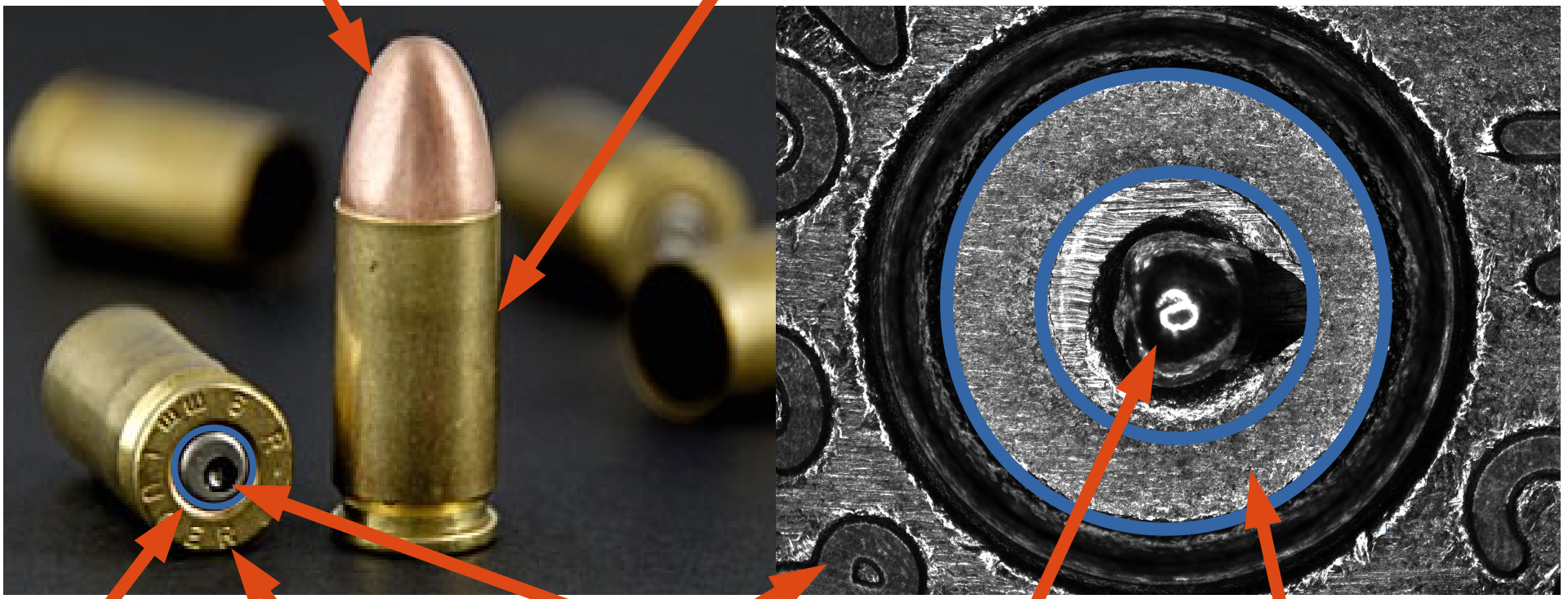
Developing Methods for Comparison of Cartridge Breechface Images

Xiao Hui Tai

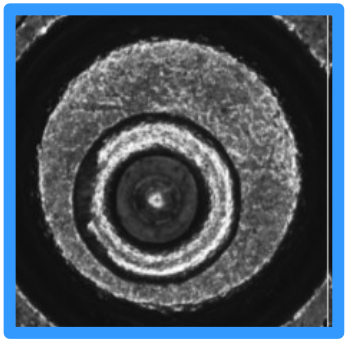
Advisors: William F. Eddy, Xiaoyu Alan Zheng

Firing a gun leaves marks on the bottom surface of the cartridge case

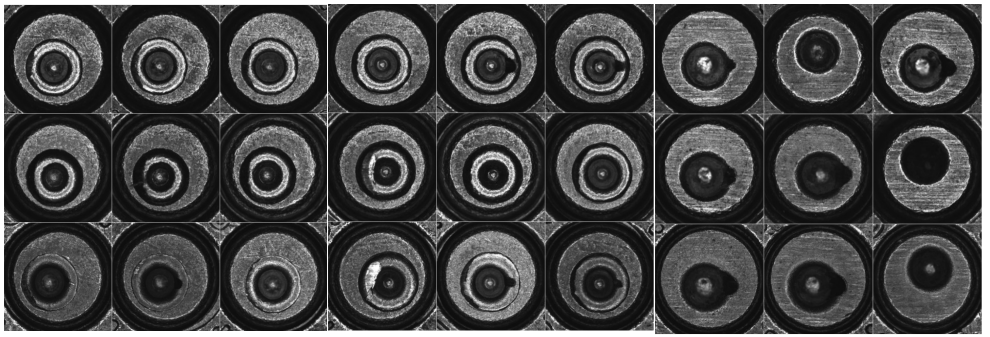


Each gun is thought to produce unique marks

Research Questions



New Image

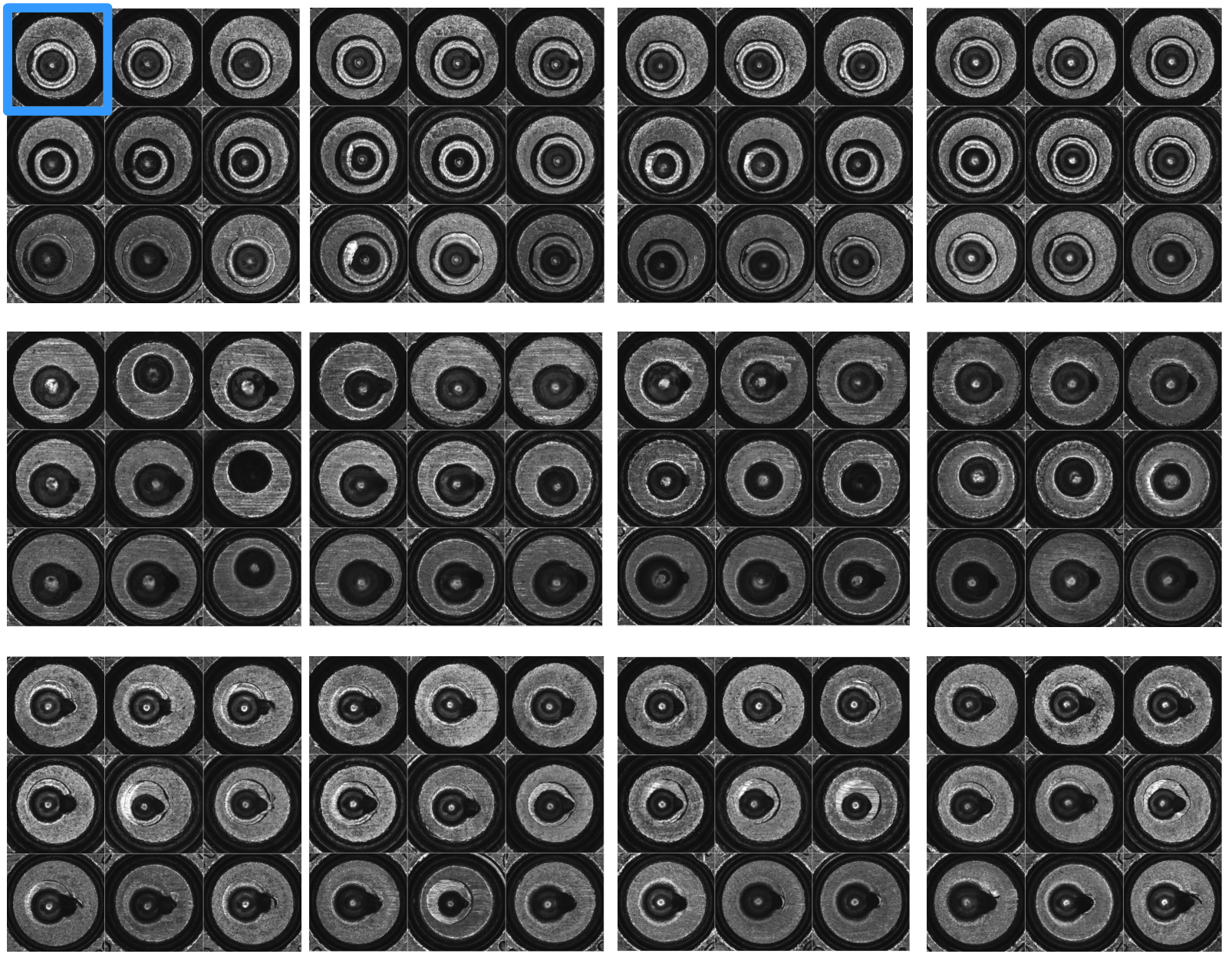


Database of Images

How similar is the new image to images in the database?

