Some approaches for analysis of ballistics signatures using cross-correlation functions

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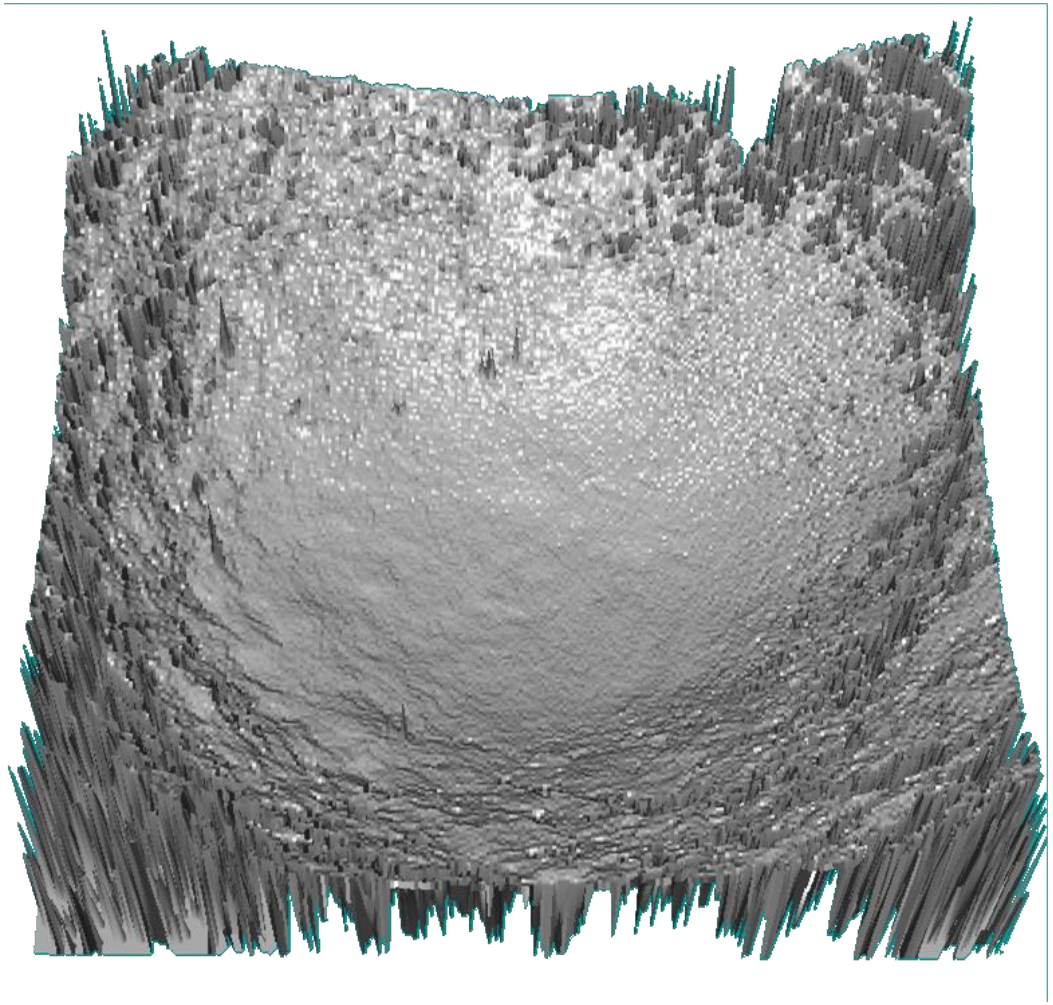
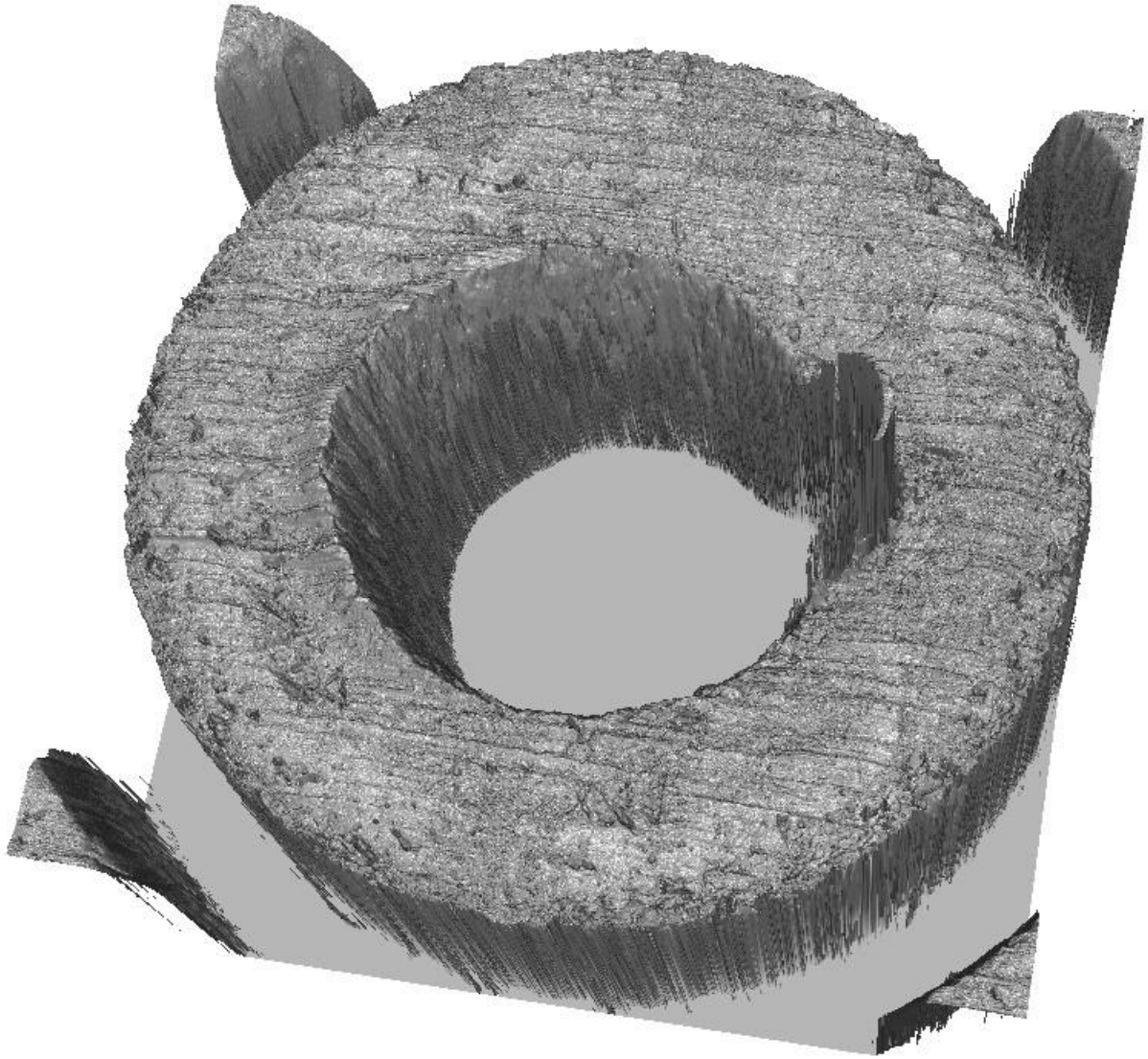
Introduction

