The Same Smoking Gun?
Approaches and Implementation

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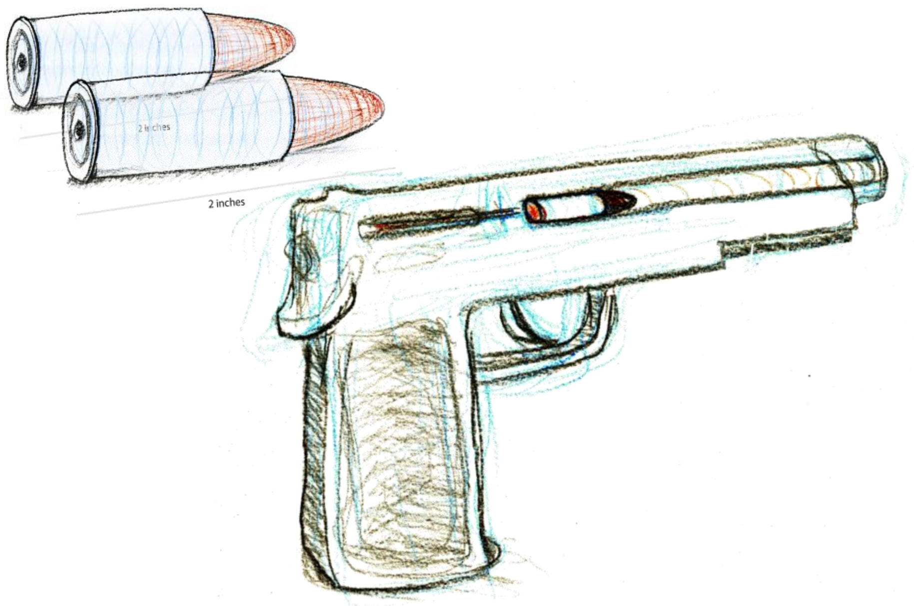
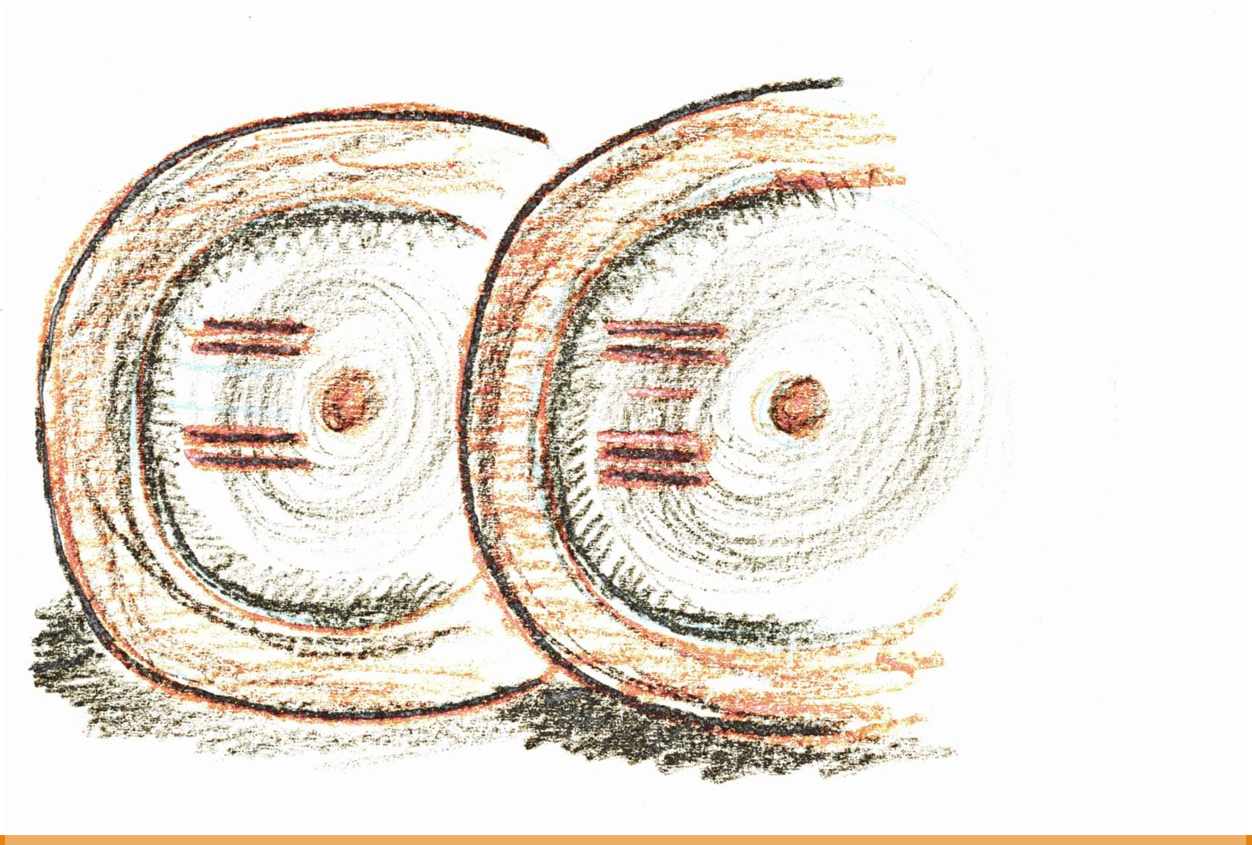
Introduction





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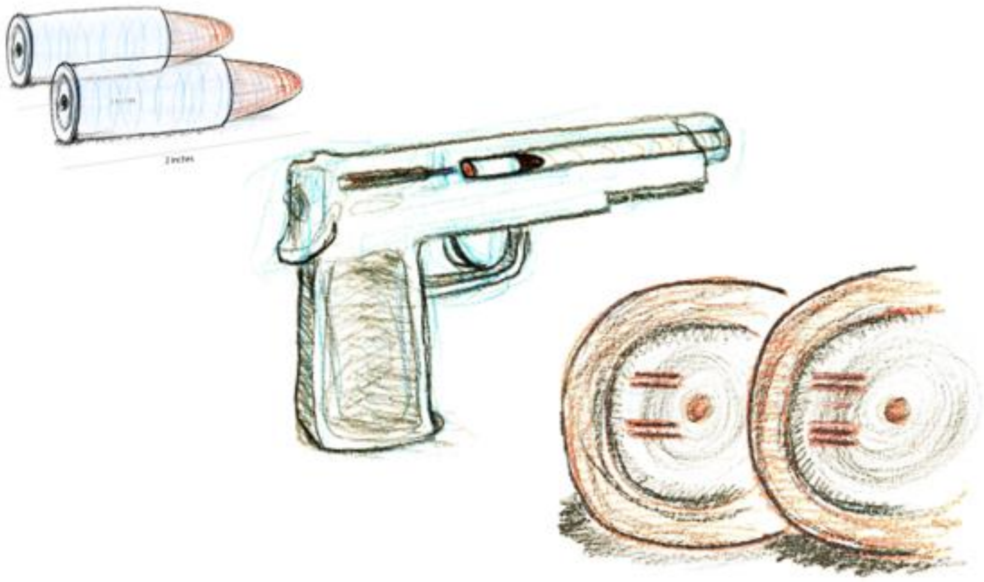

