

Measurements and Scoring Procedures for Footwear Impression Comparisons

Presented by:

Martin Herman

Other Team Members:

**John Buckleton, Gunay Dogan, Simone Gittelson,
Hari Iyer, Yooyoung Lee, Steve Lund**

Information Technology Laboratory, NIST

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Outline

- Motivation and goals
- Description of SHOECALC – a software system under development
- Two example scenarios for SHOECALC
 - Footwear impression comparison
 - Database retrieval
- Summary



Motivation

- Need to improve measurement science underpinnings of forensic footwear analysis through **quantitative analysis** of observed characteristics
- Provide **software-based approaches** for quantitative analysis to the forensic footwear community



GOAL:

Develop SHOECALC (a prototype system)

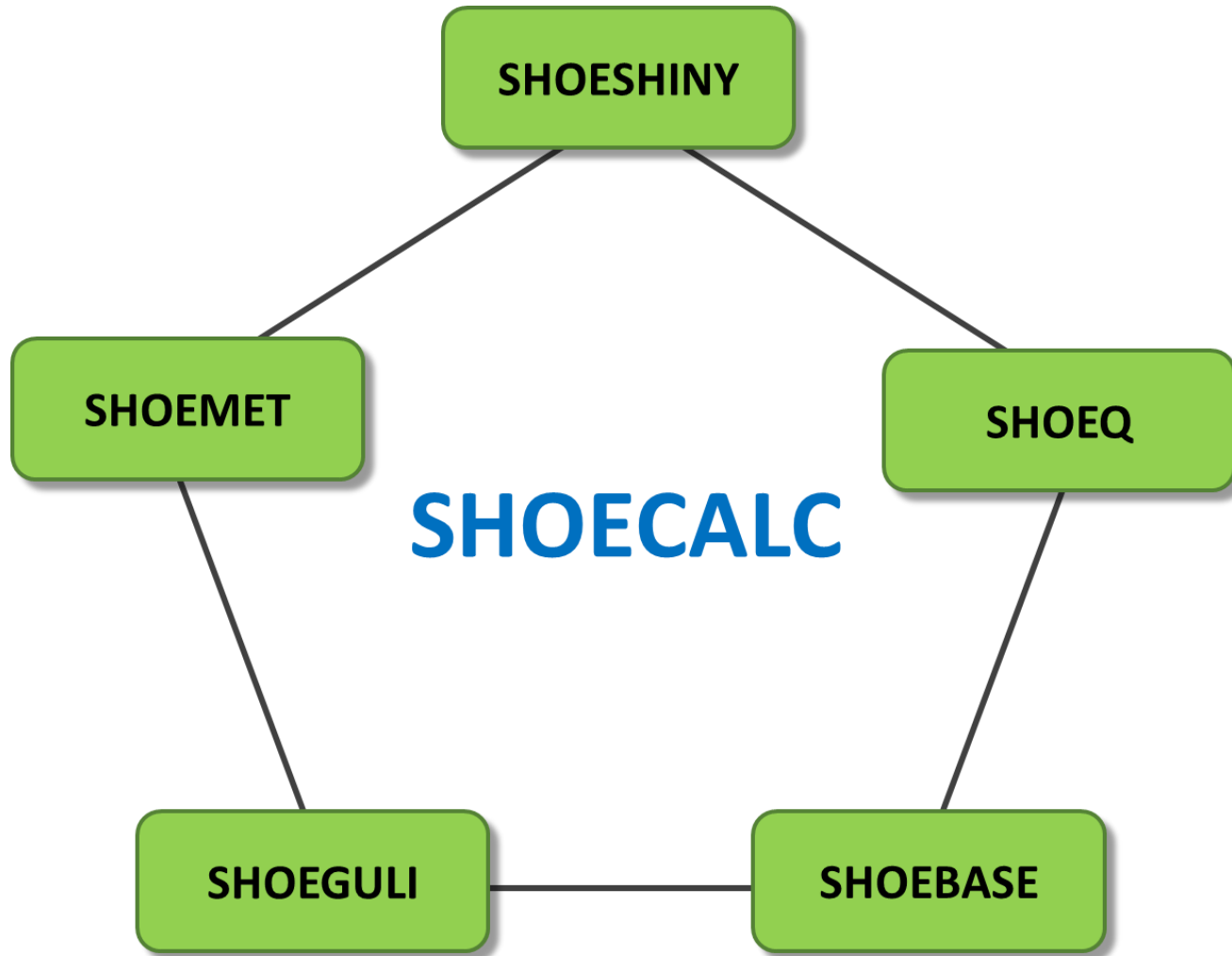
- Inputs:
 - Crime scene marks
 - Test impressions
- Outputs:
 - Similarity scores
 - Image quality values
 - For objectively informing weight of evidence assessments
 - For intelligence applications



