

Handwriting Generation

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Motivation

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://commons.wikimedia.org/wiki/File:Broken_right_hand_in_orange_cast.jpg (CC-BY-SA) | <https://www.pinterest.ru/pin/499125571171917604/>

Outline

Word Generation

Method Overview

SmartPatch

Full-Line Generation

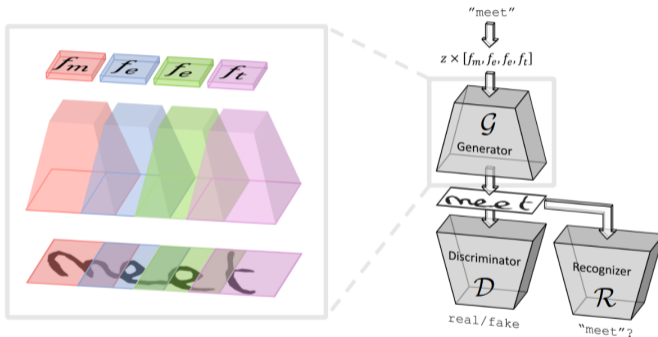
Summary & Outlook

Word Generation



Method Overview

ScrabbleGAN - Synthesizing Handwriting



Sharon Fogel et al. "ScrabbleGAN: Semi-Supervised Varying Length Handwritten Text Generation". In: *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR)*. June 2020

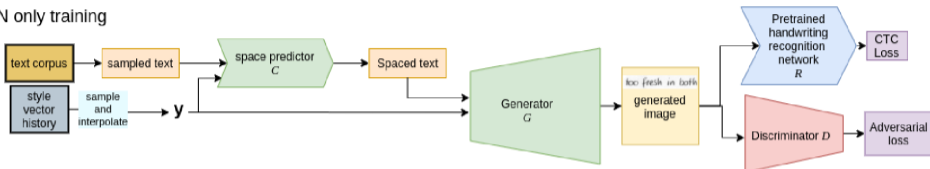
ScrabbleGAN

retrouvailles	écriture	les	étoile	feuilles	soleil	péripatéticien	chaussettes
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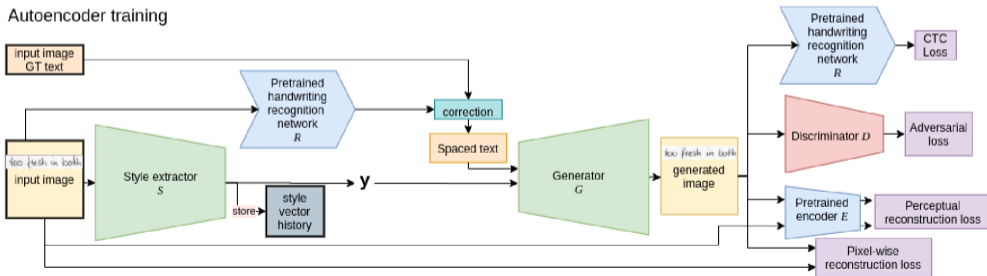
Sharon Fogel et al. "ScrabbleGAN: Semi-Supervised Varying Length Handwritten Text Generation". In: *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR)*. June 2020

Davis et al.

GAN only training



Autoencoder training



Brian Davis et al. "Text and Style Conditioned GAN for Generation of Offline Handwriting Lines". In: *British Machine Vision Conference (BMVC)*. 2020. arXiv: 2009.00678 [cs. CV]

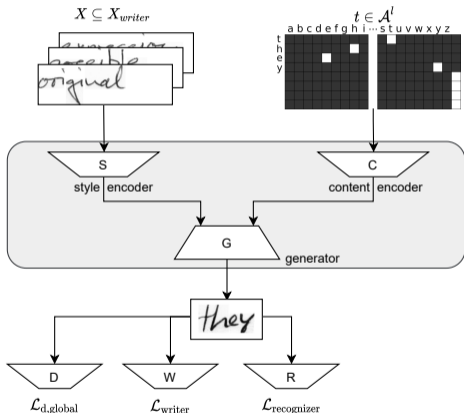
ScrabbleGAN vs. Davis et al.