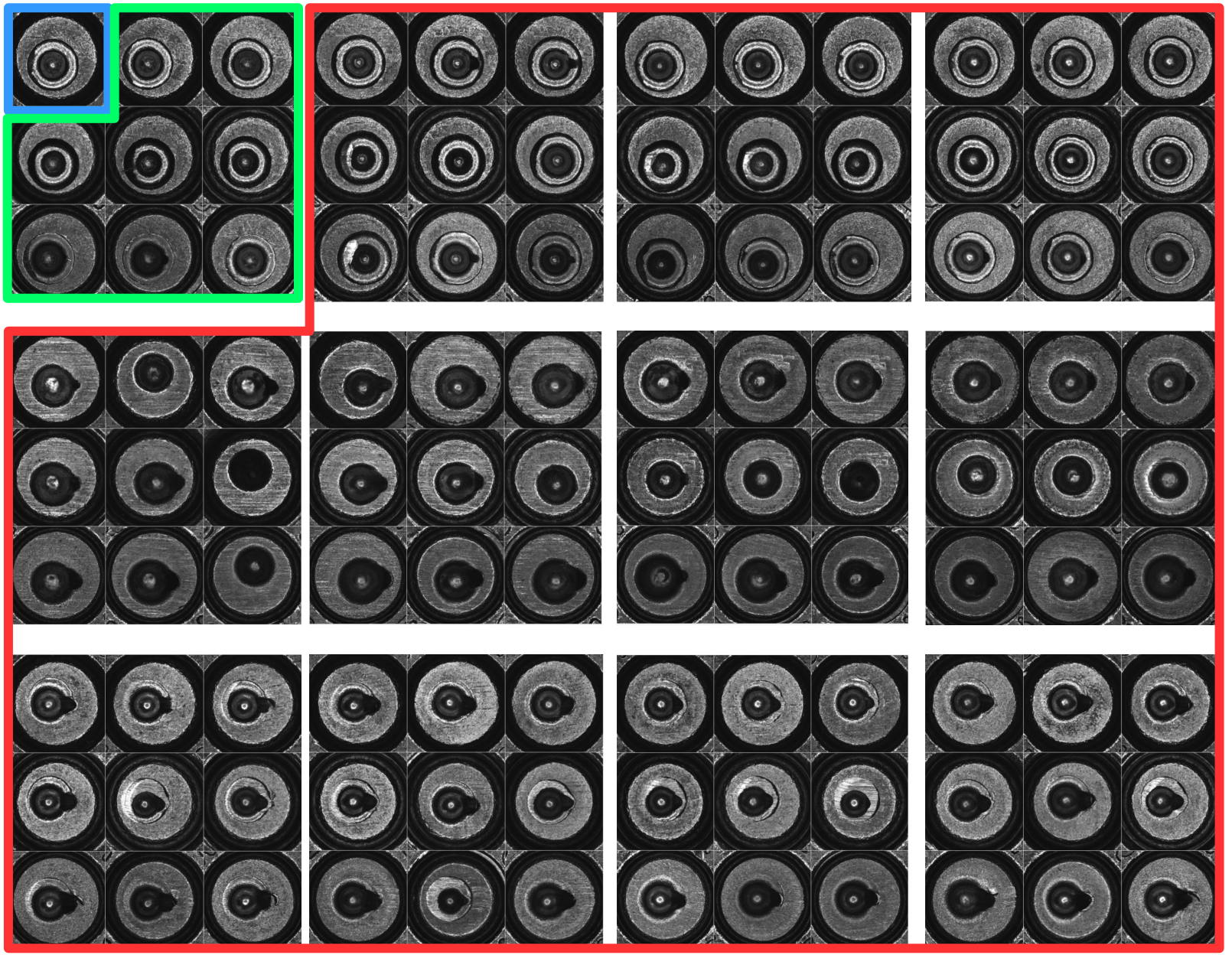
What is the probability of obtaining this result by chance?

108 images, 12 guns (9 images per gun)



108 images, 12 guns (9 images per gun)

True Matches



True Non-matches

Steps for One Pairwise Comparison

1) **Automatically select breechface marks**
2) Level image
3) **Remove circular symmetry**
4) Outlier removal and filtering

Pre-process

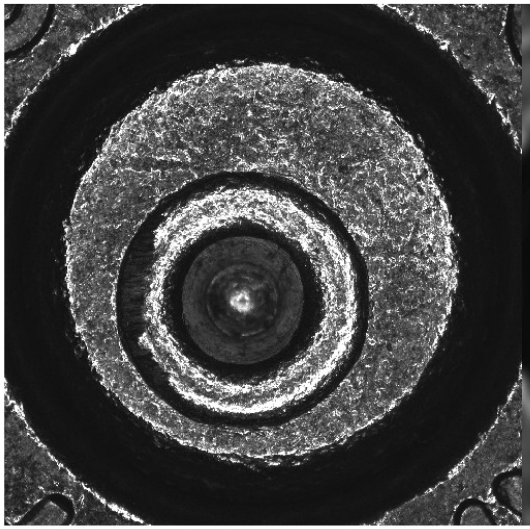
5) Maximize correlation by translations and rotations

Compute similarity metric

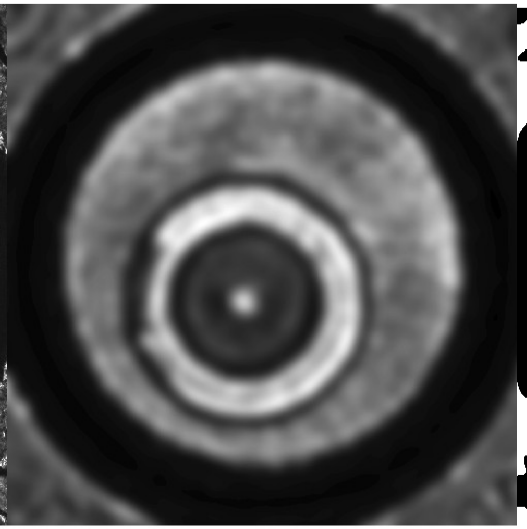
6) **Compute probability of obtaining a higher score by chance**

