

Unraveling Scribal Authorship: New Frontiers in Writer Retrieval

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Thank you!

Nominator:
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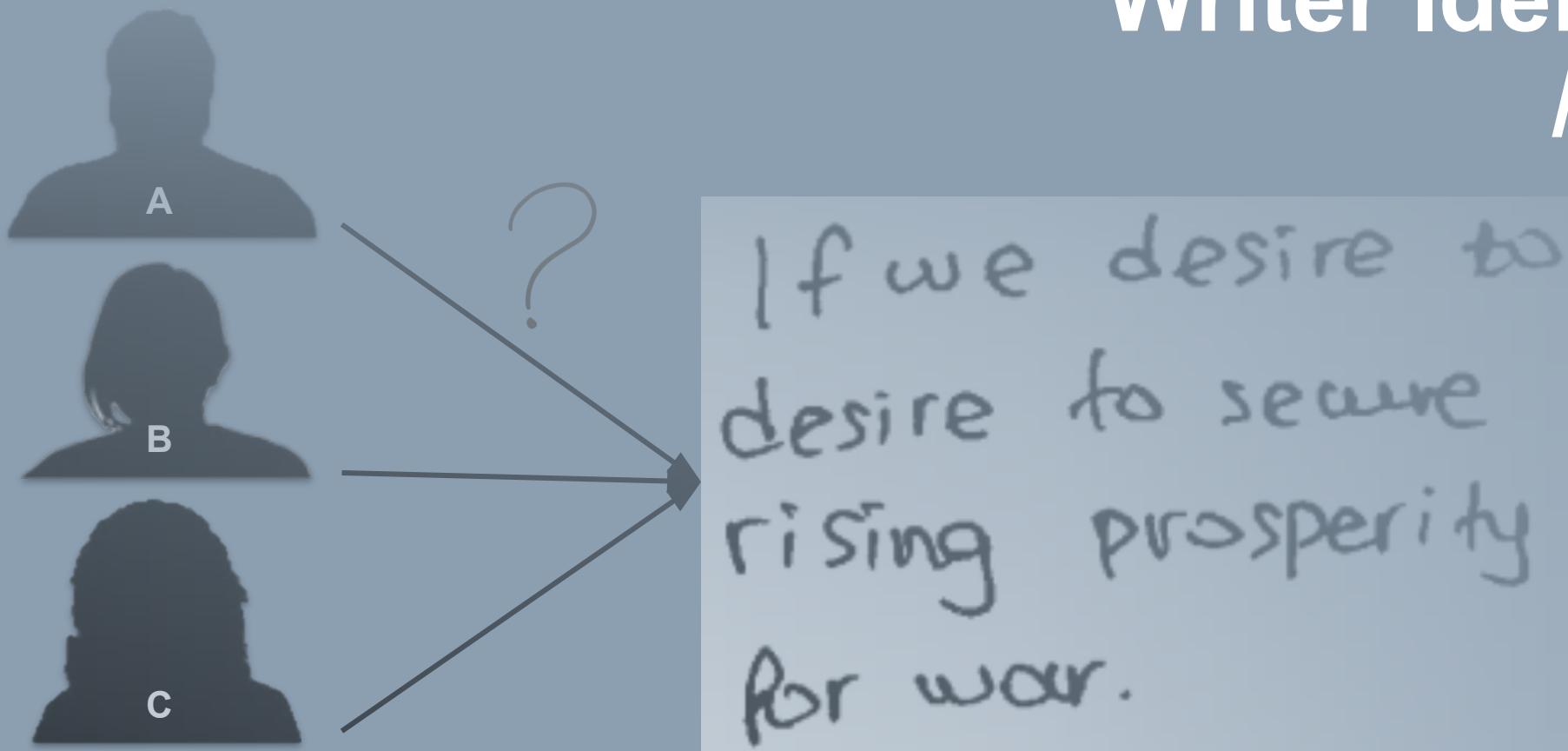
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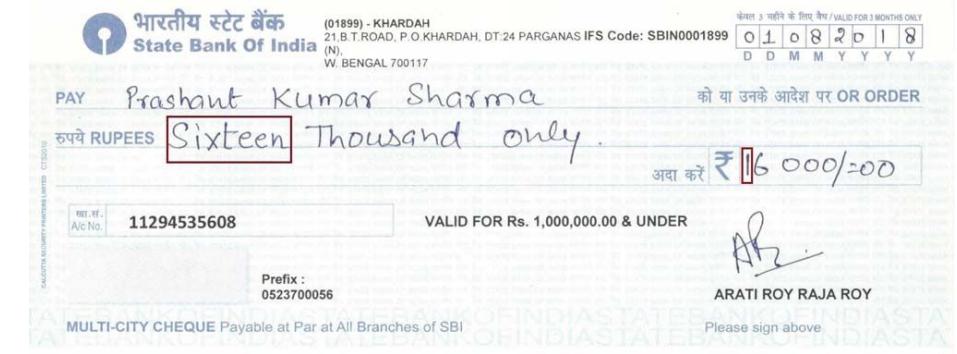
All collaborators and the amazing DAR community!

Writer Identification / Retrieval



Forensics

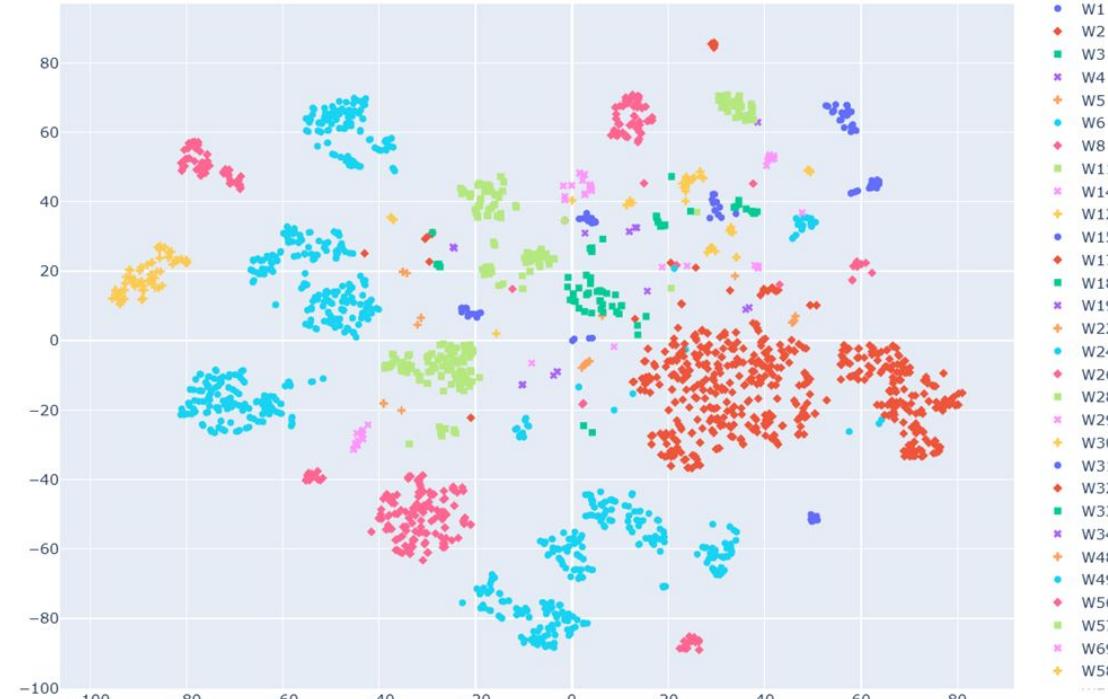
- Assessing authenticity
- Examples:
 - Bank cheques
 - Threat letters
 - Testaments



Source: P Roy, S Bag, "Forensic performance on handwriting to identify forgery owing to word alteration", ISBA 2019

Paleography

- Analysis of historical writing
 - Date writings
 - Assign writings to known (or unknown) scribes



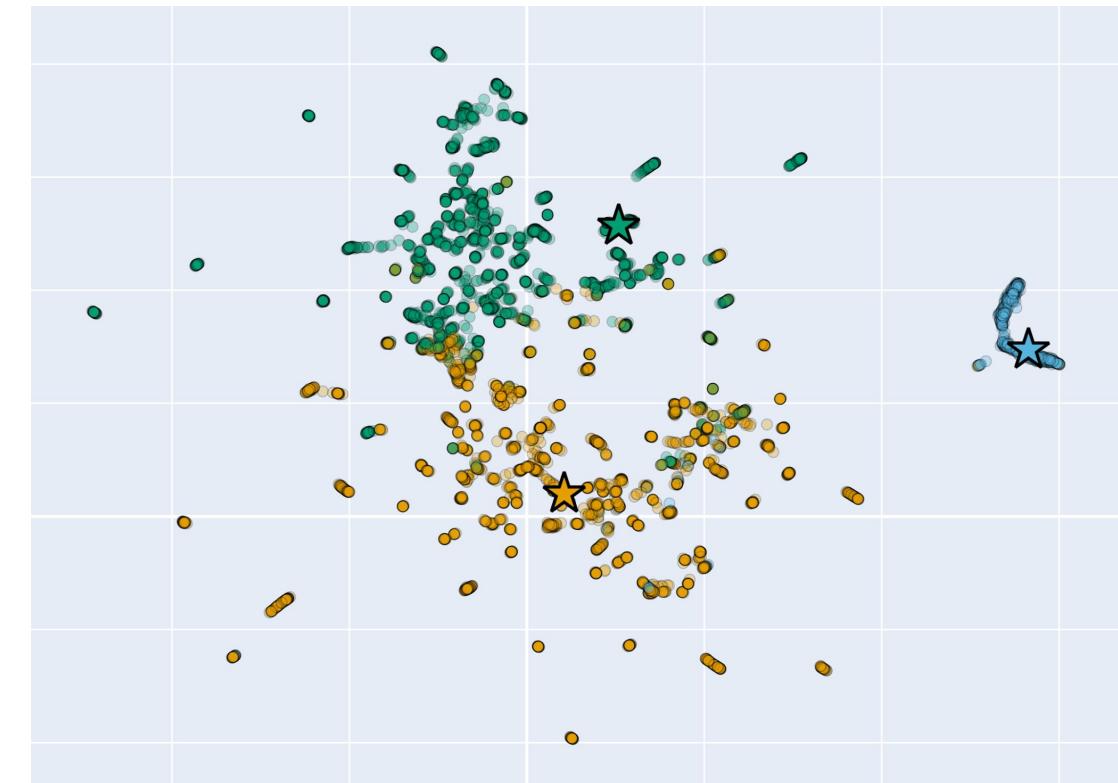
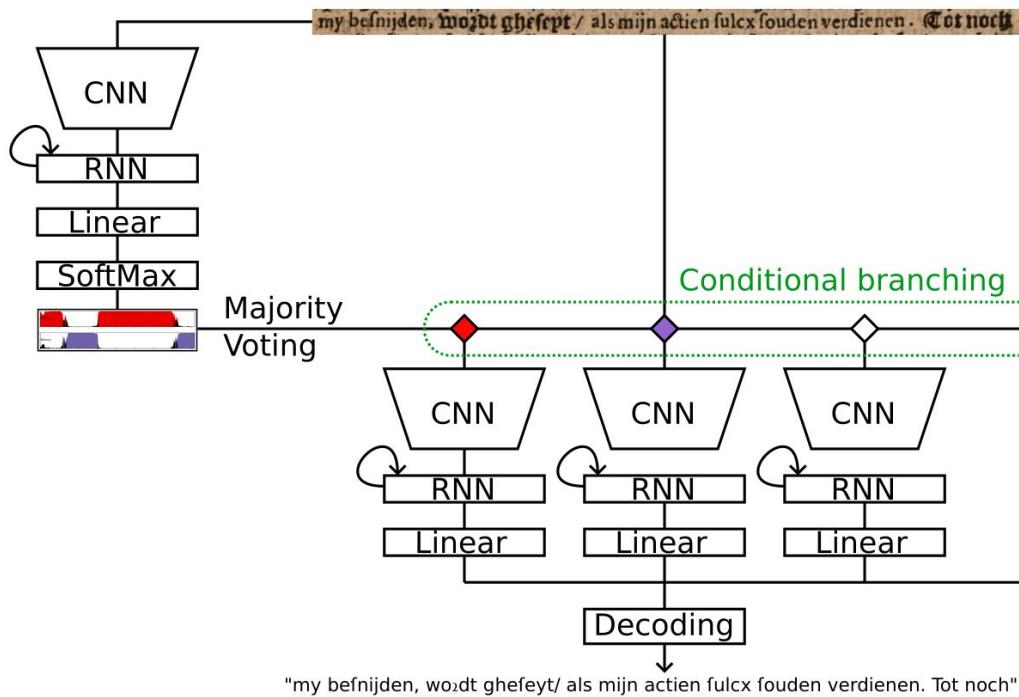
Registers of the French royal chancery (Paris, Arch. Nat., JJ37-JJ50)

Writer id. data: J. Guérout, in R. Fawtier, ed., *Registres du trésor des chartes: inventaire analytique*, 1958
T-SNE based on V. Christlein et al., "Unsupervised Feature Learning for Writer Identification and Writer Retrieval", *ICDAR* 2017

Stutzmann, Dominique. "Les livres de chartes et leur écriture : registres et cartulaires dans l'espace français (1250-1500)." In *Twenty-second Colloquium of the Comité international de paléographie latine: Encounters in written culture: influence, interchange, transfer, reception? / XXIIe colloque du Comité international de paléographie latine. Rencontres et culture écrite : influence, échange, transfert, réception ?* Praha, Czech Republic, 2022. <https://hal.science/hal-03916938>.