SHOECALC

- **For use by footwear examiners**
 - Gain experience and understanding of use of automated methods
 - Use feedback from examiners to improve system
 - Eventually utilize in casework -- assist examiner by providing similarity scores and image quality values
- **Workbench for researchers/developers**
 - Develop new similarity measures and quality metrics
 - Develop and test measures for discriminating between “mated” and “non-mated” footwear impressions
 - Develop approaches and algorithms to “match” footwear images





SHOEBASE

Database consisting of

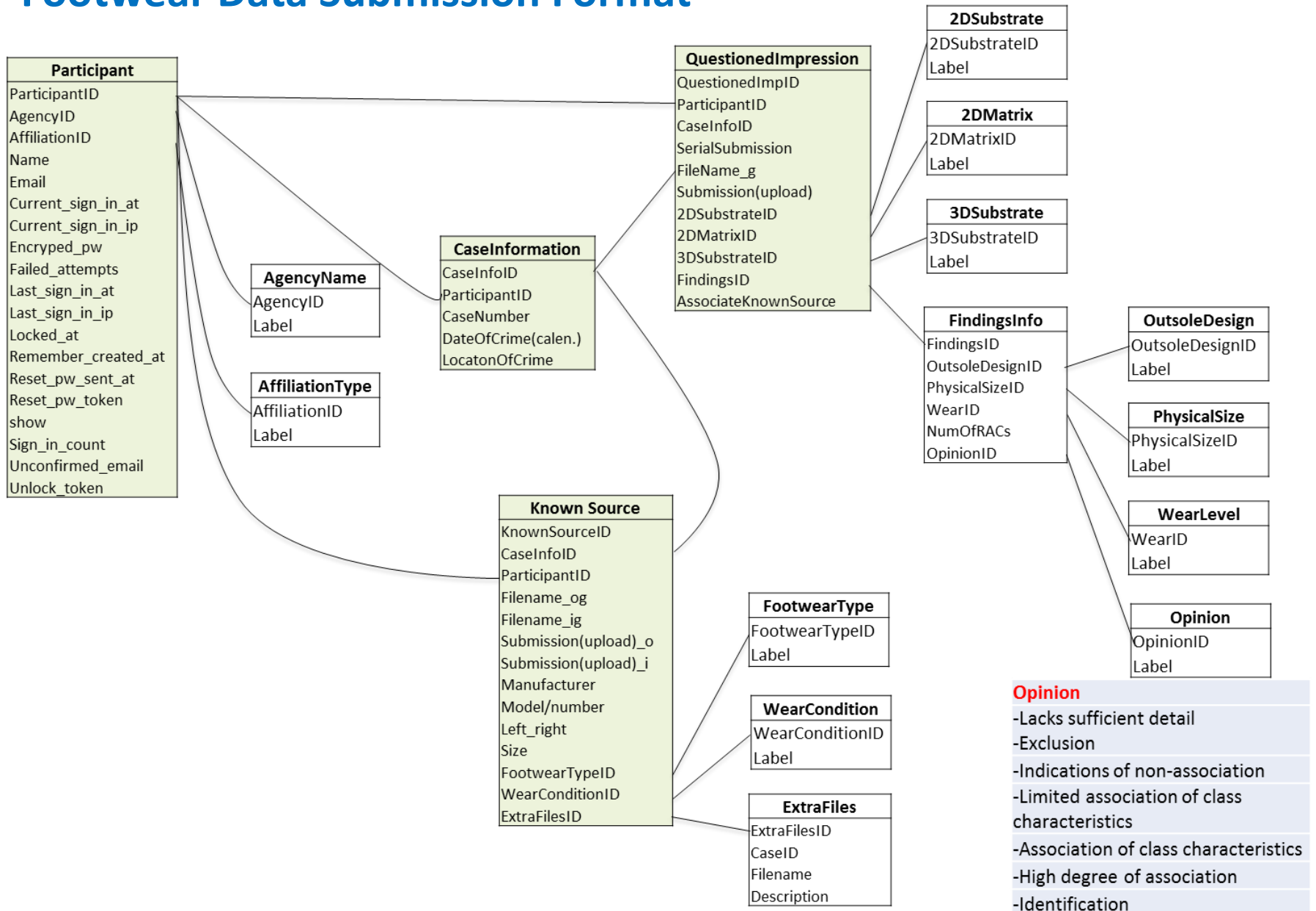
- Crime scene impressions and metadata
- Catalogue of outsole designs and metadata
- Test impressions from shoes of arrestees
- Catalogue of Randomly Acquired Characteristics (RACs) along with shape, size, location, brand, outsole design, etc.
- Interfaces and formats for submitting and maintaining footwear data

Current status:

- Obtaining data from various sources, including crime labs, academia, and companies



