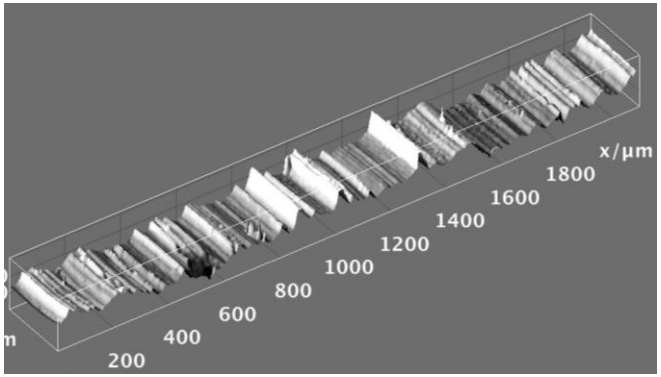
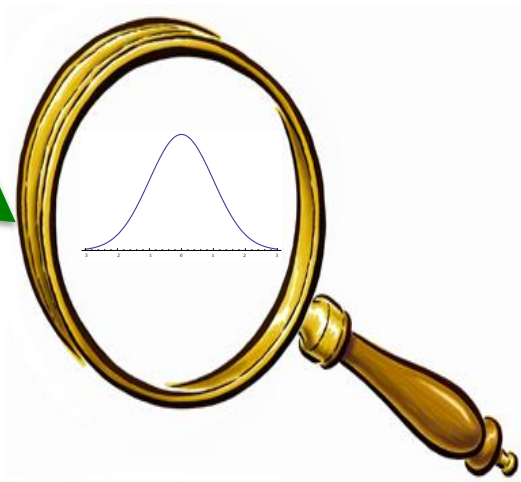
Computational Strategies for Toolmarks: Principal Component Analysis and Other Methods





Outline

- Introduction
- Details of Our Approach
  - Data acquisition
  - Methods of statistical discrimination
  - Error rate estimates
  - Measures of a association quality
  - Future directions

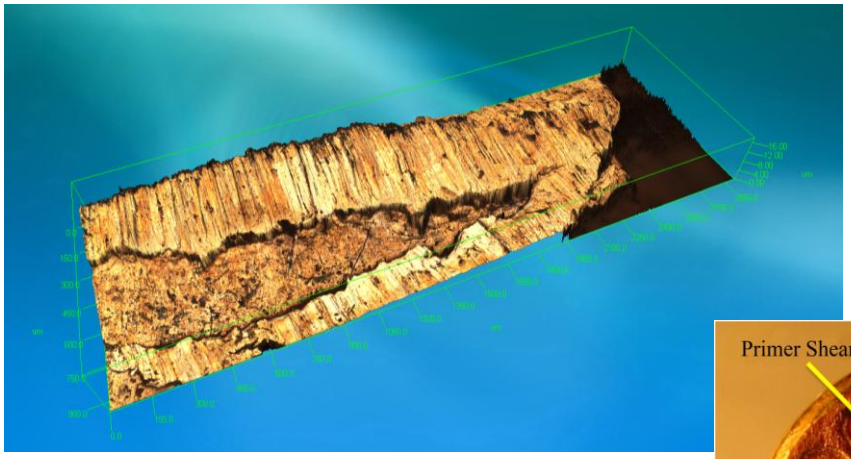
Background Information

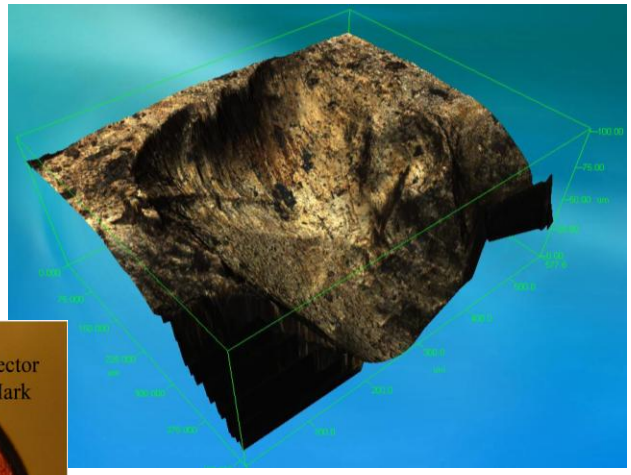
- *All impressions* made by tools and firearms can be represented as *numerical patterns*
  - **Machine learning** trains a computer to recognize patterns
    - Can give "…the quantitative difference between an identification and non-identification"Moran
    - Can yield **identification error rate estimates**
    - May be even **confidence measures for I.D.s**……

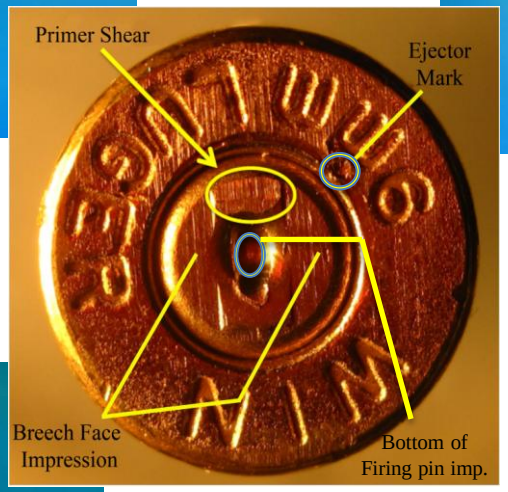
Data Acquisition

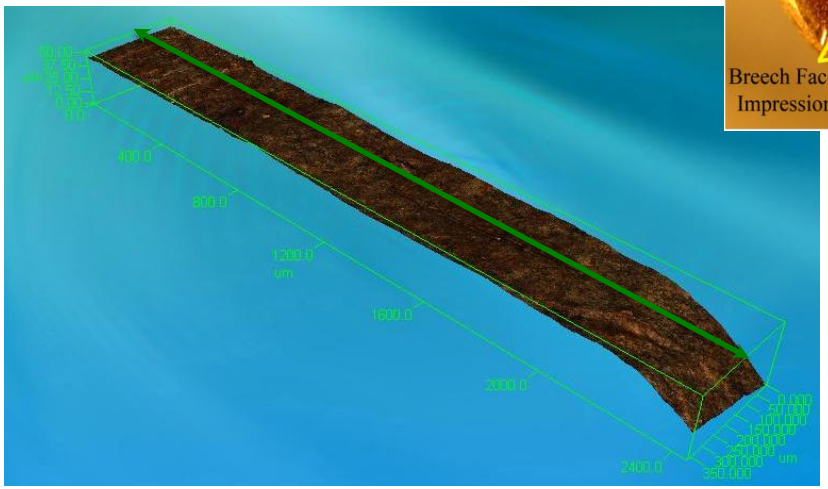
- Obtain striation/impression patterns from **3D confocal microscopy**
- Store files in ever expanding database
- Data files are available to practitioner and researcher community through web interface

