

Statistical Analysis of Handwriting: Probabilistic outcomes for closed-set writer identification

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Forensic Statistics Research at CSAFE

The **C**enter for **S**tatistics and **A**pplications in **F**orensic **E**evidence

- ▶ NIST Center of Excellence
- ▶ Three-part mission: **research**, outreach, training.

Funding Statement

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Introduction

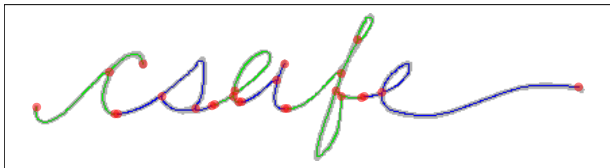
Objective

Use a statistical model to provide probabilistic statements of writership for handwritten documents.

- ▶ Without character recognition
- ▶ Robust to writing style - cursive, print
- ▶ Closed set of writers - search a collection

Data Processing with *handwriter*

The R package *handwriter*¹ takes in a scanned handwritten document. Then,



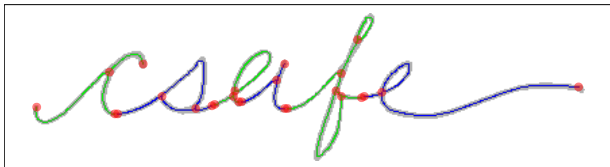
1. Binarize

- Turn the image to pure black and white.

¹<https://github.com/CSAFE-ISU/handwriter>

Data Processing with *handwriter*

The R package *handwriter*¹ takes in a scanned handwritten document. Then,



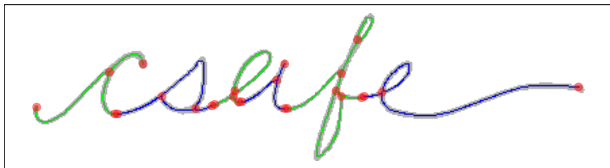
2. Skeletonize

- ▶ Reduce writing to a 1 pixel wide skeleton.

¹<https://github.com/CSAFE-ISU/handwriter>

Data Processing with *handwriter*

The R package *handwriter*¹ takes in a scanned handwritten document. Then,



3. Break

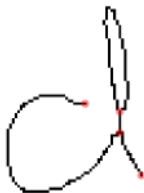
- ▶ Connected writing is decomposed into small manageable graphical structures.
- ▶ Often, but not always, correspond to Roman letters.

¹<https://github.com/CSAFE-ISU/handwriter>

Handwriting as Data



(a)



(b)



(c)



(e)



(d)



(f)

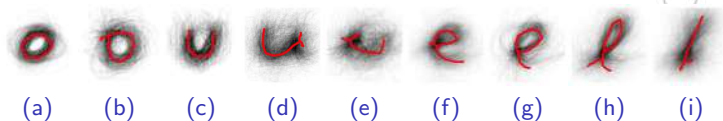
Writing as graphical structures.

- ▶ Parziale, et al. (2014), Miller et. al. (2017), others
- ▶ For us, attributed graphs with nodes and edge locations

Parziale, Antonio, et al. *An interactive tool for forensic handwriting examination*. 14th International Conference on Frontiers in Handwriting Recognition. IEEE, 2014.

Miller, J. J. et al. (2017). *A set of handwriting features for use in automated writer identification*. *Journal of forensic sciences*, 62(3), 722-734.

Group like structures with K -Means - I



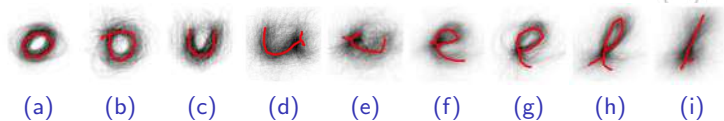
Handwriting elements/measurements into “bins” / “buckets”.

- ▶ Bulacu and Schomaker (2007) , Saunders et al. (2011) , others
- ▶ For us, flexible and structure based through clustering.