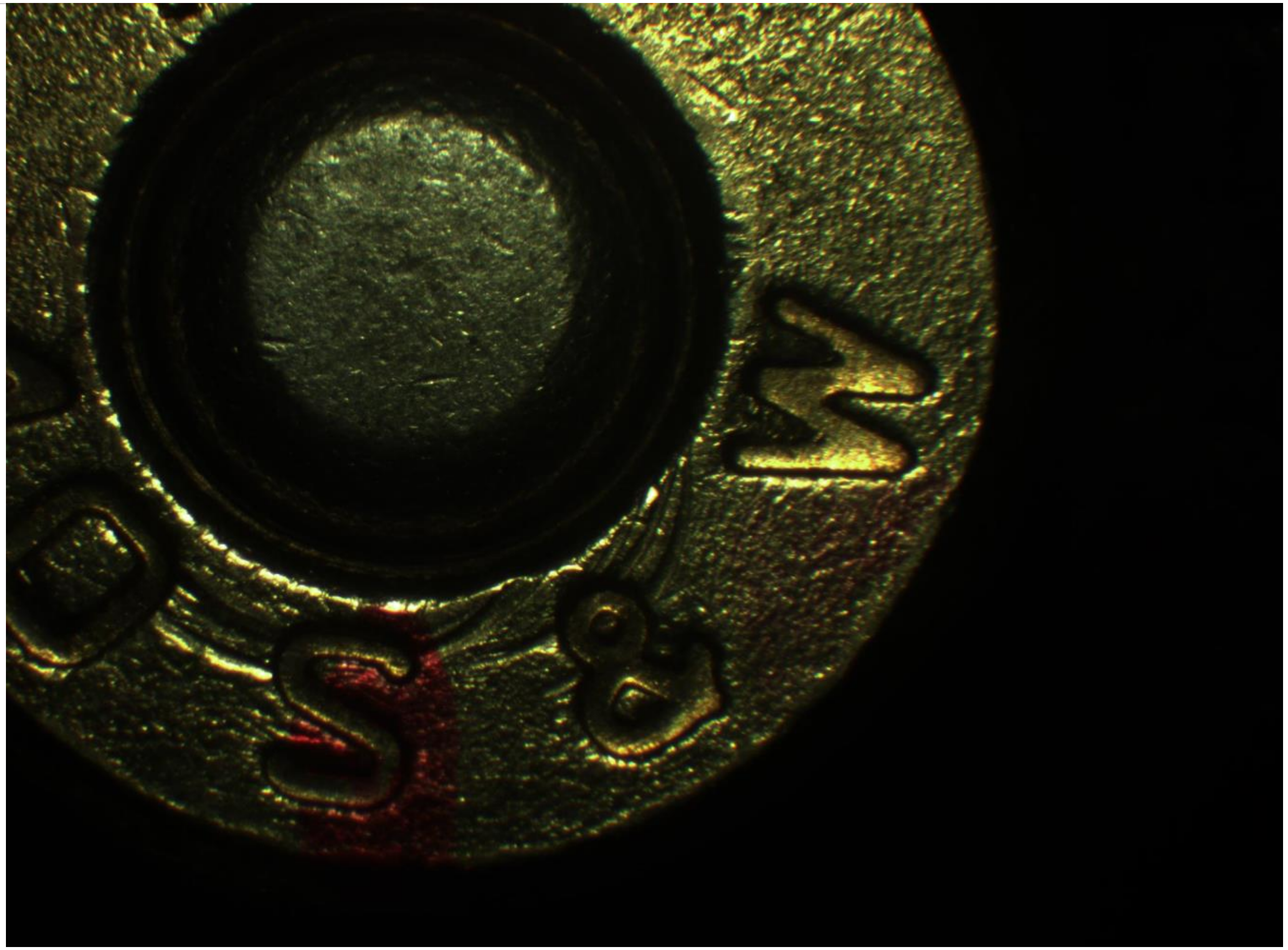

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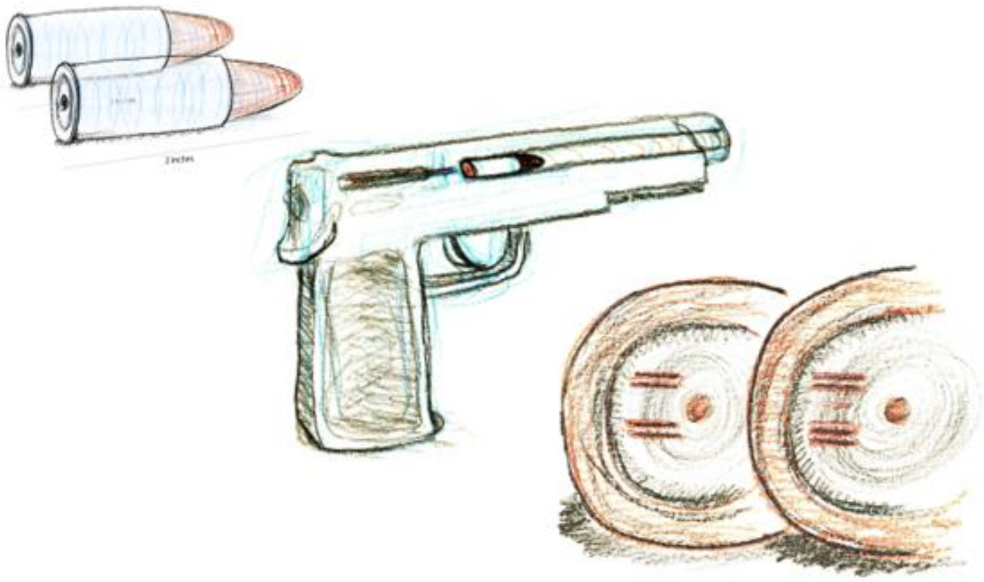
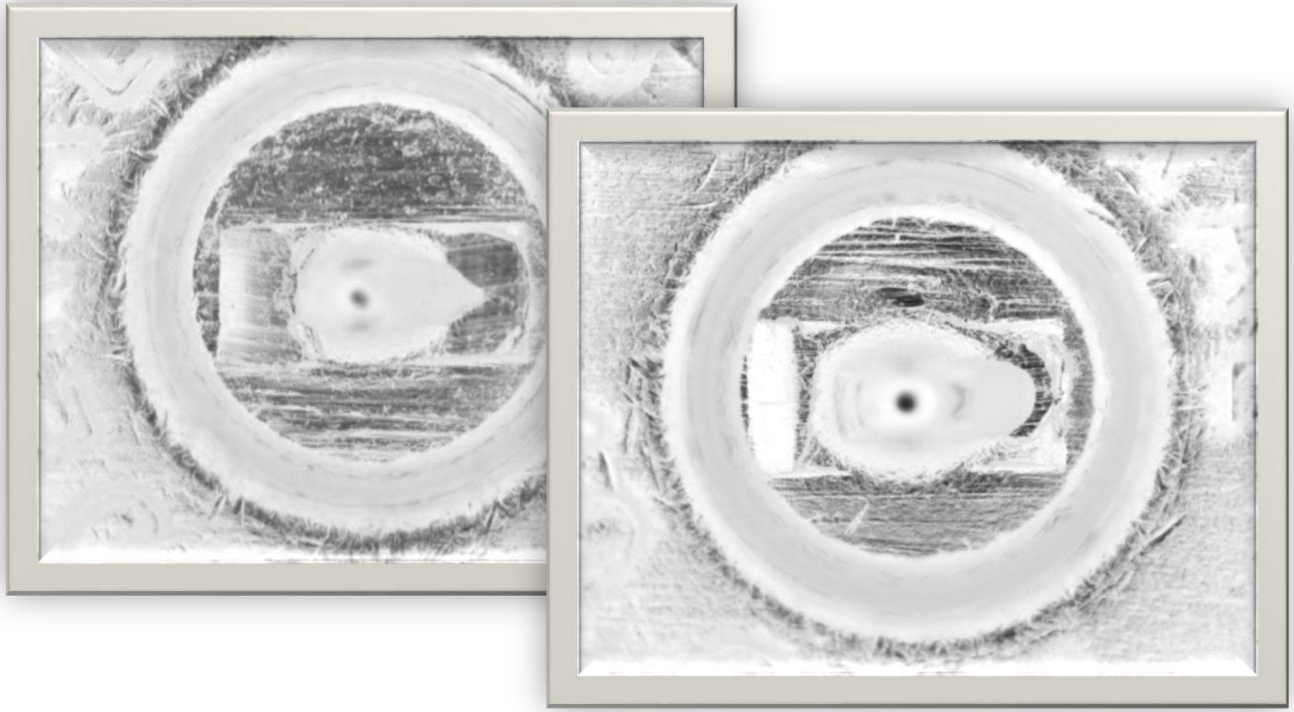