Footwear Data Submission Format



SHOEGULI

Synthetic footwear impressions

- For research and testing, will generate synthetic footwear impressions with ground truth known, and with user specified characteristics
- Characteristics will include particular subpopulation of outsole designs, wear amounts, sizes, and distributions of RACs; also different matrix/substrate combinations
- Will generate both synthetic *test* impressions and *crime scene* impressions (e.g., partial impressions)

Current status:

- As an interim step, generated soft synthetic (crime-scene-like) footwear data from actual test impressions



SHOEGULI

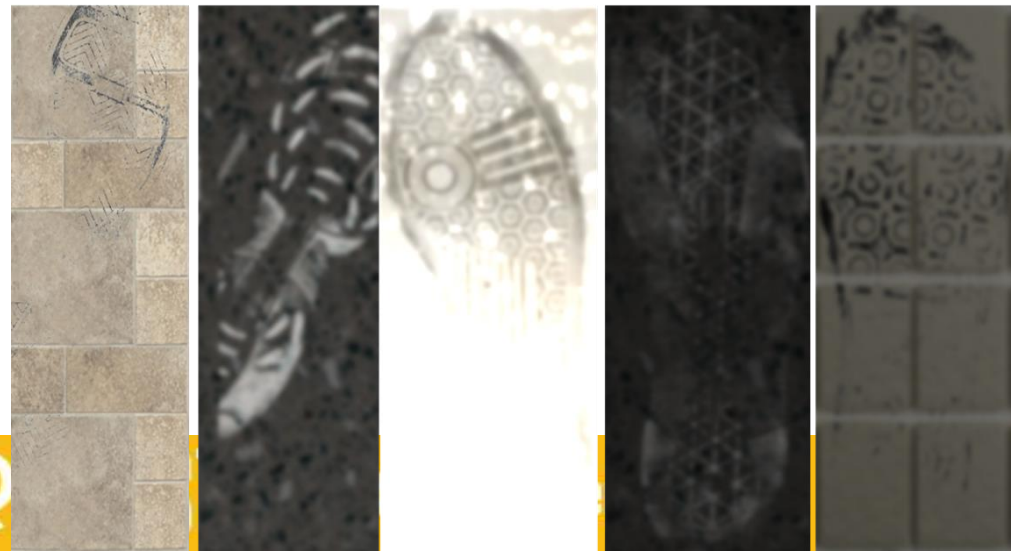
Level 1



Level 1: Outsole features are very clear and unambiguous

Level 2

Level 2: Clarity of outsole features is debatable



SHOEMET

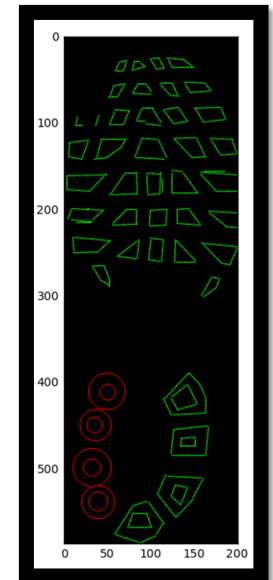
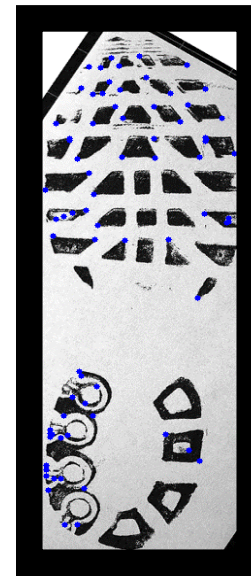
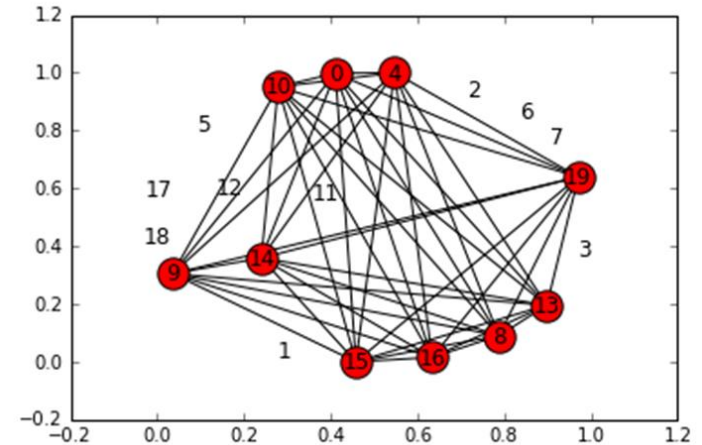
Similarity measures

- Will be a workbench for experimentation with different similarity measures. Some measures lead to better discrimination between mated and non-mated pairs of images than others.
- User will input a function for computing a similarity score and apply it to any given pair of images; numerical score will be reported.
- Also will use SHOEGULI to conduct experiments and produce Receiver Operating Characteristic (ROC) plots for comparing with a catalog of known, high performance similarity measures.



