Similarity of 2D images: An application to the forensic comparison of shoe outsole impressions

Soyoung Park, Ph.D and Alicia Carriquiry, Ph.D

CSAFE/Iowa State University

March, 11, 2019

Center for Statistics and Applications in Forensic Evidence

Acknowledgements

Thanks to,

- Dr. Hariharan K. Iyer at NIST
- Dr. Eric Hare at Omni Analytics
- Ms. Lesley Hammer at Hammer Forensics
- Dr. Guillermo Basulto-Elias and Mr. James Kruse at CSAFE
- 160 participants in our shoe study

Some references

- Bodziak, William J. (2017). *Footwear impression evidence: detection, recovery and examination*. CRC Press.
- Speir, Jacqueline A., et al. (2016). *Quantifying randomly acquired characteristics on outsoles in terms of shape and position.* Forensic science international 266 : 399-411.
- Richetelli, Nicole, et al. (2017). *Classification of footwear outsole patterns using fourier transform and local interest points.* Forensic science international 275 : 102-109.
- Park, Soyoung and Carriquiry, Alicia (2018). *Similarity of two-dimensional images: An application to the forensic comparison of shoe outsole impressions*. Submitted.
- Park, Soyoung. (2018). *Learning algorithms for forensic science applications.* PhD dissertation. Iowa State University

A crime is committed...

Partial shoe print
found at crime scene

Putative source shoe

Comparing outsole impressions

- Footwear impressions are found in 35% of all crime scenes[1].
- Examiners are tasked with determining whether the suspect's shoe could have left the print at the crime scene.
- Current practice relies on visual comparison of the two impressions, and a subjective assessment of the degree of similarity between them.
- If impressions are similar, then the next question is whether the degree of similarity is **probative**: would we observe the same degree of similarity if prints were produced by <u>different</u> shoes?

[1] Bodziak, William J. (2017). *Footwear impression evidence: detection, recovery and examination*. CRC Press.

Two steps

- Quantify similarity :
  - Questioned shoe prints (Q) : Shoe prints found at crime scene
  - Control or Known shoe prints (K) : Shoe outsole impressions recovered from the suspect's shoes
- Determining source :
  - *Specific source question* : Did the crime scene impressions originate from the suspect's shoes?
  - *Common source question* : Could two shoe impressions from two different crime scenes have the same, but unknown source?

Challenges

- Latent prints can be partial and often smudged.
- Impressions need to be rotated, translated and sometimes re-scaled.
- Are subject to noise and background effects.
- Include class characteristics and RACs (Randomly Acquired Characteristics).

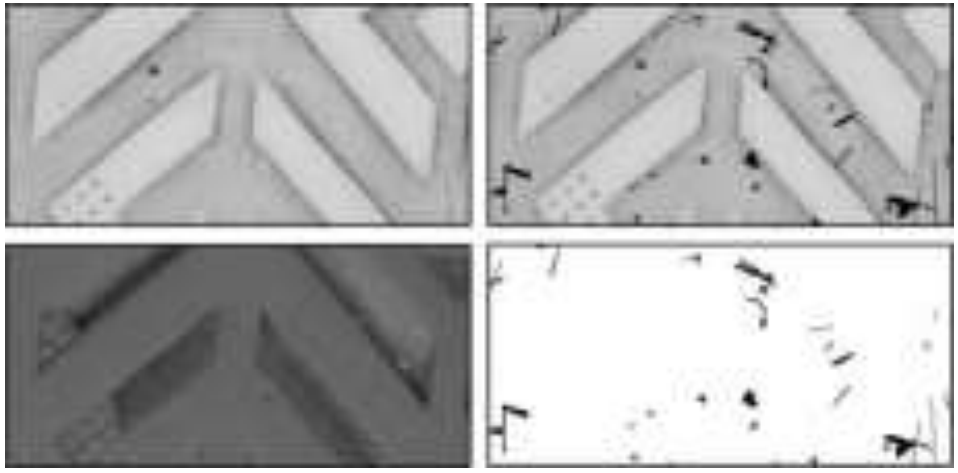
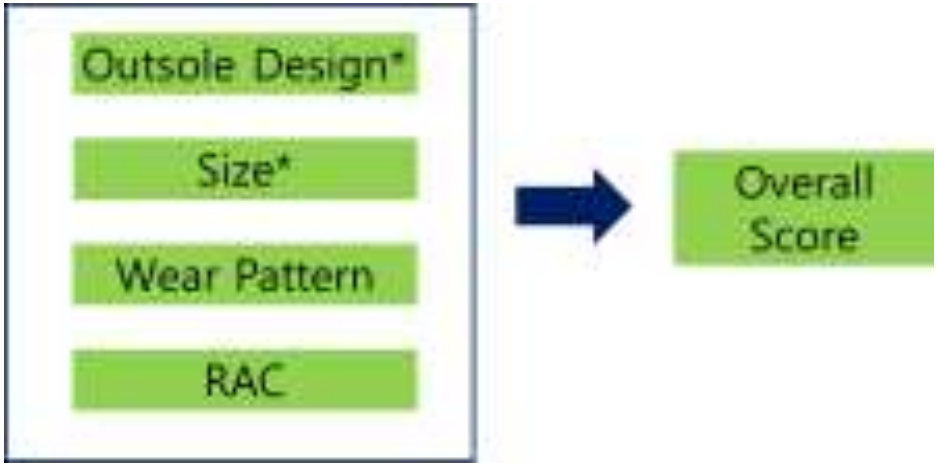


Figure 6 in Speir et al. (2016)

Our objectives

- Develop a *score* that quantifies the degree of similarity between two outsole 2D images.

