Automatic Matching of Scans from Hamby Sets
Friends, False Friends and Clones

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Dr. Susan VanderPlas
Dr. Alicia Carriquiry
An Investigation …
- the statistical way

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Matching bullets - very brief overview of the algorithm: *getting RF scores*

Applications for quantifying identifications: *using RF scores*

Scores as a diagnostics tool: *mis(?)using RF scores*
Hamby Sets

★ in collaboration with: St Louis PD, DCI Ankeny, Jim Hamby, Paul Murphy, NIST NBTRD

★ Hamby Sets 10, 36, 44, 173, 224, 252

★ Hamby Clones 159

★ Hamby Clone Test Set 224

★ each set consists of

★ 20 known bullets (2 from each of ten consecutively manufactured P-85 barrels)

★ 15 questioned bullets
Two Sensofar Confocal Light Microscopes
Six undergraduates scanning bullet lands
3d topographic images: height measurements on x-y grid
Two Sensofar Confocal Light Microscopes

Six undergraduates scanning bullet lands

3d topographic images: height measurements on x-y grid
Data captured on a regular grid of 0.645 µm x 0.645 µm

Total captured area for each land ~ 2.2 mm x 0.6 mm

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### x - y - z file

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<tr>
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<th>z</th>
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Step 1: identify region suitable for matching

land from bullet fired from Smith & Wesson

Region close to heel of bullet
Avoid break-off
Automatic matching score

Step 1b: from scan to crosscut
Automatic matching score

Step 1b: from scan to crosscut
Step 1b: from scan to crosscut
Automatic matching score

Step 1b: from scan to crosscut

Identify matching region
Step 1b: from scan to crosscut
Step 2: Identify groove locations

Shoulders (locations outside the grooves) are removed
Step 2: Identify groove locations

Shoulders (locations outside the grooves) are removed
Step 3: Fit curvature
Automatic matching score

Step 3: Fit curvature

Identify matching region

Identify groove locations
Step 3: Fit curvature & get signature
Step 3: Fit curvature & get signature

Automatic matching score

Identify matching region

Identify groove locations
Step 3: Fit curvature & get signature

- Automatic matching score
- Identify matching region
- Identify groove locations
Automatic matching score

Step 4: Align signatures
Step 4: Align signatures

Automatic matching score

Identify matching region

Identify groove locations

Extract signature
Step 4: Align signatures
Step 4: Align signatures

Horizontal shifts to find best alignment
Step 5: Identify Peaks & Valleys

Peaks and valleys in the same locations of two lands are matching striae on the scans.
Step 6: Extract features

Feature should distinguish between a match and a non-match
Step 6: Extract features

Feature should distinguish between a match and a non-match

- # matches/mis-matches of peaks & valleys
- # consecutive matching striae (cms)
- Depth of peaks/valleys
- Area between the signatures
- Cross-correlation function
Step 7: Assign Score (Random Forest Model)

★ Matching score between 0 and 1

★ Higher score indicates more similarity between two lands
let’s assume that two bullet (land)s are compared, the model spits out a number ...
What does it mean?

★ let’s assume that two bullet (land)s are compared, the model spits out a number …

0.91
Let’s assume that two bullet (land)s are compared, the model spits out a number … 0.91
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![Graph showing density distribution for RF score with different sources.]

- RF score: 0.91
- Different Source: 2.77
- Same Source: 1.6 x 10^{-16}
let’s assume that two bullet (land)s are compared, the model spits out a number …
What does it mean?

★ let’s assume that two bullet (land)s are compared, the model spits out a number …

The likelihood ratio indicates how much more likely it is to observe a value of 0.91 from two same-source LEAs than from two different-source LEAs.

\[
\frac{2.77}{1.6 \times 10^{-16}} = 1.7 \times 10^{16}
\]
What does it mean?

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The likelihood ratio indicates how much more likely it is to observe a value of 0.91 from two same-source LEAs than from two different-source LEAs.

2.77 / 1.6 x 10^{-16} = 1.7 x 10^{16} supports identification
Let’s assume that two bullet (land) samples are compared, the model spits out a number …

- RF score
- Density

<table>
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<th>Different Source</th>
<th>Same Source</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.91</td>
<td>0.69</td>
</tr>
</tbody>
</table>

\[
\frac{2.77}{1.6 \times 10^{-16}} = 1.7 \times 10^{16}
\]

Supports identification
let’s assume that two bullet (land)s are compared, the model spits out a number …

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supports identification

0.69
0.67 / 0.05 = 13.4
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- 0.91
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  Supports identification

- 0.69
  \[ \frac{0.67}{0.05} = 13.4 \]
  Supports identification

- 0.50
  \[ \frac{0.43}{1.65} = 0.26 \]
  Inconclusive
Shades of RF Scores
How well do LEAs match between a bullet and its clone?

HS 224 to Clone HS 224
Random Forest Scores
How well do LEAs match between a bullet and its clone?

HS 224 Br 1 - Bullet 1 - Land 1

HS 224 Barrel 1 - Bullet 1 - Land 2

HS 224 Clone Br 1 - Bullet 1 - Land 1

HS 224 Clone Br 1 - Bullet 1 - Land 2
How well do LEAs match between a bullet and its clone?

<table>
<thead>
<tr>
<th>Set</th>
<th>Bullet</th>
<th>Bullet 1</th>
<th>Clone</th>
<th>Bullet 1</th>
<th>Bullet 2</th>
<th>Original</th>
<th>Bullet 1</th>
<th>Bullet 2</th>
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</thead>
<tbody>
<tr>
<td>Clone</td>
<td>Bullet 1</td>
<td>1.00</td>
<td>Clone</td>
<td>Bullet 2</td>
<td>0.80</td>
<td>Original</td>
<td>Bullet 1</td>
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<tr>
<td></td>
<td>Bullet 2</td>
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Original bullets match with higher RF score than clones.
How well do LEAs match between a bullet and its clone?