Bulacu, M. and Schomaker, L. (2007). Text-independent writer identification and verification using textural and allographic features. IEEE transactions on pattern analysis and machine intelligence, 29(4):701-717.

Saunders, C. P., Davis, L. J., Lamas, A. C., Miller, J. J., and Gantz, D. T. (2011). Construction and evaluation of classifiers for forensic document analysis. The Annals of Applied Statistics, 5(1):381-399.

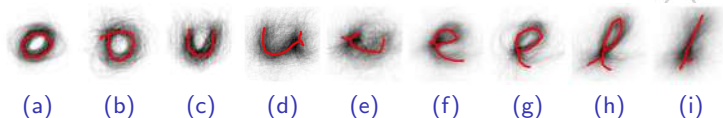
Group like structures with K -Means - II



Joint work with Nick Berry, PhD.

40 clusters $\rightarrow$ 40 centers that make up the template.

Group like structures with K –Means - III



Three data sources for template creation.

1. CSAFE Handwriting Database², 25 documents, 1 prompt.
2. CVL Database³, 25 documents, 6 prompts.
3. IAM Handwriting Database⁴, 50 documents, 50 prompts.

²A Crawford, A Ray, A Carriquiry, J Kruse, M Peterson (2019). CSAFE Handwriting Database. Iowa State University. Dataset. <https://doi.org/10.25380/iastate.10062203.v1>

³F Kleber, S Fiel, M Diem, R Sablatnig (2013). CVL-DataBase: An Off-Line Database for Writer Retrieval, Writer Identification and Word Spotting in 2013 12th International Conference on Document Analysis and Recognition. pp. 560–564.

⁴UV Marti, H Bunke (2002). The IAM-database: An English sentence database for offline handwriting recognition. Int. J. on Document Analysis Recognit.5, 39–46.

Feature Extraction with Template



All graphs from training and testing documents are filtered through the template and assigned to the nearest center.

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All graphs from training and testing documents are filtered through the template and assigned to the nearest center.

$Y_{doc,writer}$	Cluster ₁	Cluster ₂	Cluster ₃	Cluster ₄	...	Cluster ₃₉	Cluster ₄₀
$Y_{1,1}$	42	21	9	5	...	1	1
$Y_{1,38}$	39	91	23	6	...	0	1
$Y_{1,95}$	38	81	16	14	...	0	0
$\vdots$							

Model #1

$$Y_{doc,writer} \sim \mathbf{f}_1(Y_{doc,writer} | \pi_{writer})$$

⁵A.S. Osborn, 1929. Questioned documents, 2nd edn. New York, NY: Boyd Printing Co.

⁶L. F. Baum, 1900. The Wonderful Wizard of Oz, illustrated by W.W. Denslow. Chicago and New York: G.M. Hill Co.

Model #1

$$Y_{doc,writer} \sim \mathbf{f}_1(Y_{doc,writer} | \pi_{\text{writer}})$$

Model data come from 90 writers in the CSAF Database.

- ▶ 3 training documents (most), London Letters⁵

⁵A.S. Osborn, 1929. Questioned documents, 2nd edn. New York, NY: Boyd Printing Co.

⁶L. F. Baum, 1900. The Wonderful Wizard of Oz, illustrated by W.W. Denslow. Chicago and New York: G.M. Hill Co.

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$$Y_{doc,writer} \sim \mathbf{f}_1(Y_{doc,writer} | \pi_{writer})$$

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$$Y_{1,writer} \sim \mathbf{f}_1(Y_{1,writer} | \pi_{writer})$$

$$Y_{2,writer} \sim \mathbf{f}_1(Y_{2,writer} | \pi_{writer})$$

$$Y_{3,writer} \sim \mathbf{f}_1(Y_{3,writer} | \pi_{writer})$$

⁵A.S. Osborn, 1929. Questioned documents, 2nd edn. New York, NY: Boyd Printing Co.