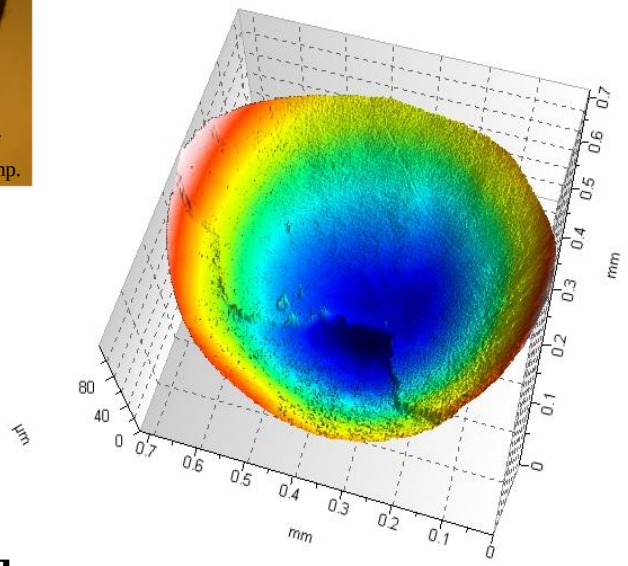
Glock Fired Cartridges





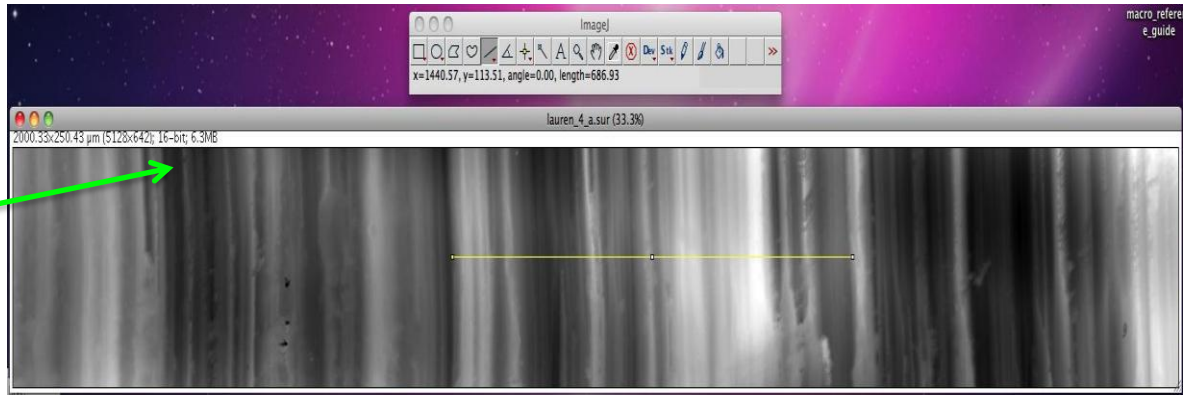


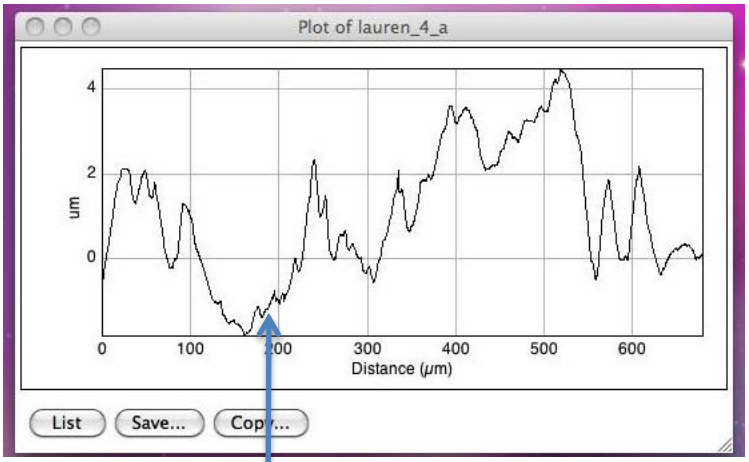


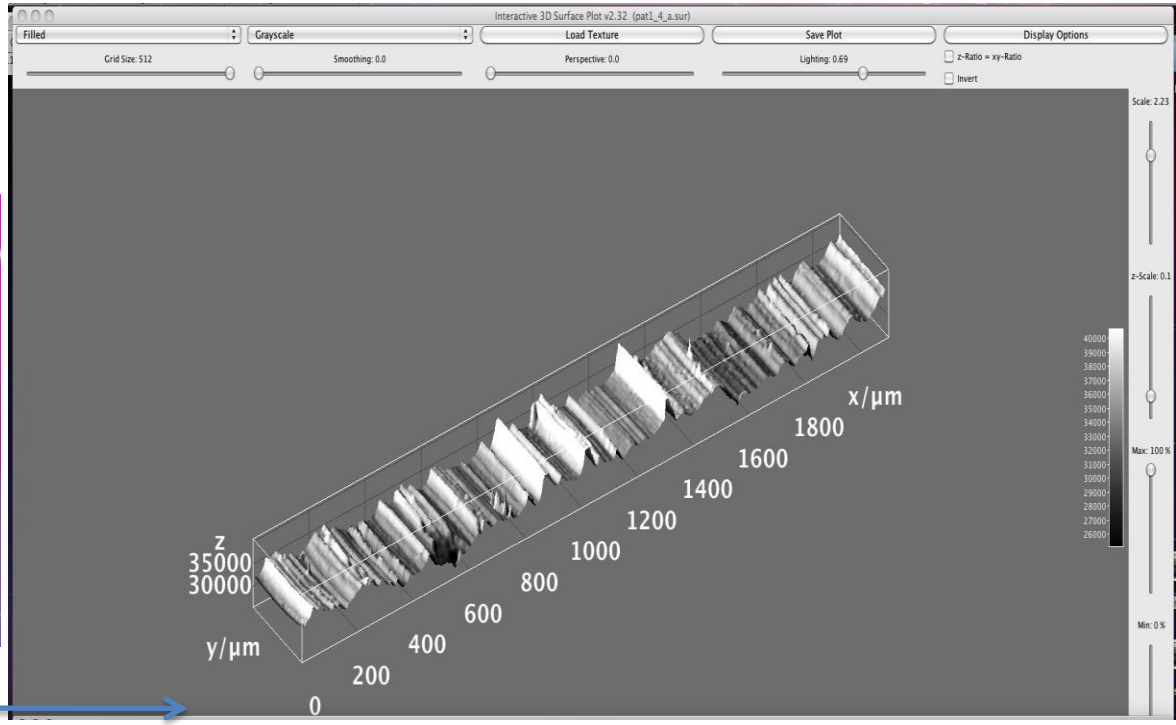


Glock 19 fired cartridge cases

Screwdriver Striation Patterns in Lead



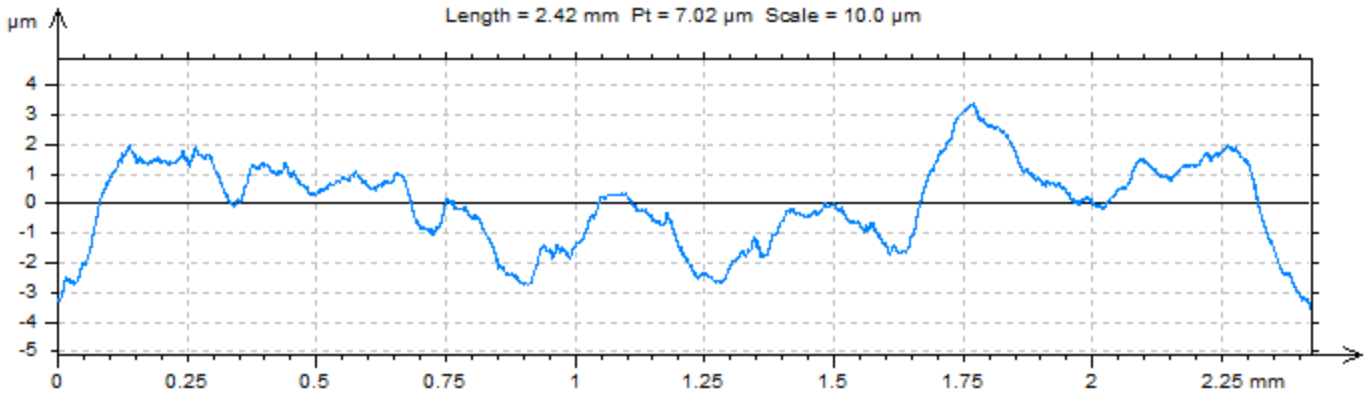