Quantify uncertainty

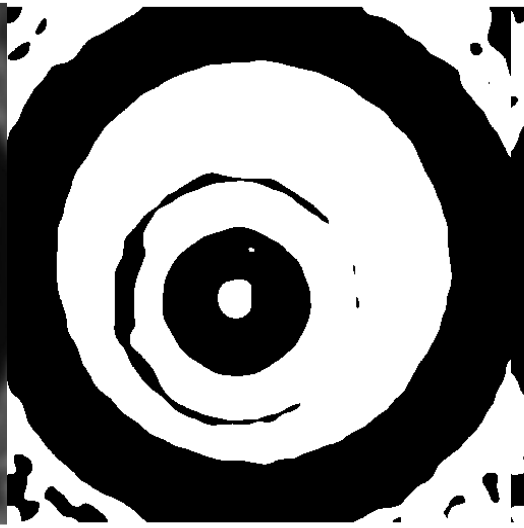
Step 1: Select Breechface Marks



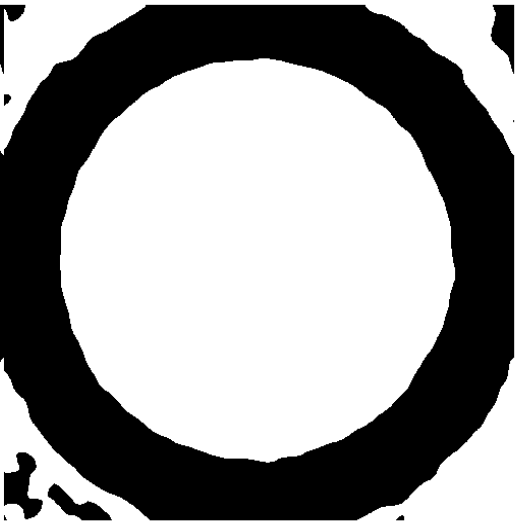
Original image



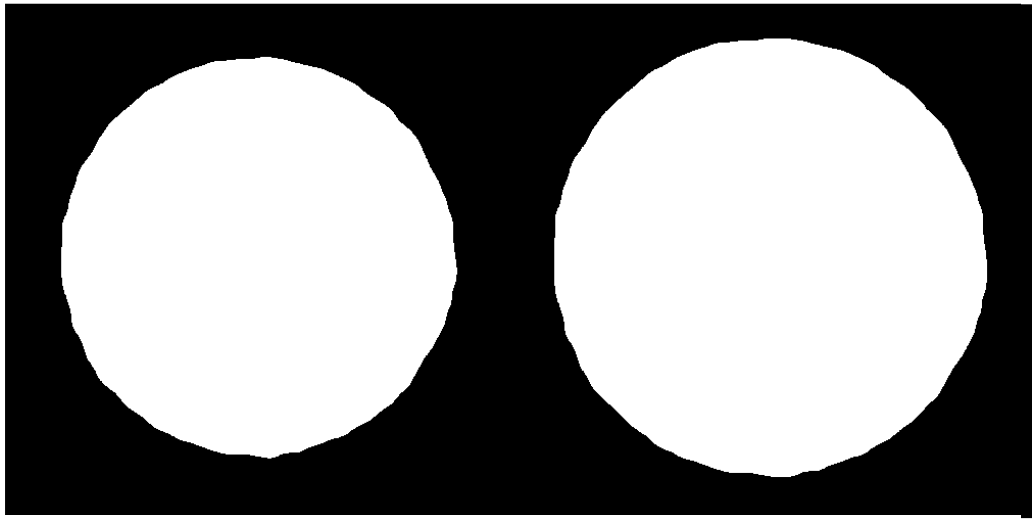
Apply a Gaussian filter



Histogram equalization with 2 bins

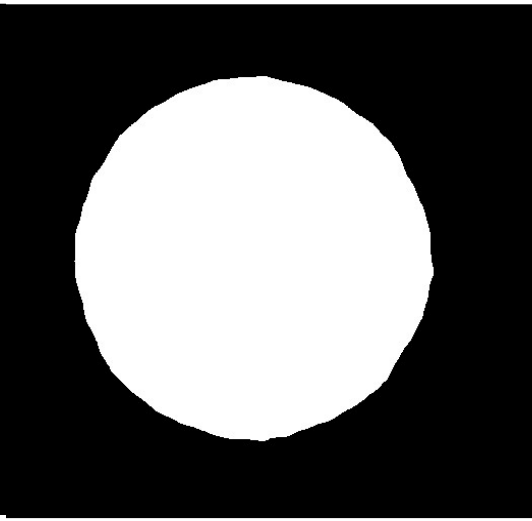


Flood fill

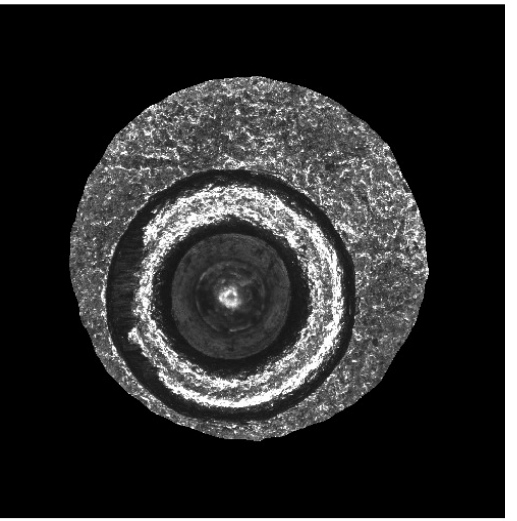


Select center region

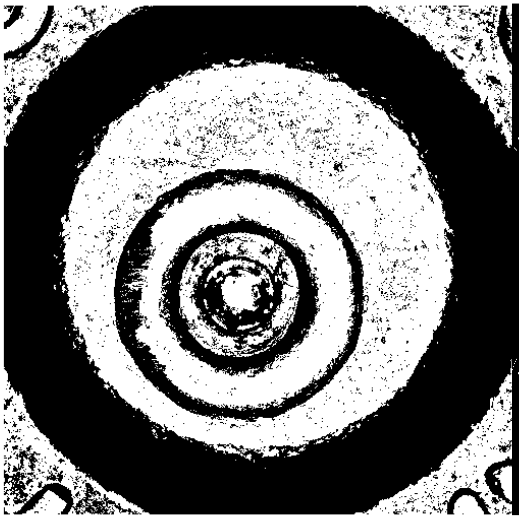
Dilate



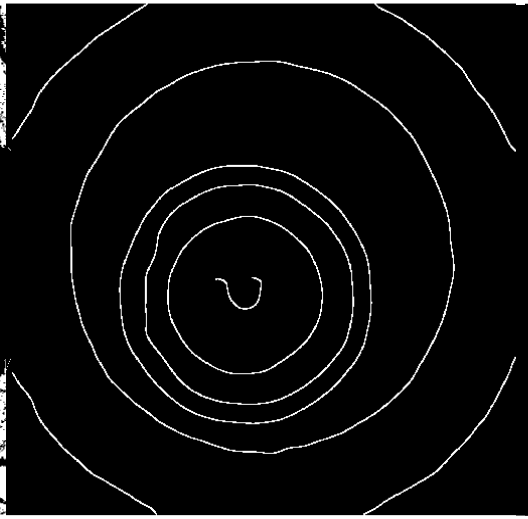
Erode



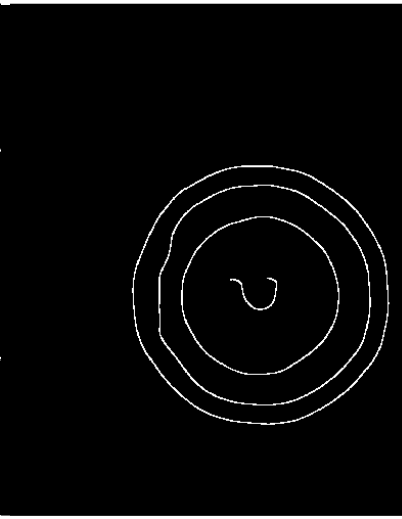
Selected primer region



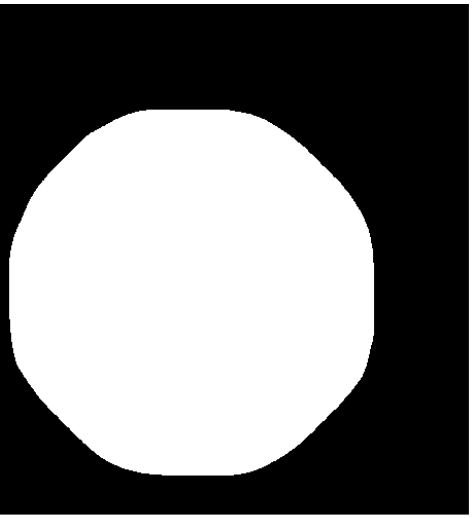
Histogram equalization with 2 bins



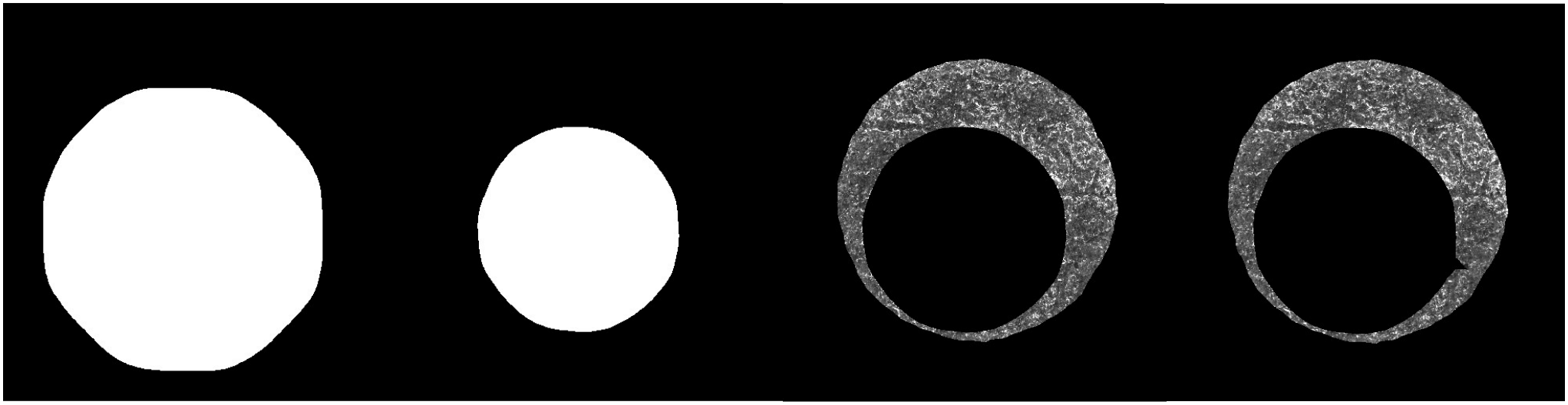
Canny edge detector



Only consider primer region