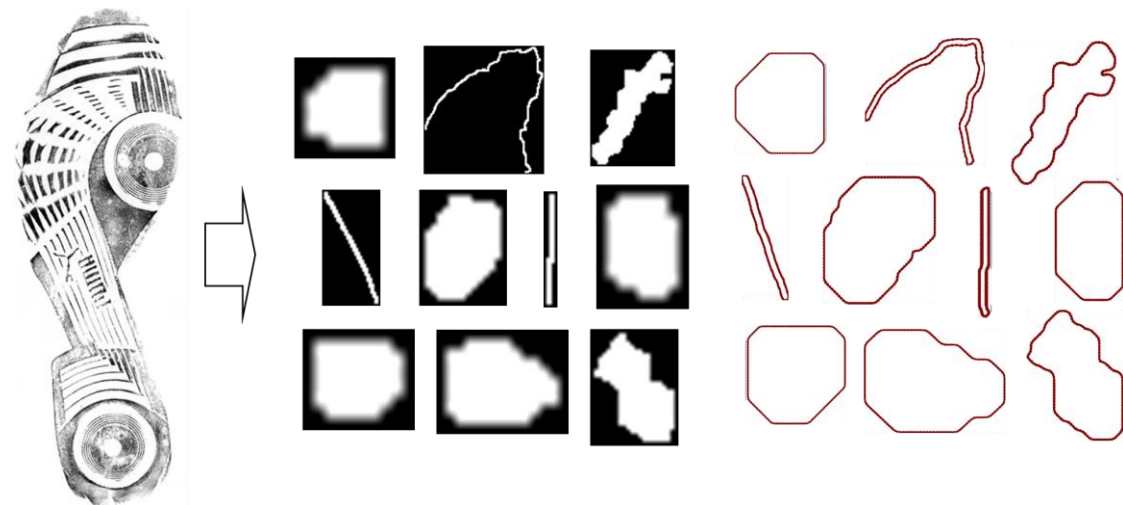
Maximum Clique Algorithm

- Baseline algorithm for similarity
- Finds maximum cliques in a graph
 - each node specifies a mapping from a feature in the first image in the comparison to a like feature in the second
 - each edge specifies that the “relationship” (e.g., distance between features) between the two nodes connected by the edge is similar in the two images
- Image features used – corners, circles, straight line segments

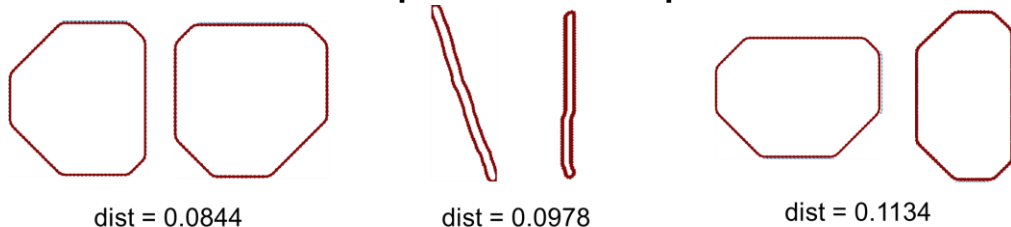


Shape Dissimilarity for RAC Boundary Curves

RACs segmented from footwear impressions (courtesy of J. Speir, U of WV).



Similar RAC pairs -- shape distances:



Dissimilar RAC pairs -- shape distances:



Square-Root Velocity Function
(Srinivista et. al. (2011))

Boundary curve:

$$\beta(t) = (x(t), y(t))$$

SRVF representation:

$$q(t) = \dot{\beta}(t) / \|\dot{\beta}(t)\|^{1/2}$$

The shape $[q]$ is the set of all rotated and reparameterized SRVF functions:

$$\tilde{\beta}(t) = R\beta(\gamma(t)) \Rightarrow \tilde{q}(t) = \sqrt{\dot{\gamma}(t)}Rq(\gamma(t))$$

The distance between the shapes of β_1 and β_2 is defined by

$$\text{dist}([q_1], [q_2]) =$$

$$\min_{\gamma, R} \int_{S^1} \left\| q_1(t) - \sqrt{\dot{\gamma}(t)}Rq_2(\gamma(t)) \right\|^2 dt$$

SHOEQ

Quality measures

- Measuring quality: different characteristics that describe the degradation, distortion, completeness, and quantity of features in the impression
- User will input a footwear image; output will be a list of quality scores
- SHOEQ can be used
 - To calculate better scores for casework, and
 - As a workbench for researchers to develop better image quality metrics



SHOEQ

Current status:

- Implemented over 20 different quality metrics
- Demonstrated use of quality to improve similarity measures in casework
- Demonstrated use of quality to improve database retrieval performance