⁶L. F. Baum, 1900. The Wonderful Wizard of Oz, illustrated by W.W. Denslow. Chicago and New York: G.M. Hill Co.

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$$Y_{1,writer} \sim \mathbf{f}_1(Y_{1,writer} | \pi_{writer})$$

$$Y_{2,writer} \sim \mathbf{f}_1(Y_{2,writer} | \pi_{writer})$$

$$Y_{3,writer} \sim \mathbf{f}_1(Y_{3,writer} | \pi_{writer})$$

- ▶ 1 testing document, Wizard of Oz⁶ Excerpt

⁵A.S. Osborn, 1929. Questioned documents, 2nd edn. New York, NY: Boyd Printing Co.

⁶L. F. Baum, 1900. The Wonderful Wizard of Oz, illustrated by W.W. Denslow. Chicago and New York: G.M. Hill Co.

Model #1

Fit/train with

$$Y_{doc,writer} \sim \mathbf{f}_1(Y_{doc,writer} | \pi_{writer})$$

Model #1 Results

Data for testing document, $Y_{????}$

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$$Y_{doc,writer} \sim \mathbf{f}_1(Y_{doc,writer} | \pi_{writer})$$

Model #1 Results

Data for testing document, $Y_{????}$

$$\mathbf{f}_1(Y_{????} | \pi_{writer})$$

Model #1

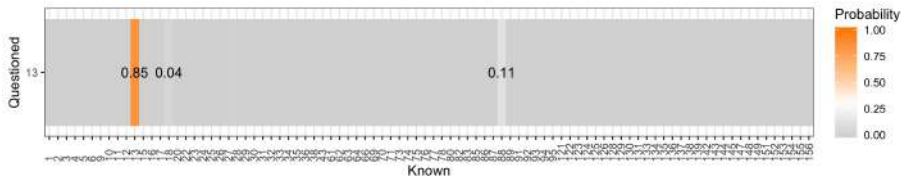
Fit/train with

$$Y_{doc,writer} \sim \mathbf{f}_1(Y_{doc,writer} | \pi_{writer})$$

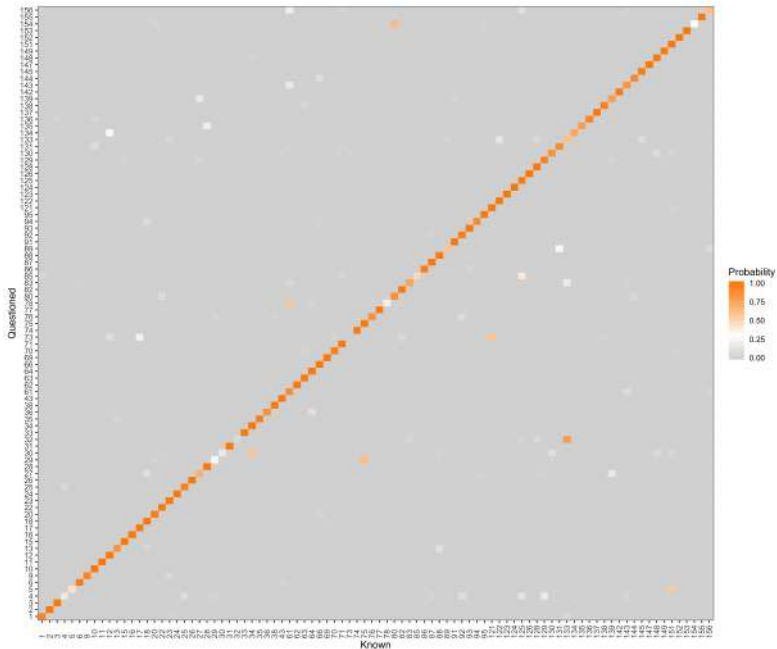
Model #1 Results

Data for testing document, $Y_{????}$

$$\mathbf{f}_1(Y_{????} | \pi_{writer})$$

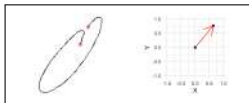


88.05% probability is on-diagonal.