Text Recognition

- Writer-individual HTR models



M. Seuret, J. van der Loop, N. Weichselbaumer, M. Mayr, J. Molnar, T. Hass & V. Christlein, "Combining OCR Models for Reading Early Modern Books", ICDAR 2023

Online



Text-dependent

Imagine a vast sheet of paper



Imagine a vast sheet of paper

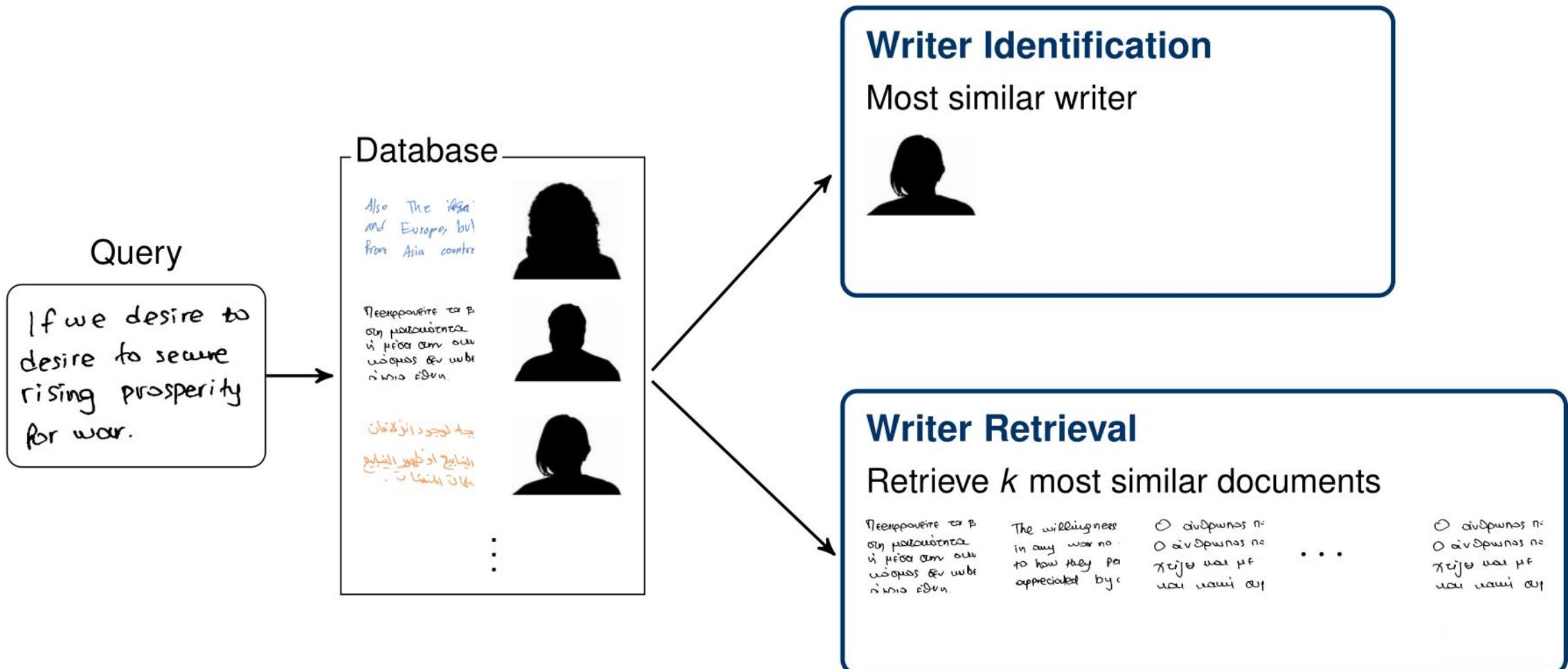
Offline



Text-independent

Also The *iftqa*:
and Europe, but
from Asia countries

جده لوجود انزلاقان
النتائج او تهور النتائج
بيان المنهيات .



Source: ICDAR13 dataset, QUWI15 dataset, freepik.com

Writer Identification

Most similar writer



- Each writer appears in Train + Test splits
 - End-to-end training possible
 - Focus: **Classification**
- Metric: Accuracy/AUC/etc

Writer Retrieval

Retrieve k most similar documents

The willingness
to help others
in their own self
interests for little
or no return.

The willingness
in any way no
to how they're
appreciated by

○ documents n:
○ documents n:
Xref: user pf
user name out

...

○ documents n:
○ documents n:
Xref: user pf
user name out

- Typically writer-independent test set
- Leave-one-document-out cross-validation of the test set
 - Focus: **Image retrieval, zero/one-shot learning**
- Metric: Top-1/mAP

Many papers compare results of different evaluation protocols or different test sets 😊

Writer A

You You You
You You You
You You You

Writer B

Yer Yer Yer
Yer Yer Yer
Yer Yer Yer

Writer C

You You You
You You You
You You You

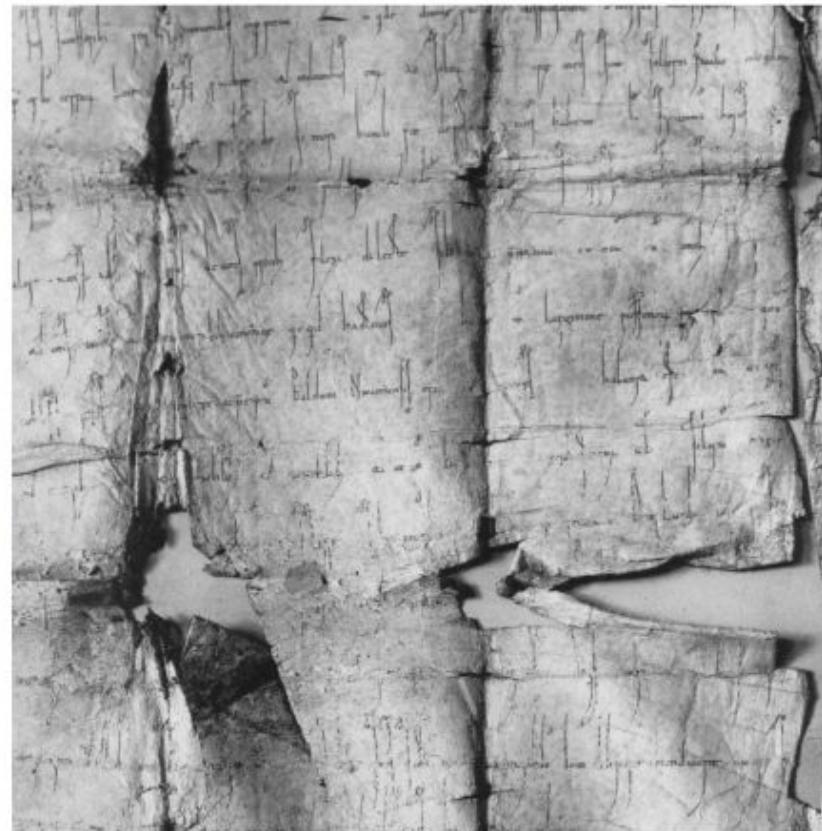


- Within-writer variability
- Between-writer variability

Challenges

External Factors

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eandollatitudine decūt om̄iuſ ecclāqū n̄
debeamus audiuſ excedere. ubi p̄r̄ religioni
petruſi tuę quā r̄ſpectu ſupne remun-
audienciuſ m̄e approbārum illataꝝ auctor
tuę augēatiaꝝ audiū benigñſſime exhor-
qū teneſ ſibiq; uſte priueniaꝝ ornaꝝ
victoriatē cfirmamus. oꝝ phuiſ m̄i pri-

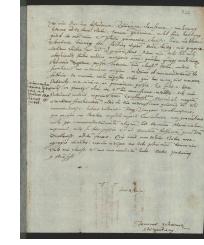


- Pen
- Document Material
- Artifacts

Source: Göttingen Academy of Sciences and Humanities, JL 4490, 4671

The willingness with which
in any war no matter how
to how they perceive veterans
appreciated by our nation.

Neeroppenaire te Bibbia eet's nou
on paradoxe wat ons gesag
ui pleid om ouwneia. Aanai o
wissens oer unbewieter naps



Contemporary

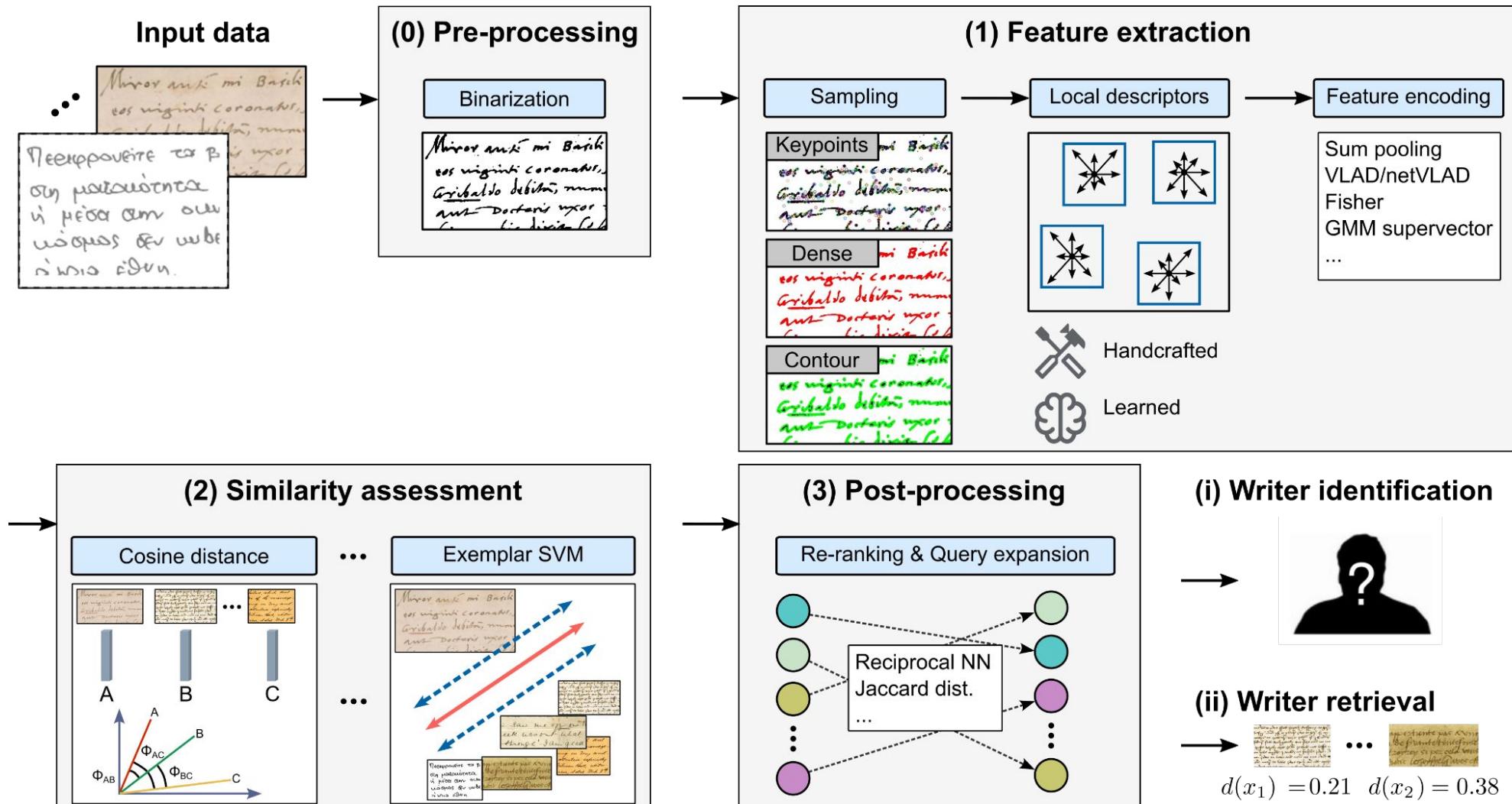
- ICDAR'13
 - Test-set: 4 samples of 250 writers
 - Multi-lingual
- CVL'13
 - Test-set: 5 samples of 283 writers
- Others: IAM, CERUG, Firemaker, QUWI, KHATT, ..
- Typically too small & too clean
- Saturated performances > 97% Top-1

Historical

- ICDAR'17
 - Test-set: 5 samples of 720 writers
 - historical letters
 - binarized version available
- ICDAR'19
 - Test-set: 20k images from ~10k writers
 - very heterogeneous (manuscripts, letters, charters)
- Challenging but some mistakes due to wrong annotations
- Several other datasets (typically lower number of writers)

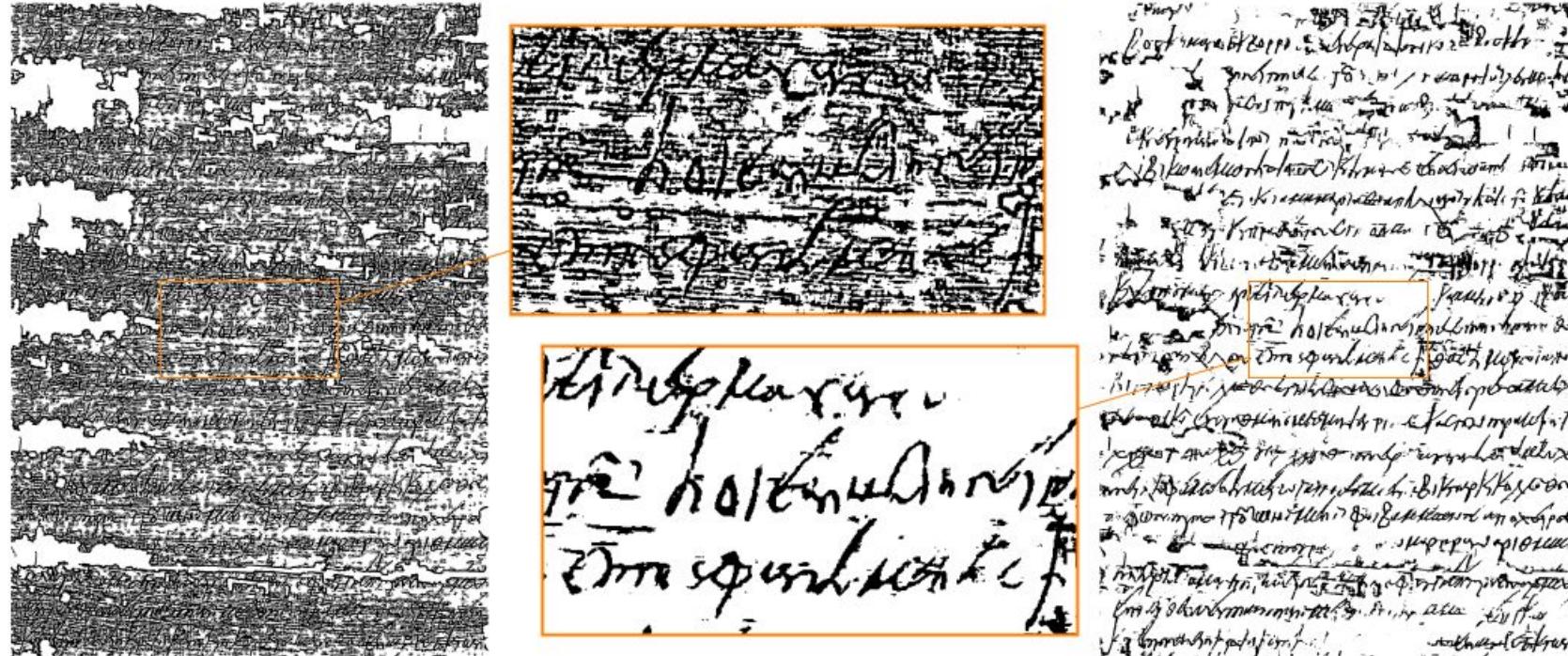
→ Larger (dirty) datasets would be great