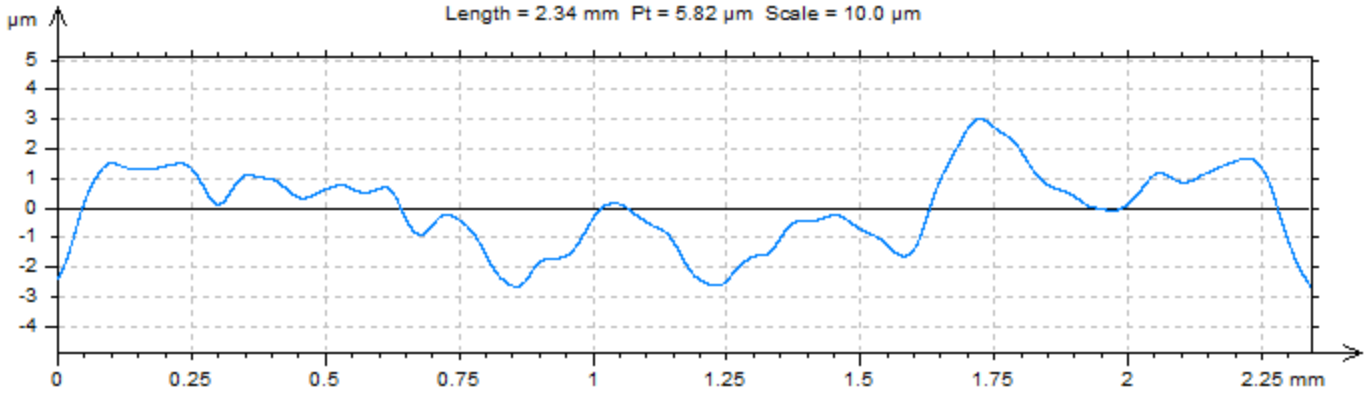
2D profiles

3D surfaces (interactive)

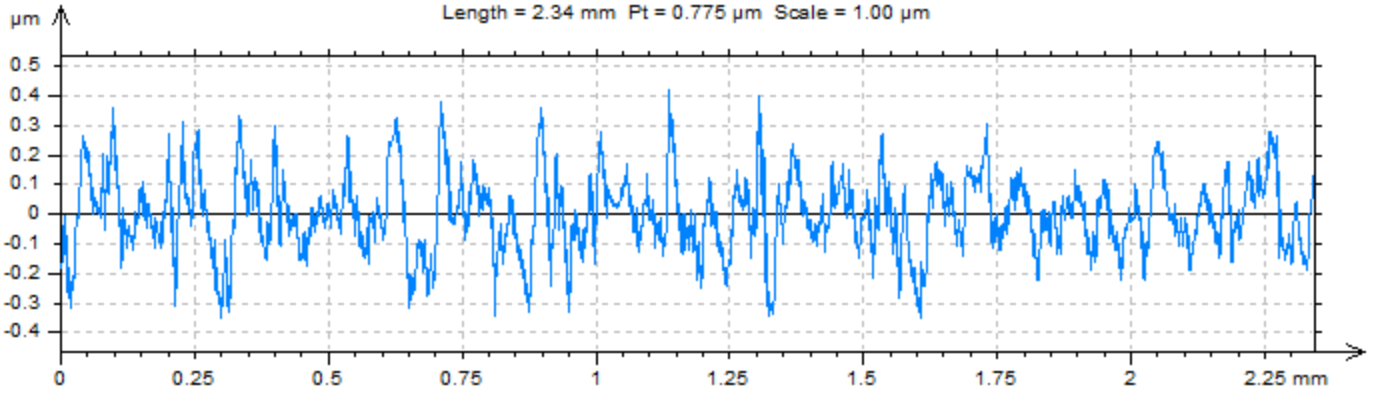
Mean total profile:



Mean "waviness" profile:

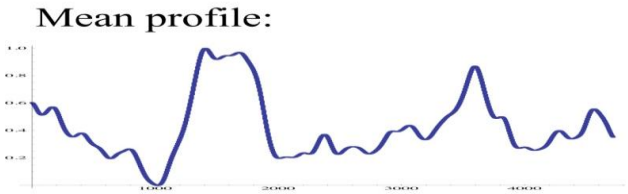


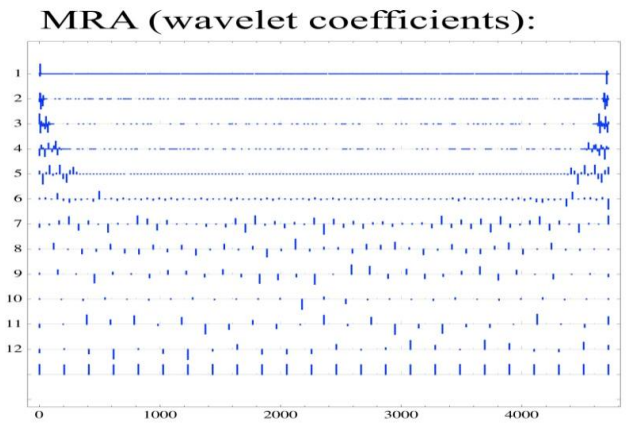
Mean "roughness" profile:

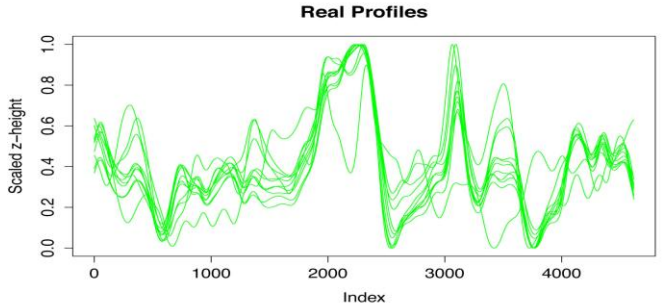


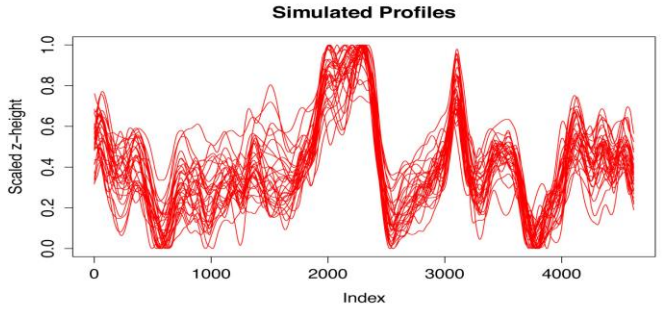
Profile Simulator

- We can simulate profiles as well
- Based on DWT MRA
  - May shed light on processed generating surfaces
  - Should be extendable to 2D striations/impressions…



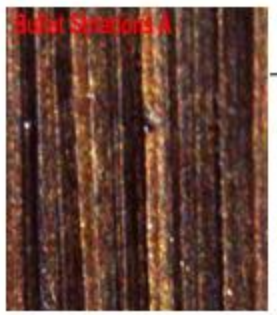


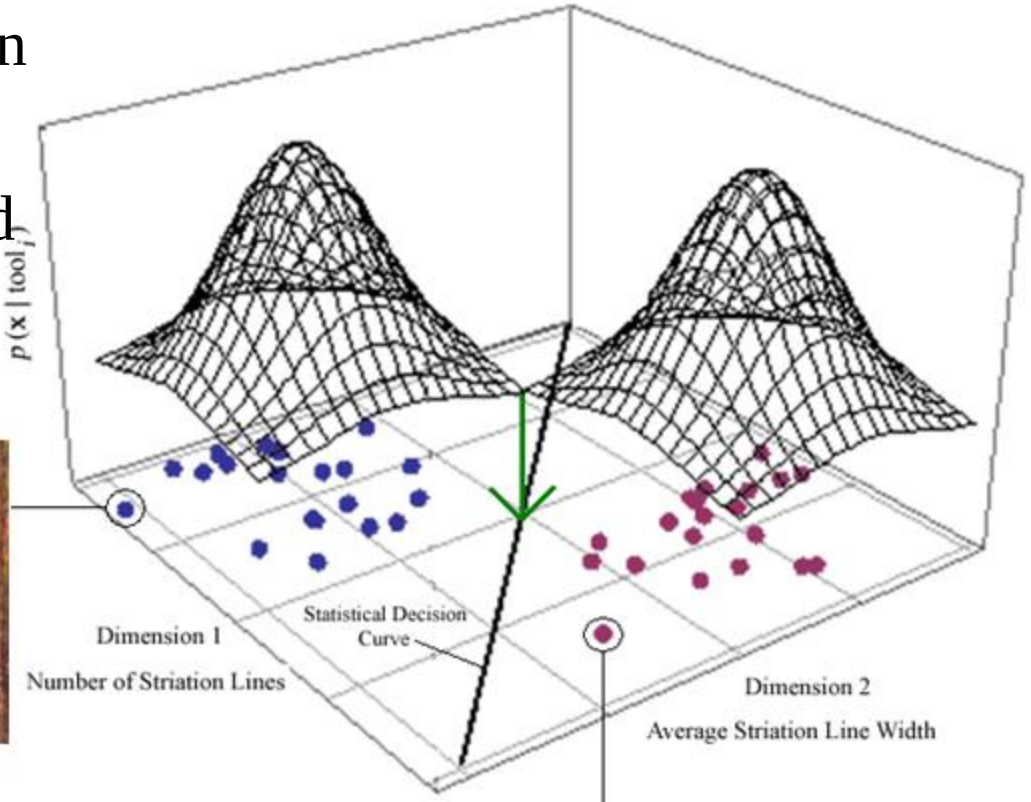


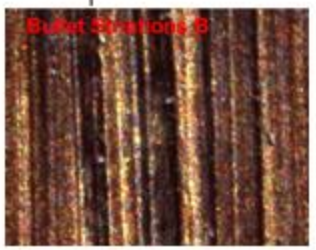


What Statistics Can Be Used?

- Multivariate statistical pattern comparison!
- Modern algorithms are called **machine learning**
  - Idea is to measure **features** of the physical evidence that characterize it







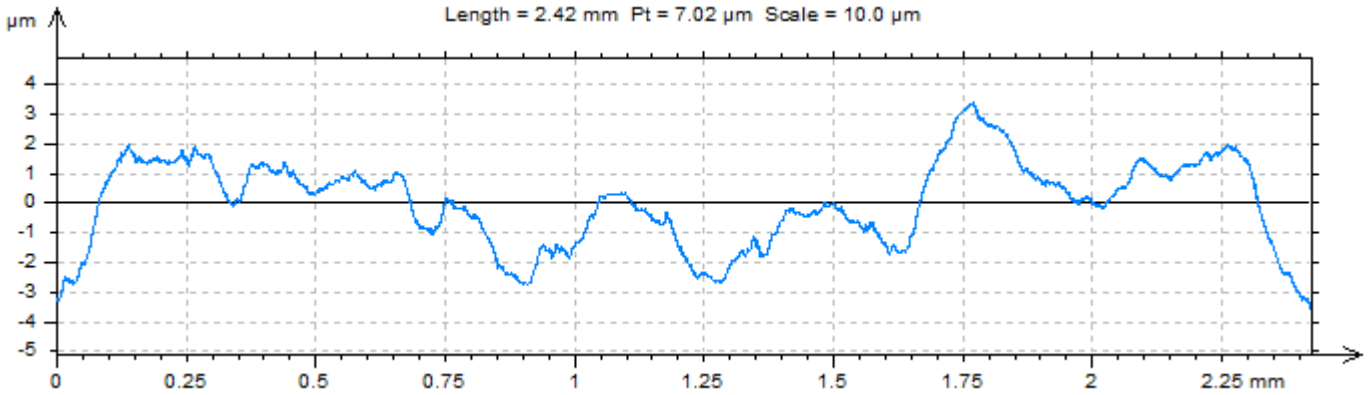
- Train algorithm to recognize "major" differences between groups of features while taking into account natural variation and measurement error.