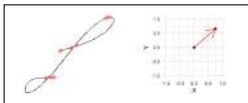


Rotation Angles

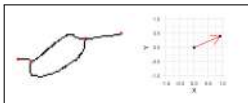
Our London business is good,



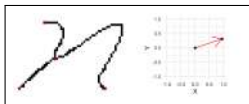
(a)



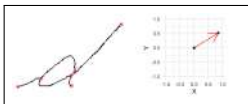
(b)



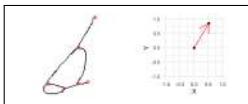
(c)



(d)



(e)



(f)

Rotation Angles by Cluster, Writer 95

Our London business is good,

Rotation Angles by Cluster, Writer 95

Our London business is good,



U



U



U

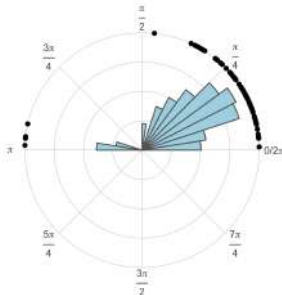
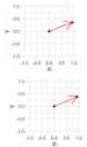


U



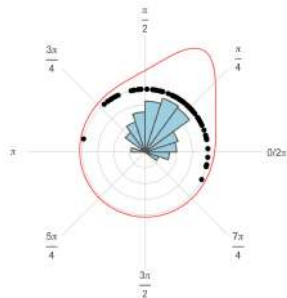
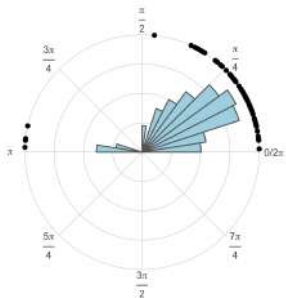
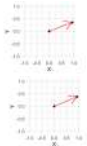
Rotation Angles by Cluster, Writer 95

Our London business is good,



Rotation Angles by Cluster, Writer 95

Our London business is good,



Rotation Angles by Cluster, Writer 1

Our London business is good

Rotation Angles by Cluster, Writer 1

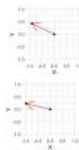
Our London business is good



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Rotation Angles by Cluster, Writer 1

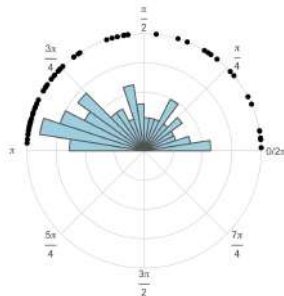
Our London business is good



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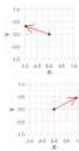


Rotation Angles by Cluster, Writer 1

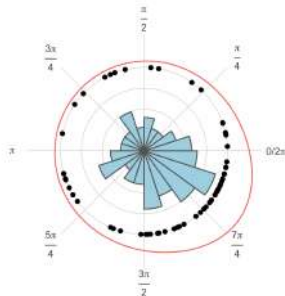
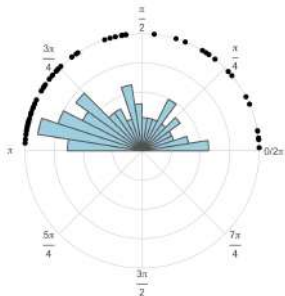
Our London business is good



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e



Model #2

$$Y_{doc,writer}, RA_{cluster,writer} \sim \mathbf{f}_2(Y_{doc,writer}, RA_{cluster,writer} | \pi_{\text{writer}}, \alpha_{\text{cluster,writer}})$$

Model #2

$$Y_{doc,writer}, RA_{cluster,writer} \sim \mathbf{f}_2(Y_{doc,writer}, RA_{cluster,writer} | \pi_{\text{writer}}, \alpha_{\text{cluster,writer}})$$

Model #2 Results

Data for testing document, $Y_{????}$ & $RA_{cluster,????}$ for all 40 clusters.

