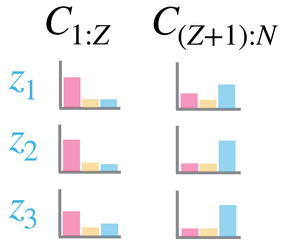


Relevant case information could be used to specify what changepoints are probable

$X_{1:Z} \mid H_2, \theta_1 \overset{iid}{\sim} Categ(\theta_1)$

$X_{(Z+1):N} \mid H_2, \theta_2 \overset{iid}{\sim} Categ(\theta_2)$

Count before and after each possible Z → $C_{1:Z}$, $C_{(Z+1):N}$

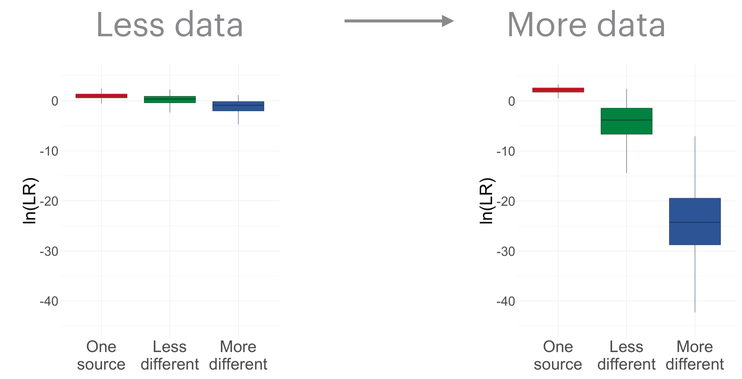


Formula for the likelihood ratio: conjugate prior for θ; easy to calculate

$$LR = \frac{B(\alpha + C_{1:N})B(\alpha)}{\sum_z B(\alpha + C_{1:z})B(\alpha + C_{(z+1):N})p(Z = z)}$$

Results + Discussion

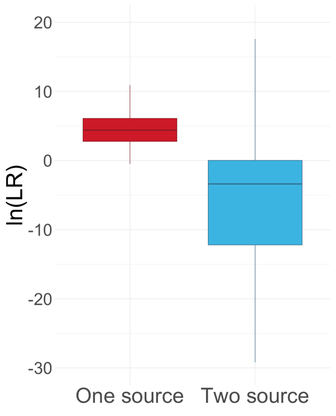
Simulations: vary amount of data and differences in event patterns



Experiments: evaluate performance using email dataset (2)

TPR@1	FPR@1	AUC
97.7%	25.6%	92.7%

C_{llr}	C_{llr}^{min}	C_{llr}^{cal}
1.13	0.37	0.75



(1) Longjohn, Rachel, Padhraic Smyth, and Hal Stern. "Likelihood Ratios for Categorical Evidence with Applications in Digital Evidence." *AAFS Annual Conference*, 2022.

(2) Paranjape, Ashwin, Austin R. Benson, and Jure Leskovec. "Motifs in temporal networks." *Proceedings of the tenth ACM international conference on web search and data mining*. 2017.

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