Setup for Multivariate Analysis

- Need a data matrix to do machine learning

$$\mathbf{X} = \begin{bmatrix} X_{11} & .. & X_{1j} & .. & X_{1p} \\ : & & : & & : \\ X_{i1} & .. & X_{ij} & .. & X_{ip} \\ : & & : & & : \\ X_{n1} & .. & X_{nj} & .. & X_{np} \end{bmatrix}$$

Represent as a vector of values

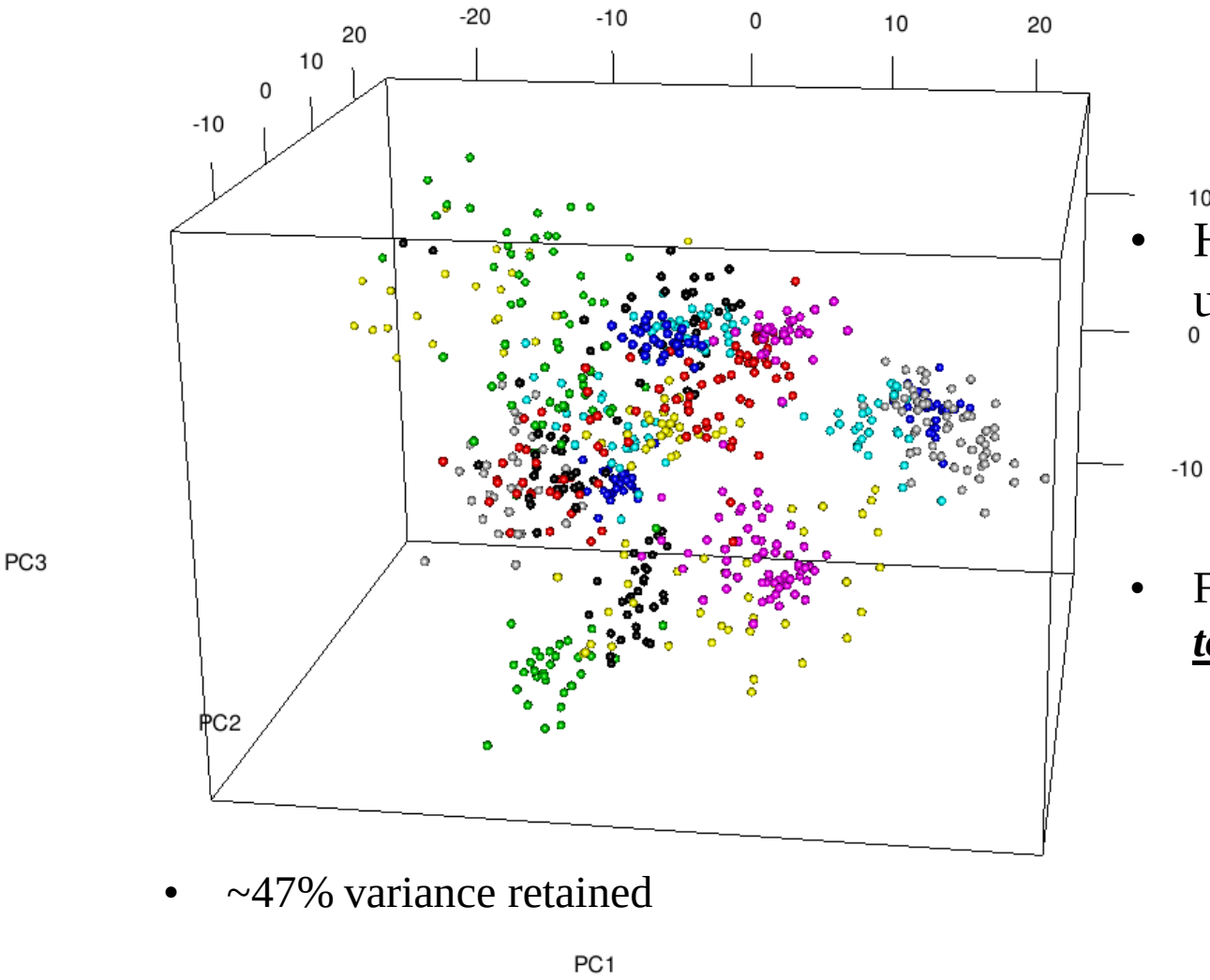


{-4.62, -4.60, -4.58, ...}

- Each profile or surface is a row in the data matrix
- Typical length is **~4000 points/profile**
- 2D surfaces are far longer
  - HIGHLY REDUNDANT representation of surface data

- PCA can:
  - Remove much of the redundancy
  - Make discrimination computations far more tractable

- 3D PCA 24 Glocks, 720 simulated and real primer shear profiles:



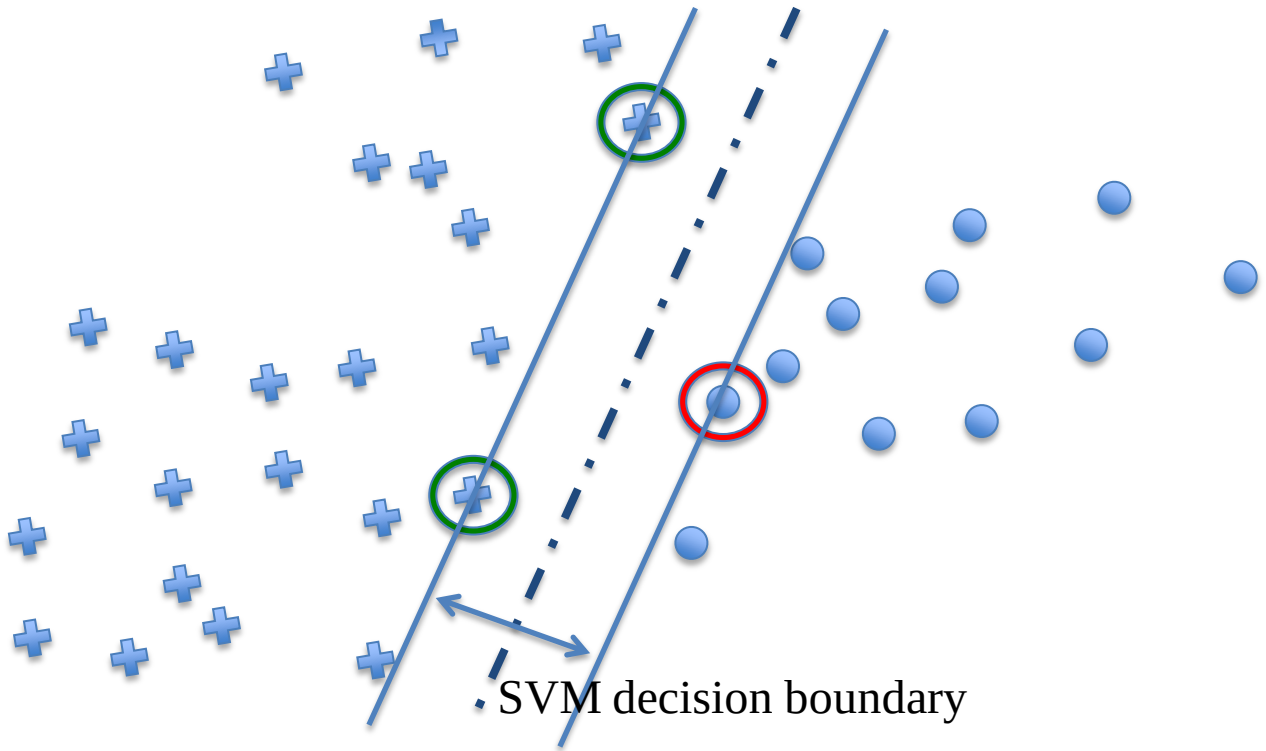
- ~47% variance retained

- How many PCs should we use to represent the data??
  - No unique answer

- FIRST we ***need an algorithm to I.D. a toolmark*** to a tool

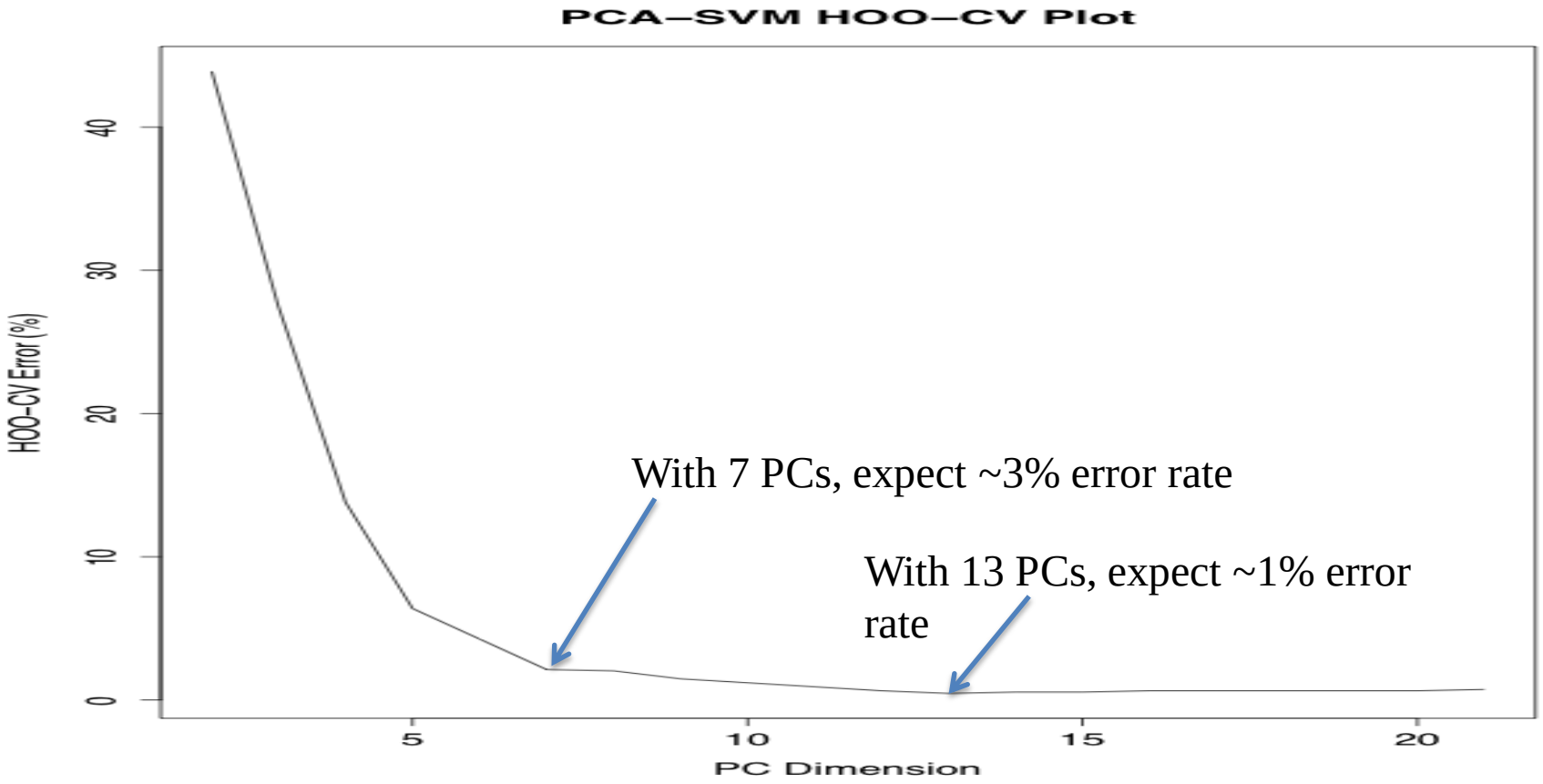
Support Vector Machines

- Support Vector Machines (SVM) determine efficient association rules
  - ***In the absence of any knowledge of probability densities***



PCA-SVM

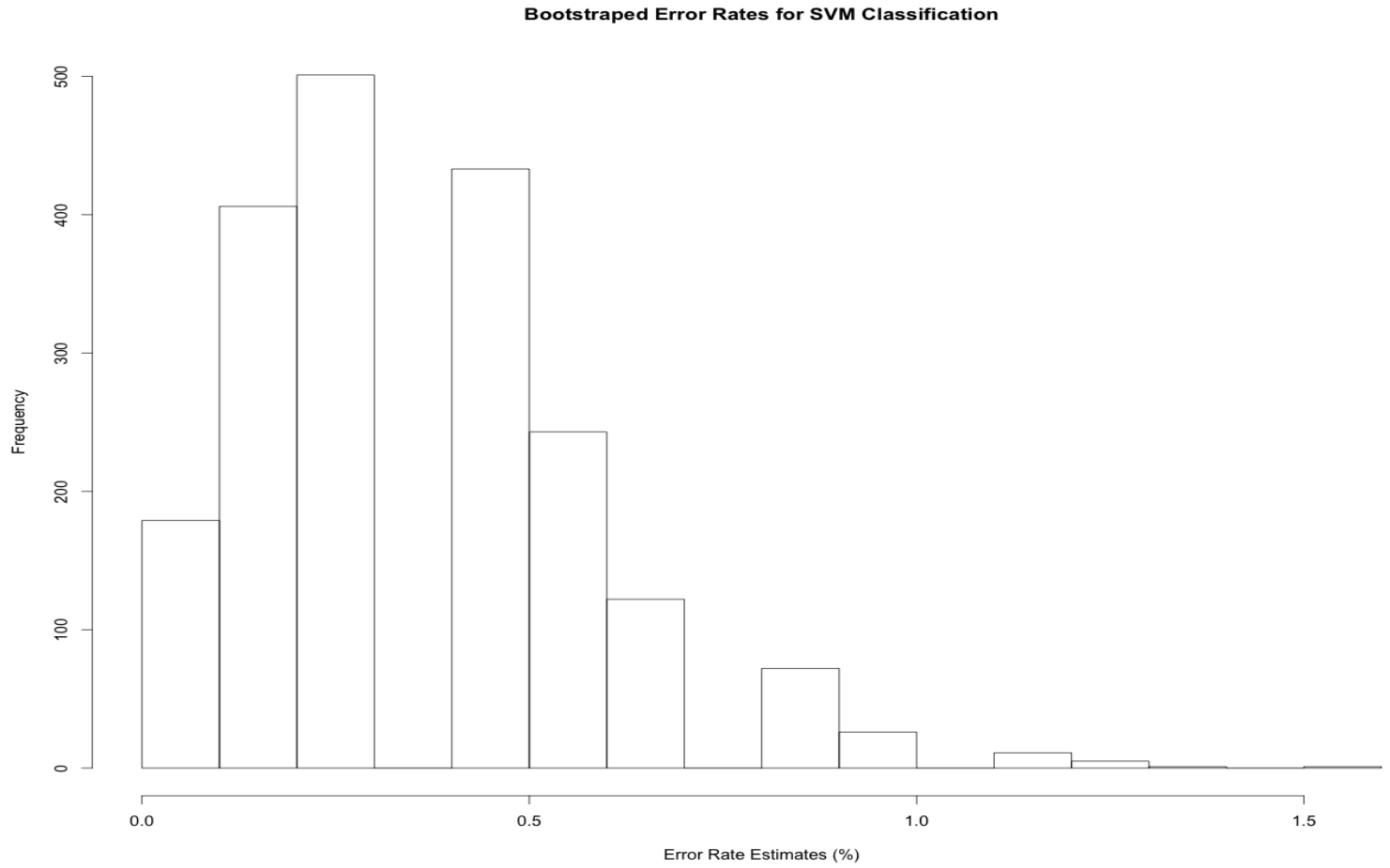
- How many Principal Components should we use?