Writer Identification/Retrieval



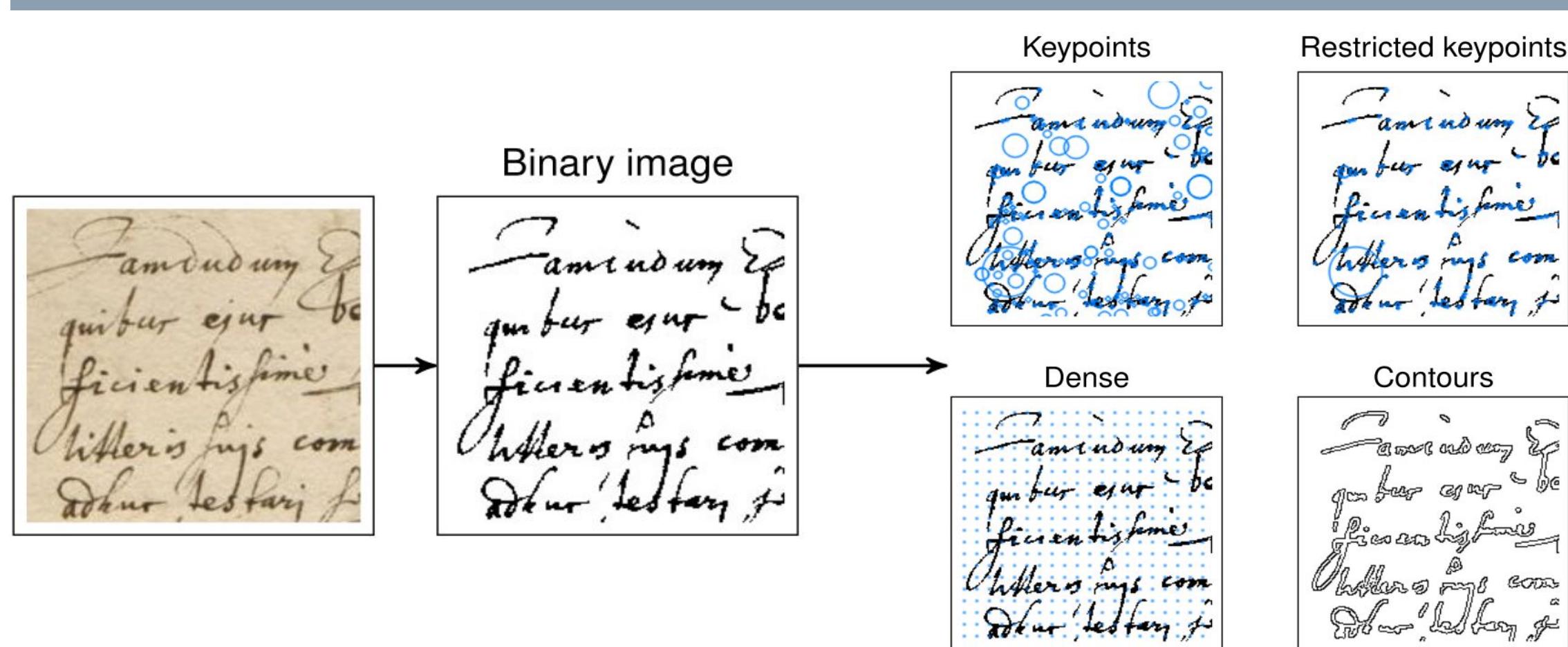
Binarization is not dead

... at least for Writer Retrieval/Identification



Source: GRK-Papyri, ID: Abraamios_4

- Needed or not?
- Depends on material and scenario → Especially important for papyri data
- → So far: No systematic study available

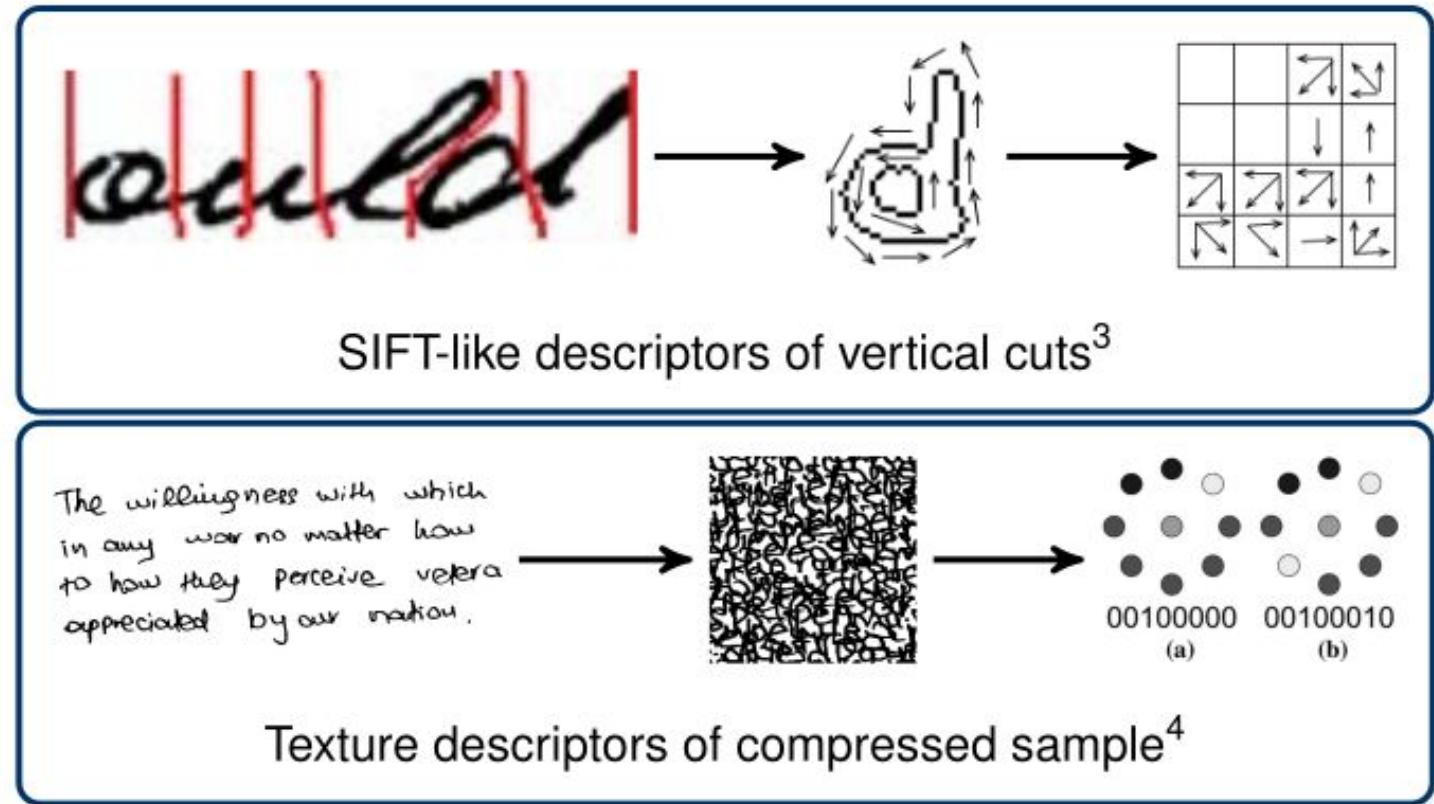
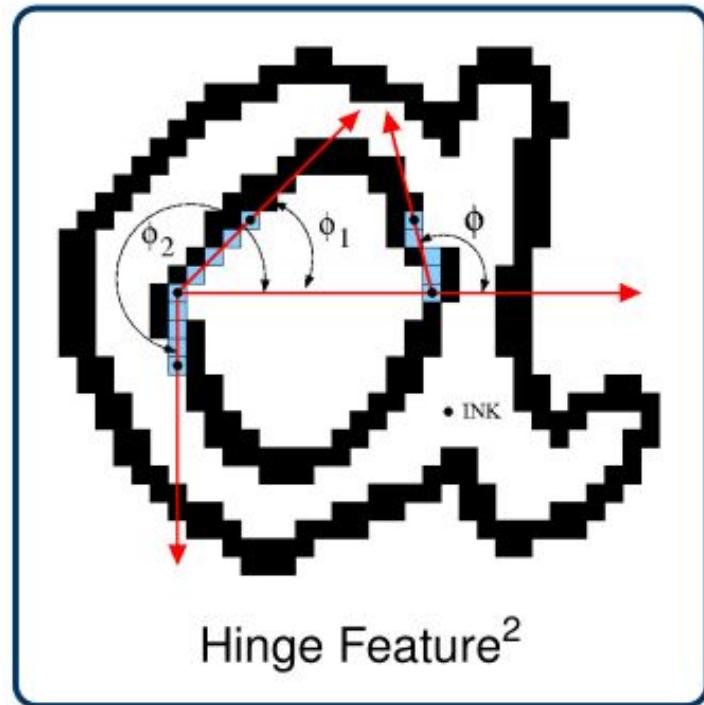


Most common:

- Patches at keypoints (if you have enough text)
- Alternatively: dense with filtering

Feature Extraction

Handcrafted



²A. Brink, J. Smit, M. Bulacu, and L. Schomaker, "Writer Identification Using Directional Ink-Trace Width Measurements", Pattern Recognition 2012

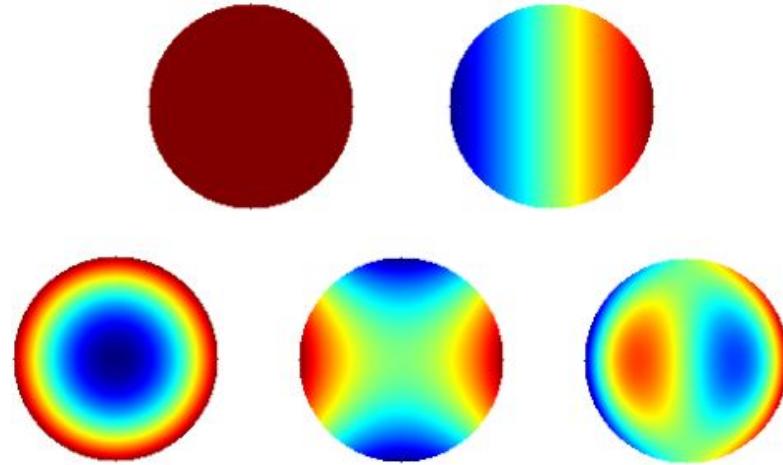
³R. Jain and D. Doermann, "Writer Identification Using an Alphabet of Contour Gradient Descriptors", ICDAR 2013

⁴D. Bertolini, L. Oliveira, E. Justino, and R. Sabourin, "Texture-based Descriptors for Writer Identification and Verification", Expert Systems with Applications 2013

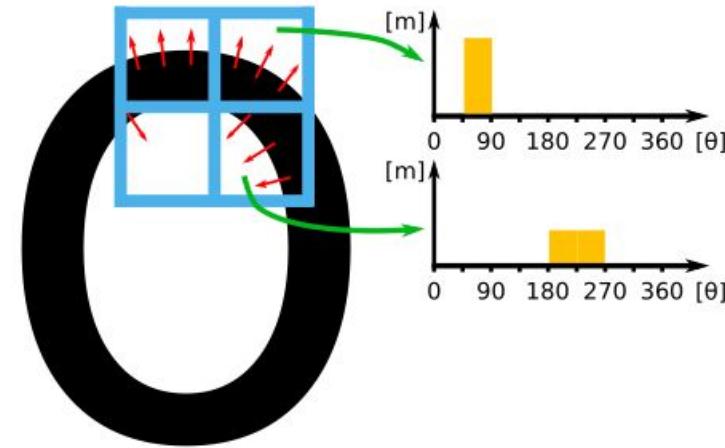
A. Nicolaou, A.D. Bagdanov, M. Liwicki, D. Karatzas, "Sparse radial sampling LBP for writer identification", ICDAR 2015

Feature Extraction

Handcrafted



Zernike Moments



SIFT

Important Tweaks:

- Remove angle (= Upright)
- Power-normalization (RootSIFT)
- Decorrelation (PCA whitening)

V. Christlein, D. Bernecker and E. Angelopoulou, "Writer identification using VLAD encoded contour-Zernike moments," *ICDAR*, 2015

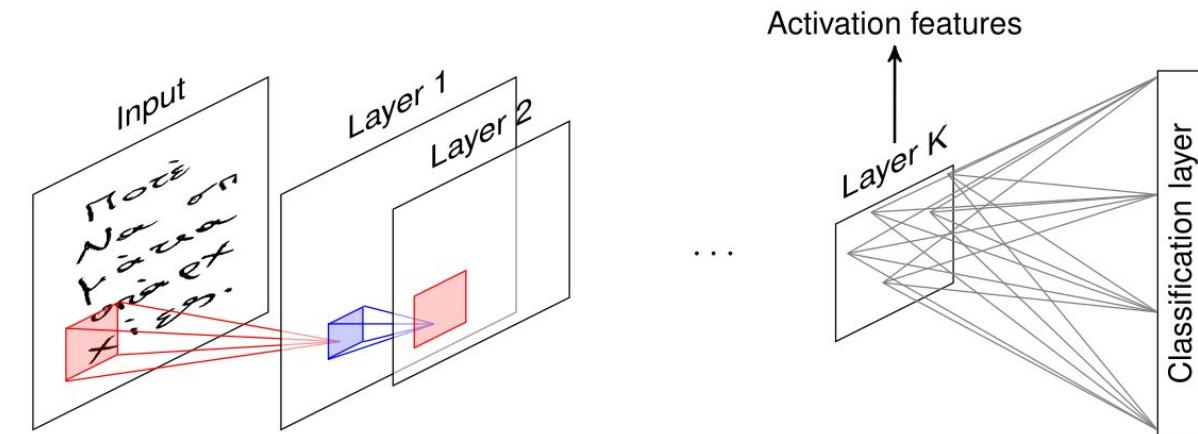
V. Christlein, D. Bernecker, F. Höning and E. Angelopoulou, "Writer identification and verification using GMM supervectors," *WACV* 2014

V. Christlein, D. Bernecker, F. Höning, A. Maier, and E. Angelopoulou, "Writer identification using GMM supervectors and exemplar-SVMs," *Pattern Recognition* 2017

CNN Activation Features

- Recall: no end-to-end training possible
⇒ Surrogate task: classify writers of the training set
- Use CNN^{1,2} or CNN + Transformer³ as feature extractor
 - Cross-entropy loss
 - Triplet-loss

→ Drawback: training set with known identities necessary



¹V. Christlein, D. Bernecker, A. Maier, A., E. Angelopoulou, "Offline Writer Identification Using Convolutional Neural Network Activation Features", GCPR 2015

²S. Fiel, and R. Sablatnig, "Writer identification and retrieval using a convolutional neural network", CAIP 2015

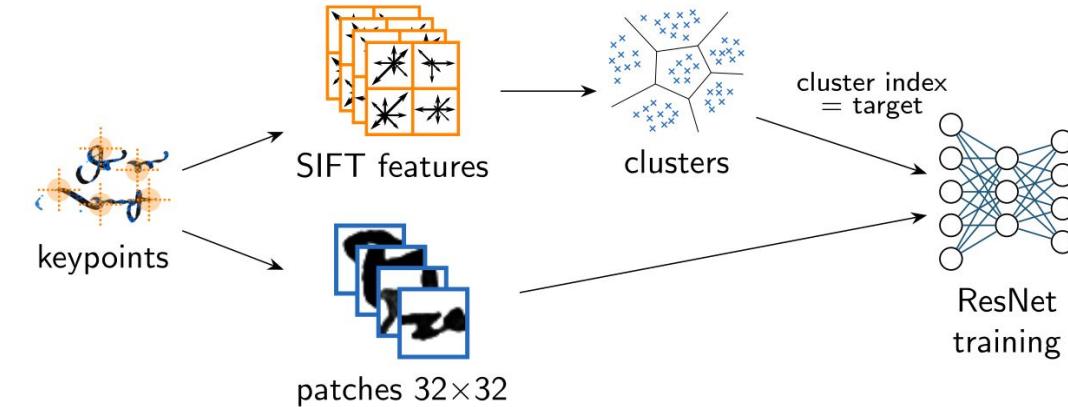
³M. Peer, F. Kleber, and R. Sablatnig, "Self-supervised Vision Transformers with Data Augmentation Strategies Using Morphological Operations for Writer Retrieval", ICFHR 2022