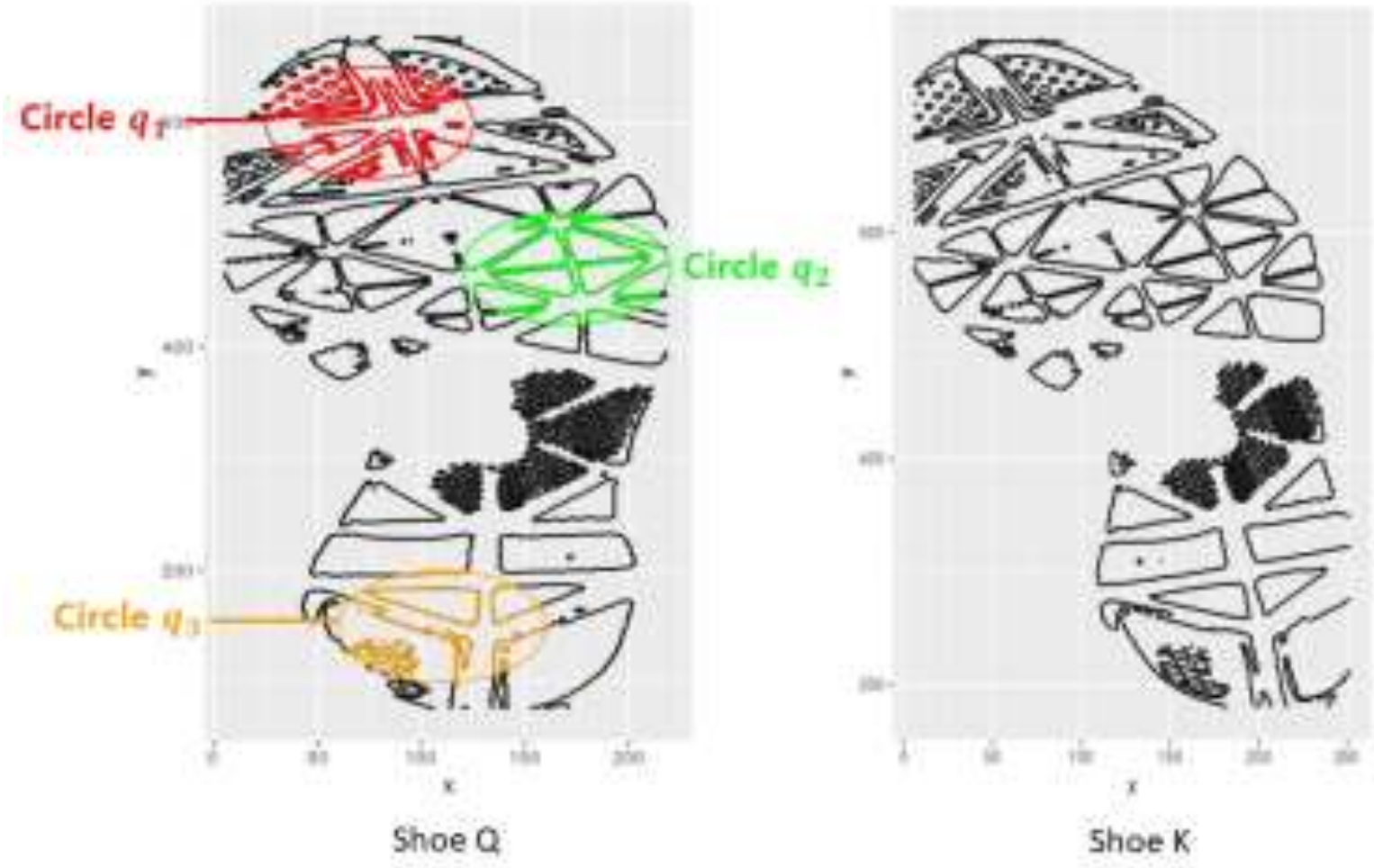


- Assess the probative value of the score.
- Today we focus on the first objective.