SHOESHINY

- **GUI for user interaction** with the other modules of SHOECALC
- Will allow user to upload images for calculation of similarity and quality scores
- Will allow user to examine various choices of similarity metrics and their ROC curves, and select choices for reporting the information in the evidence
- Will allow exploratory pattern analysis

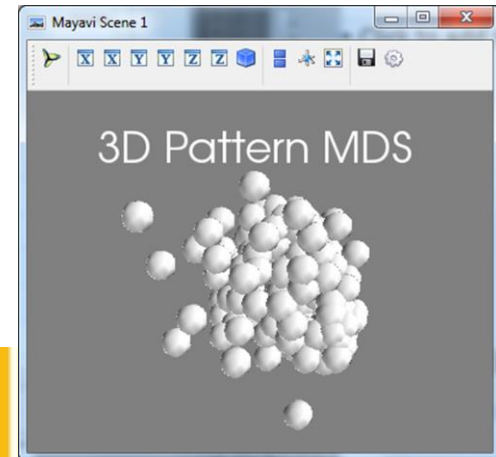
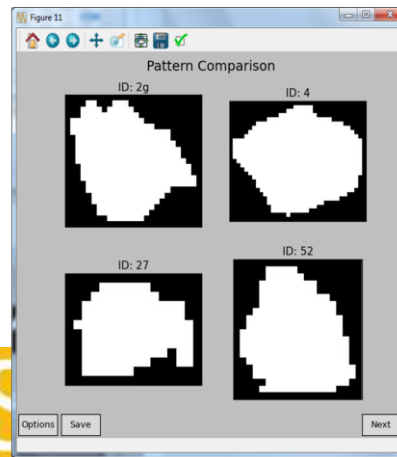
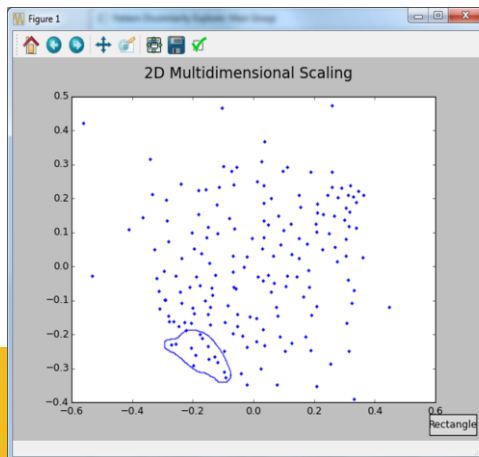
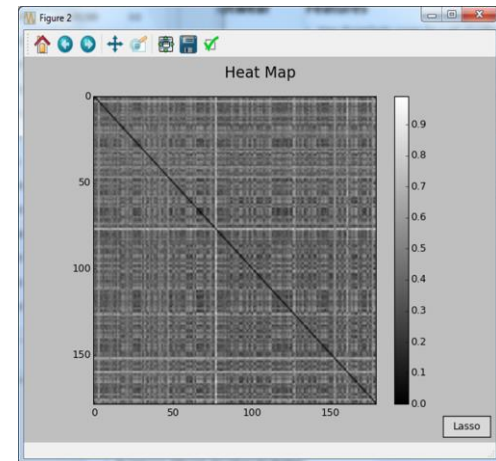
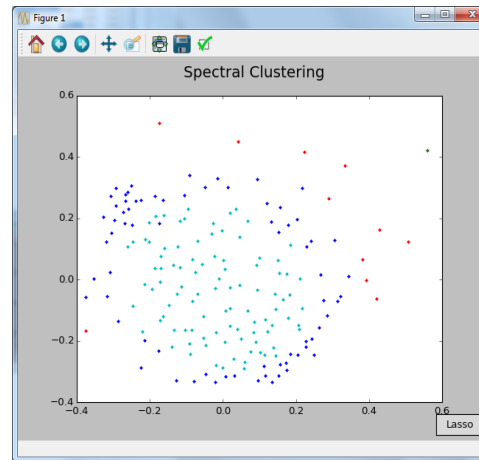
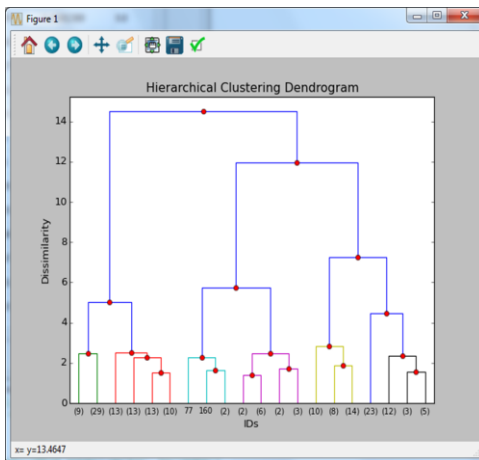


SHOESHINY

Current status:

Developed user interface to view, compare & analyze patterns and dissimilarity scores for pairs of patterns

- Clustering, heat maps, multidimensional scaling, statistics and histograms



Two Examples: Assisting Footwear Examiner Through Similarity and Quality Measures

Two example scenarios of using SHOECALC

1. Comparison of Crime Scene to Test Impressions
2. Database Retrieval

***Here we only present initial studies to show
proof of concept.***



Comparison of Crime Scene to Test Impressions (1)

- Similarity scores can inform weight of evidence assessments
- Algorithmic comparison of questioned to known impressions
- Similarity score can provide additional information to examiner in evaluating observations

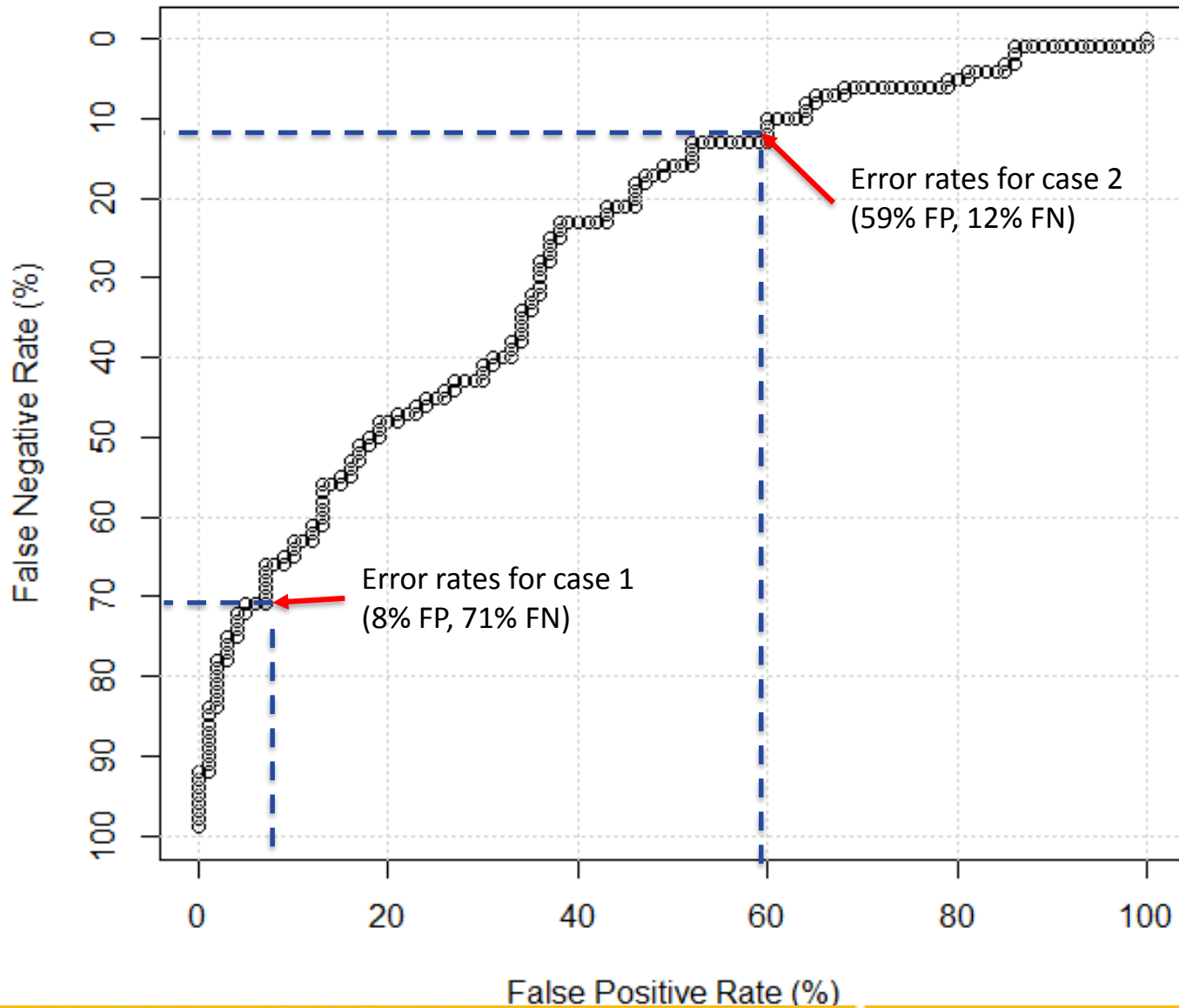


Comparison of Crime Scene to Test Impressions (2)

- For the given similarity measure, an ROC plot is obtained from empirical comparison tests using reference data samples (that have ground truth)
- The score obtained for the casework can be plotted on the ROC plot to determine identification error rates **obtained on the reference test samples**, using the score as a threshold. (see next slide)