Feature Extraction

Learning-based

Self-supervised Features

- Clustering-based:¹
 - New surrogate classes: cluster indices of SIFT descriptors
→ Map similar patches to each other



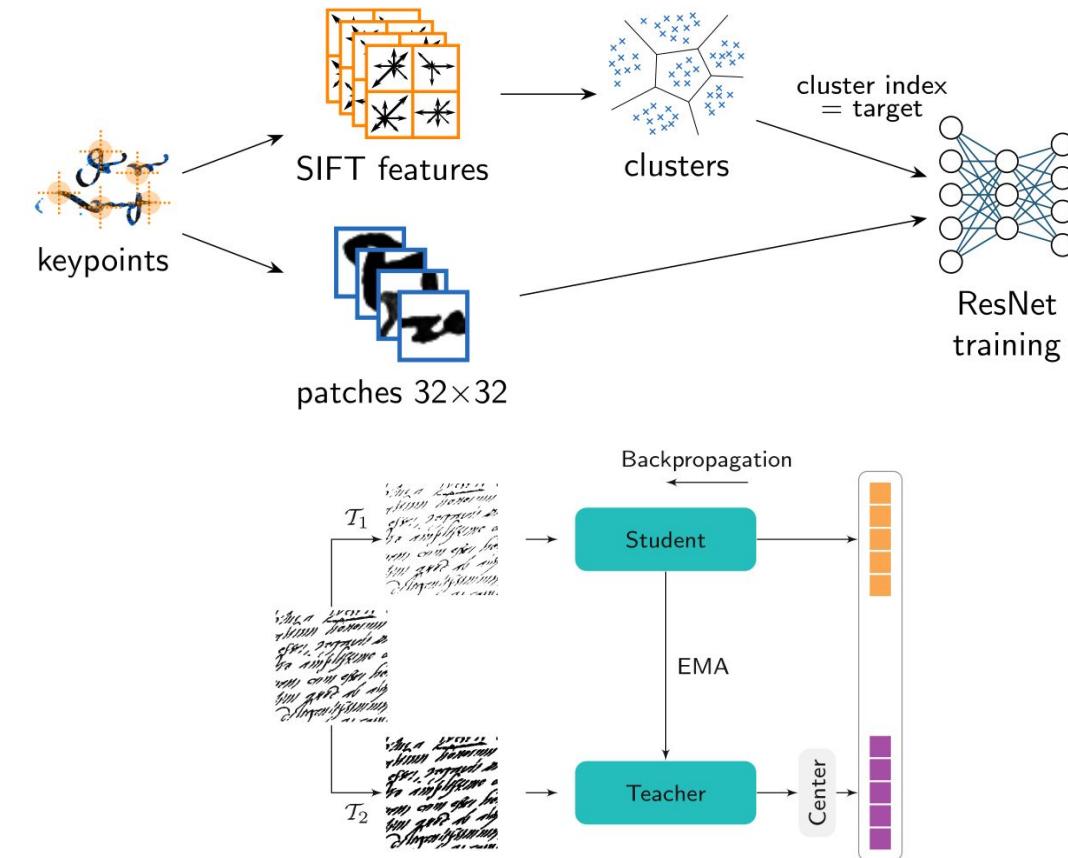
¹V. Christlein, M. Groppe, S. Fiel and A. Maier, "Unsupervised Feature Learning for Writer Identification and Writer Retrieval," ICDAR 2017

Feature Extraction

Learning-based

Self-supervised Features

- Clustering-based:¹
 - New surrogate classes: cluster indices of SIFT descriptors
→ Map similar patches to each other
- Contrastive-learning-based:
 - Siamese-Network²
 - DINO³
 - AttMask⁴ (Extension of DINO w. masking patches)
 - VICReg⁵
- Masked AutoEncoder⁶



¹V. Christlein, M. Gropp, S. Fiel and A. Maier, "Unsupervised Feature Learning for Writer Identification and Writer Retrieval," ICDAR 2017

²A. Pirrone, M. Beurton-Aimar, and N. Journet "Self-supervised deep metric learning for ancient papyrus fragments retrieval. IJDAR 2021

³M. Peer, F. Kleber, and R. Sablatnig, "Self-supervised Vision Transformers with Data Augmentation Strategies Using Morphological Operations for Writer Retrieval," ICFHR 2022

⁴T. Raven, F. Gernot "Self-Supervised Vision Transformers for Writer Retrieval", ICDAR 2024

⁵A Mattick, M Mayr, M Seuret, F Kordon, F Wu, V. Christlein, "Evaluating learned feature aggregators for writer retrieval", IJDAR 2024

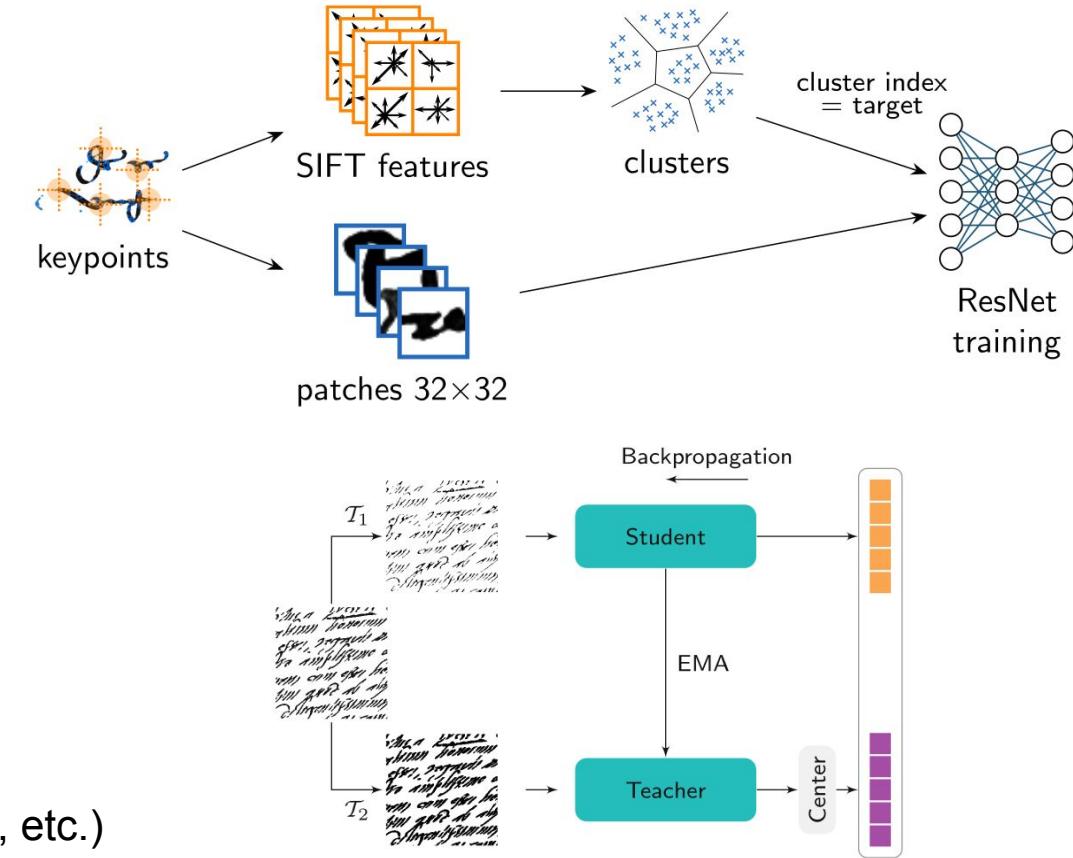
⁶Peer, M. Kleber, F., Sablatnig R. "SAGHOG: Self-Supervised Autoencoder for Generating HOG Features for Writer Retrieval", ICDAR 2024

Feature Extraction

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- Contrastive-learning-based:
 - Siamese-Network²
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 - VICReg⁵
- Masked AutoEncoder⁶
- → So far: no systematic study of SSL-based methods & learned keypoint-based features (SuperPoint, ALIKE, etc.)



¹V. Christlein, M. Gropp, S. Fiel and A. Maier, "Unsupervised Feature Learning for Writer Identification and Writer Retrieval," ICDAR 2017

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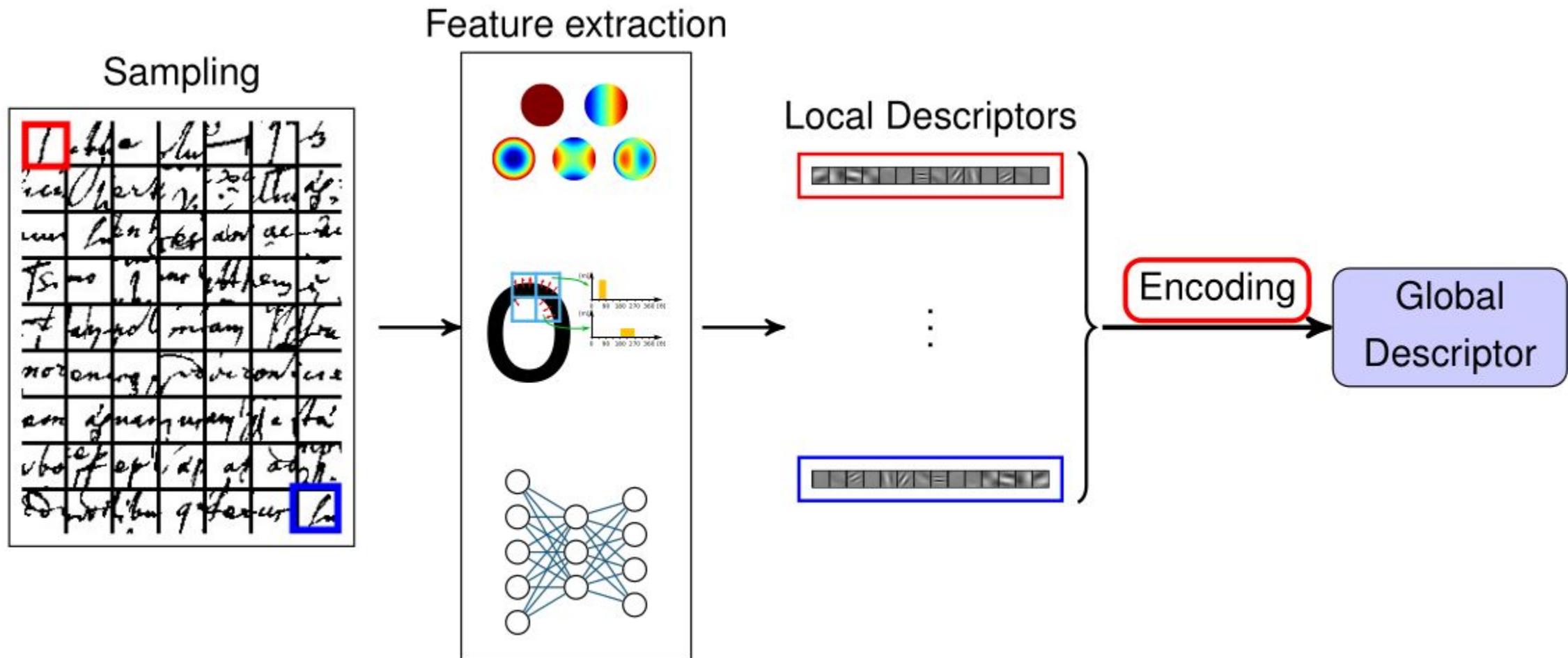
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Writer Identification/Retrieval

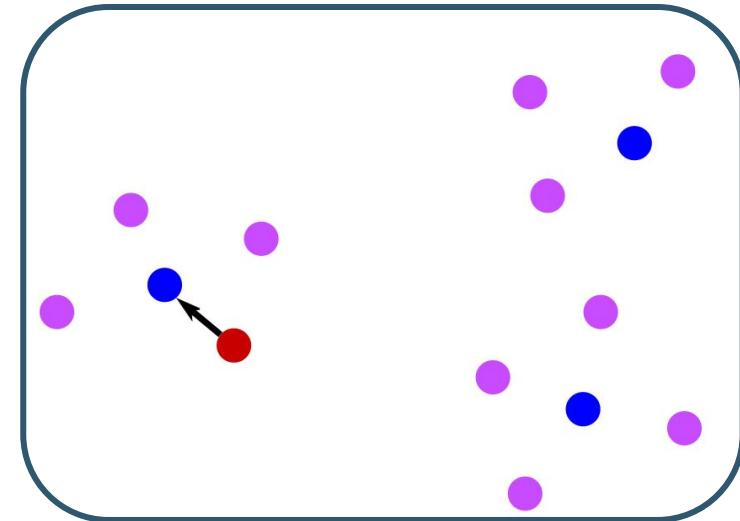
Pipeline



Traditional:

- Sum-pooling
- Bag-of-words (0th order stats), Fisher Vectors (1st + 2nd order stats)¹
- VLAD encoding (1st order stats)²

$$v_k = \sum_{i=1}^N \alpha_k(\mathbf{x} - i)(\mathbf{x}_i - \mathbf{c}_k)$$
$$\alpha_k(\mathbf{x}) = \begin{cases} 1 & \text{if } k = \operatorname{argmin}_{j=1, \dots, K} \|\mathbf{x} - \mathbf{c}_j\|_2 \\ 0 & \text{else} \end{cases}$$



¹S. Fiel and R. Sablatnig, "Writer Identification and Writer Retrieval Using the Fisher Vector on Visual Vocabularies", ICDAR 2013

²V. Christlein, D. Bernecker and E. Angelopoulou, "Writer identification using VLAD encoded contour-Zernike moments", ICDAR 2015

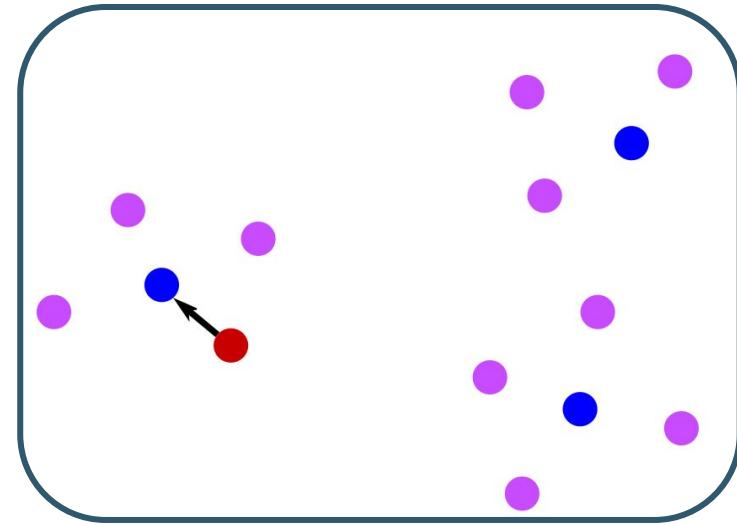
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- M-VLAD: use-multiple vocabularies, fuse outputs (PCA whitening)
- bagged VLAD³
- Others:⁴ GMM Supervectors, T-Emb, GVR, ...
→ Takeaway: most of the time VLAD just works nicely