Introduction

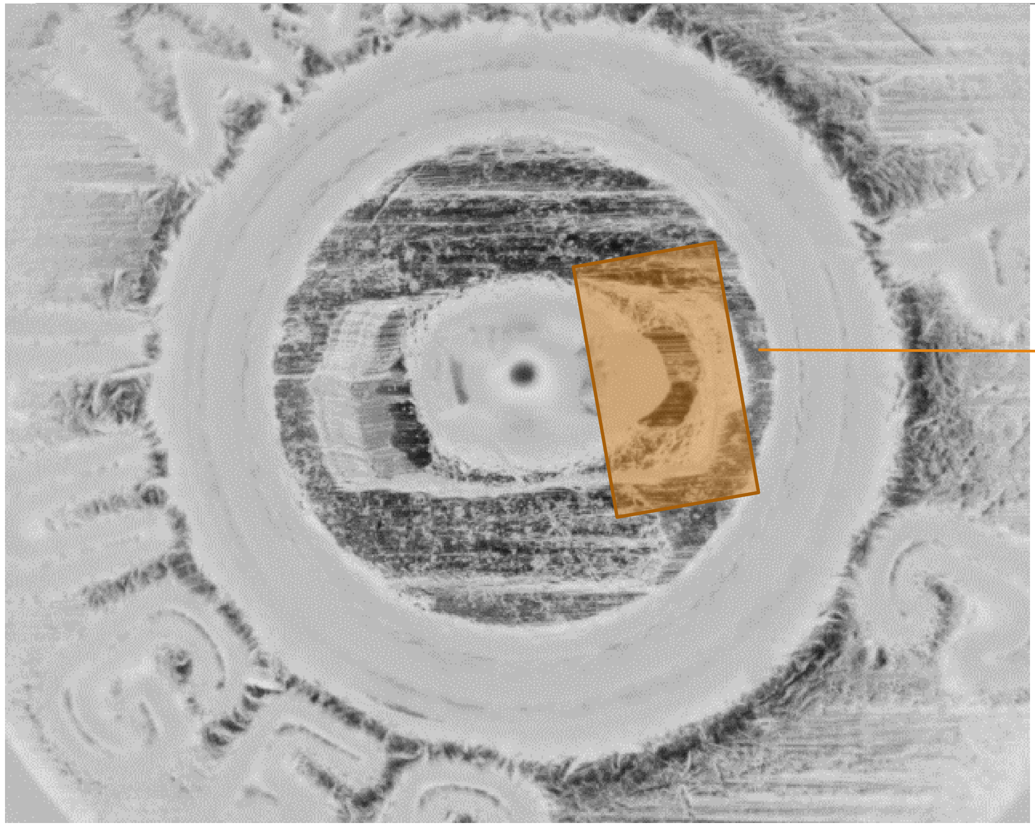
Natural lighting produces highlights and shadows

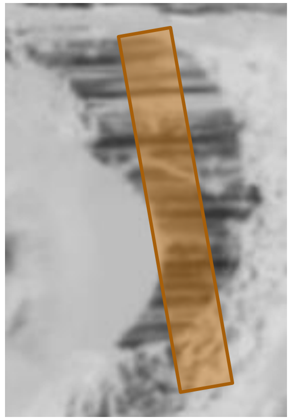
Introduction

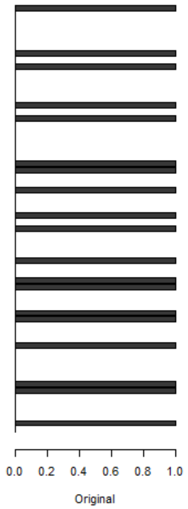


Infrared lighting produces neither highlights nor shadows

Initial Approach: Barcodes







Begin with: an infrared image

Convert to: a vector of 0s and 1s (a barcode)

Determine: how “close” these bullet cartridges (i.e. barcodes) are to each other

Initial Approach: Barcode Distance

$$\text{symmetric KL} = \frac{1}{2}\sum_i (p_i - q_i)\ln\left(\frac{p_i}{q_i}\right)$$

$$\text{local averaging} \quad p_i = \frac{1}{3}\sum_{i-1}^{i+1} x_j \qquad \text{for} \qquad 2 \le j \le n-1$$

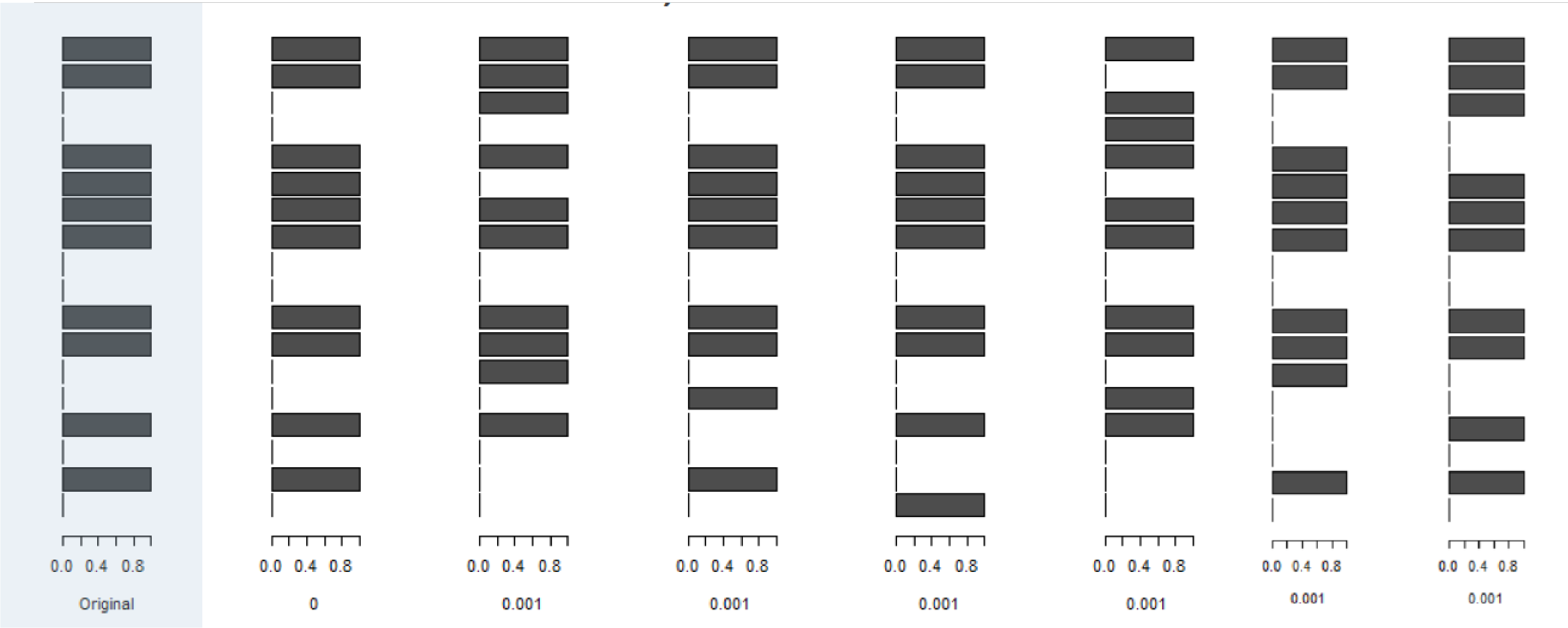
Initial Approach: Barcode Distance

Example

Original			Local Average	
P	**Q**		**P**	**Q**
0	0		1/2	0*
1	0		1/3	1/3
0	1		1/3	2/3
0	1		0*	2/2

$$\sum_i \frac{1}{2}(P_i - Q_i)\ln\left(\frac{\mathrm{P_i}}{\mathrm{Q_i}}\right) = 2.05$$