Dilate



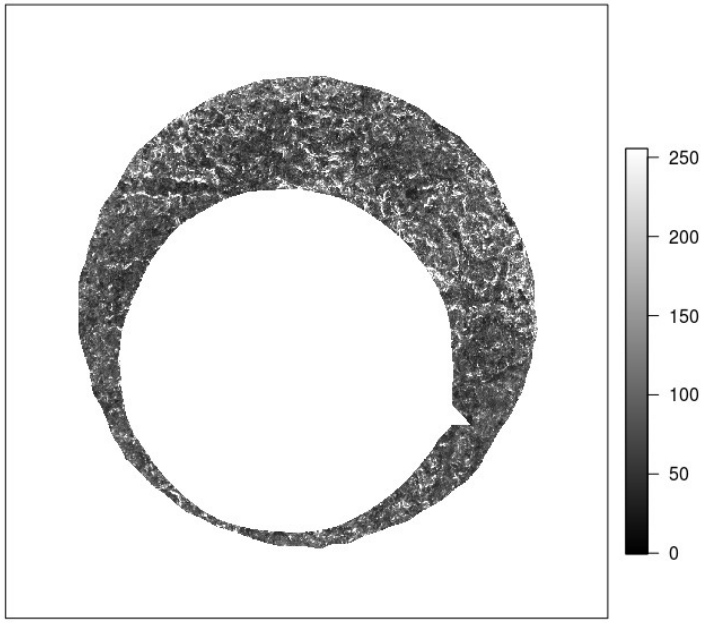
Flood fill

Erode

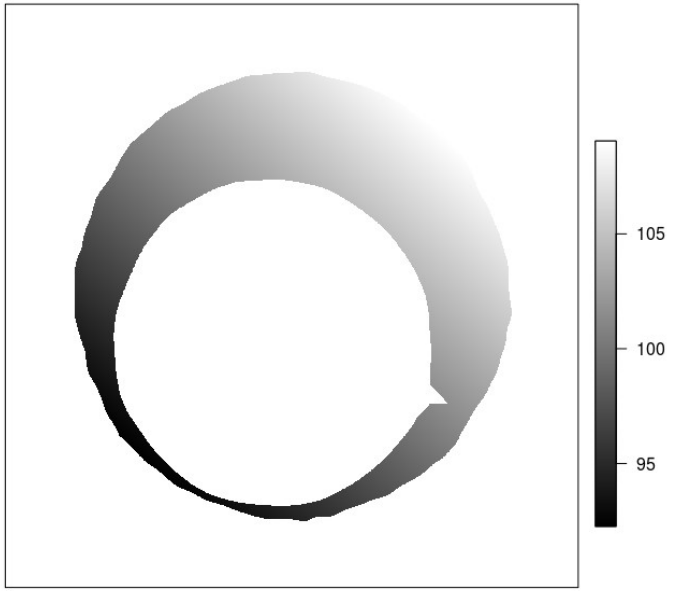
Currently selected firing pin region

Second pass

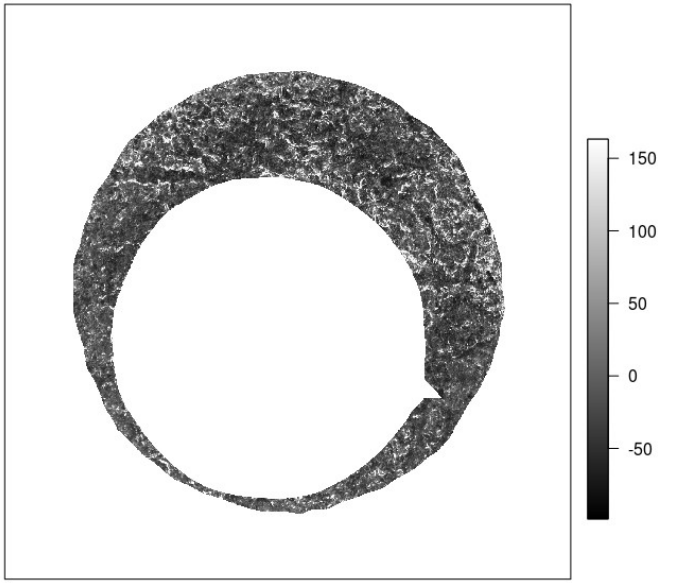
Step 2: Level Image



Original



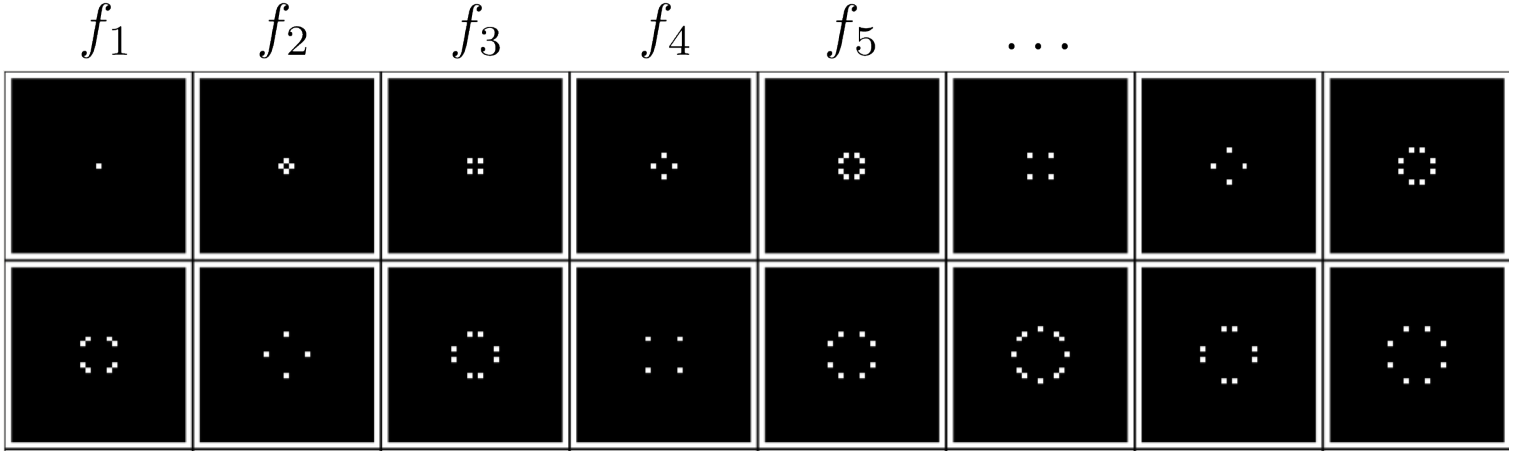
Fitted Plane



Residuals

Step 3: Remove Circular Symmetry

Decompose each image into a linear combination of circularly symmetric basis

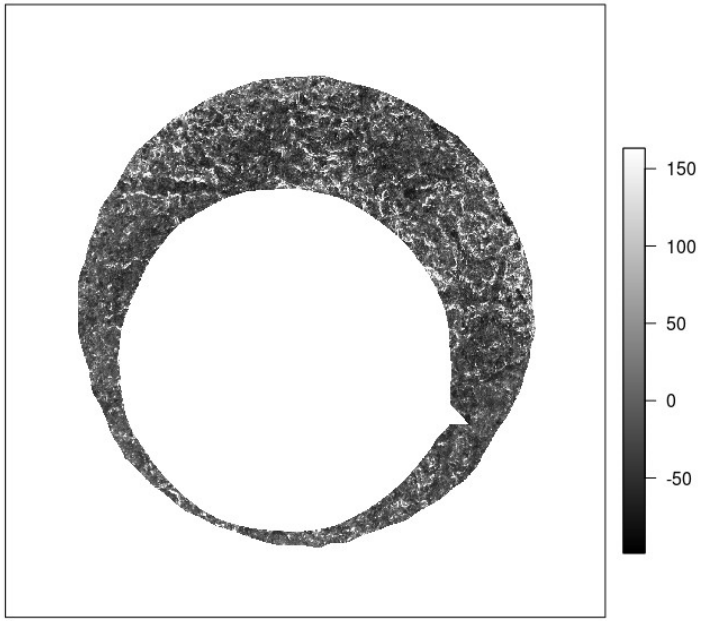


$$Image(i,j) = \sum_{k=1}^{K} \beta_k f_k(i,j) + \epsilon(i,j)$$

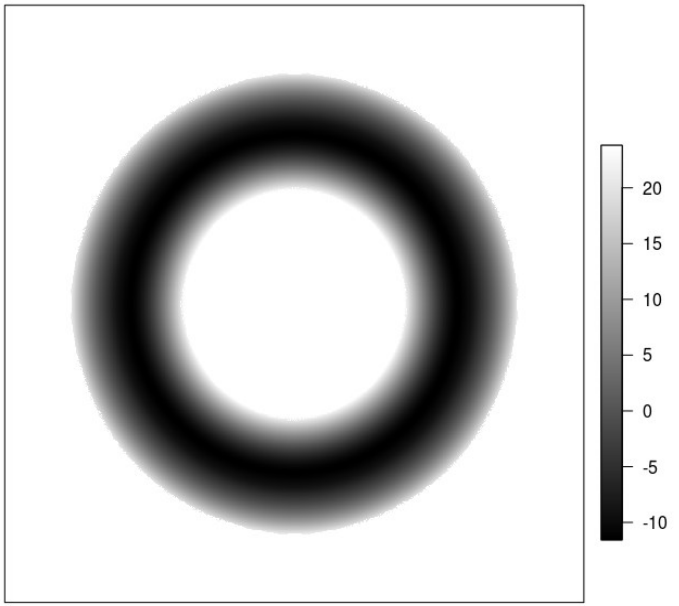
- K is the number of basis functions,
- f_k is the kth basis function, and
- β_k is the basis function coefficient for f_k.