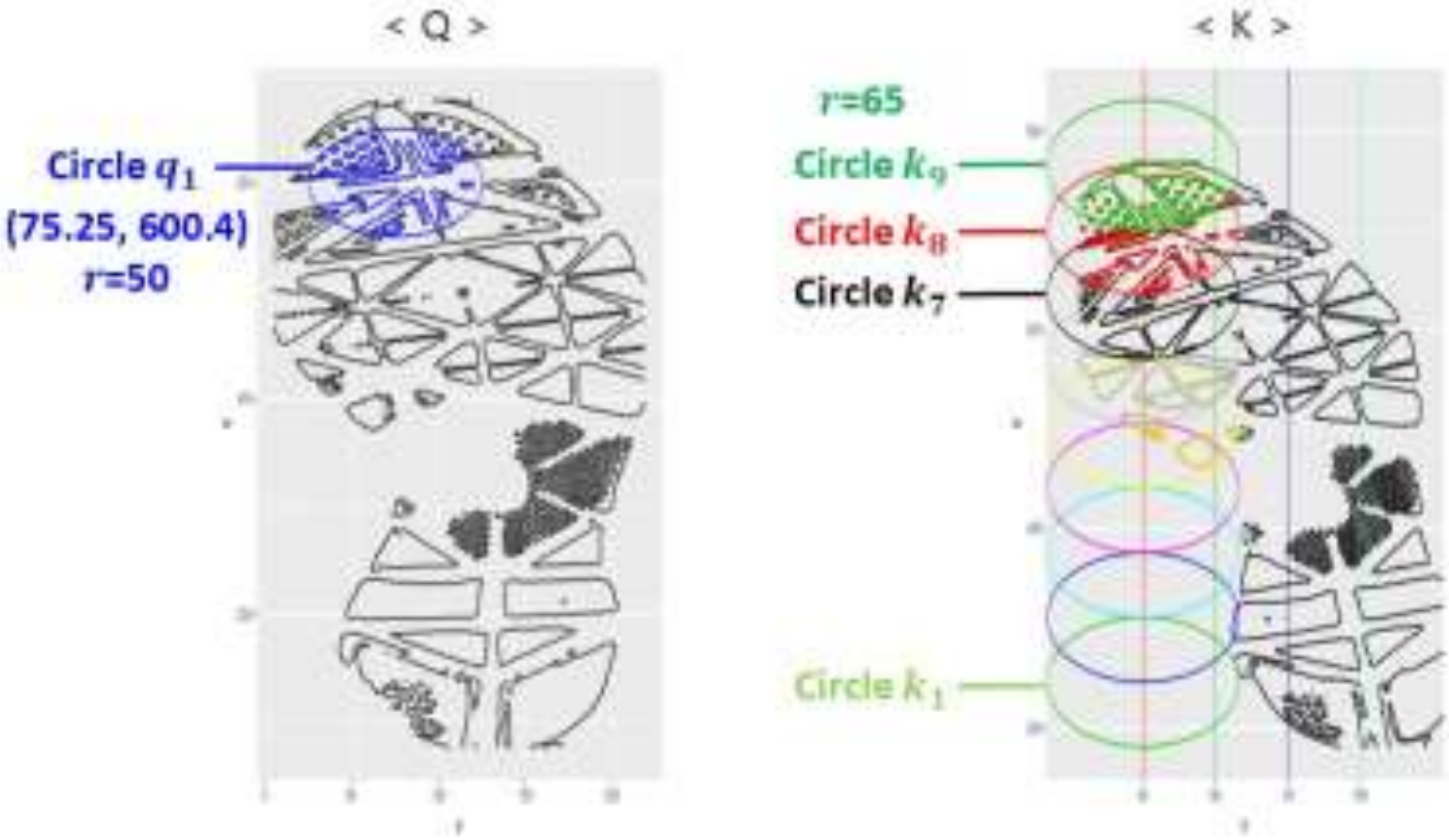
Quantify similarity

- We propose a computer-assisted method to quantify the similarity between two impressions.
- Steps:
  1. Select "interesting" sub-areas in the **Q** impression found at the crime scene.
  2. Find the closest corresponding sub-areas in the **K** impression.
  3. Overlay sub-areas in **Q** with the closest corresponding areas in **K**.
  4. Define similarity features we can measure to create an outsole **signature**.
  5. Combine those features into one single score.