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<th>Set</th>
<th>Bullet 1</th>
<th>Bullet 2</th>
<th>Clone Bullet 1</th>
<th>Clone Bullet 2</th>
<th>Original Bullet 1</th>
<th>Original Bullet 2</th>
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</thead>
<tbody>
<tr>
<td>Clone</td>
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<td>0.80</td>
<td>0.96</td>
<td>0.96</td>
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<tr>
<td>Original</td>
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<td>0.98</td>
<td>0.98</td>
<td>1.00</td>
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Original bullets match with higher RF score than clones

Original bullets match well to clones, almost as well as to each other
Some LEA scans of clones are showing artifacts:
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Some LEA scans of clones are showing artifacts:

- droplets
Some LEA scans of clones are showing artifacts:

- droplets
Some LEA scans of clones are showing artifacts:

- droplets
- air pockets between clone and cast
Some LEA scans of clones are showing artifacts:

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Some LEA scans of clones are showing artifacts:

- droplets
- air pockets between clone and cast
- some other structure but no striae
Some LEA scans of clones are showing artifacts:

- droplets
- air pockets between clone and cast
- some other structure but no striae

Automatic RF scores allow us to assess clone quality quantitatively.
Hamby Set 10 and Set 44 are from the same 10 barrels of Ruger P-85s

Bullets from Hamby Set 44 are fired some time later (~ 240 shots in each barrel between the sets)

Two Goals:

- **check** identifications between the sets
- **quantify** identifications
Hamby Set 10 and 44 Barrel 1

Relative Location (in millimeter)

Depth of striae (in microns)

Set–Barrel–Bullet  
 Identification between Sets 10 and 44 are possible

<table>
<thead>
<tr>
<th></th>
<th>HS10-B1</th>
<th>HS10-B2</th>
<th>HS44-B1</th>
<th>HS44-B2</th>
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<td>HS10-B2</td>
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<td>HS44-B2</td>
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</thead>
<tbody>
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<td>0.56</td>
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RF scores between sets are not as high as within sets
Identification between Sets 10 and 44 are possible

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<td>HS44-B2</td>
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<td></td>
<td>0.79</td>
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RF scores between sets are not as high as within sets

RF scores can be used to quantify the strength of an identification
RF Scores in context

CSAFE
Center for Statistics and Applications in Forensic Evidence
ForensicStats.org
Hamby Set 44
RF Scores in context of a study

Known bullets (left) and Questioned bullets (right)

Questioned bullets
RF score
Hamby Set 44
Random Forest Scores

★ Land-to-land matches for bullets 1 and 2 from barrel 1
Hamby Set 44
Random Forest Scores

★ Land-to-land matches for bullets 1 and 2 from barrel 1
Hamby Set 44
Random Forest Scores

⭐ Land-to-land matches for bullets 1 and 2 from barrel 1

![Graph showing land-to-land matches for bullets 1 and 2 from barrel 1.]

- **Ground Truth:**
  - Same Source

- **RF score**:
  - 0.8
  - 0.6
  - 0.4

---

Barrel 1: Bullet 1 Land 3 versus Bullet 2 Land 1

![Graph showing relative surface height (in microns) vs. relative location (in millimeters).]
Hamby Set 44
Random Forest Scores

★ Land-to-land matches for bullets 1 and 2 from barrel 1

Barrel 1 - Bullet 1 - Land 3

Barrel 1 - Bullet 2 - Land 1
Land-to-land matches for bullets 1 and 2 from barrel 1
Land-to-land matches for bullets 1 and 2 from barrel 1

Barrel 1: Bullet 1 Land 1 versus Bullet 2 Land 5

Ground Truth
- Same Source
- 0.8
- 0.6
- 0.4
Hamby Set 44
Random Forest Scores

★ Land-to-land matches for bullets 1 and 2 from barrel 1

Barrel 1 - Bullet 1 - Land 1
Barrel 1 - Bullet 2 - Land 5
Using the RF Score for diagnostics

* Land-to-land matches for two bullets show oddities
Using the RF Score for diagnostics

★ Land-to-land matches for two bullets show oddities

scans for lands 3 and 4 were mislabelled for one bullet
Using the RF Score for diagnostics

★ Land-to-land matches for two bullets show oddities

- Scans for lands 3 and 4 were mislabelled for one bullet
- Instead of turning right to scan land 6, scanner turned left and scanned land 4 again
Using the RF Score for diagnostics

★ Land-to-land matches for two bullets show oddities

- Scans for lands 3 and 4 were mislabelled for one bullet
- Instead of turning right to scan land 6, scanner turned left and scanned land 4 again
- Scans for land 2 and land 3 are identical
Using the RF Score for diagnostics

★ Land-to-land matches for two bullets show oddities

- Scans for lands 3 and 4 were mislabelled for one bullet
- Instead of turning right to scan land 6, scanner turned left and scanned land 4 again
- Scans for land 2 and land 3 are identical

These things went wrong in our scanning lab
Random Forest Model provides interpretable and consistent scores for quantifying identifications:
- matching clones to original bullets - assess clone quality
- matching bullets between Hamby sets
- quantification of bullet and scan deficiencies

Visualizations with increased context used for diagnostics

Limitations: traditional rifling only (LEAs are matched)
Thank You!

Questions?

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