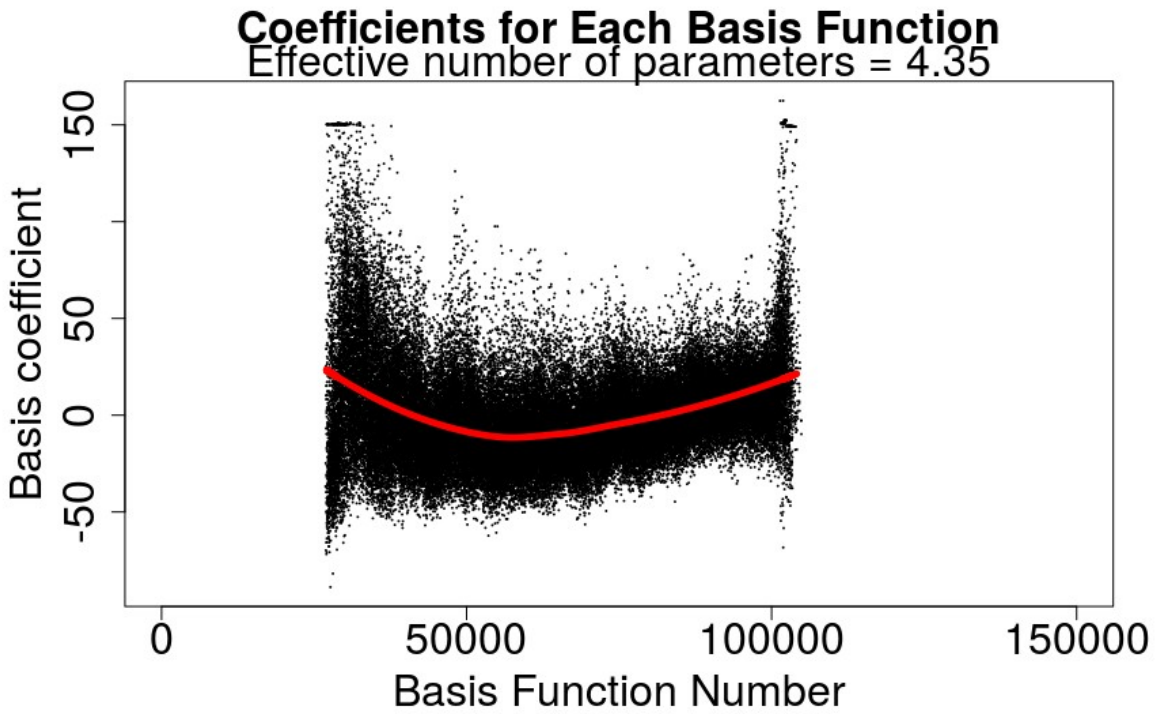
Captures circular symmetry

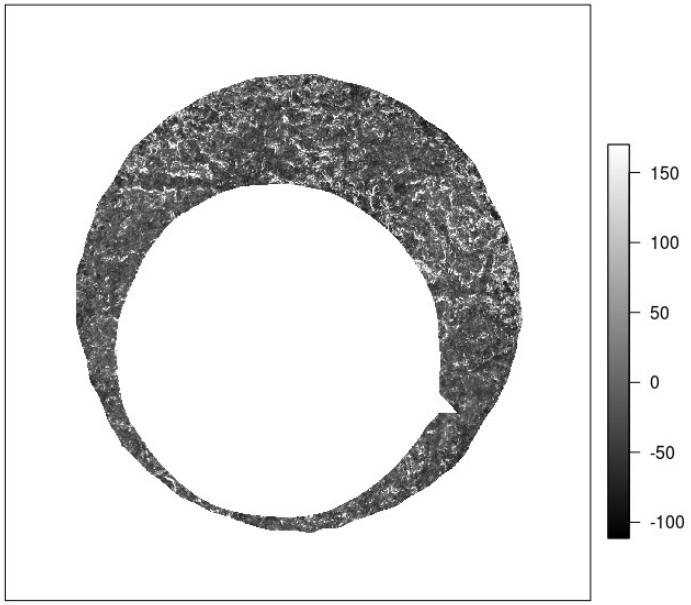
Residuals from previous step



Fitted Circularly Symmetric



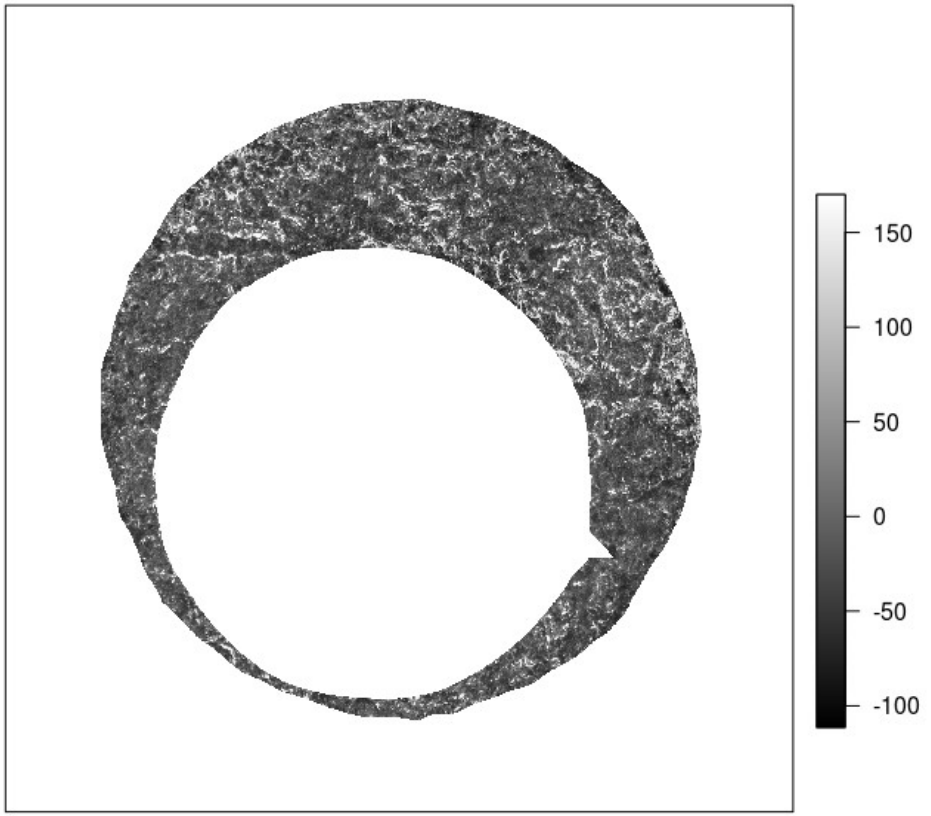




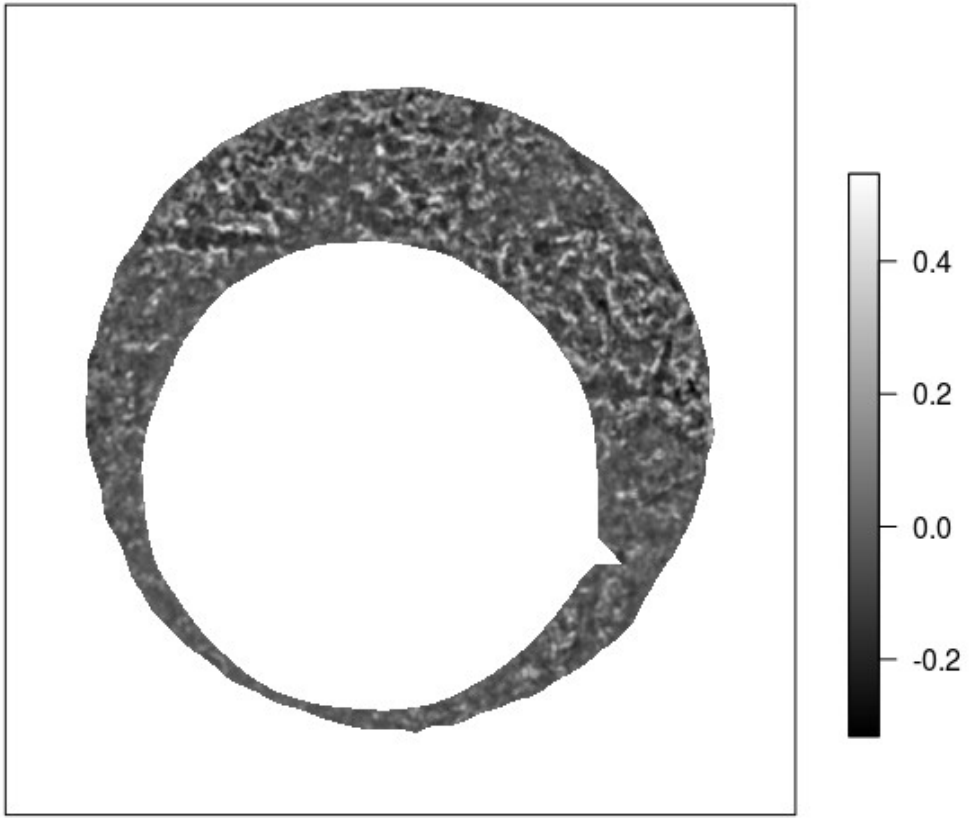
Residuals

Step 4: Outlier Removal and Filtering

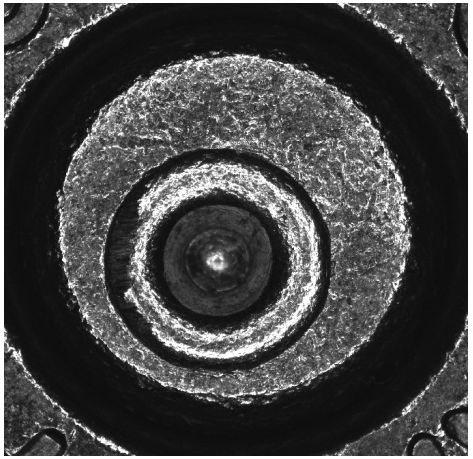
Residuals from Previous Step



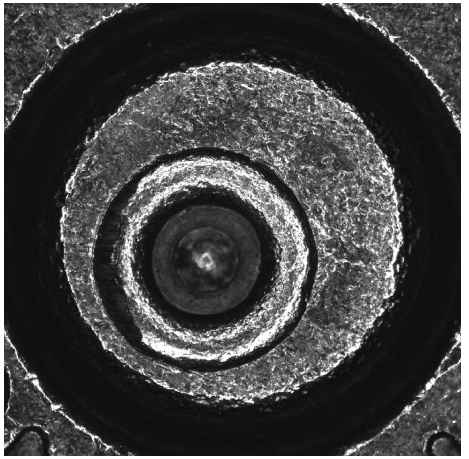
After All Pre-processing



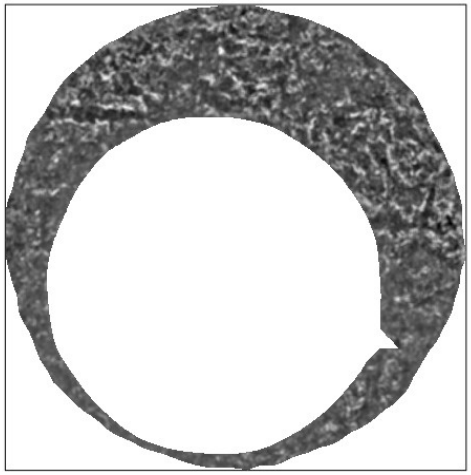
Step 5: Maximize Correlation by Translations and Rotations

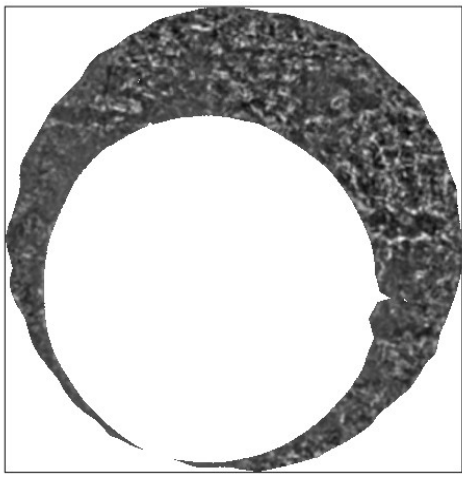


Reference Image



Comparison Image





For each rotation angle,

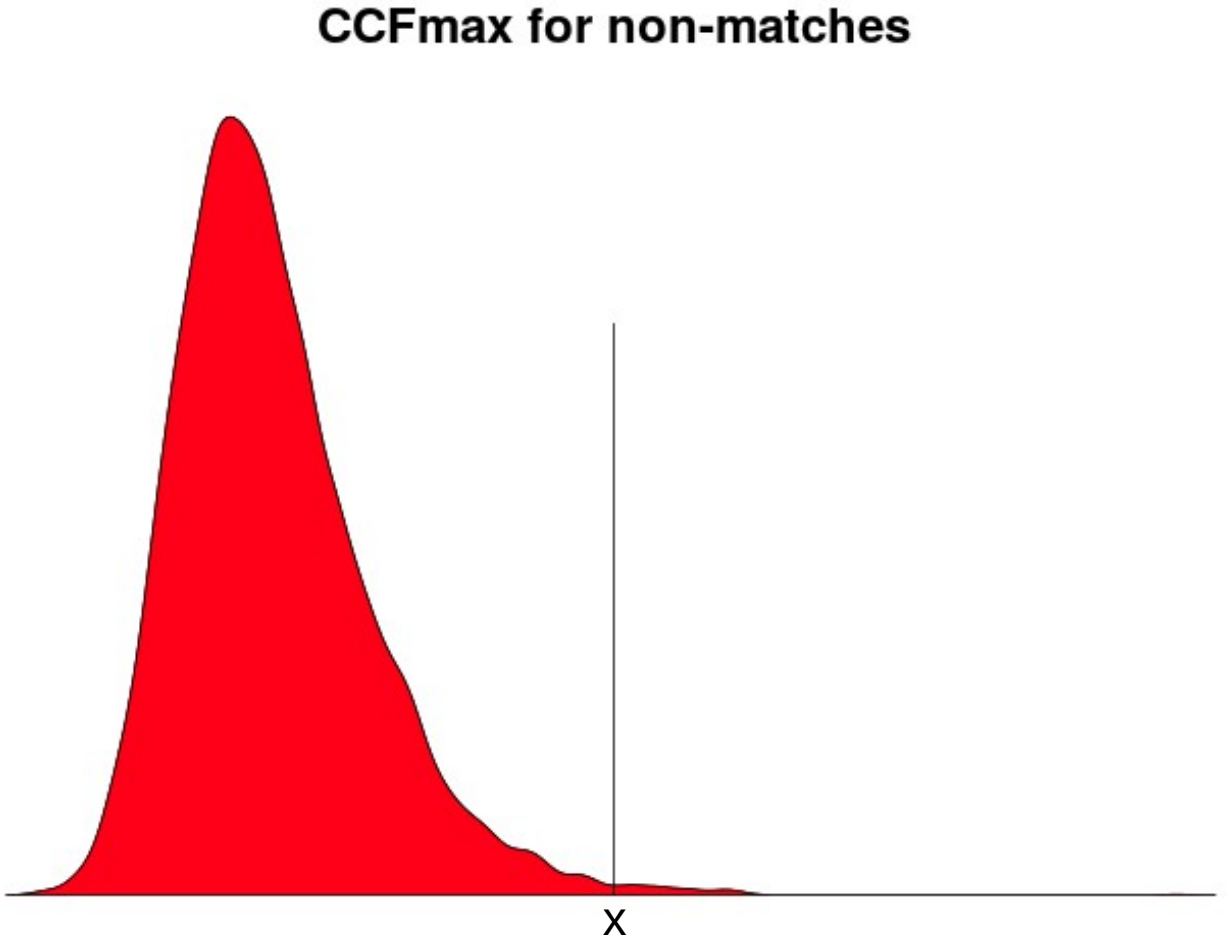
Translations

$$CCF(I_1, I_2) = \frac{\sum_{i,j} I_1(i,j) I_2(i+dx, j+dy)}{\sqrt{\sum_{i,j} I_1(i,j)^2} \sqrt{\sum_{i,j} I_2(i,j)^2}}$$