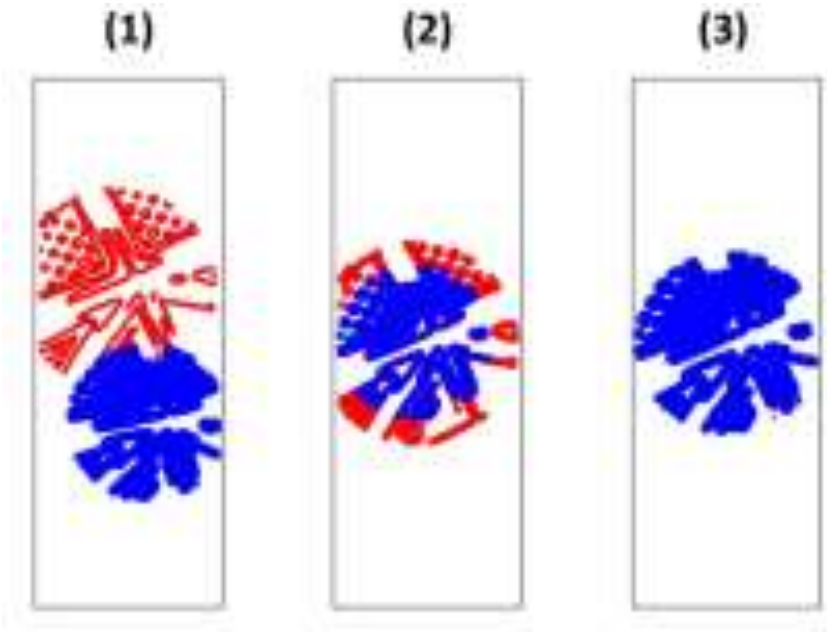
Local areas



Step 1 & Step 2

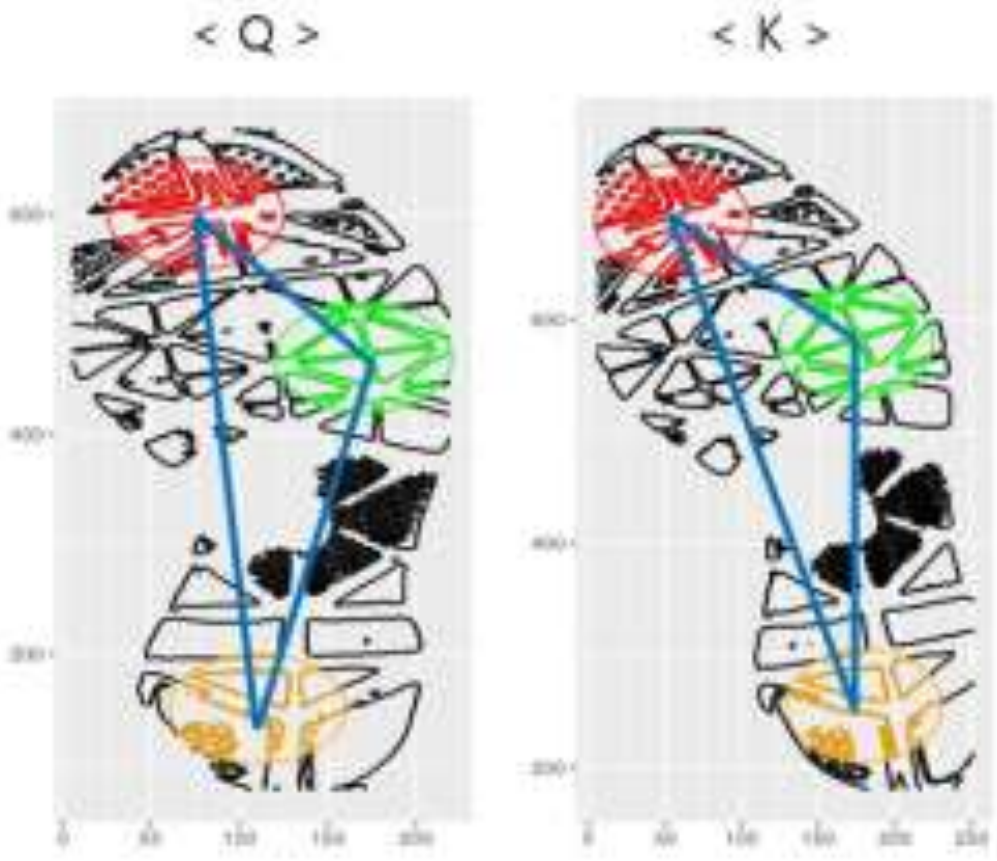

< Q >
Circle q_1
(75.25, 600.4)
r=50
< K >
r=65
Circle k_9
Circle k_8
Circle k_7
Circle k_1

Circle q_1 vs. circle k_8



clique size	rot. angle	overlap on k_8	overlap on q_1^K	median distance
18	12.05	0.75	0.97	0.3

Repeat for three circles



Results

Comparison $q_i - k_i^*$	Clique size	Rotation angle	Overlap on k_i^*	Overlap on q_i	Median distance
$q_1 - k_1^*$	18	12.13	0.73	0.97	0.29
$q_2 - k_2^*$	17	10.57	0.53	0.91	0.43
$q_3 - k_3^*$	20	12.14	0.63	1.00	0.24

Triangle side	Distance of Δ in q's	Distance of Δ in k^*'s
1-2	451.74	451.16
1-3	161.19	161.74
2-3	325.58	324.55

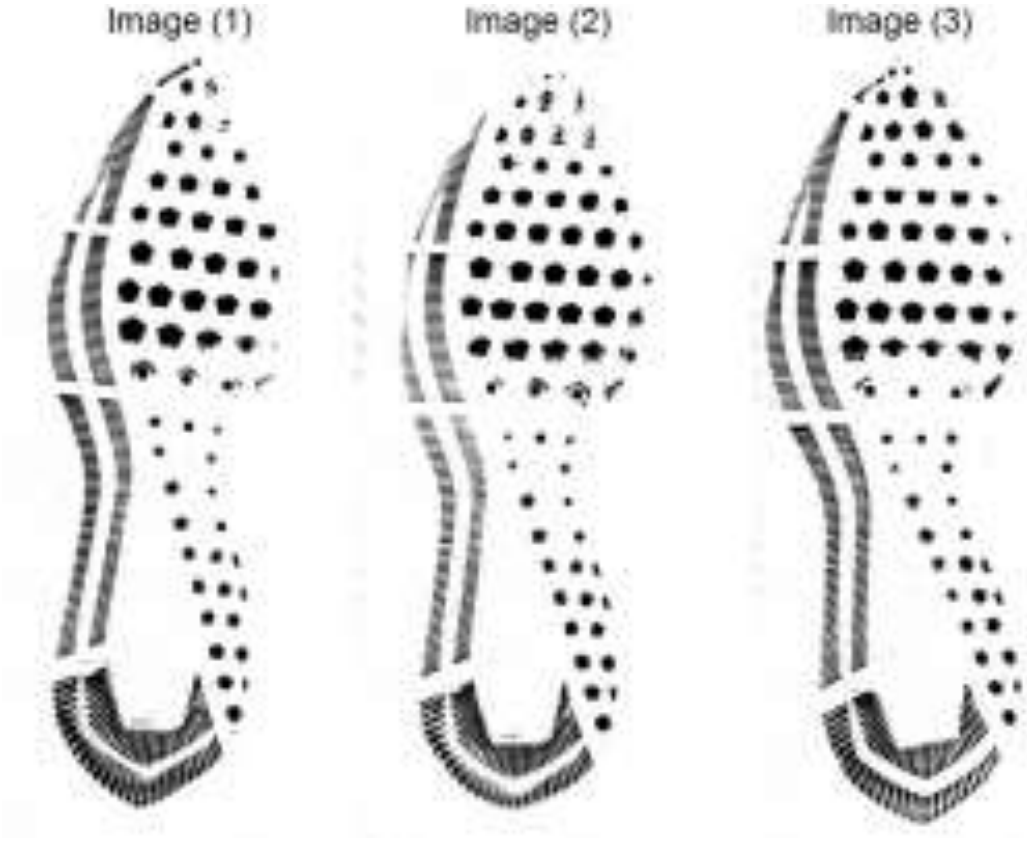
Data I

- CSAFE constructed a longitudinal database of 2D shoe outsole impressions.
- 160 participants were recruited and received a pair of brand new shoes.
- Participants were asked to use the shoes and return to CSAFE every six weeks, for a period of six months (T_1, T_2, T_3, T_4).
- At each time T, shoes were scanned 4 times, using an EverOS scanner[2].
- Here we use the T_4 images from 60 pairs of Nike, Winflow 4 shoes, size 8.5 (38 pairs) and 10.5 (22 pairs).