¹S. Fiel and R. Sablatnig, "Writer Identification and Writer Retrieval Using the Fisher Vector on Visual Vocabularies", ICDAR 2013

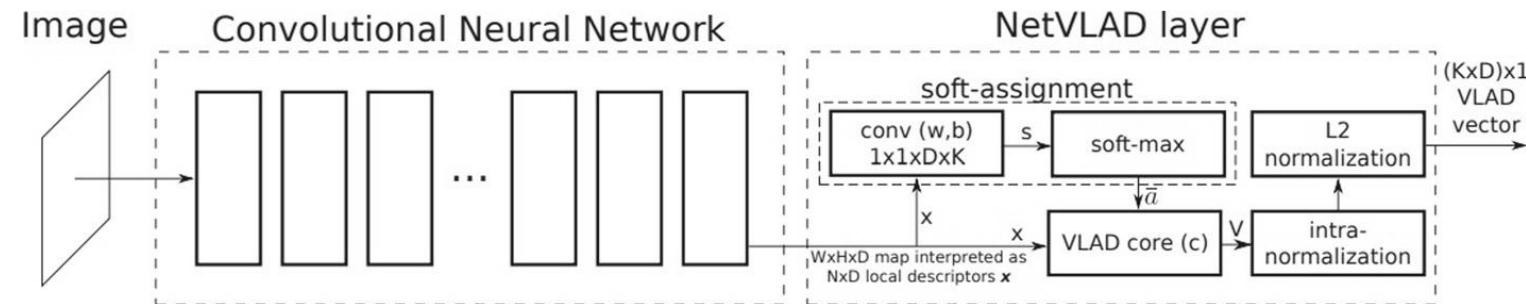
²V. Christlein, D. Bernecker and E. Angelopoulou, "Writer identification using VLAD encoded contour-Zernike moments", ICDAR 2015

³S. Lai, Y. Zhu and L. Jin, "Encoding Pathlet and SIFT Features With Bagged VLAD for Historical Writer Identification", TIFS 2020

⁴V. Christlein and A. Maier, "Encoding CNN Activations for Writer Recognition", DAS 2018

V. Christlein "Handwriting Analysis with Focus on Writer Identification and Writer Retrieval", Doctoral Thesis 2019

Deep-learning: • NetVLAD¹

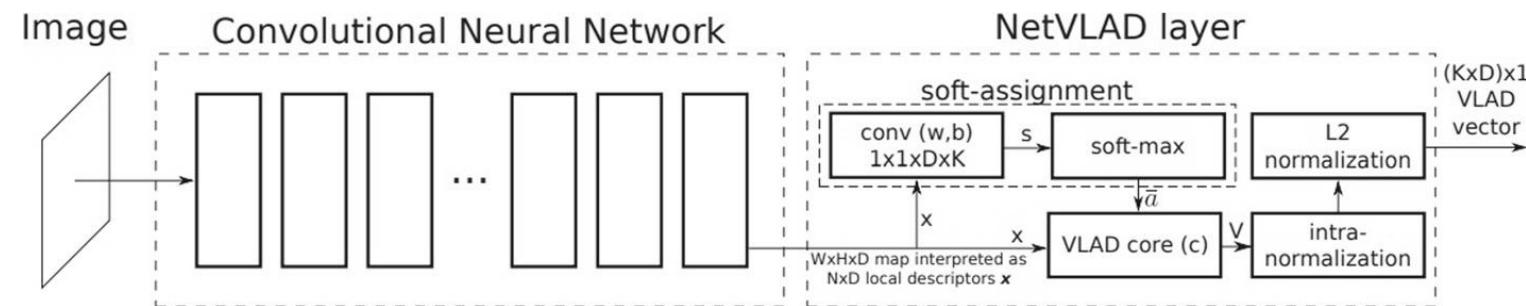


Source: Arandjelovic et al. "NetVLAD: CNN architecture for weakly supervised place recognition", CVPR'16

¹S. Rasoulzadeh & B. BabaAli, "Writer identification and writer retrieval based on NetVLAD with Re-ranking", *IET Biometrics* 2021

Deep-learning:

- NetVLAD¹
 - A-VLAD²
 - Added attention weight
 - NetMVLAD³
 - Multiple vocabularies
 - NetRVLAD⁴
 - Different normalization
 - DeepTEN⁵



Source: Arandjelovic et al. "NetVLAD: CNN architecture for weakly supervised place recognition", CVPR'16

¹S. Rasoulzadeh & B. BabaAli, "Writer identification and writer retrieval based on NetVLAD with Re-ranking", *IET Biometrics* 2021

²T.T. Ngo, H.T., Nguyen, M. Nakagawa, "A-VLAD: An End-to-End Attention-Based Neural Network for Writer Identification in Historical Document", *ICDAR* 2021

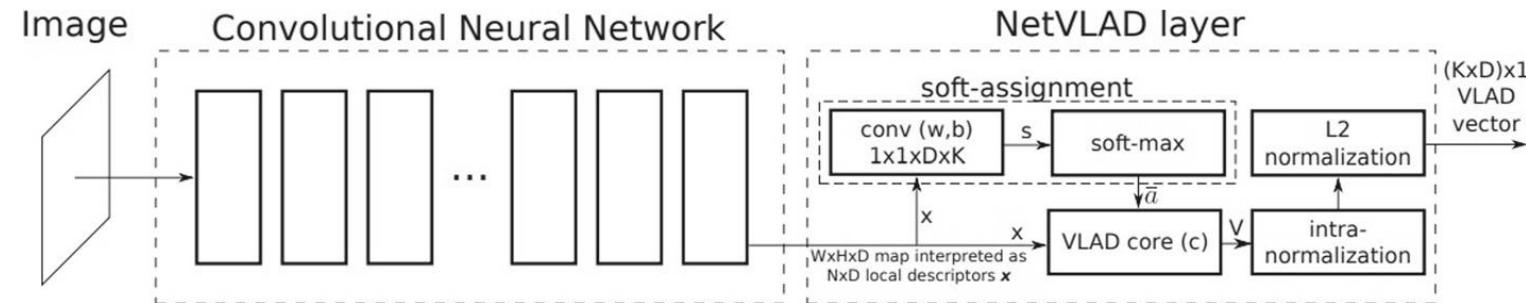
³M. Peer, F. Kleber and R. Sablatnig, "Writer Retrieval using Compact Convolutional Transformers and NetMVLAD", *ICPR* 2022

⁴M. Peer, F. Kleber, and R. Sablatnig, "Towards Writer Retrieval for Historical Datasets", *ICDAR* 2023

⁵Z. Wang, A. Maier, V. Christlein, "Towards End-to-End Deep Learning-based Writer Identification", *INFORMATIK* 2020

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- NetVLAD¹
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 - Multiple vocabularies
 - NetRVLAD⁴
 - Different normalization
 - DeepTEN⁵
- (Deep) Generalized Max-pooling⁶



Source: Arandjelovic et al. "NetVLAD: CNN architecture for weakly supervised place recognition", CVPR'16

¹S. Rasoulzadeh & B. BabaAli, "Writer identification and writer retrieval based on NetVLAD with Re-ranking", *IET Biometrics* 2021

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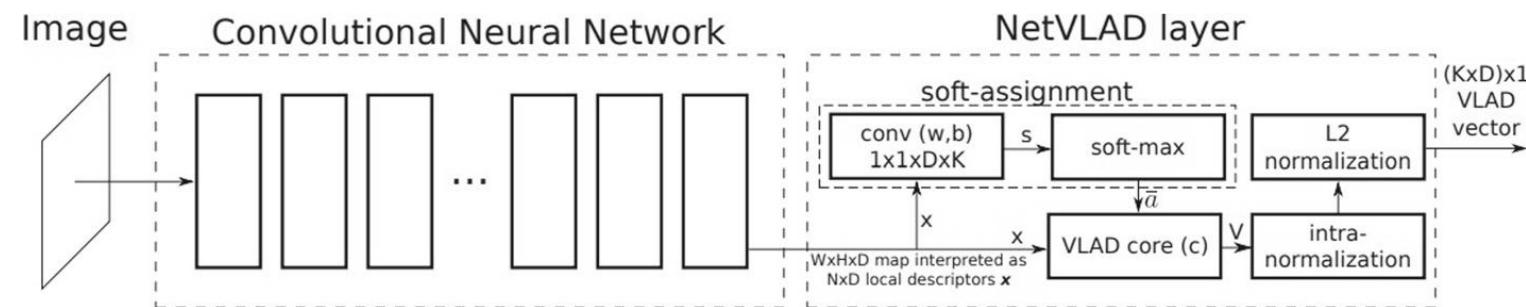
⁴M. Peer, F. Kleber, and R. Sablatnig, "Towards Writer Retrieval for Historical Datasets", *ICDAR* 2023

⁵Z. Wang, A. Maier, V. Christlein, "Towards End-to-End Deep Learning-based Writer Identification", *INFORMATIK* 2020

⁶V. Christlein, L. Spranger, M. Seuret, A. Nicolaou, P. Král and A. Maier, "Deep Generalized Max Pooling", *ICDAR* 2019

Deep-learning:

- NetVLAD¹
 - A-VLAD²
 - Added attention weight
 - NetMVLAD³
 - Multiple vocabularies
 - NetRVLAD⁴
 - Different normalization
 - DeepTEN⁵
- (Deep) Generalized Max-pooling⁶
- Transformers⁷
 - not as feature encoder but feature aggregation
→ performance potentially better than (Net)VLAD but needs a lot of compute



Source: Arandjelovic et al. "NetVLAD: CNN architecture for weakly supervised place recognition", CVPR'16

¹S. Rasoulzadeh & B. BabaAli, "Writer identification and writer retrieval based on NetVLAD with Re-ranking", *IET Biometrics* 2021

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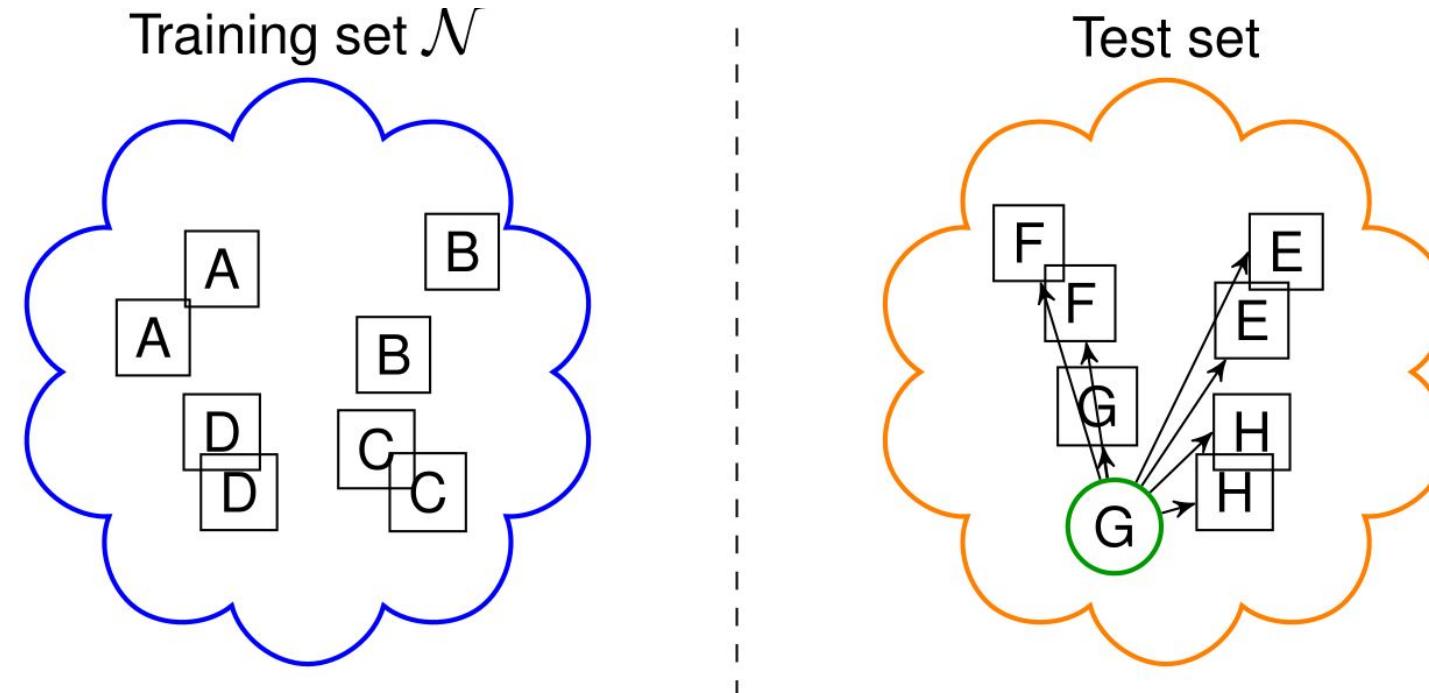
³M. Peer, F. Kleber and R. Sablatnig, "Writer Retrieval using Compact Convolutional Transformers and NetMVLAD", *ICPR* 2022

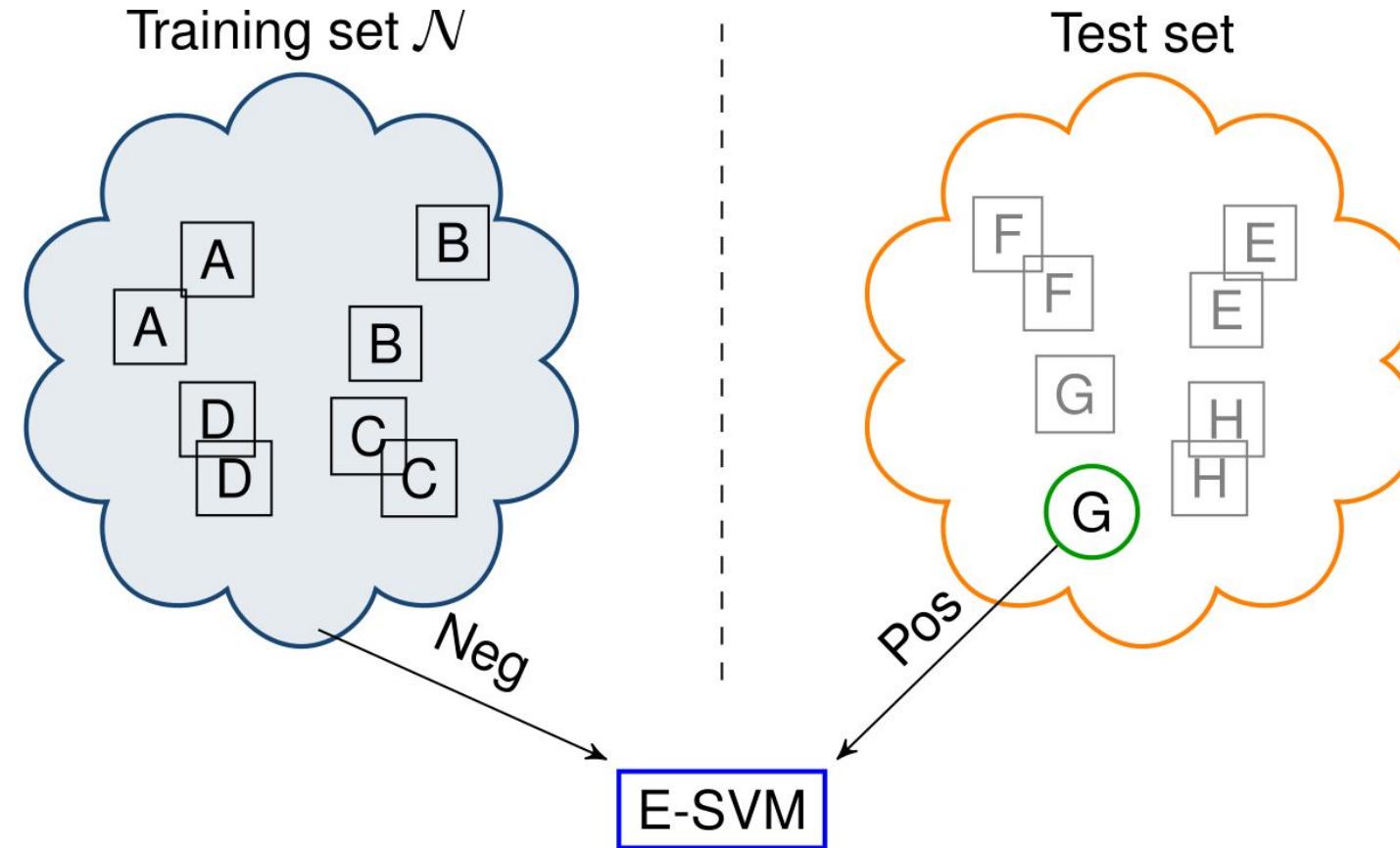
⁴M. Peer, F. Kleber, and R. Sablatnig, "Towards Writer Retrieval for Historical Datasets", *ICDAR* 2023