Model #2

$$Y_{doc,writer}, RA_{cluster,writer} \sim \mathbf{f}_2(Y_{doc,writer}, RA_{cluster,writer} | \pi_{writer}, \alpha_{cluster,writer})$$

Model #2 Results

Data for testing document, $Y_{????}$ & $RA_{cluster,????}$ for all 40 clusters.

$$\mathbf{f}_2(Y_{????}, RA_{cluster,????} | \pi_{writer}, \alpha_{cluster,writer})$$

Model #2

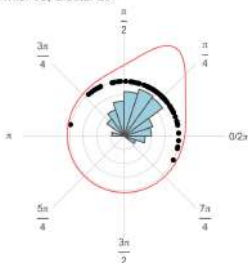
$$Y_{doc,writer}, RA_{cluster,writer} \sim \mathbf{f}_2(Y_{doc,writer}, RA_{cluster,writer} | \pi_{writer}, \alpha_{cluster,writer})$$

Model #2 Results

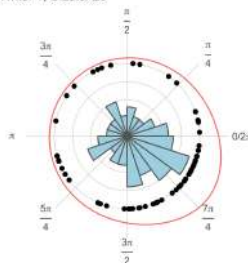
Data for testing document, $Y_{????}$ & $RA_{cluster,????}$ for all 40 clusters.

$$\mathbf{f}_2(Y_{????}, RA_{cluster,????} | \pi_{writer}, \alpha_{cluster,writer})$$

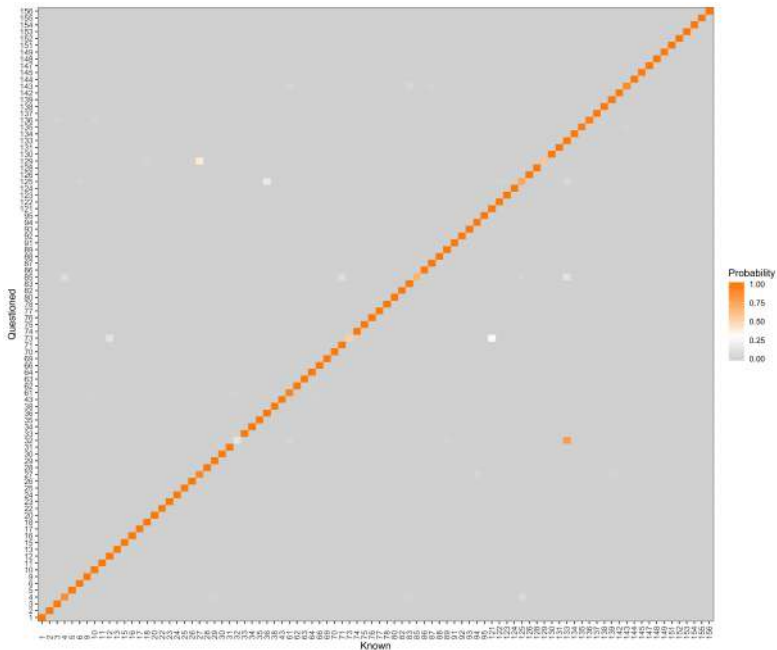
Writer 95, Cluster 29



Writer 1, Cluster 29



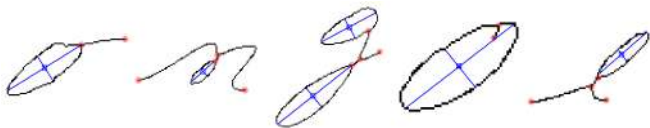
96.99% probability is on-diagonal.



More measurements...

Loops, for example.

Writer 95:



Writer 1:





Thank you!