- Goal: Demonstrating approaches to analyzing and modeling similarity scores for forensic identifications
- The approaches are demonstrated on the NBIDE (NIST Ballistic Identification Designed Experiment) breech face impression set analyzed by maximum areal cross-correlation function
- Tools include graphical representations of the data, and estimating contributions to correlation from various effects

A firing pin topographical image
(vertical proportions not drawn to scale)



A breech face topographical image
(vertical proportions not drawn to scale)



Areal Cross-Correlation Function

- A similarity measure is

$$\text{CCF}=\boldsymbol{ACCF}_{\max}=\frac{\sum_{\boldsymbol{m}}\sum_{n}(\mathbf{A}_{mn}-\bar{A})(B_{mn}-\bar{B})}{\left[\sum_{m}\sum_{n}\left(\mathbf{A}_{mn}-\bar{\mathbf{A}}\right)^{2}\ \sum_{m}\sum_{n}\left(\mathbf{B}_{mn}-\bar{\mathbf{B}}\right)^{2}\right]^{1/2}},$$

  where A and B are registered at the maximum correlation position

- Areal correlation of one surface to another
- After requisite trimming of areas, drop-outs, and outliers, and filtering for form and waviness

CCF properties

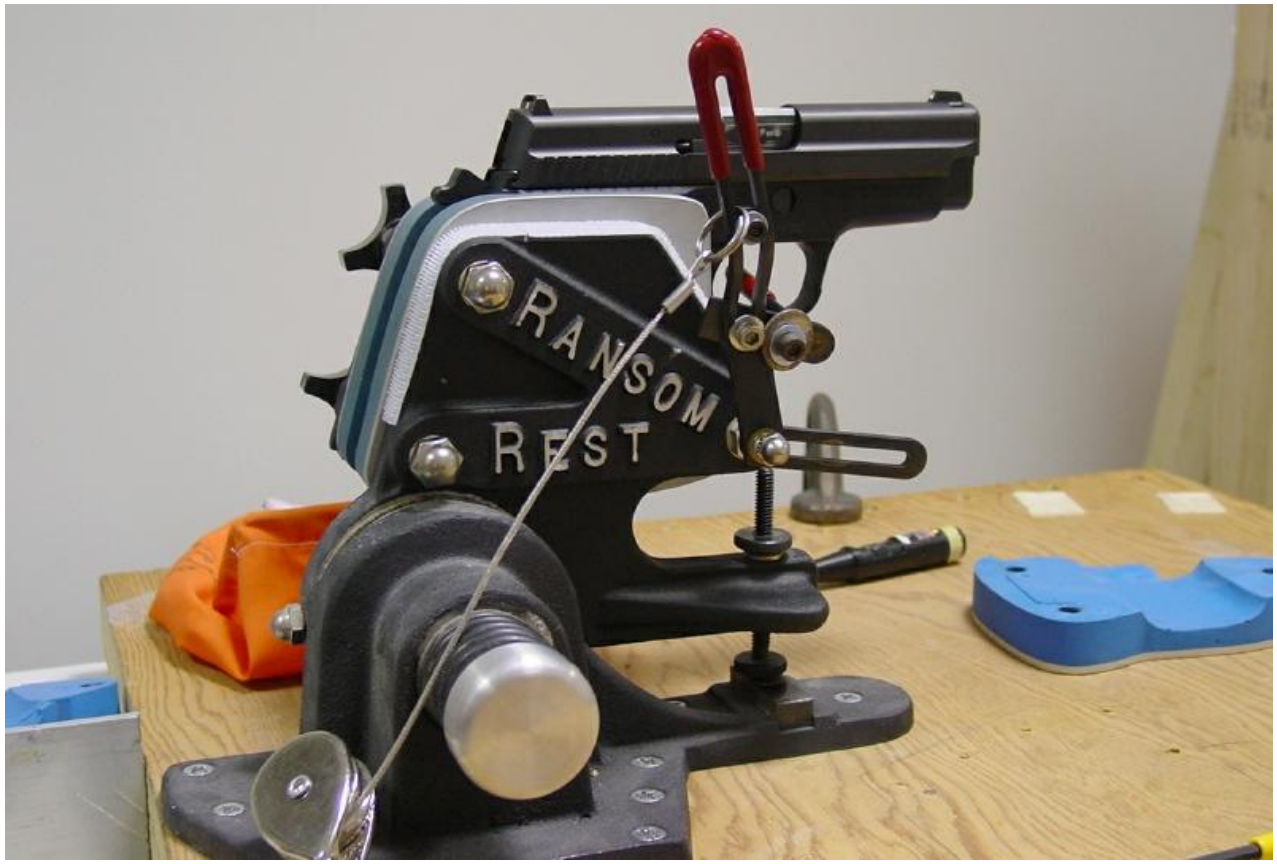
- CCF is brute force in being global and un-weighted (and computationally intensive)
- CCF is especially appropriate for NIST SRM bullets and cartridge cases (each surface was manufactured to be virtually identical)
- There are more “clever” strategies for identification: Consecutive matching striae for bullets, Congruent matching cells (NIST), application of multivariate pattern and discrimination methods by Petraco, et al.