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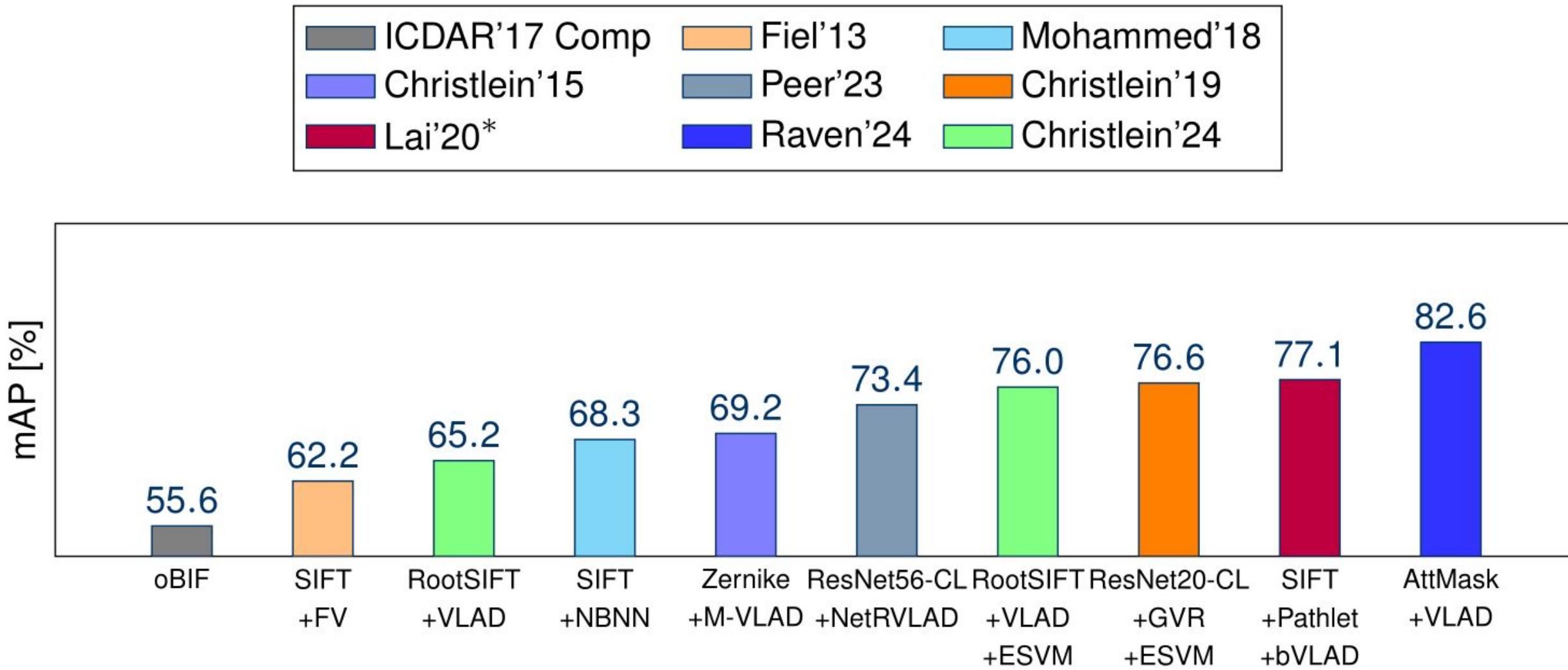
⁷A Mattick, M Mayr, M Seuret, F Kordon, F Wu, V. Christlein, "Evaluating learned feature aggregators for writer retrieval", *IJDAR* 2024



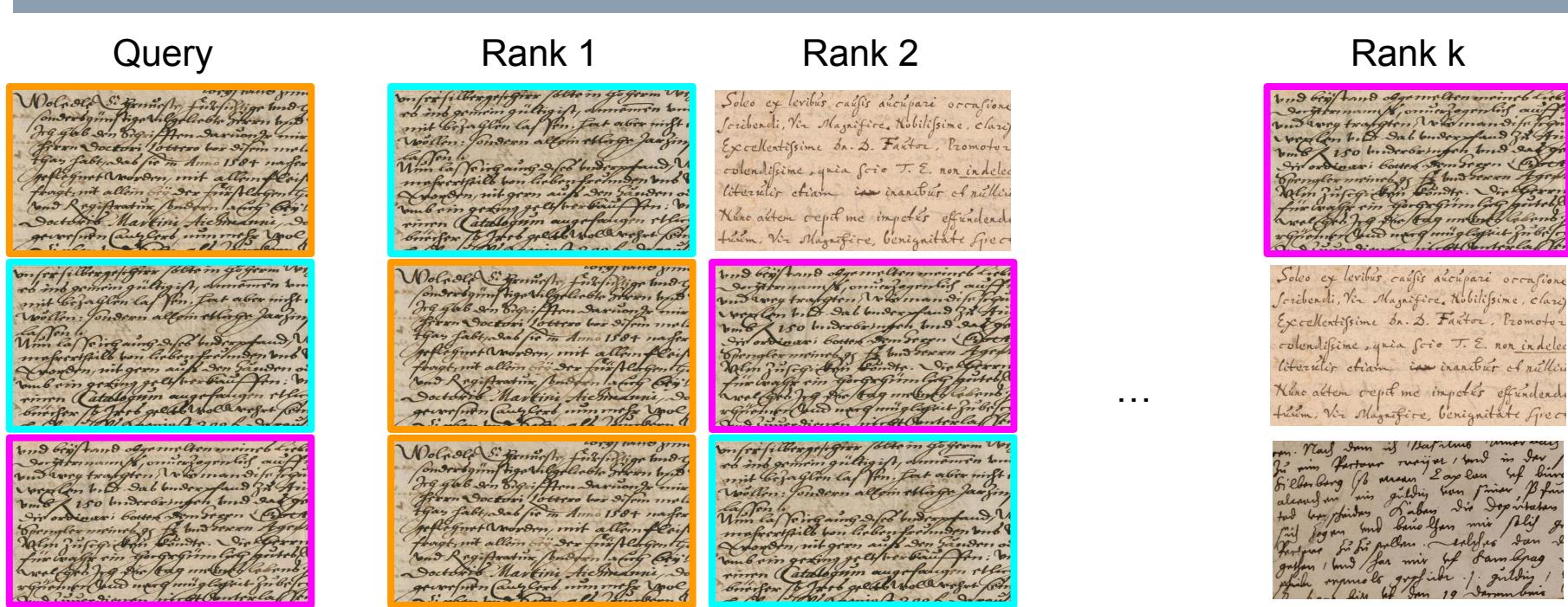


Some Results

Writer Identification/Retrieval



*Used differently binarized dataset

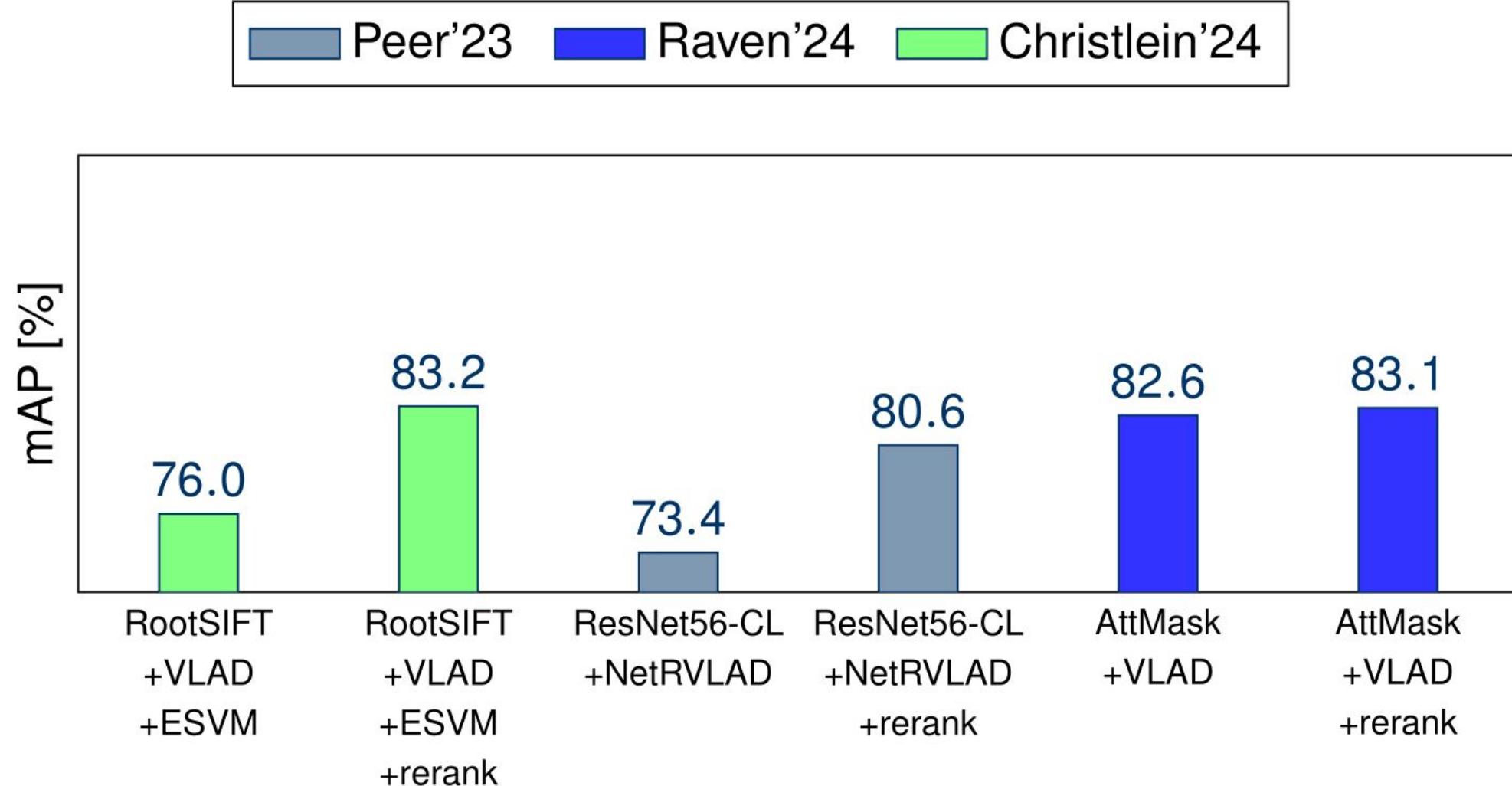


Different methods exist, e.g.,

- k-reciprocal re-ranking¹
- Similarity Graph re-ranking²

¹S. Jordan, M. Seuret, P. Král, L. Lenc, J. Martínek, B. Wiermann, T. Schwinger, A. Maier & V. Christlein, "Re-Ranking for Writer Identification and Writer Retrieval", DAS 2020

²M. Peer, F. Kleber, and R. Sablatnig, "Towards Writer Retrieval for Historical Datasets", ICDAR 2023



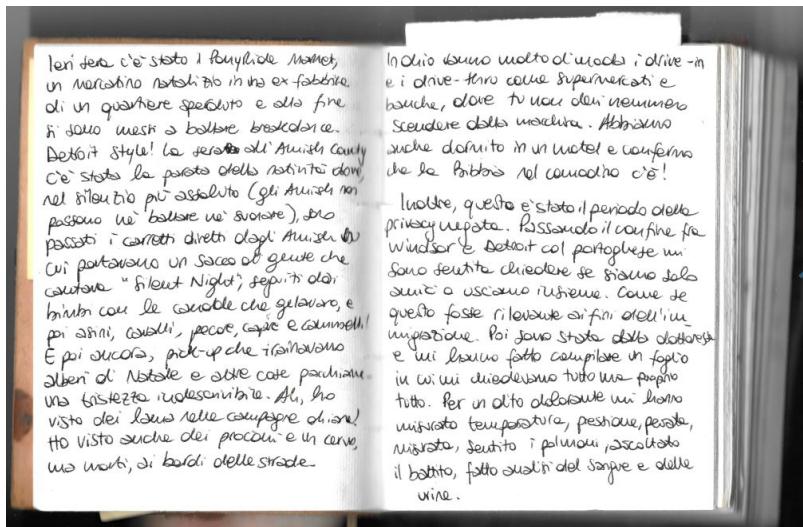
Handwriting Imitation

was not written
it was not written by
it was not written by me

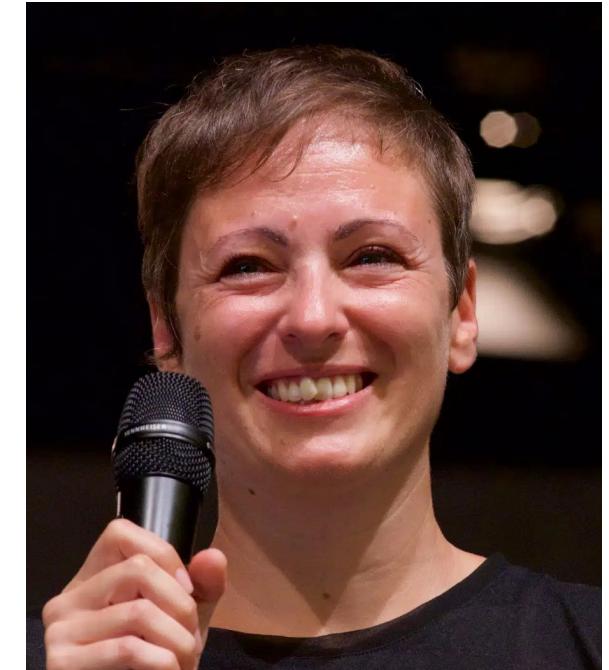
- Help people when writing is physically impaired