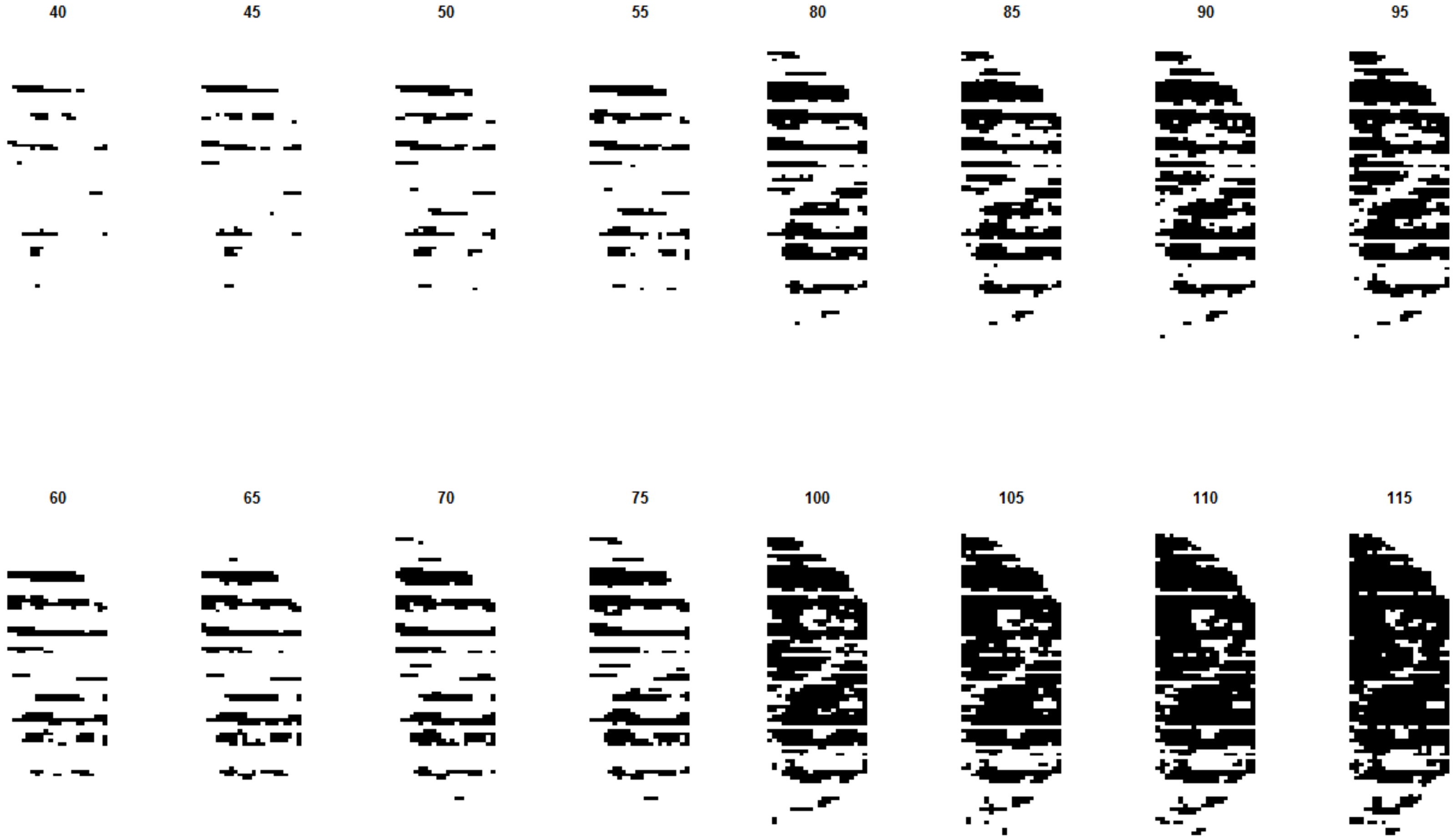
Initial Approach: Barcode Distance



Simulating 10,000 barcodes as Bernoulli(18,0.4)

Looking for the smallest Kullback-Leibler divergence

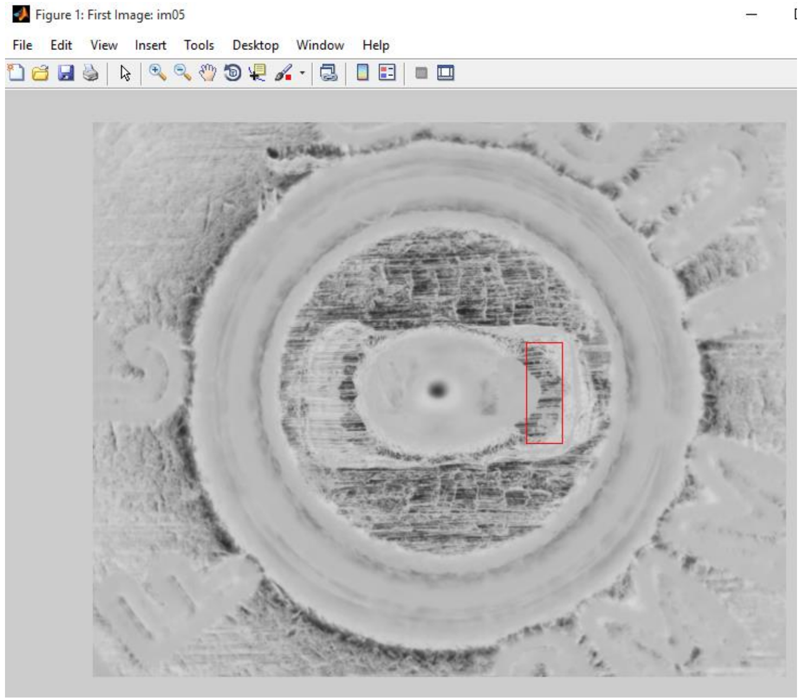
Initial Approach: Implementation

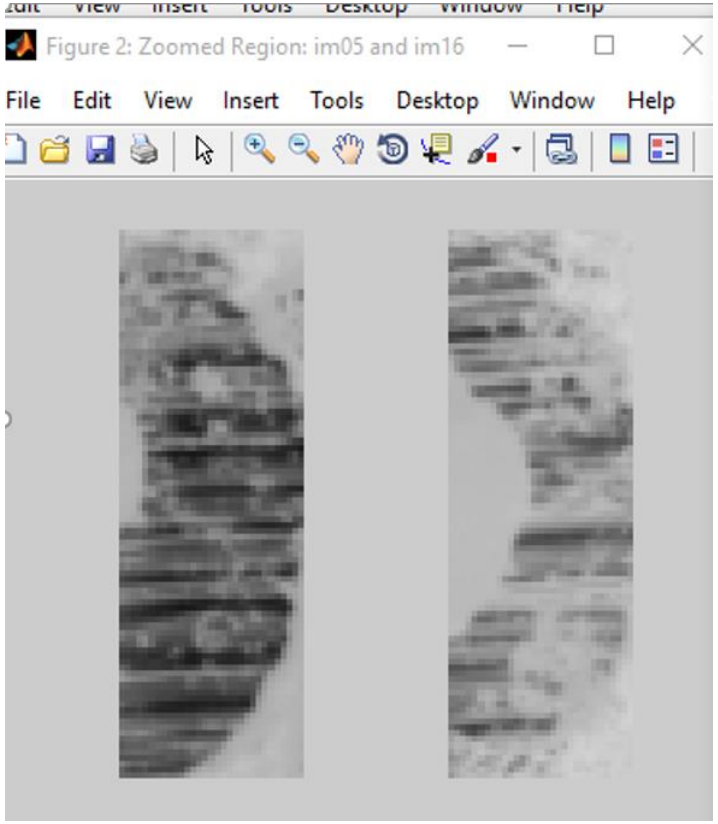


Need to determine an optimal threshold

Or remain continuous

Second Approach: Conceptual





For each infrared image of the cartridge casing, allow the *practitioner* to select the relevant regions of interest.

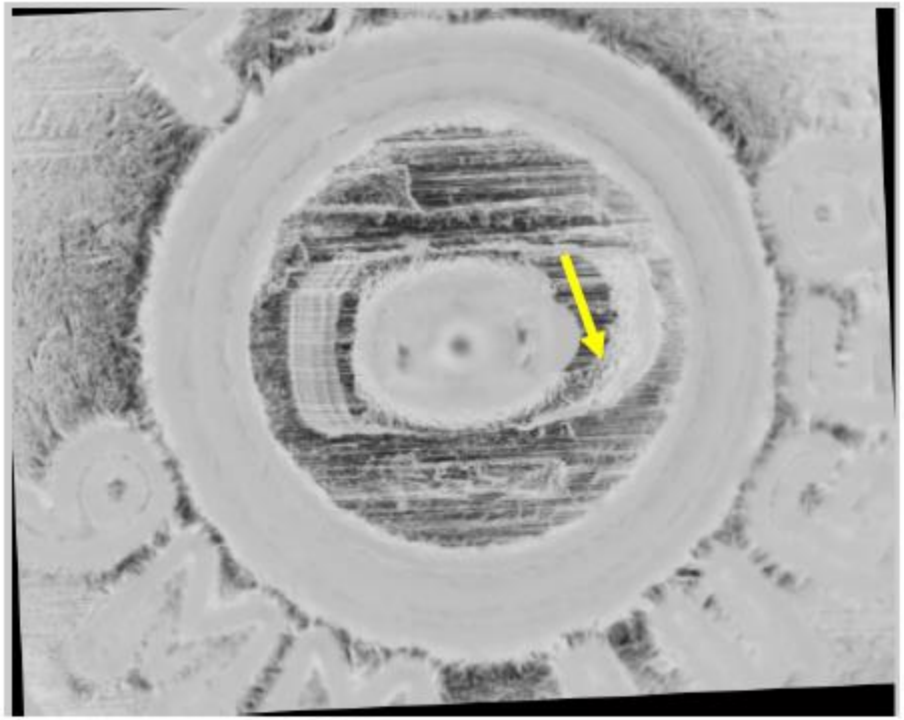
Appropriately align and smooth these regions, and convert the question of:

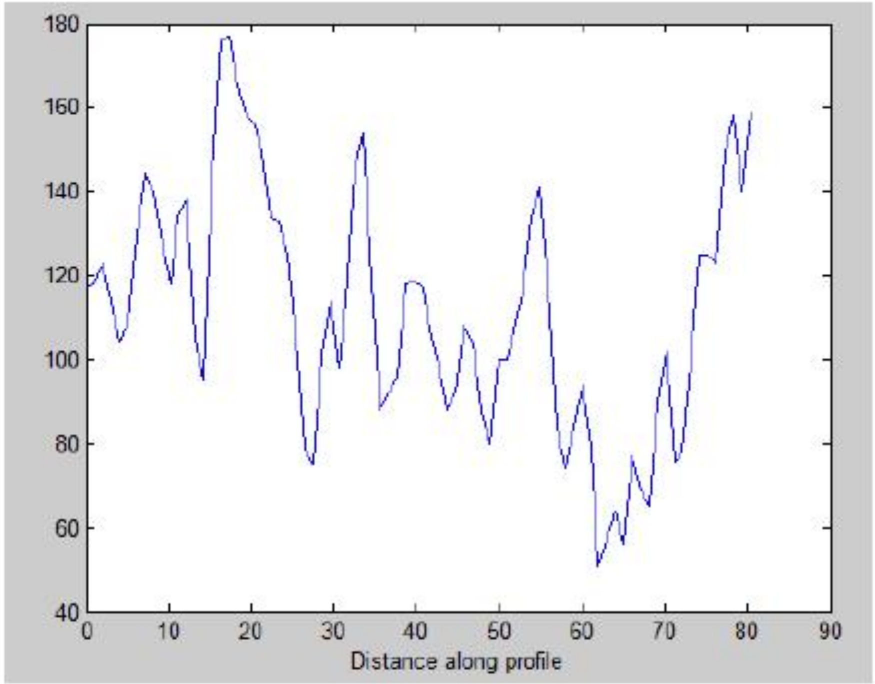
1) How similar are these images; to

2) How “far apart” are randomly selected slices on these images from each other?

Example Program

Visualizing the pixel intensity





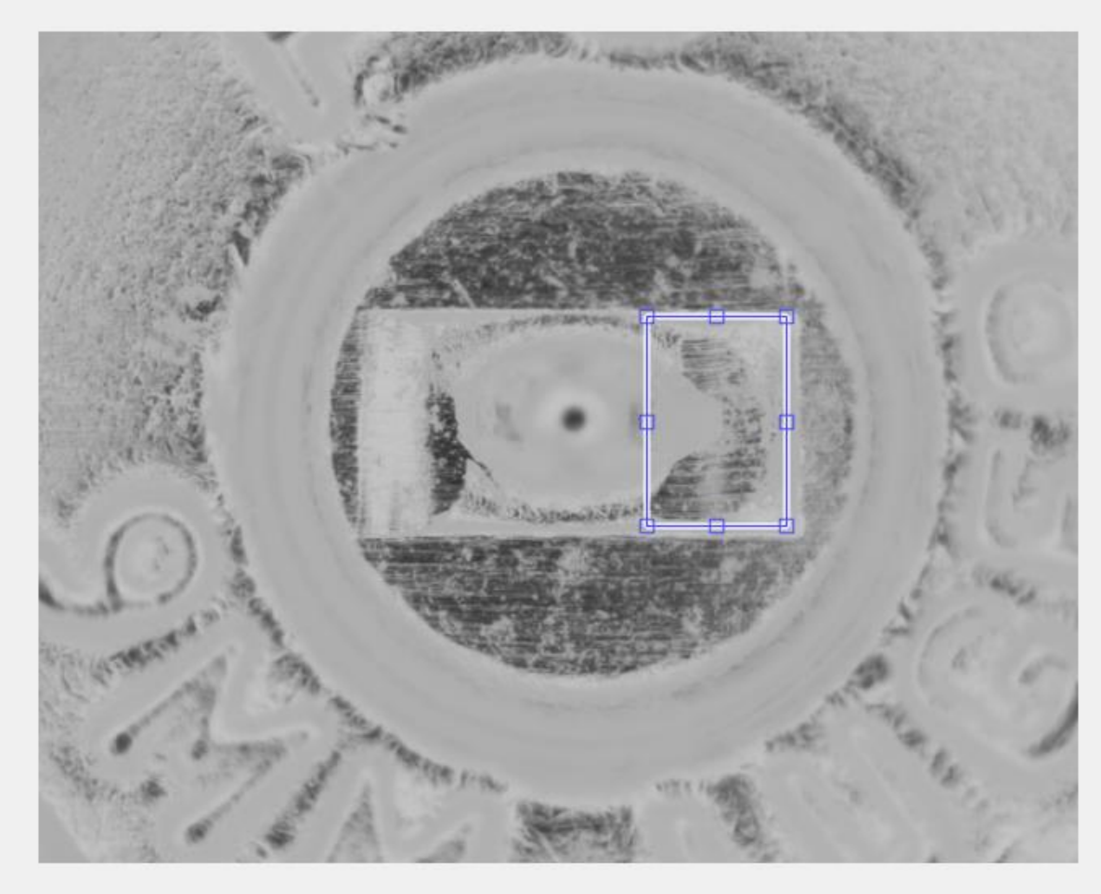
Second Approach: Distance

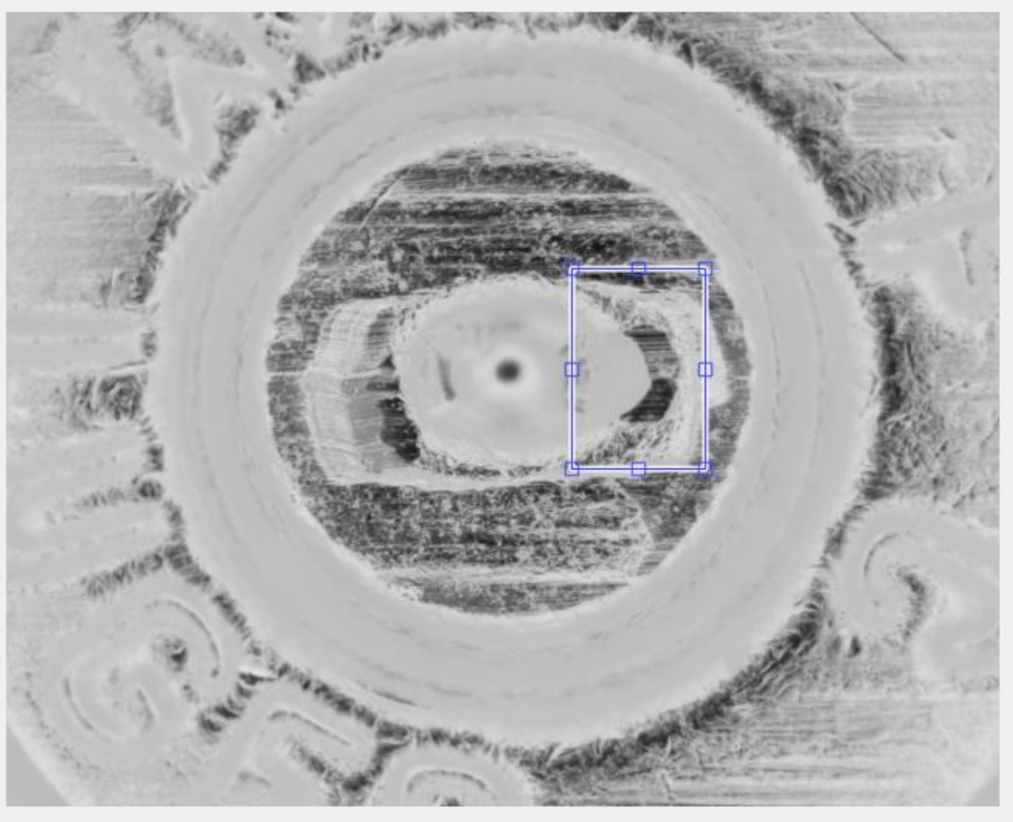
Symmetric Kullback-Leibler divergence using local averaging and requiring non-zero entries.