NBIDE (NIST Ballistic Identification Designed Experiment)

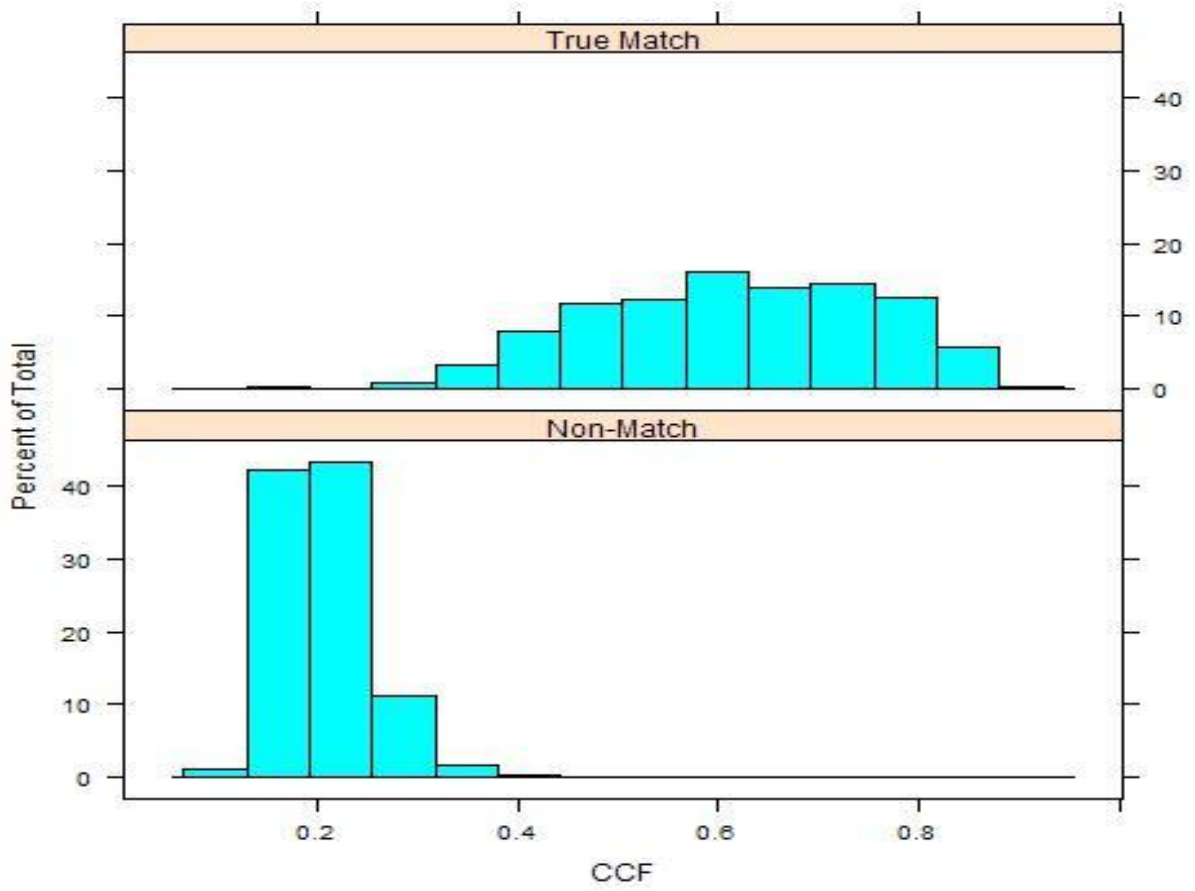
- 12 new guns: 4 Ruger, 4 Smith-Wesson, 4 Sig Sauer
- Each gun fired 9 times: 3 times each of ammunition brands: Winchester, Remington, PMC
- 3 x 4 x 3 x 3 = 108 cartridge cases
- CCF of each casing to every other casing measured
- Experiment Design by J.Filliben; casings were fired at OLES facility, and were given random ID before measurements and correlations
- Note: Certain commercial equipment may be identified in this presentation in order to specify certain experimental procedures. This does not imply recommendation or endorsement by NIST, nor does it imply that the equipment are the best available for the purpose.