“Buona lettura dalla scrittrice non scrivente, Paola”

(‘Enjoy reading from the non-writing writer, Paola’)



Buona lettura
dalla scrittrice
non scrivente,
Paola



Paola Tellaroli

Source: <https://www.intoscana.it/it/vince-il-premio-pieve-saverio-tutino-2023-paola-tellaroli-che-ha-raccontato-lictus-in-tutta-la-polvere-del-mondo-in-faccia/>

Generate handwriting without a pen

- Help people when writing is physically impaired
- Produce personalized cards / invitations
- Automatic manipulation of handwriting in movies to match the specific language
- Training data for automatic text recognition

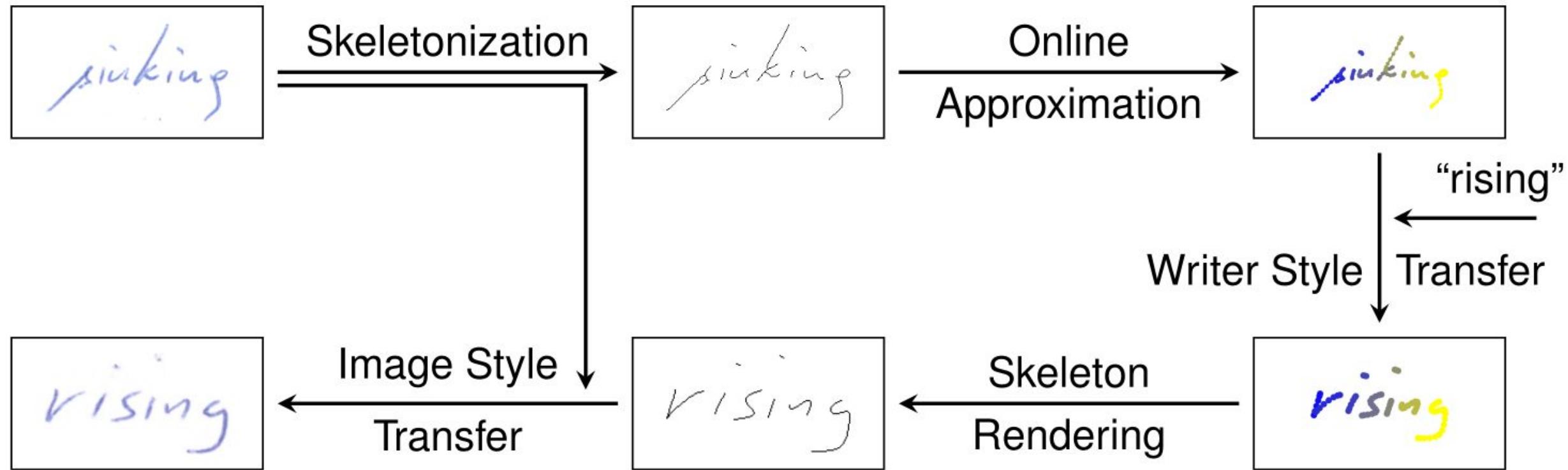


Source: <https://www.pinterest.ru/pin/499125571171917604/>

She looked closely as she ~~prison welfare Officer complement~~
when the network is primed
with a real sequence
the samples mimic
the writer's style

when the network is primed
and biased, it writes
in a cleaned up version
of the original style

A. Graves "Generating Sequences With Recurrent Neural Networks", arXiv 2013



(a)

Imagine a vast sheet of paper on which straight
straight attention curiosity

(b)

Assembly Higher isolated

(c)

You have killed my love. You used to it was not written by me

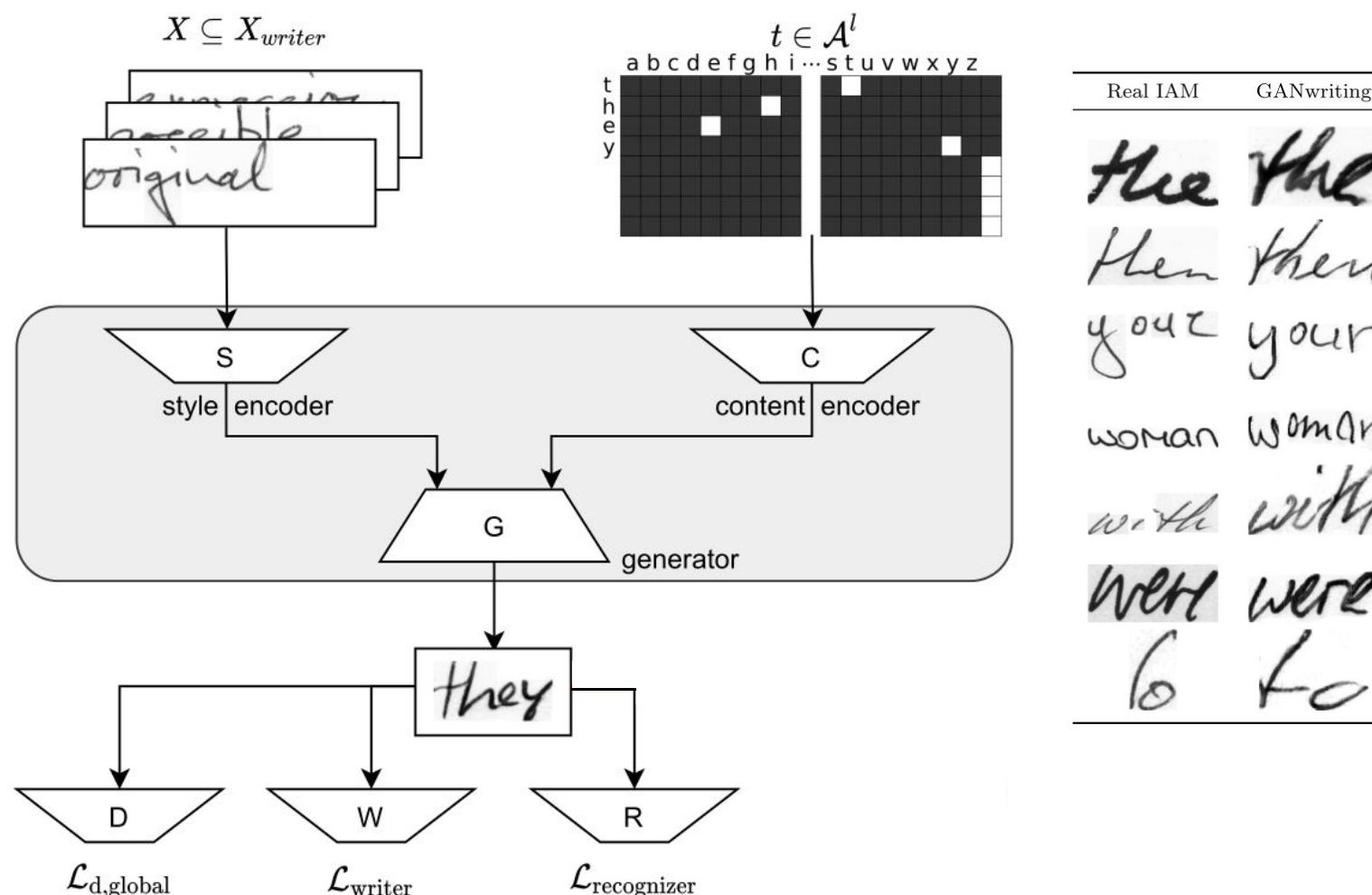
(d)

You have killed my love. you used to stir my plants and animals one

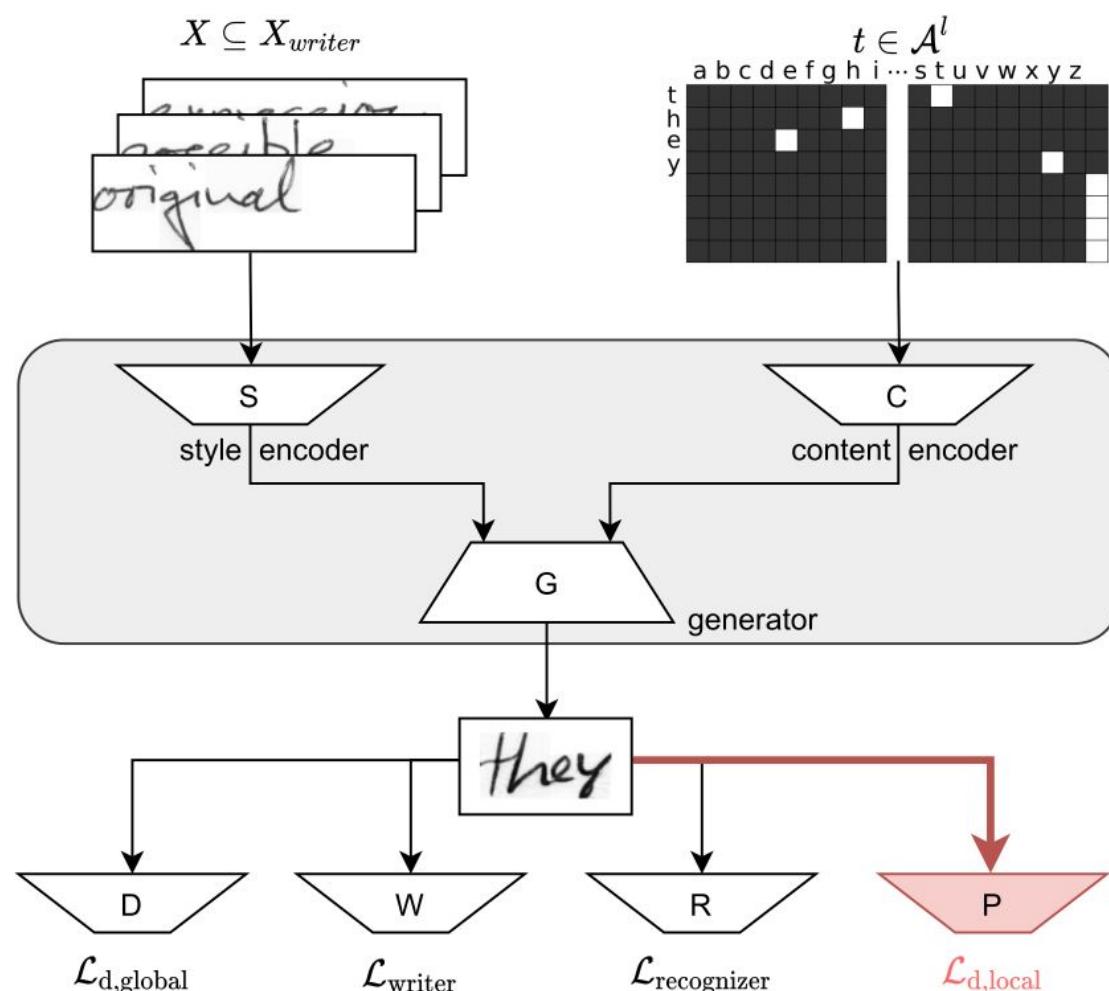
(e)

This was not written by me

This was not written by me

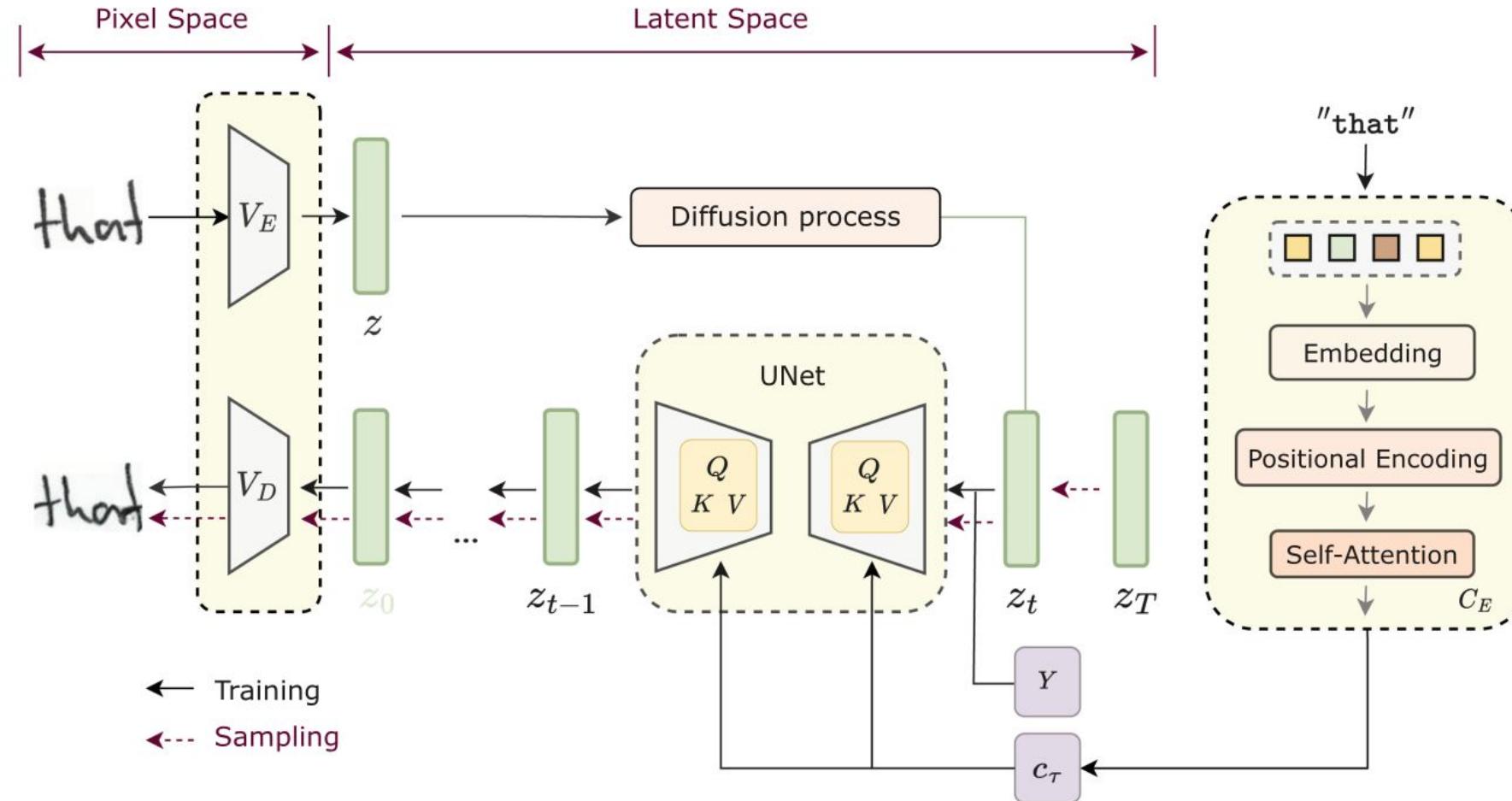


Kang, L., Riba, P., Wang, Y., Rusinol, M., Fornés, A., & Villegas, M. "GANwriting: content-conditioned generation of styled handwritten word images." ECCV 2020