Error Rate Estimation

- **Cross-Validation**: hold-out chunks of data set for testing
  - Known since 1940s
  - Most common: **Hold-one-out**
- **Bootstrap**: Randomly selection of observed data (with replacement)
  - Known since the 1970s
  - Can yield ***confidence intervals around error rate estimate***
- **The Best**: Small training set, BIG test set

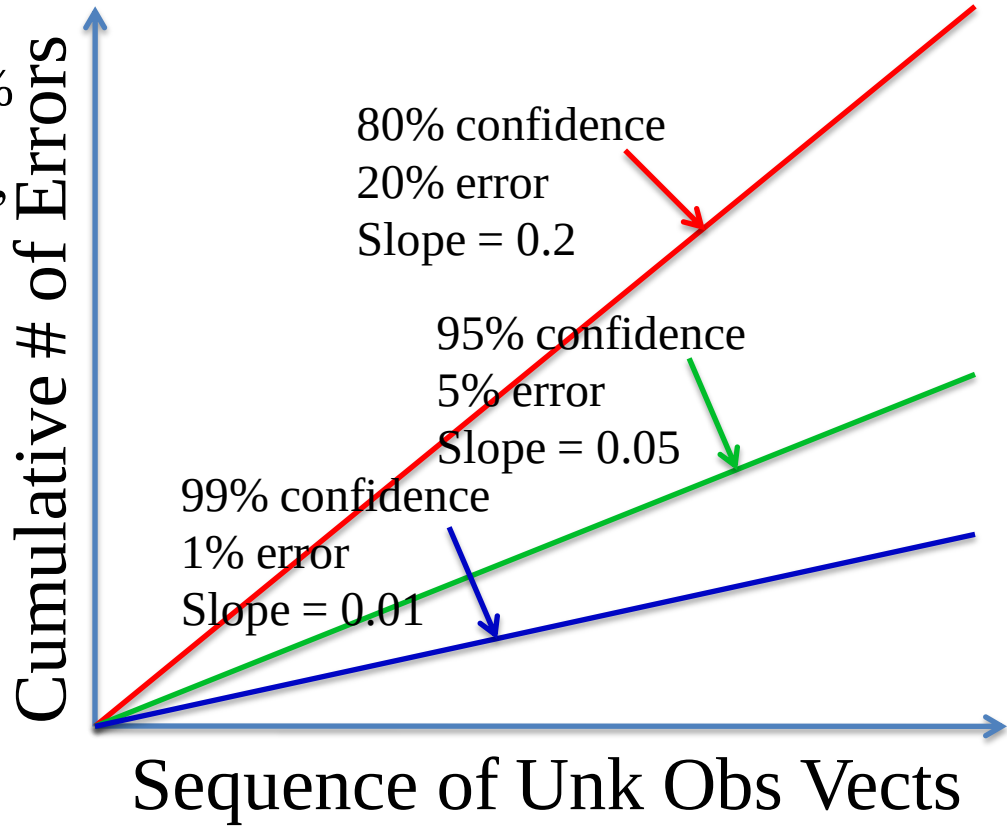
18D PCA-SVM Primer Shear I.D. Model, 2000 Bootstrap Resamples



Refined bootstrapped I.D. error rate for primer shear striation patterns= 0.35%
95% C.I. = [0%, 0.83%]
(sample size = 720 real and simulated profiles)

How good of a "match" is it?
Conformal Prediction

- Can give a judge or jury an easy to understand measure of reliability of classification result
  - Confidence on a scale of 0%-100%
- This is an orthodox "frequentist" approach
- Developed from principals known since the 1930s



Empirical Bayes'

- Computer outputs a "match"
  - What's the **probability it is truly not a "match"**?

Get it from Bayes' Rule:

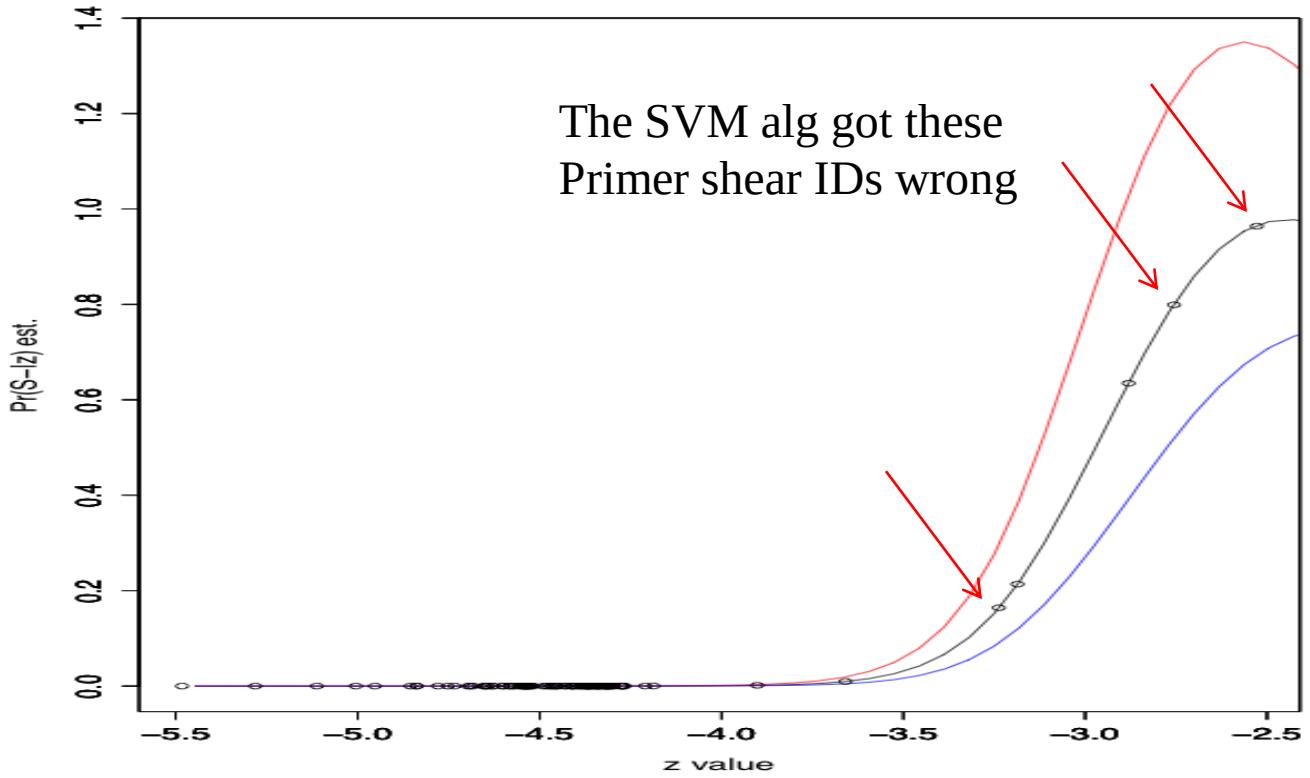
Probability of no actual association given a test/algorithm indicates a positive ID

$$\Pr\left(S^- \mid t^+\right) = \frac{\Pr\left(t^+ \mid S^-\right)}{\Pr\left(t^+\right)} \Pr\left(S^-\right)$$

Name: **Posterior error probability (PEP)**

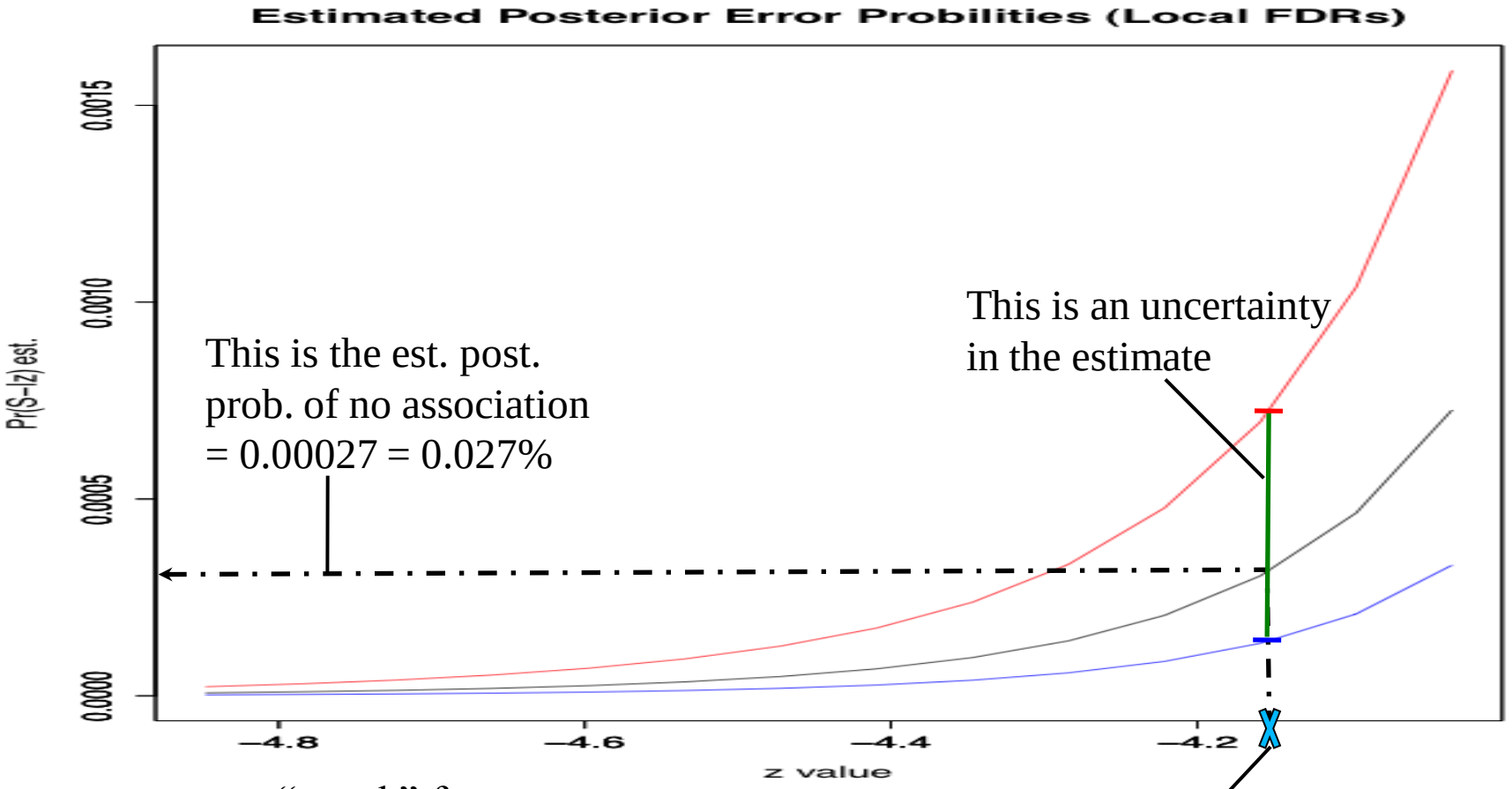
Empirical Bayes'

- Use Brad Efron's machinery for "empirical Bayes' two-groups model"
  - Get a calibrated PEP model



Empirical Bayes'

- Model's use with crime scene "unknowns":



Computer outputs "match" for:
unknown crime scene toolmarks-with knowns from "Bob the burglar" tools

Future Directions

- **Extend ImageJ** surface metrology functionality
- **Eliminate alignment** step
  - Try invariant feature extraction
- **Parallel** implementation of computationally intensive routines
- **Standards board** to review statistical methodology/algorithms

Acknowledgements

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  - Stephanie Pollut
  - Chris Singh
  - Melodie Yu

Website Information and Reprints/Preprints:

toolmarkstatistics.no-ip.org/

npetraco@gmail.com

npetraco@jjay.cuny.edu