$$\theta^* = -15^\circ$$

$$CCF_{max} = .38$$

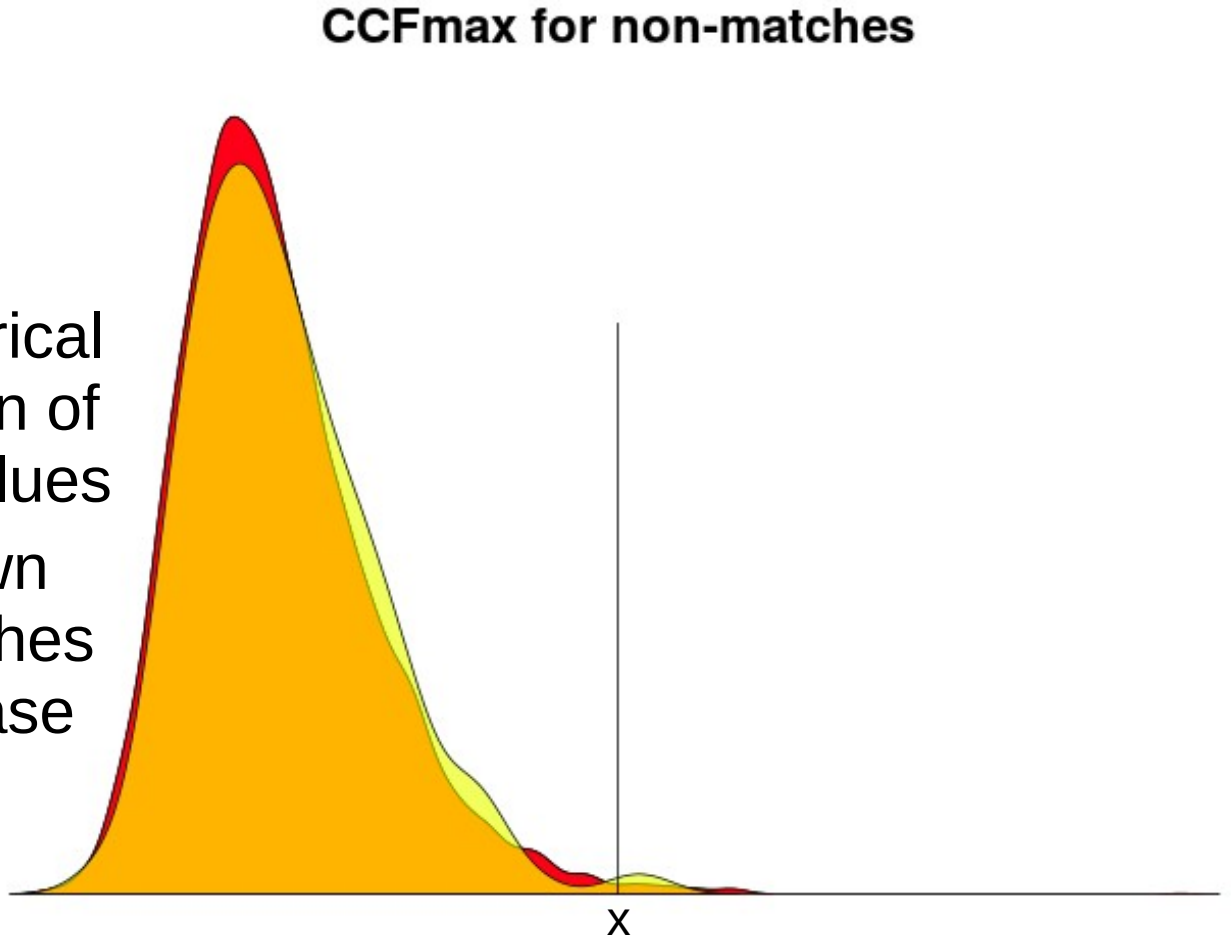
Step 6: Compute Probability of Obtaining a Higher Score by Chance



If the two images are not a match, the probability of observing $CCF_{max} > x$ is .01%.

Step 6: Compute Probability of Obtaining a Higher Score by Chance

Use empirical distribution of CCF_{max} values for known non-matches in database



If the two images are not a match, the probability of observing $CCF_{max} > x$ is .01%.

Step 6: Compute Probability of Obtaining a Higher Score by Chance

The probability that we are calculating is a p-value in the context of the following hypothesis test

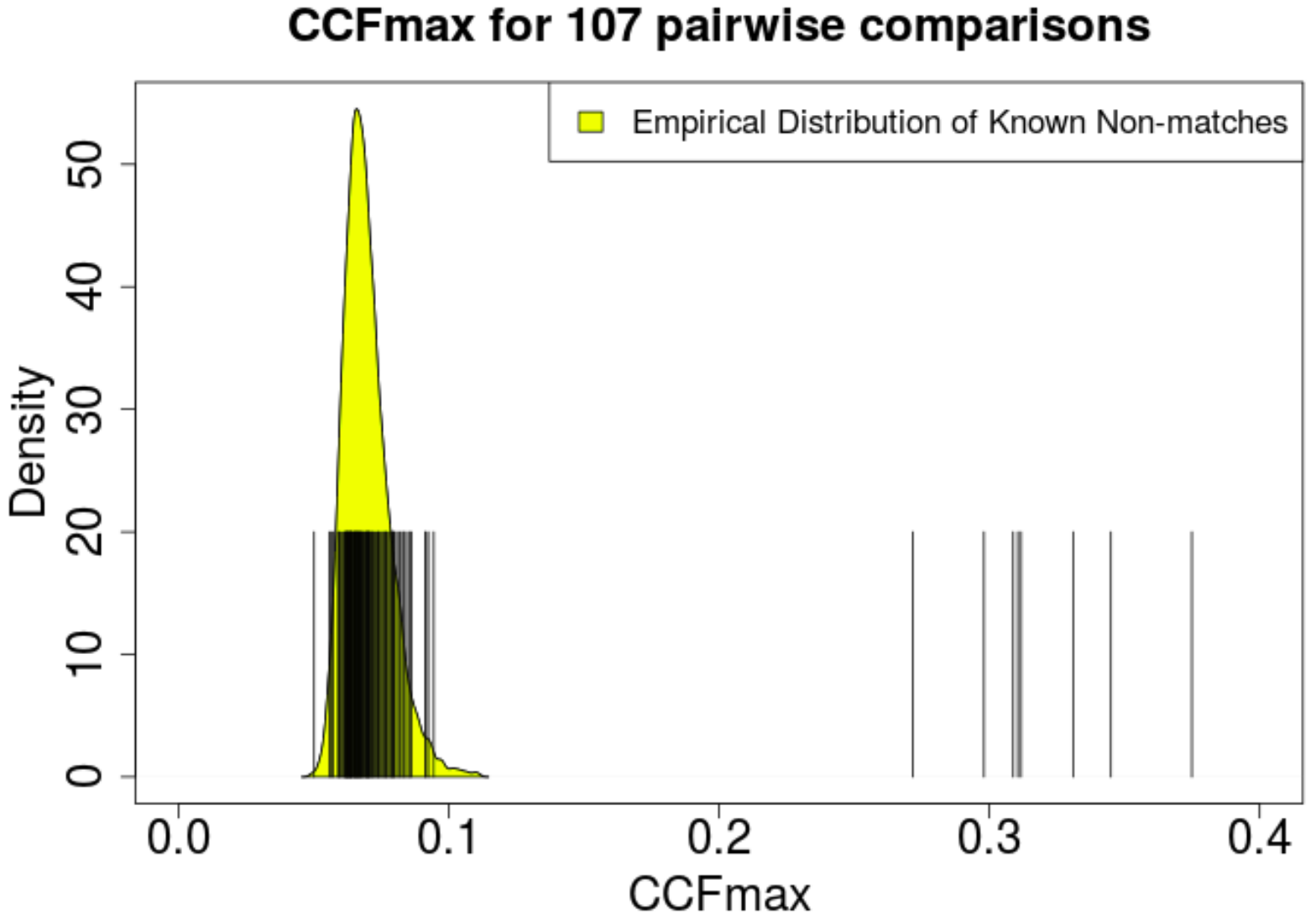
H_0: Images are not a match (not from the same gun)