Real IAM	GANwriting	lineGen	NaivePatch (ours)	CenteredPatch (ours)	SmartPatch (ours)
the	the	the	the	the	the
then	then	then	then	then	then
your	your	your	your	your	your
woman	woman	woman	woman	woman	woman
with	with	with	with	with	with
were	were	were	were	were	were
to	to	to	to	to	to

A. Mattick, M Mayr, M Seuret, A Maier, V.Christlein, "SmartPatch: Improving Handwritten Word Imitation with Patch Discriminators". ICDAR 2021



Nikolaïdou K., Retsinas G., Christlein V., Seuret M., Sfikas G., Barney Smith E., Mokayed H., Liwicki M.: "WordStylist: Styled Verbatim Handwritten Text Generation with Latent Diffusion Models", ICDAR 2023

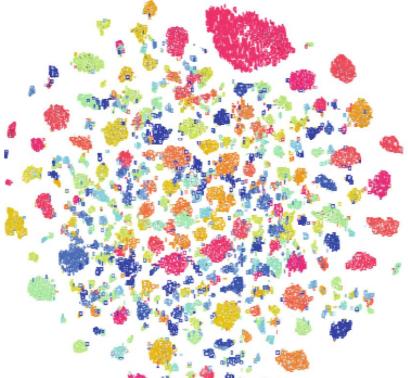
In-Vocabulary (IV) Generated Words

between almost boat prop
 clearly was detail style
 sound life colour And
 Loop pounds freedom radar

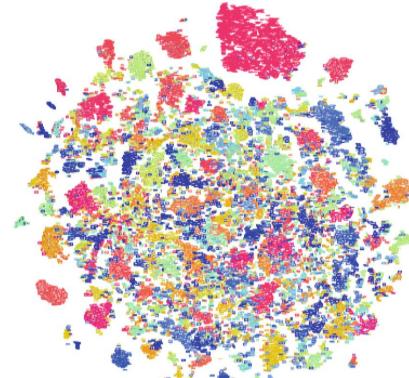
Out-of-Vocabulary (OOV) Generated Words

cosmic juice panda befell
 waist vitro enrich Harding
 Dried troll florist weaves
 Ease wedge dance guides

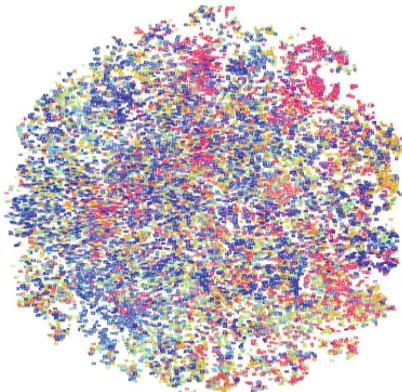
Real IAM	WordStylist (ours)	SmartPatch	GANwriting
Labour	Labour	Labour	Labour
dearer	dearer	clearer	clearer
the	the	the	the
because	because	because	because
Volume	Volume	volume	volume



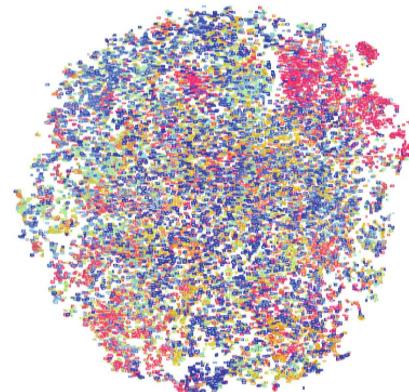
Real IAM



WordStylist



SmartPatch



GANWriting

Nikolaidou K., Retsinas G., Christlein V., Seuret M., Sfikas G., Barney Smith E., Mokayed H., Liwicki M.: "WordStylist: Styled Verbatim Handwritten Text Generation with Latent Diffusion Models", ICDAR 2023

	Top-1 [%]	↑mAP [%]	↑
IAM + IAM	97.45	97.61	
IAM + GANwriting	3.18	7.23	
IAM + SmartPatch	3.18	7.72	
IAM + WordStylist (Ours)	97.13	97.84	

- Preserves writing-style very well
- Only 96x96 dimension output
- Has to be trained for specific writer

Paragraph-wise Imitation

What his story
he'll confine him
origin of her rece
will be touch b l

What his story will be. I reckon he'll confine himself to the nervous origin of her recent illness. His notes will be touchy, but what he leaves out will matter most. Strange how just then Philip was so certain that Nicholas would never betray him. He loved Sandra too too deeply to ruin her future happiness. Had ever circumstances conspired? Philip's pride does

Style

He was better; he had made a miraculous recovery and Sandra would soon be his wife. The Devil, he thought, certainly looked after his own. Something in Sandra's attitude struck him suddenly, making him say - You can't forgive him for this - can you? Forgive is an unctuous, patronizing word, she replied. I despise the deceit. The lies!

Ours

He was better & he ha
miraculous recovery &
soon be his wife . T
certainly looked after
Something in Sandra'

He was better & he had made a miraculous recovery and Sandra would soon be his wife. The Devil & he thought, certainly looked after his own. Something in Sandra's attitude struck him suddenly, making him say & ! You can't forgive him for this - can you & ! Forgive is an unctuous & patronizing word & ! she replied & ! I despise the deceit. The lies .. !

HiGAN+

VATr

He was better; he
miraculous recover
soon be his wife
certainly looked after

He was better : he ha
miraculous recovery &
soon be his wife . T
certainly looked after
Something in Sandra'

Writer retrieval for

- Assessing imitation quality
 - Should be the standard for evaluation, FID is (close to) meaningless for text
- Improving imitation quality (as additional loss)
 - → So far no sophisticated method used

Writer retrieval for

- Assessing imitation quality
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Writer retrieval for

- Assessing imitation quality
 - Should be the standard for evaluation, FID is (close to) meaningless for text
- Improving imitation quality (as additional loss)
 - → So far no sophisticated method used
- **A new frontier:** Detect generated imitations
 - Diffusion-based generation can be detected by 90% with a simple ResNet18
 - Main factor: genuine samples are less clean

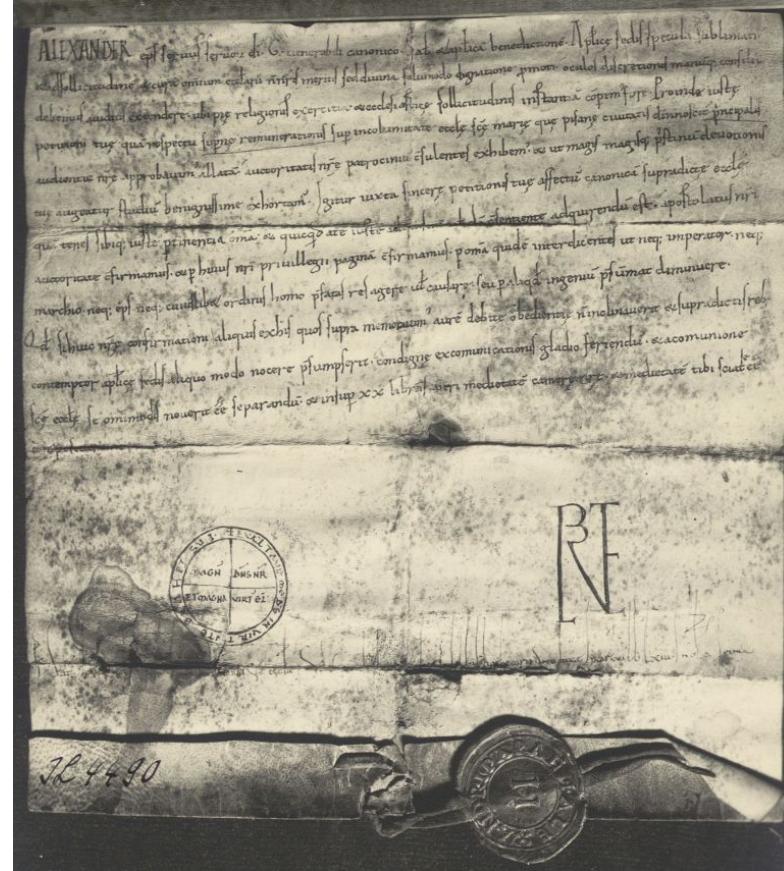
Research Frontiers:

- For the detection of forgeries
- For writer retrieval

- New datasets
 - Genuine
 - Genuine + generated
- Increase robustness against noise/artifacts

it was not written by me
it was not written by me
it was not written by me

- New datasets
 - Genuine
 - Genuine + generated
- Increase robustness against noise/artifacts
- Fine-grained identification/classification
 - Line-based
 - Word-based
- More realistic scenarios
 - OOD
 - Incremental learning
 - Identifying Imitations
- Improve interpretability

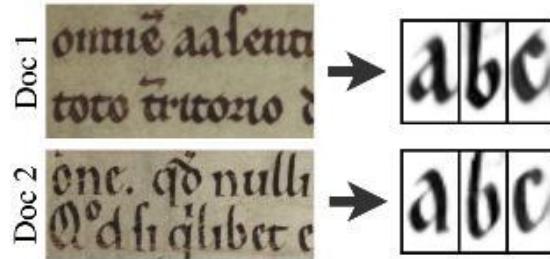


Source: Göttingen Academy of Sciences and Humanitie, JL 4490

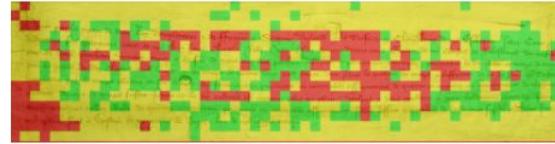
Interpretability

Several options

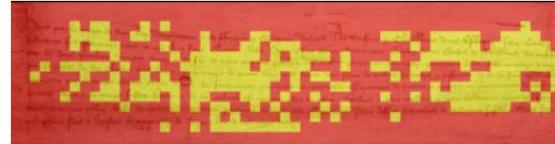
The Learnable Typewriter



The Paleographer's Eye



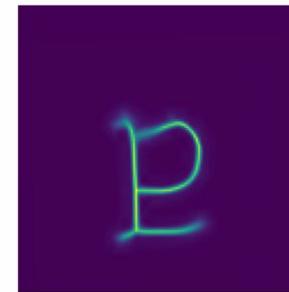
Hoccleve Example Compared to Hoccleve Template



Hoccleve Example Compared to Langeport Template

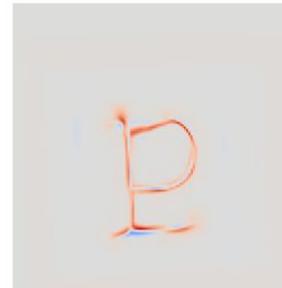
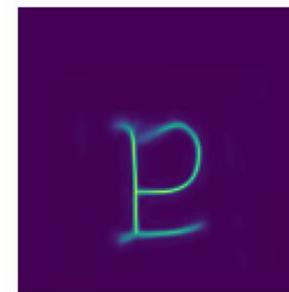
Inter-writer shape analysis using character skeletons

Writer A

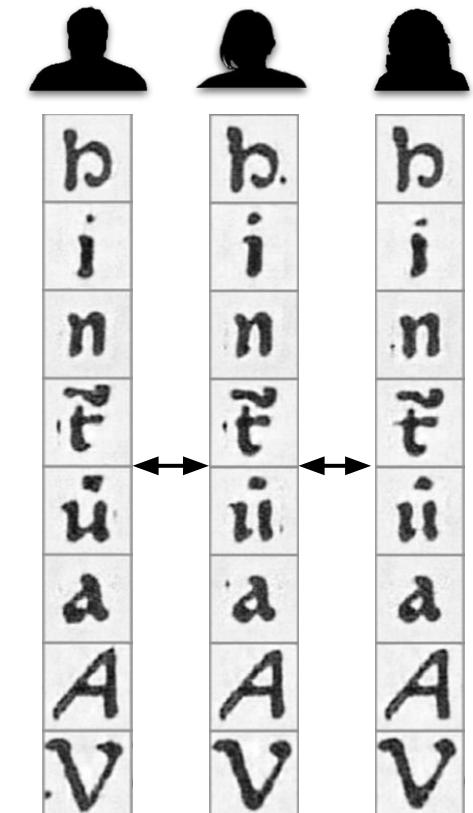


Difference

Writer B



Comparison of class prototypes with high probability mass



I. Siglidis, N. Gonthier, J. Gaubil, T. Monnier, M. Aubry: "The Learnable Typewriter: A Generative Approach to Text Analysis". *ICDAR*, 2024.

S. Grieggs, C. E. M. Henderson, S. Sobecki, A. Gillespie, W. Scheirer: "The Paleographer's Eye ex machina: Using Computer Vision to Assist Humanists in Scribal Hand Identification". *WACV*, 2024.

F. Kordon, N. Weichselbaumer, R.I Herz, S. Mossman, E. Potten, M. Seuret, M. Mayr & V. Christlein "Classification of incunable glyphs and out-of-distribution detection with joint energy-based models". *IJDAR*, 2023.

Thank you for your attention



Questions?
Questions?
Questions?
Questions?
Questions?
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Questions?

Questions?
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Questions?

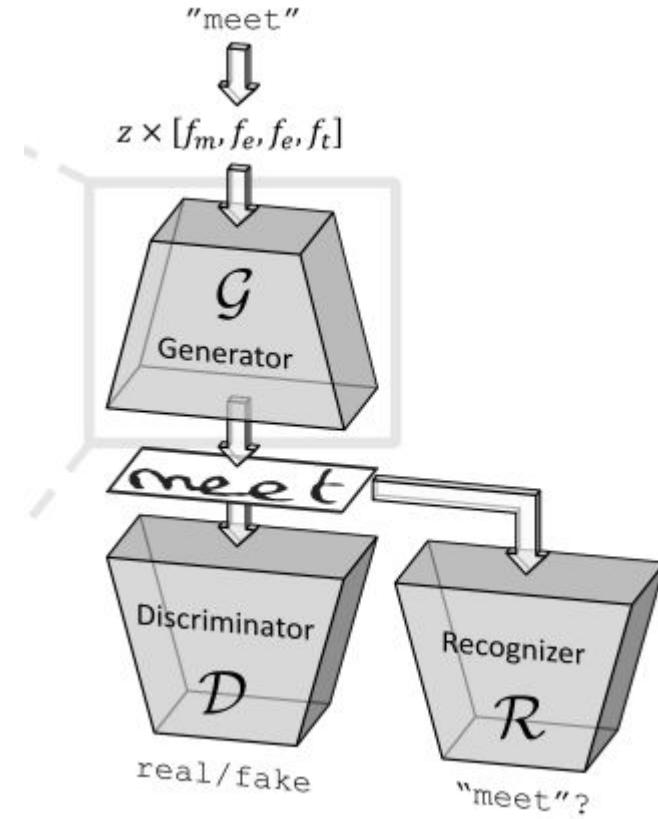
Slides + Code



<https://github.com/VChristlein/icdar24keynote>

From Handwriting Generation to Imitation

ScrabbleGAN



Supercalifragilisticexpialidocious
Supercalifragilisticexpialidocious
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Supercalifragilisticexpialidocious
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Supercalifragilisticexpialidocious

Fogel, S., Averbuch-Elor, H., Cohen, S., Mazor, S., & Litman, R. "ScrabbleGAN: Semi-supervised varying length handwritten text generation." CVPR 2020