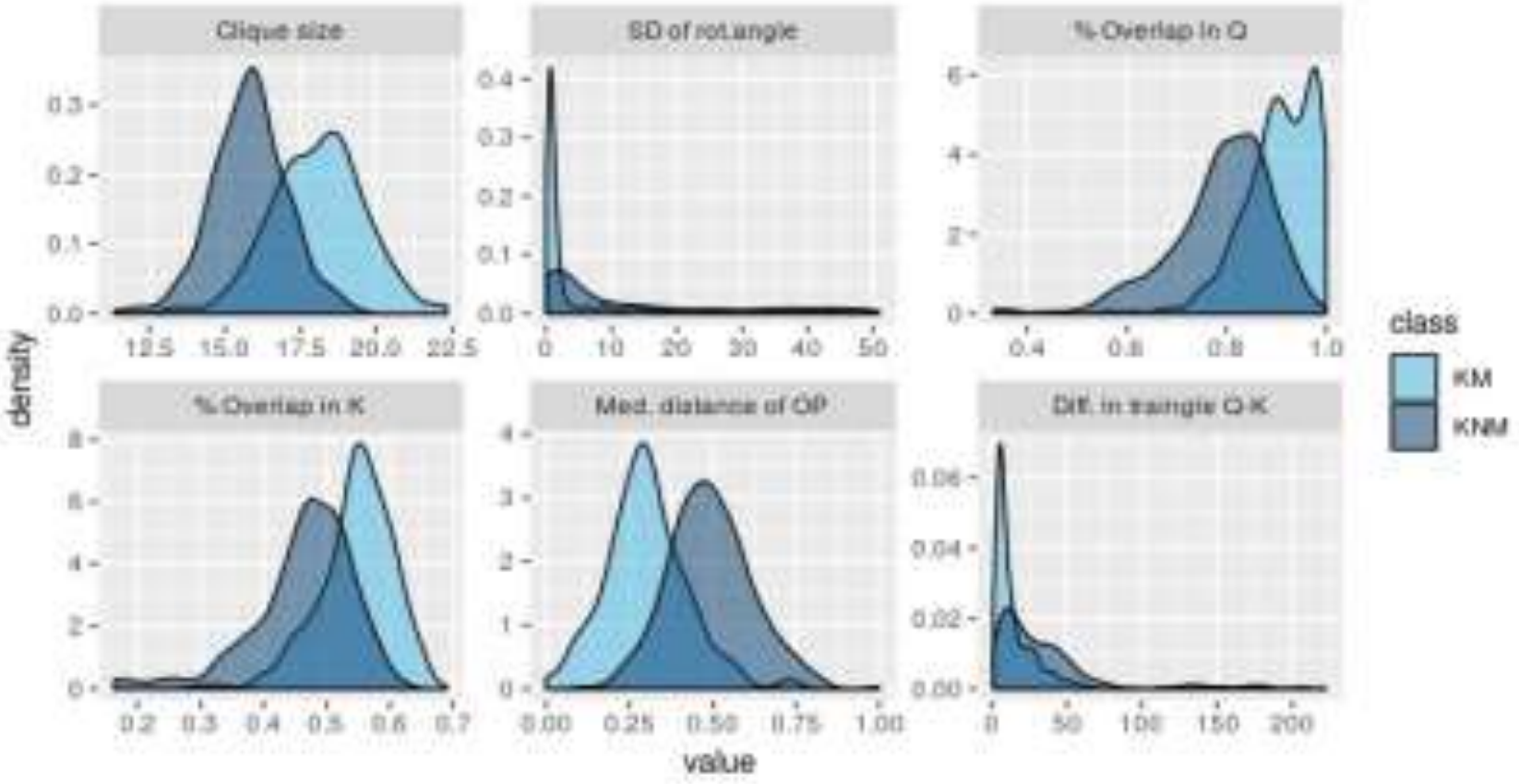
[2] https://www.shopevident.com/category/casting-footwear/

Data II

- KM: pairs of images from the same shoe, KNM: pairs of images from different shoes
- 717 KM, 600 KNM



Features among KM and KNM



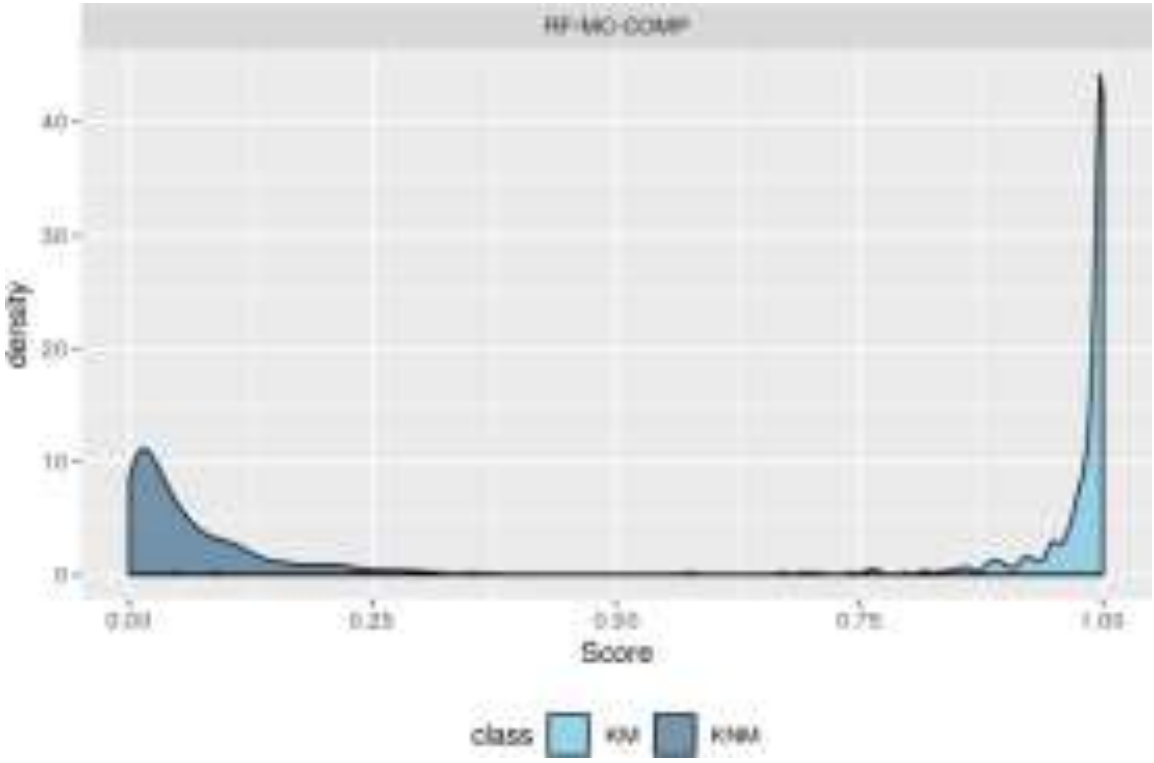
Combining features

- None of features individually can classify reliably mates and non-mates.
- Next step will be combining them into a single number that indicates similarity between two impressions.
- We call that number a **similarity score**.
- To construct the score, we use an algorithm called random forest.