$$\text{symmetric KL} = \frac{1}{2}\sum_i (p_i - q_i)\ln\left(\frac{p_i}{q_i}\right)$$

$$\text{local averaging} \quad p_i = \frac{1}{3}\sum_{i-1}^{i+1} x_j \qquad \text{for} \qquad 2 \le j \le n-1$$

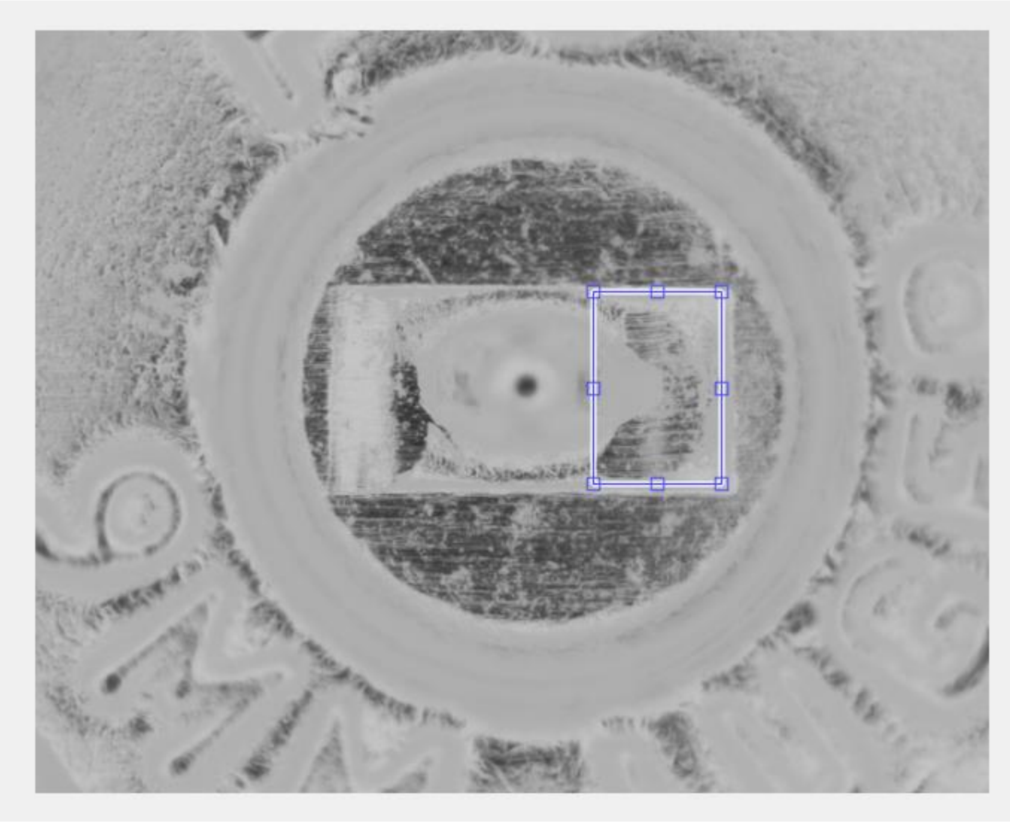
Example Program





Example Program

Storing the regions of interest



```
regions =

   375   182    86   129     1
   375   176    86   129     2
   366   177    86   129     3
   367   161    86   129     4
   365   166    86   129     5
   378   174    86   129     6
   372   179    86   129     7
   375   181    86   129     8
   358   182    86   129     9
   362   181    86   129    10
```

Example Program

Horizontal smoothing of striations

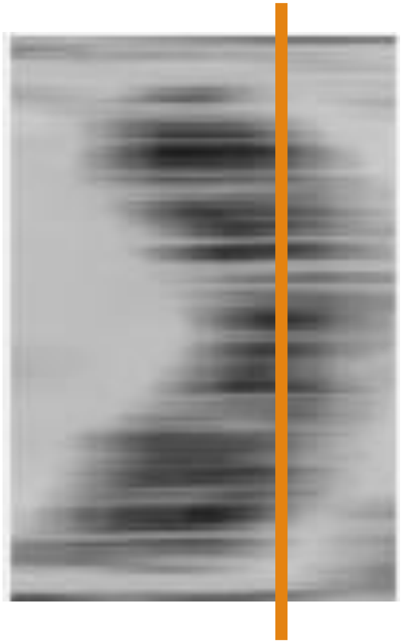
Example Program

Comparing the **same** slice within each pair of images

```
>> region_view( images, regions, 1, 10);
>> [A]      = region_compare( images, regions, 80    , 1 , 3 );
Evaluating 45 pairs, each with 80 slices, and a bandwidth of 3
44 43 42 41 40 39 38 37 36 35 34 33
```

Example Program

Comparing **different** slices within each pair of images



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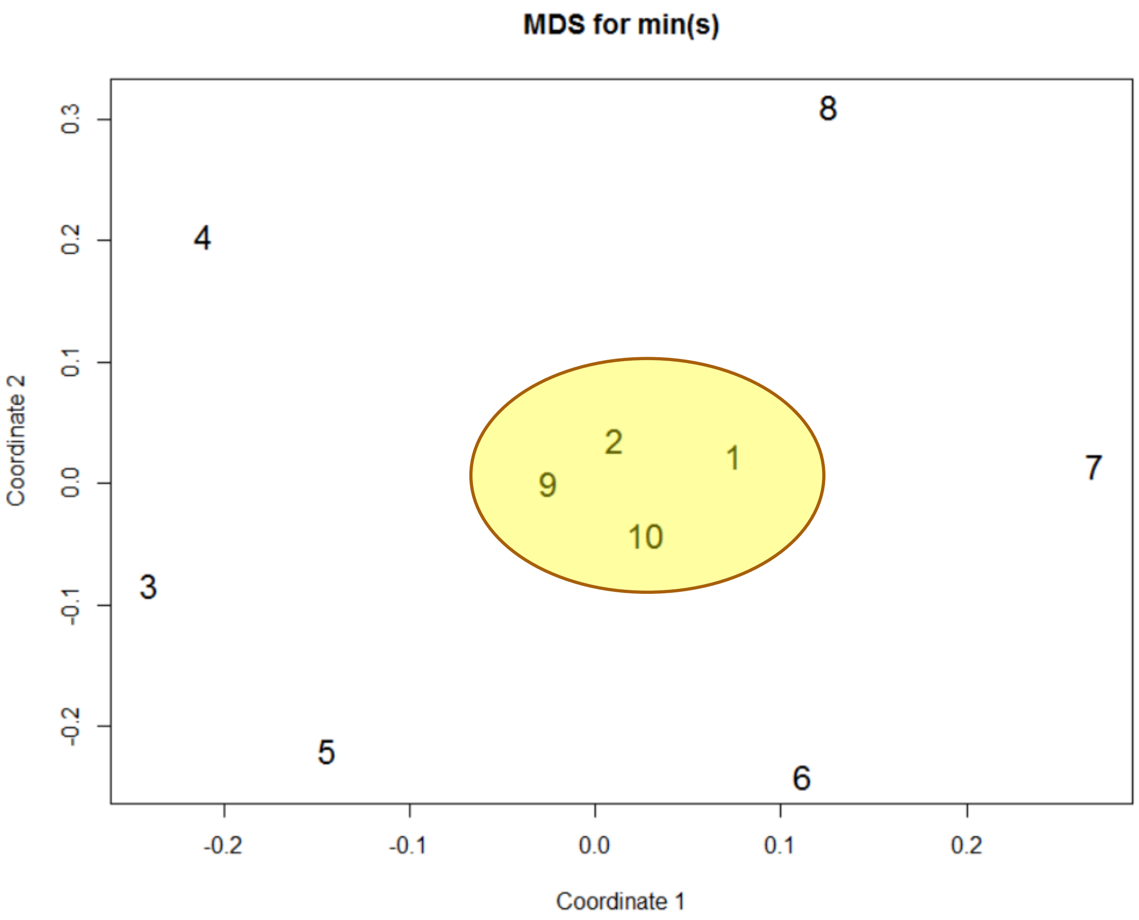
Example Program: Results