ROC Plot

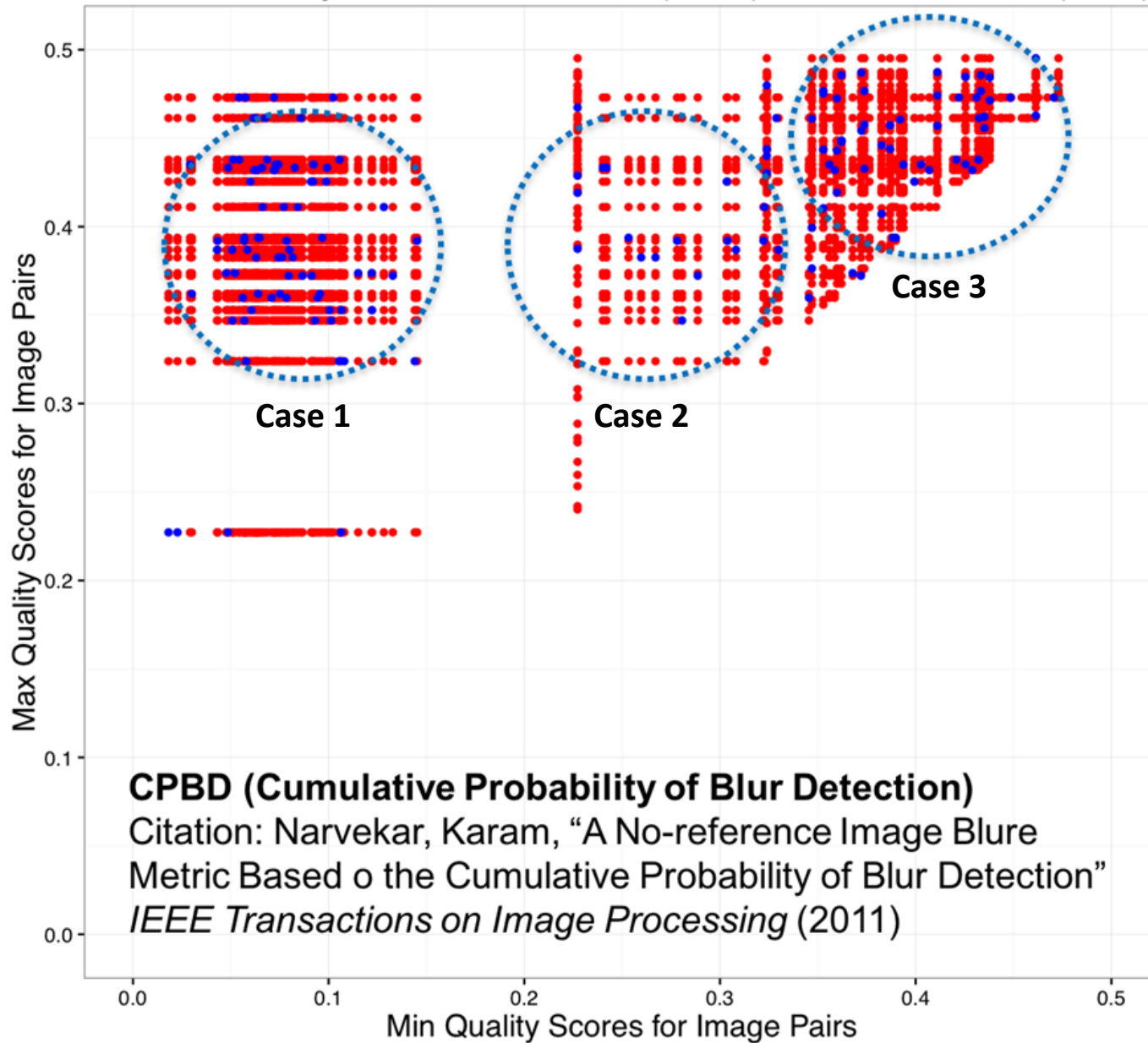


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- The score obtained for the casework can be plotted on the ROC plot to determine identification error rates obtained on the reference test samples, using the score as a threshold. (see next slide)
- Quality measures can be used to further reduce the set of experimental comparisons considered so that they are more relevant to this particular case comparison



CPBD Quality Metric for Mates (Blue) and Nonmates (Red)



CPBD (Cumulative Probability of Blur Detection)

Citation: Narvekar, Karam, "A No-reference Image Blure Metric Based o the Cumulative Probability of Blur Detection"
IEEE Transactions on Image Processing (2011)



Database Retrieval (1)

- Improve efficiency of examiner in finding matches in an automated footwear database
- Usually returns rank-ordered list of candidates
 - Examiner examines only candidates at the top of the list (e.g., top 10, 20, etc.)
- It would be valuable to have a similarity score algorithm that places the true match near the top of the list, i.e., reduce depth of search
- Quality measures can help place the true match higher up in the list