H_A: Images are a match

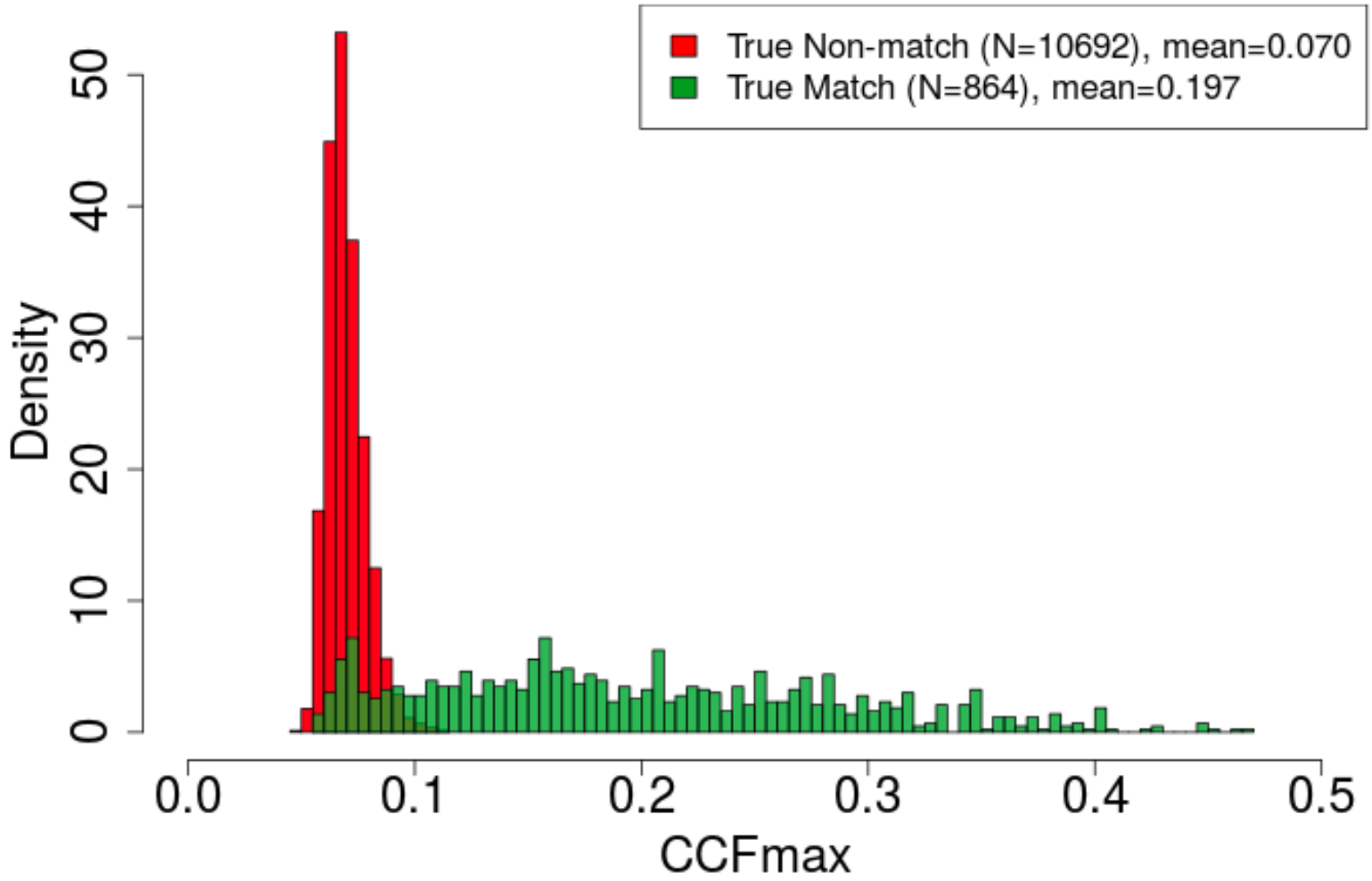
Test statistic: CCF_{max}

Interpretation of p-value: Probability of observing a larger value of CCF_{max}, under the assumption that the two images are not a match.

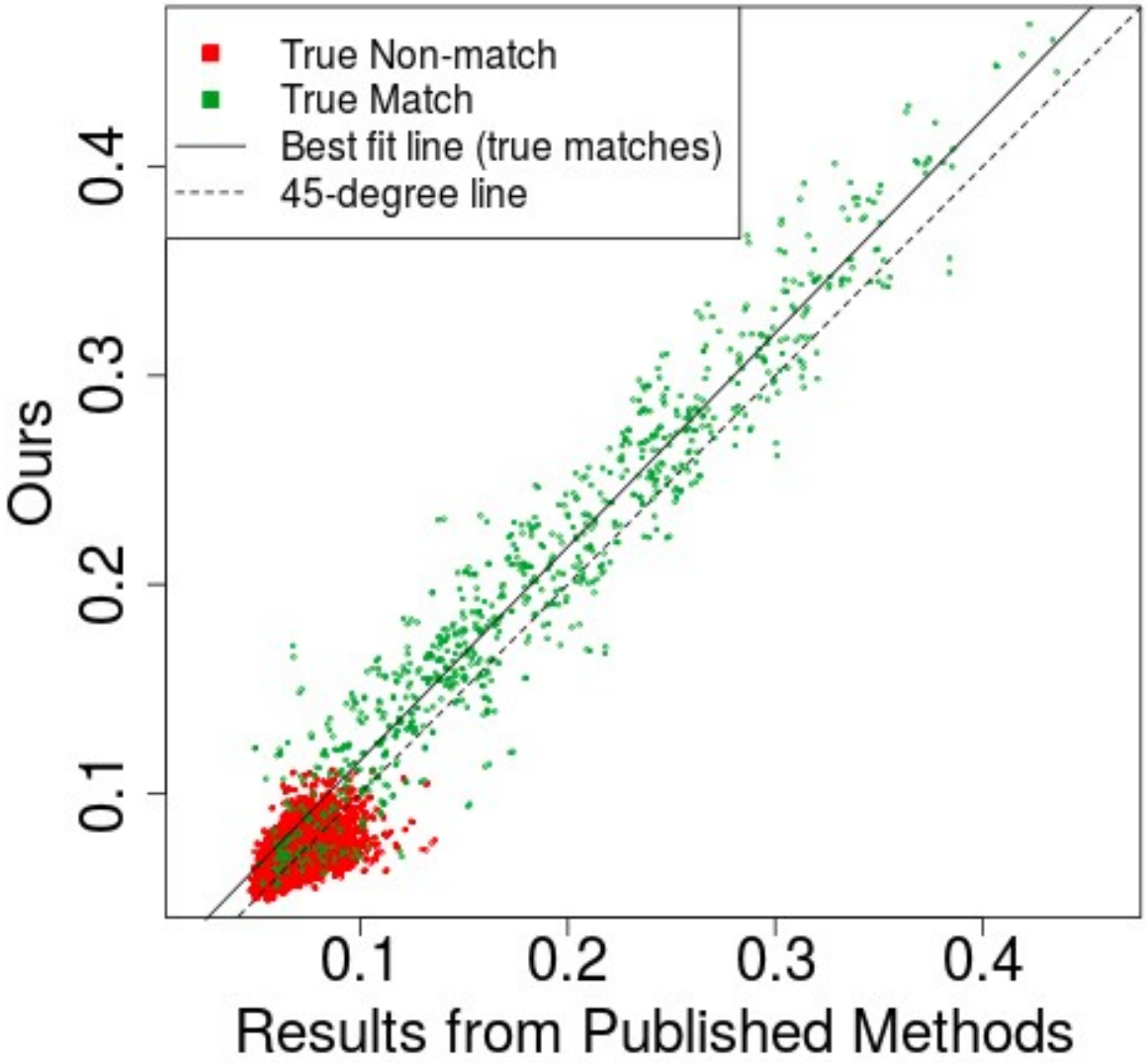
All Pairwise Comparisons for 1 Image



Distribution of CCF_{max} for All Pairwise Comparisons in Dataset



Our Method Reduces CCF_{max} of True Non-matches

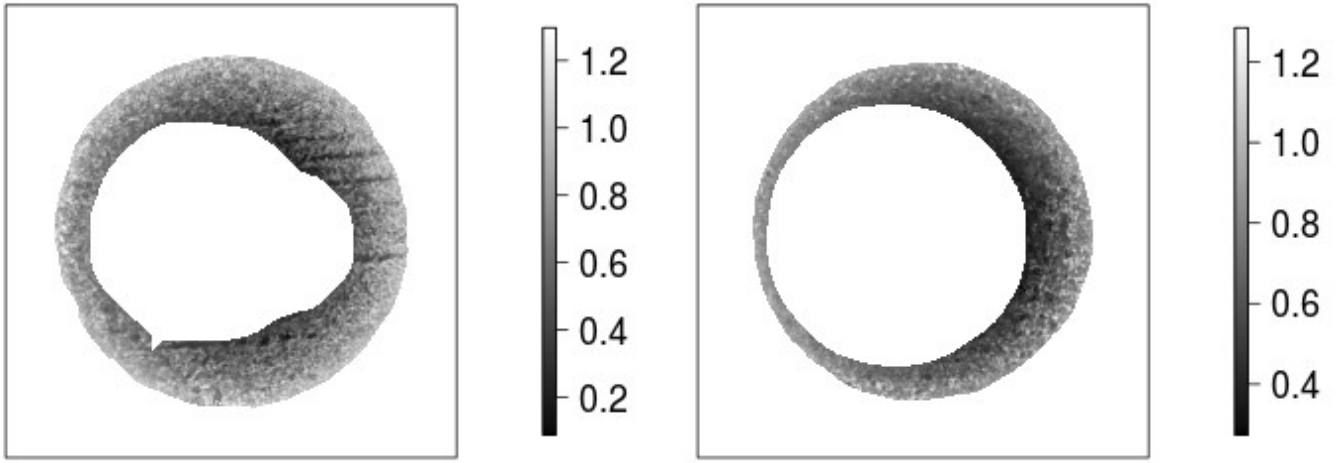


Roth, Carriveau, Liu, Jain (IEEE, 2015)
Vorburger and co-authors (NISTIR, 2007)