Example: "Distance" between image pairs							
Pairs of Images		**Same Slice**			**Different Slice**		
Image A	Image B	Mean	Mean Variance	Minimum	Mean	Mean Variance	Minimum
1	2	2.81	0.10	0.01	4.52	0.24	0.06
1	3	2.60	0.05	0.13	4.14	0.13	0.26
1	4	2.51	0.06	0.13	4.50	0.17	0.22
2	3	2.31	0.02	0.12	3.02	0.07	0.37
2	4	1.59	0.02	0.19	2.41	0.04	0.14
3	4	1.51	0.01	0.21	3.22	0.05	0.24

All summary statistics are multiplied by 100

Example Program: Visualization



Using multidimensional scaling

(R function: isoMDS in MASS)

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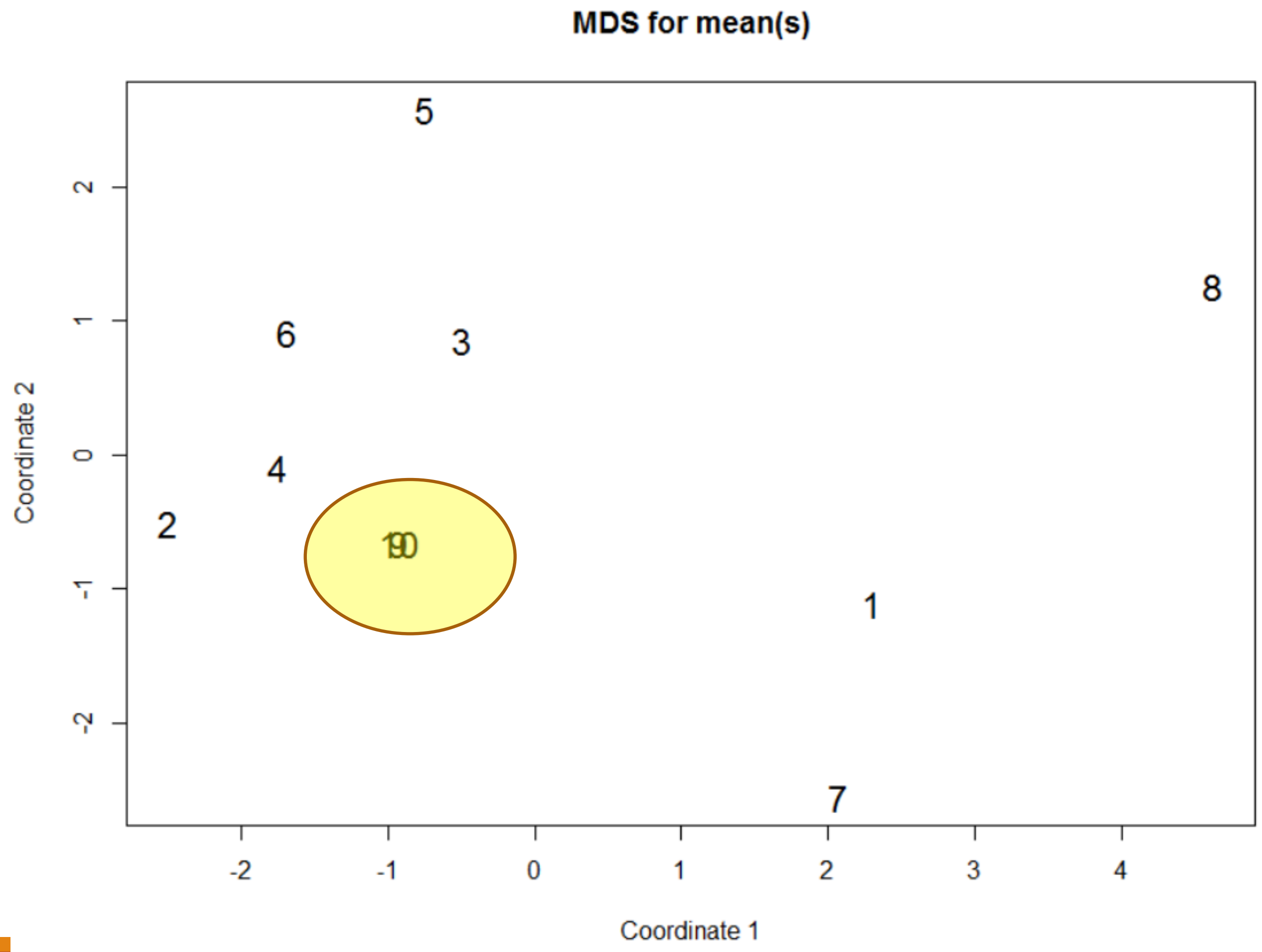