The NBIDE Guns

Mechanical firing of NBIDE guns



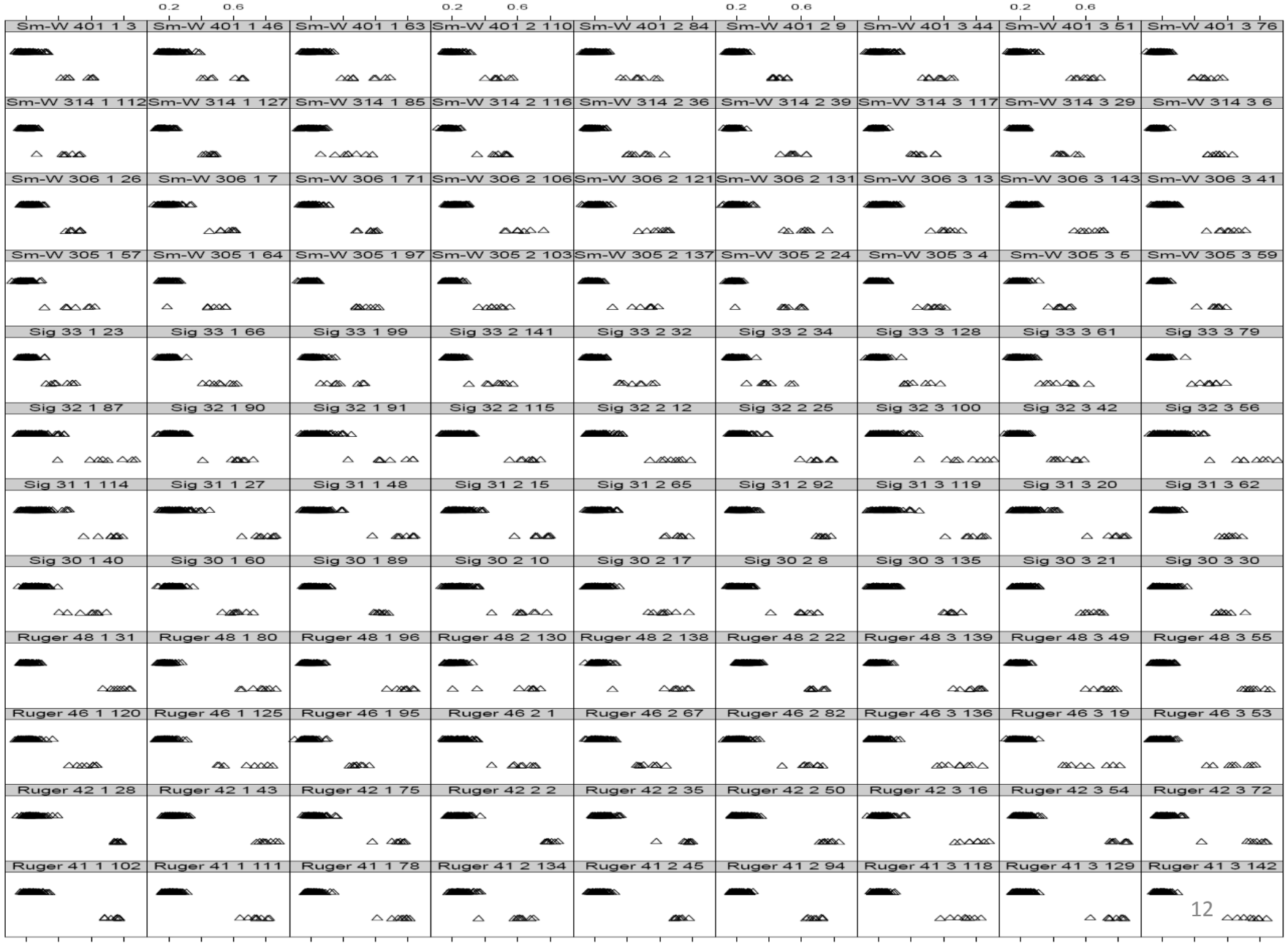
CCF values for correlations of breech faces of match and non-match cartridge cases