Circular Symmetry Inflates CCF_{max}

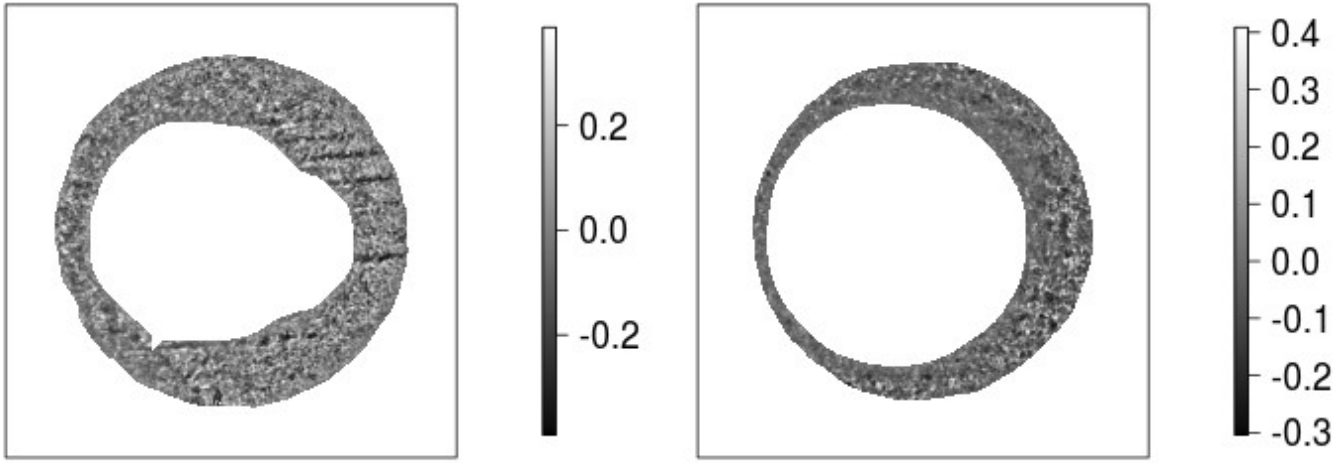
With circular symmetry

CCF_{max} = .73



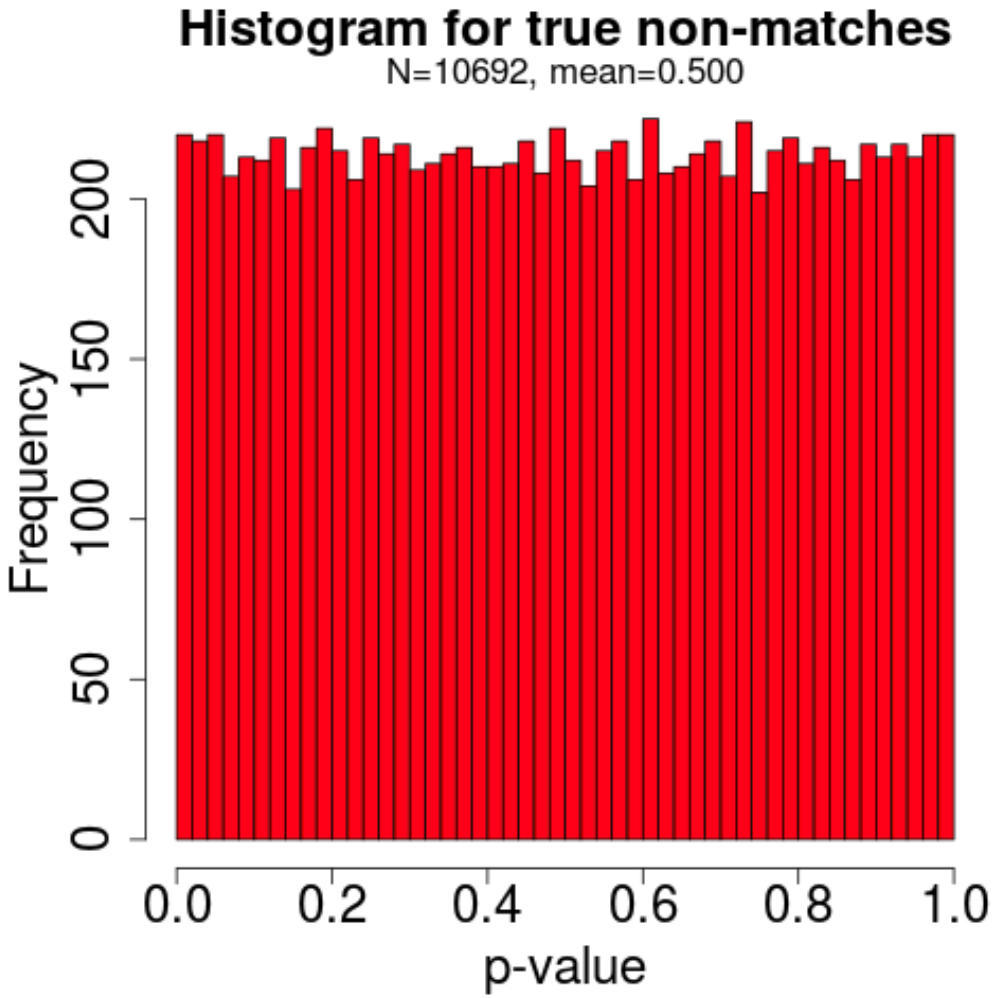
Removing circular symmetry

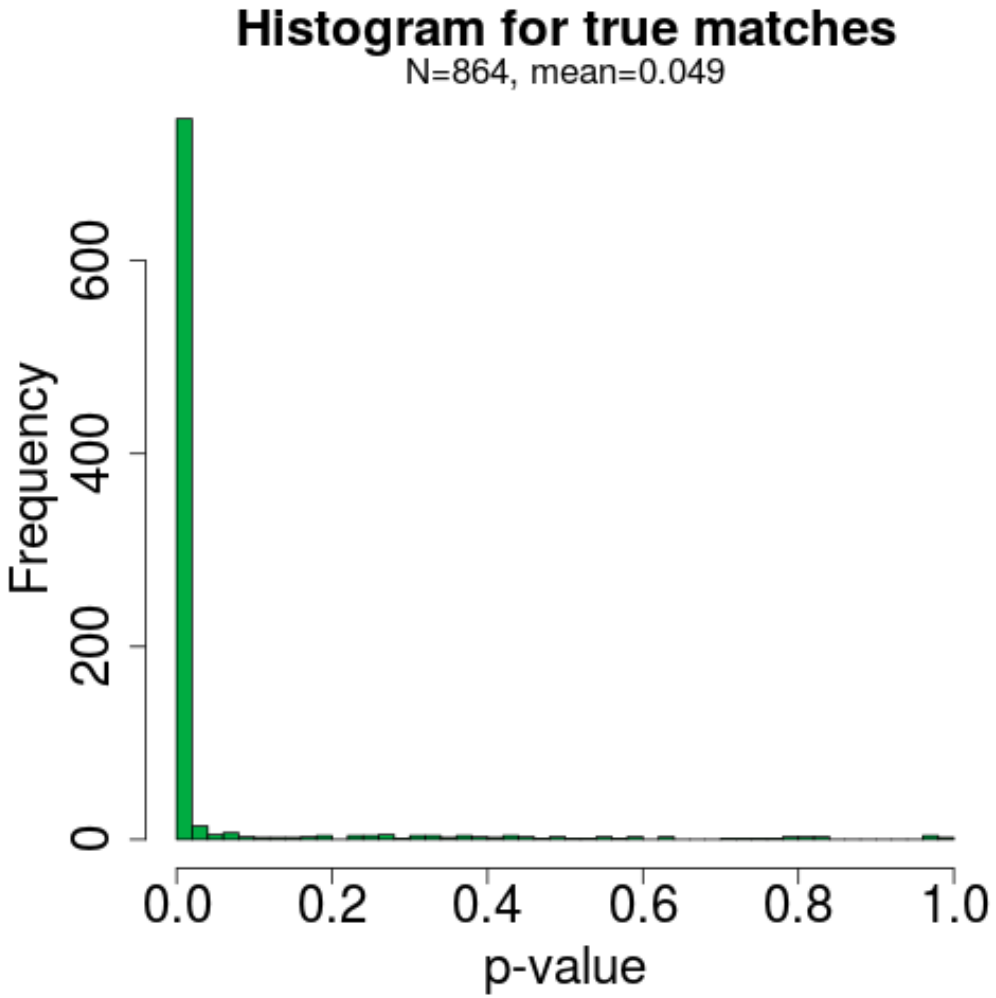
CCF_{max} = .06



Distribution of p-values for All Pairwise Comparisons in Dataset

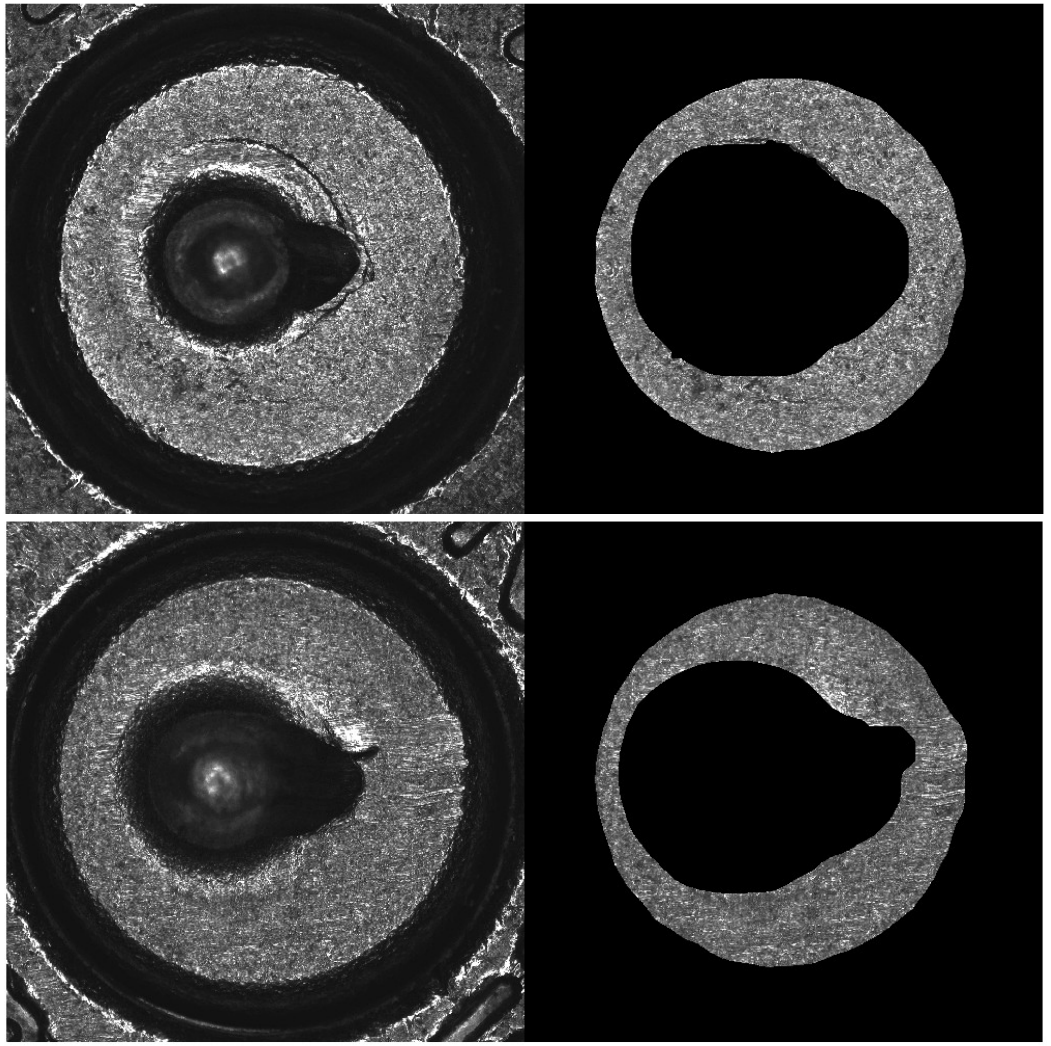
p-value = Probability of observing a higher correlation by chance





Example: True Match with Low CCF_{max}

PMC



Winchester

Smith & Wesson

CCF_{max} = .055

p-value = .99

Conclusion

- Improved on existing methods for comparing cartridge breechface images
  - Fully automated process
  - Reduced value of similarity metric for true non-matches
- Proposed a method of computing the probability of obtaining the result by chance

Thank you!