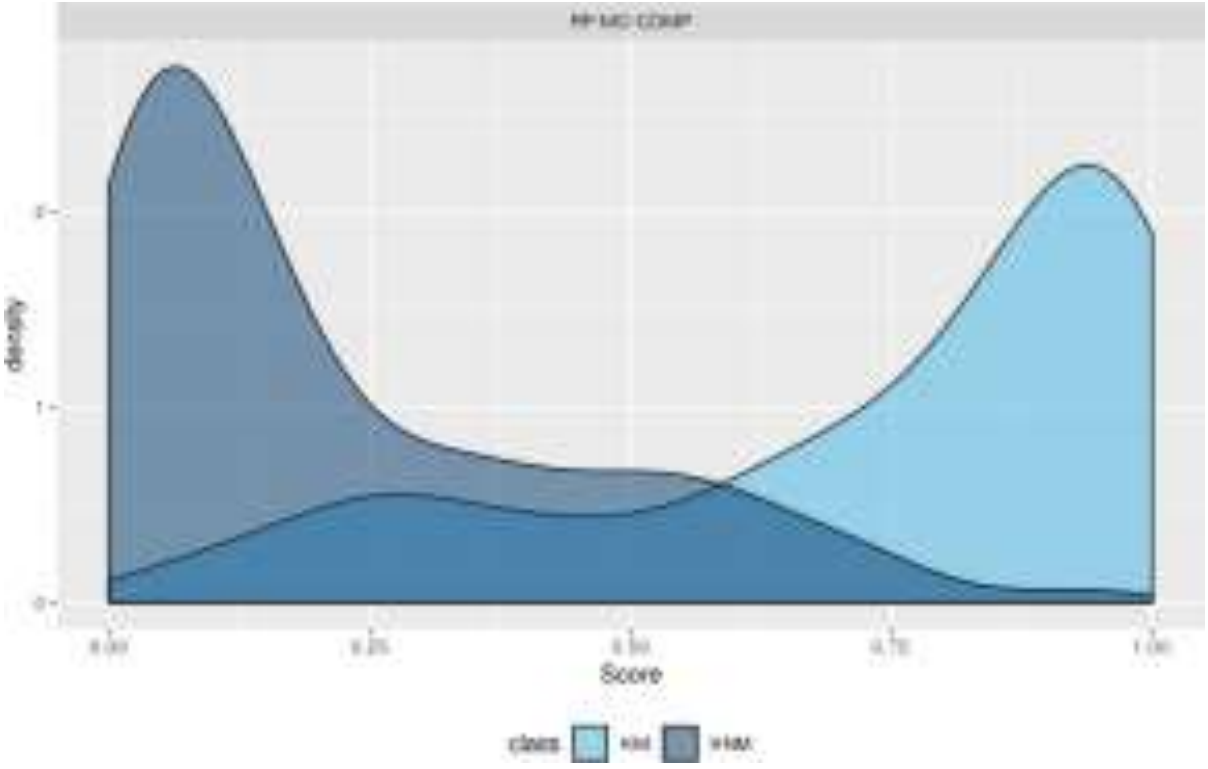
Random forest classifier

- A supervised learning algorithm.
- Idea : "train" the algorithm using a subset of pairs of images for which we tell the computer which are matches and which are non-matches (training set).
- The algorithm "learns" the values of the features associated with matches and non-matches.
- Given what it has learned, the algorithm can compute the probability of a match or non-match for a new pair of images.
- To see how well it does, we set aside a subset of the pairs of images, and ask the algorithm to classify them (testing set).