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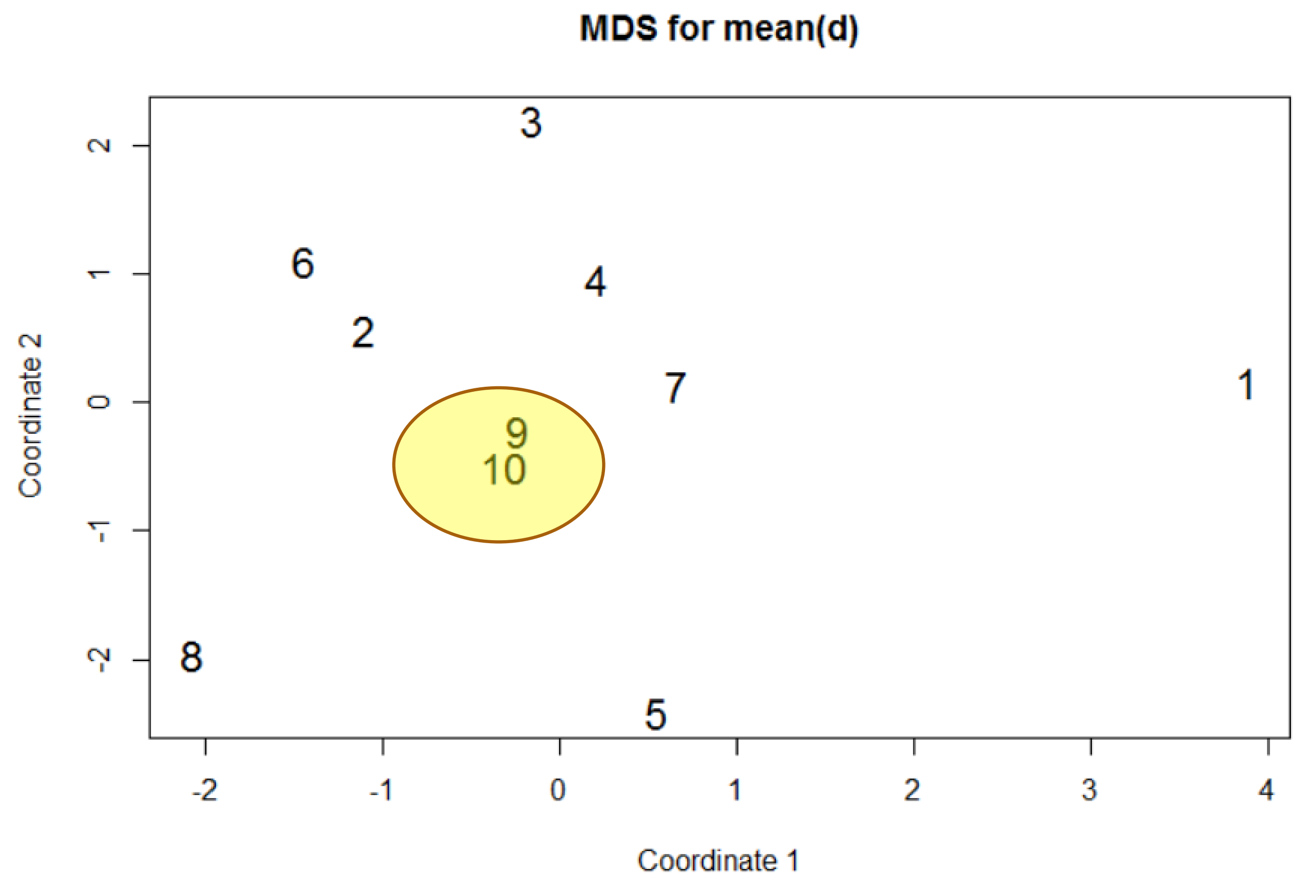
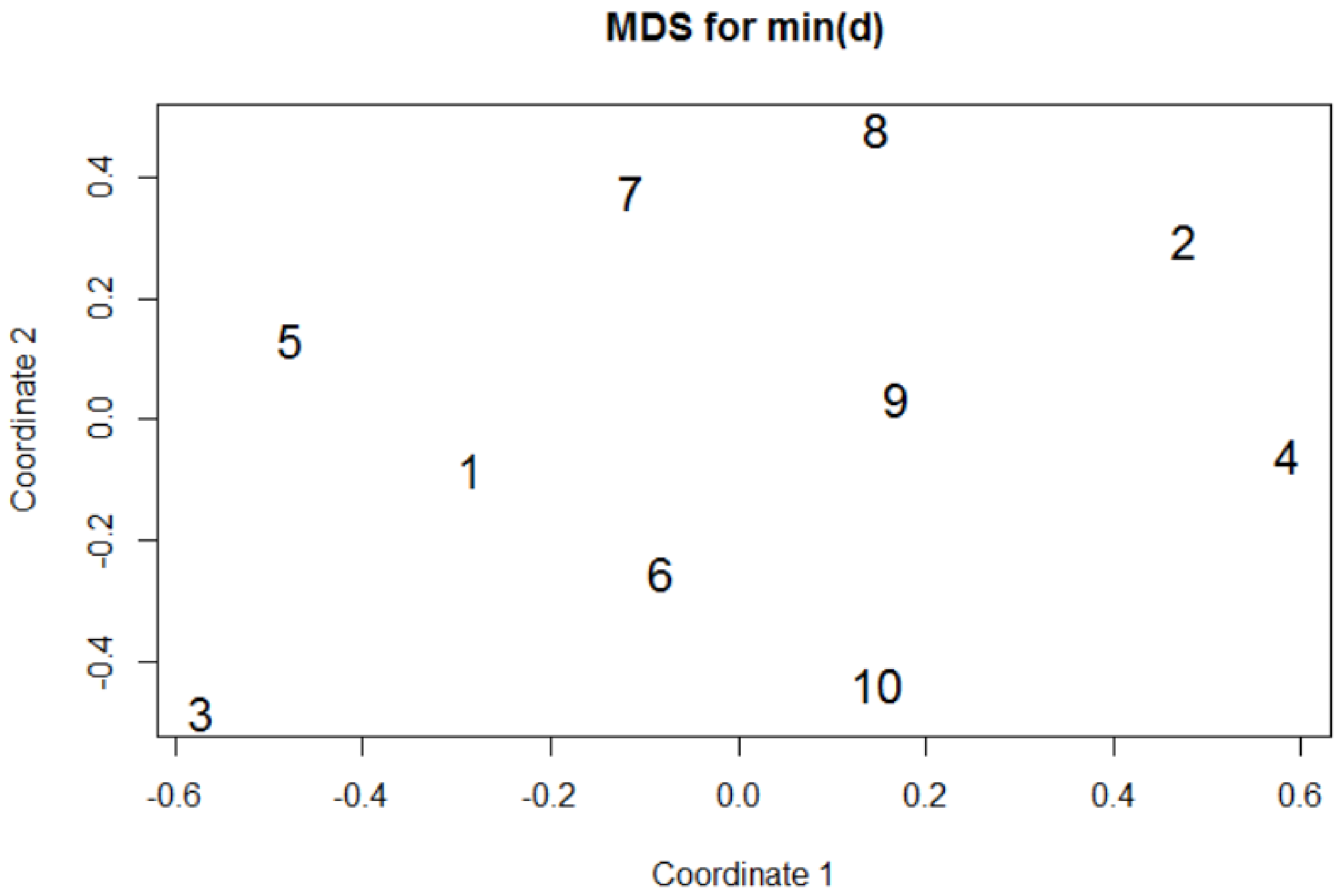


Examining different slices on larger regions

Using multidimensional scaling
(R function: isoMDS in MASS)

Example Program: Visualization



Examining different slices
on larger regions

Using multidimensional scaling
(R function: isoMDS in MASS)

Limitations and Future Research

Rotation and Alignment Issues

Sensitivity to Region Specified

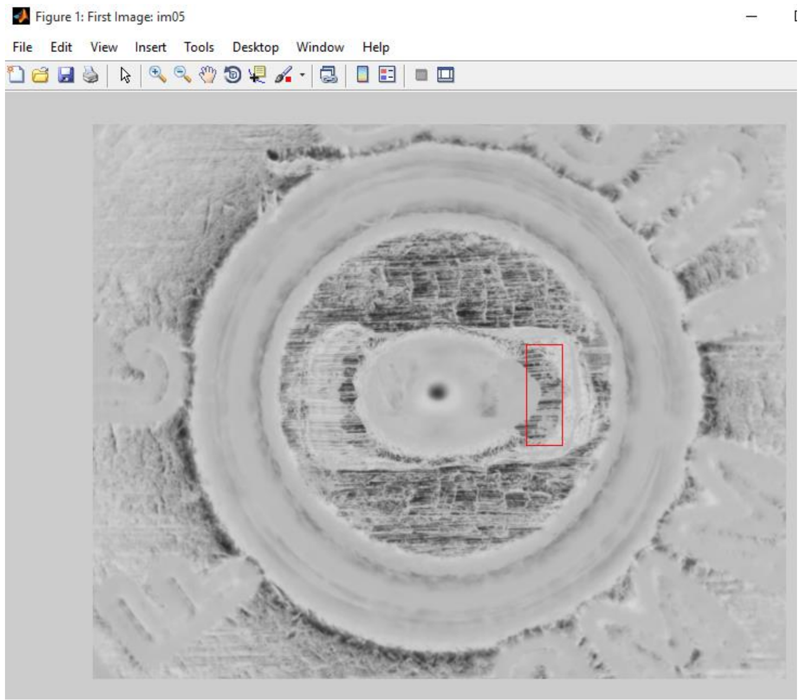
Small Sample Size

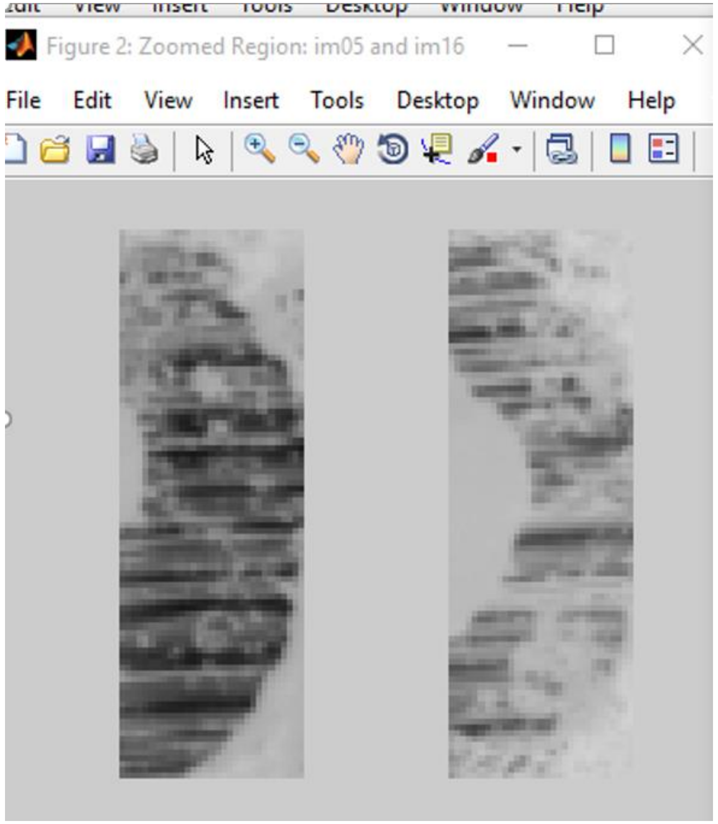
Desire for more images of cartridges fired by multiple types of brands/weapons/models

Incorporating uncertainty in the analysis

Deep learning approach?

Recap





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Acknowledgements

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