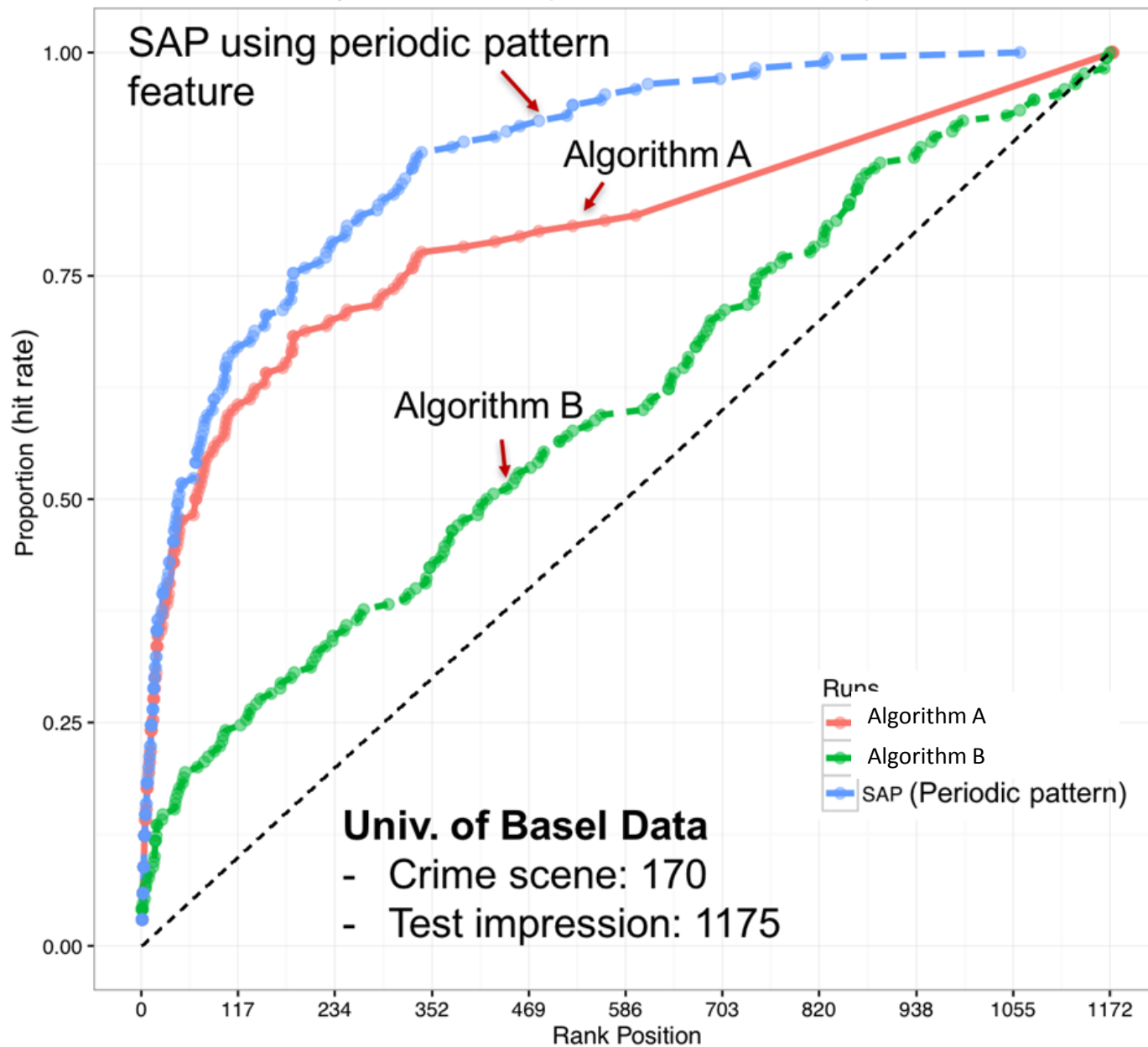


Database Retrieval (2)

- Consider the following situation:
 - Probe image:** crime scene impression
 - Gallery images:** test impressions of known offender shoes
- The process first calculates the similarity scores and lists the candidates in rank order
- Assume there are two similarity algorithms available. Certain quality metrics, when applied to the probe image, may be used as predictors to choose the better algorithm to reduce depth of search.



Comparison of CMC (Cumulative Match Curve) Results



Summary

- Described SHOECALC prototype system and its current status.
- Described a maximum clique algorithm and shape dissimilarity for RAC boundary curves as two components that can be incorporated into a similarity algorithm.
- Demonstrated use of quality values to develop ROC plots that are more relevant to particular case comparisons.
- Demonstrated use of quality values to improve database retrieval performance in terms of depth of search.
- These methods result in improved information provided to the examiner to aid in both forensic and intelligence applications.



Questions?

martin.herman@nist.gov



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