RF scores in training set



RF scores in testing set

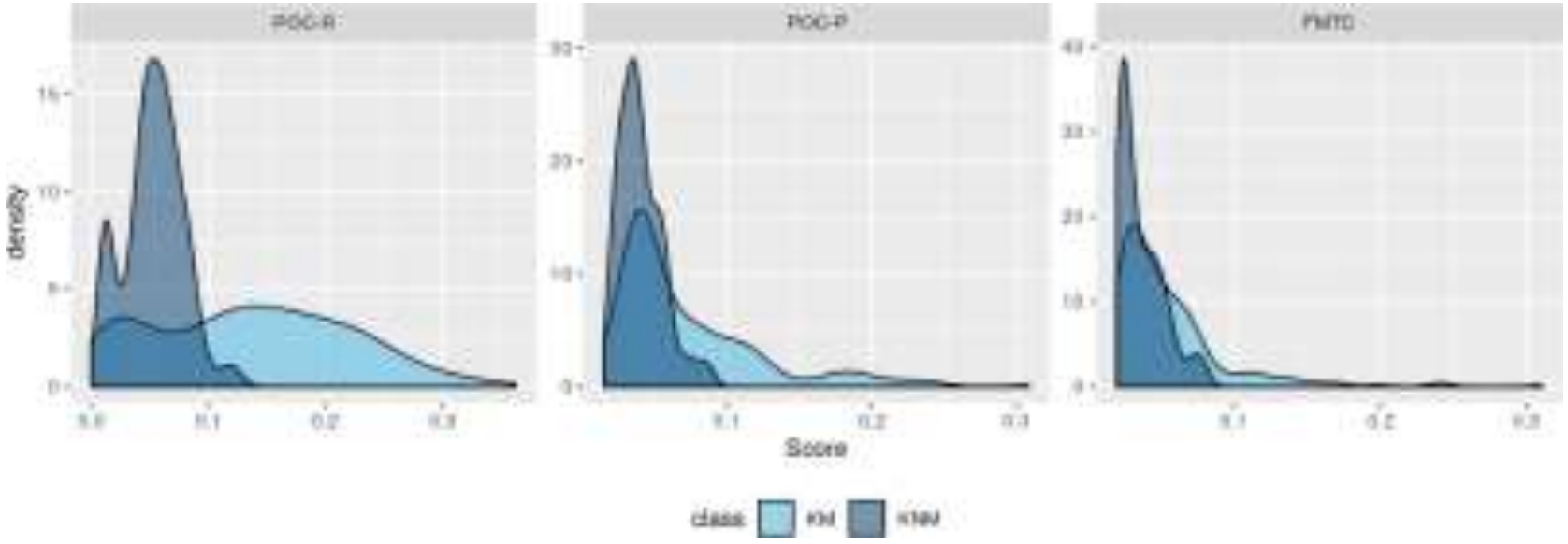


What about other methods?

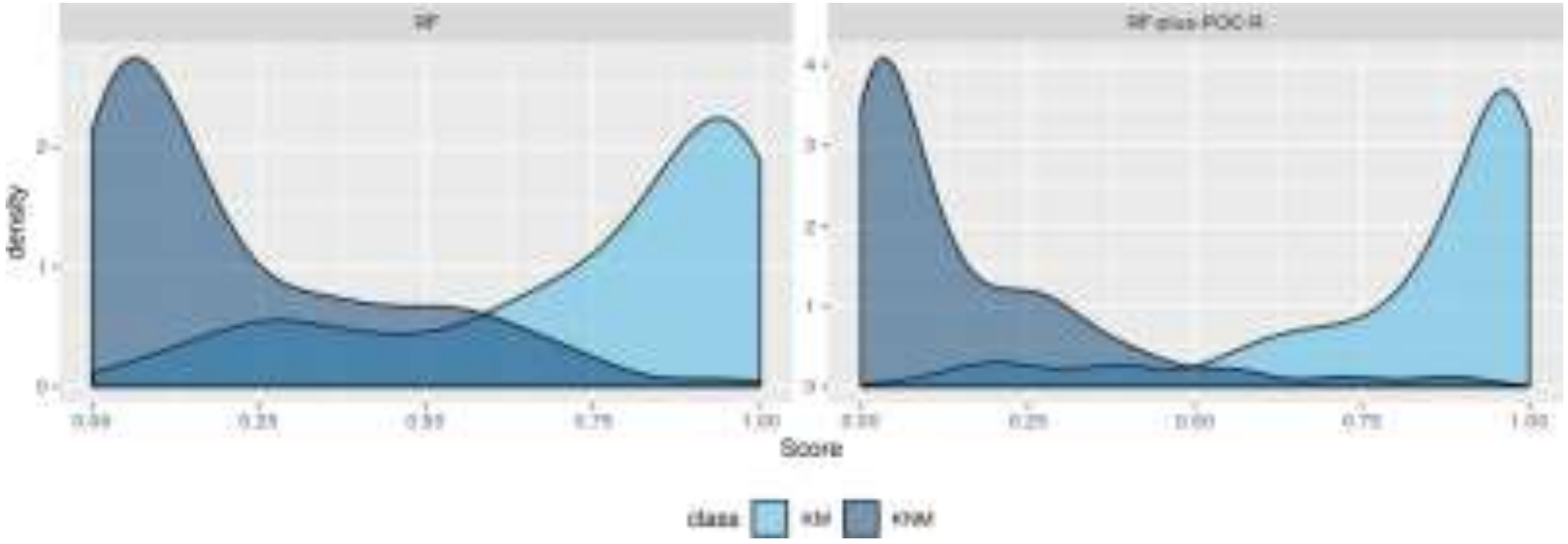
1. Phase Only Correlation (POC) [4] rotation angle estimation by registration method built in Matlab, POC-R.
2. Phase Only Correlation (POC) by detecting principal axis of shoe impressions and calculate rotation angle, POC-P.
3. Fourier-Mellin Transformation Correlation (FMTC) [4]

[4] Richetelli et al. (2017)