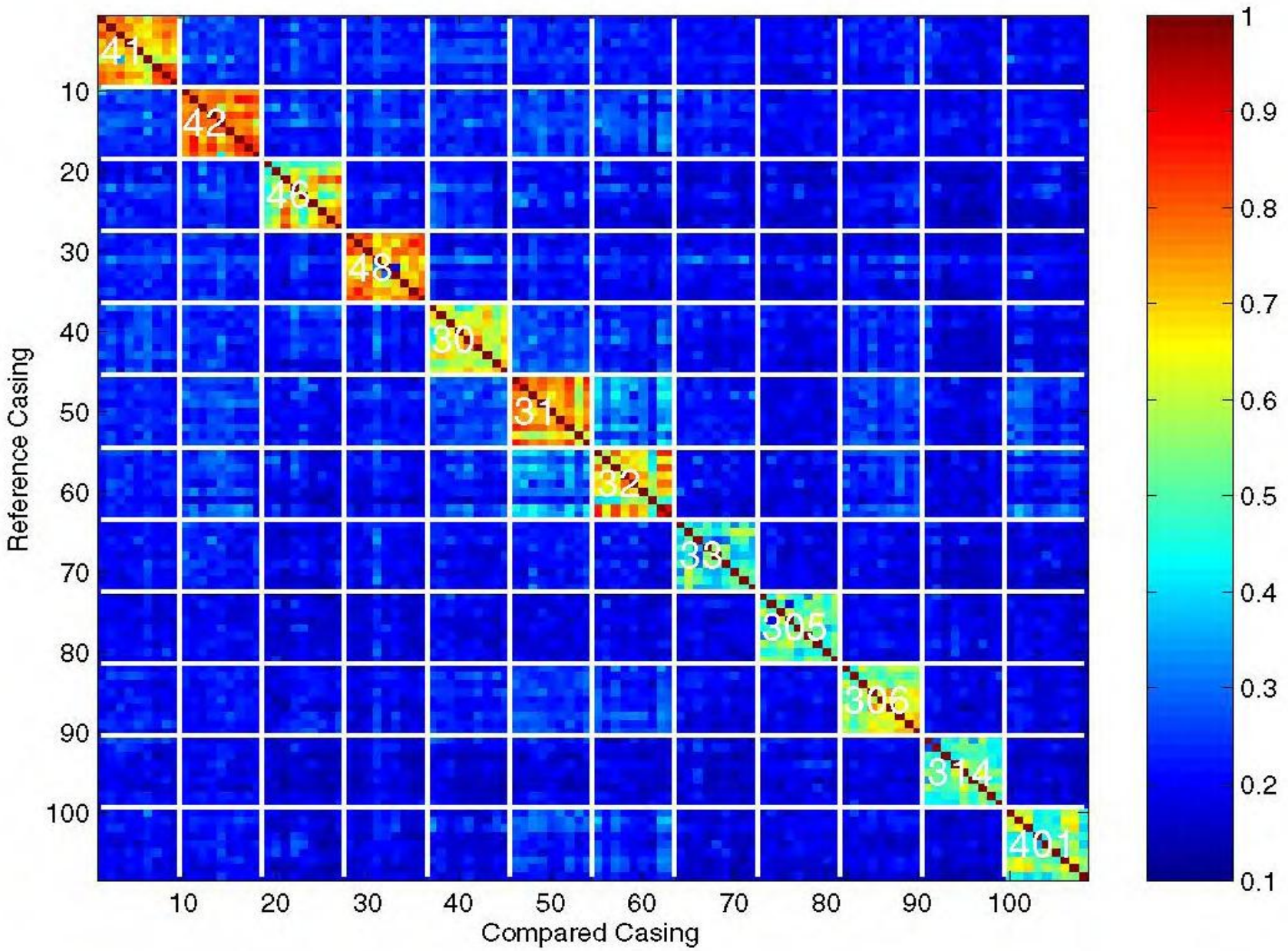


Graphical depictions of CCF data

- Exploratory data analysis: always graph the data!
- The figure on the next slide partitions the match and non-match CCFs by Reference Casing (Matches, lower triangles ; Non-matches, upper triangles).
- The plot following that is a color/intensity depiction of a CCF matrix
- (These may not be so easy for much larger sample size, or if you don't have round-robin comparisons.)

Non-match and Match CCFs by Casing





- *CCF* color matrix for topographic images of 108 breech face impressions for 12 BIDE guns. The data are ordered by gun(large groupings) then by ammo within each grouping.

Empirical Modeling of CCF scores

- *Average* CCF between two casings can *possibly* be modeled as combination of several terms:
  - Average Non-match CCF
  - Increase in average CCF due to casings being from same gun (we hope this increase is large)
  - Increase in average CCF due to same ammunition brand/type?
  - Increase in average CCF due to guns being of same brand/type (for non-matches)?

  All the above terms come with their own ‘errors’ and variabilities.

Estimated empirical effects for NBIDE BF CCFs (only)

- Average **Non-match** CCF: **0.21** (std.dev. 0.04, std.err. 0.0004)
- Average CCF for **Matches: 0.61** (std.dev. 0.14, std.err. 0.005)

Non-match CCFs for NBIDE BF

- Average effect of same gunbrand in non-matches is 0.01 (std.err. 0.001)
- All estimated brand effects and/or interactions < 0.04 in non-match CCFs
- Of the ammunitions, PMC gave lowest CCFs on the average: the lowest effect was PMC-PMC pair