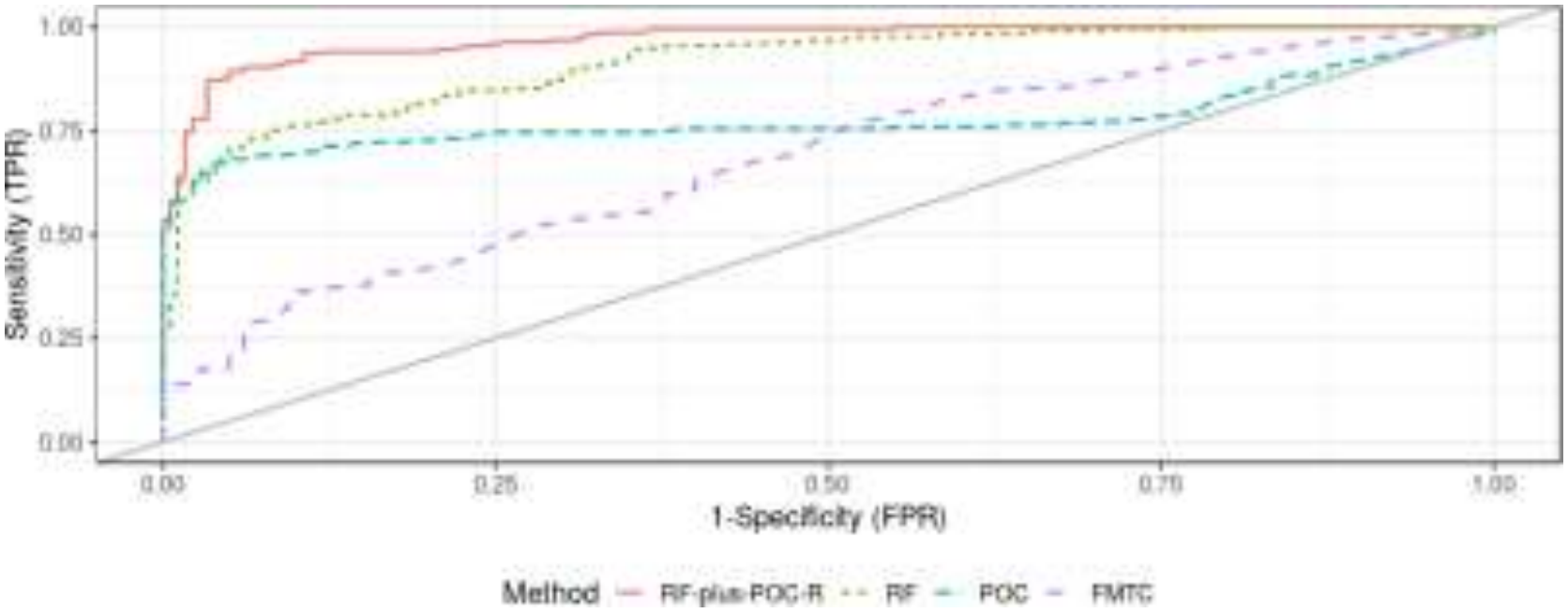
Other methods



Adding POC as a feature to RF



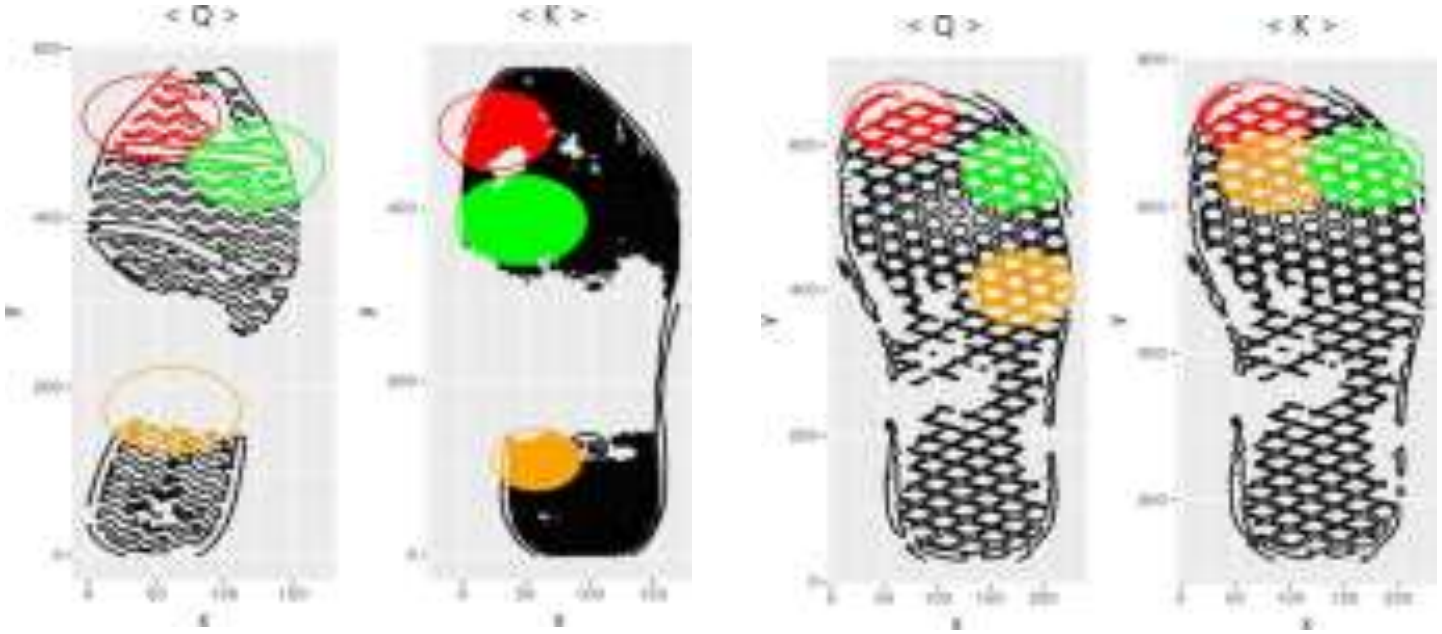
ROC curve


1.00
0.75
0.50
0.25
0.00
Sensitivity (TPR)
0.00
0.25
0.50
0.75
1.00
1-Specificity (FPR)
Method
RF-plus-POC-R
RF
POC
FMTC

Performance

Method	AUC	EER	Opt. threshold	FPR	FNR
RF-plus-POC-R	0.970	0.089	0.540	0.050	0.107
RF	0.913	0.189	0.600	0.078	0.250
POC	0.775	0.255	0.094	0.039	0.329
FMTC	0.680	0.395	0.056	0.094	0.639

Limitations



Future work

- Define additional features that maybe useful for classification.
- Explore the impact of factors such as weights of wearers on the similarity score.
- Study on the impact of tear and wear on the similarity score.
- Describe a score-based likelihood ratio to estimate probative value.
- Develop a web application that can be used by practitioners to set up and implement the matching algorithm.

Thank you

Any questions?

sypark@iastate.edu
alicia@iastate.edu