  - So having same ammunition brand may not necessarily increase the CCF for non-match casings
- Tendency: Ruger high, Smith-Wesson low

NBIDE Match BF CCF effects

- Average Match CCF:
  - Ruger 0.70 (std.dev. 0.11, std.err. 0.01)
  - Sig-Sauer 0.62 (std.dev=0.14, std.err. 0.01)
  - Smith-Wesson 0.52 (std.dev. 0.09, std.err. 0.01)

- Random effect standard deviation of individual guns (measures variability between guns of each brand):
  - Ruger 0.07
  - Sig-Sauer 0.12 (due to one gun with low match CCFs)
  - Smith-Wesson 0.05

Estimated Ammunition Brand effects in Matches

- Average effect of having Same ammunition in Matches = 0.03 [std. err. (<.01)]
- Highest average ammunition effect for matches is PMC-PMC with .04 (std. err. 0.02)
- Ammunition combination as a random effect has .02 standard deviation

NBIDE BF Points about CCF

- Manufacturer effects much more evident in matches than non-matches
- On the average, Ruger yields higher CCF, Sm-W lower CCF, for both matches and non-matches
- PMC-PMC combination yields (slightly) higher CCF for matches , lower CCF for non-matches
- Estimated gun brand effects are smaller, and ammunition effects are much smaller, than the (Match vs. Non-Match) effect on the CCF score

Final Points

- These patterns may NOT be true for human examiners or other automatic systems
- Specific conclusions do not necessarily hold in other ballistics scenarios (different guns, different ammunition, etc.)
- However, these or similar methods of analyses can be useful for a variety of ballistics and other forensics applications