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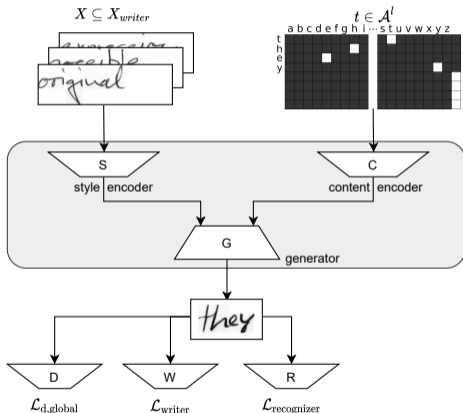
Brian Davis et al. "Text and Style Conditioned GAN for Generation of Offline Handwriting Lines". In: *British Machine Vision Conference (BMVC)*. 2020. arXiv: 2009.00678 [cs.CV]

GANwriting - Handwriting Imitation



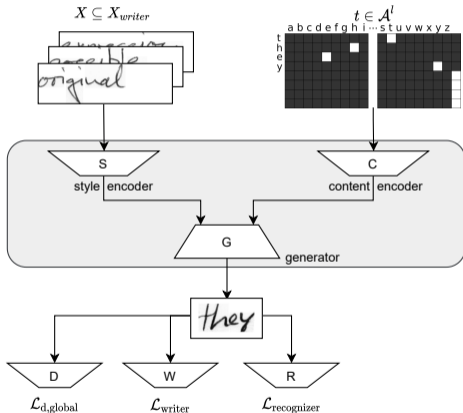
- Generator input: clear-text and word-images

GANwriting - Handwriting Imitation



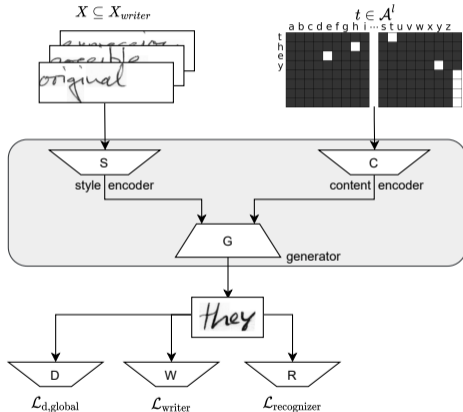
- Generator input: clear-text and word-images
- Generator output: image with content of the clear-text and style of word-samples

GANwriting - Handwriting Imitation



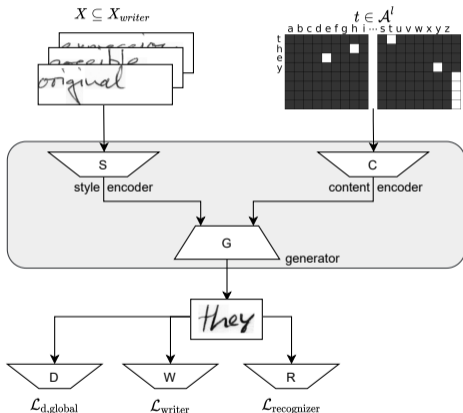
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- GAN-discriminator

GANwriting - Handwriting Imitation



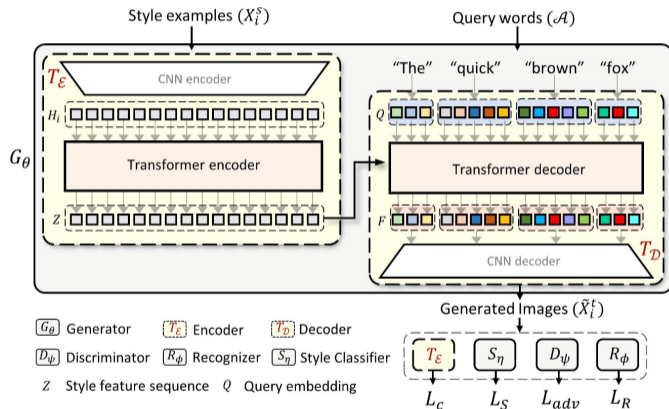
- Generator input: clear-text and word-images
- Generator output: image with content of the clear-text and style of word-samples
- GAN-discriminator
- HTR-model for content loss

GANwriting - Handwriting Imitation



- Generator input: clear-text and word-images
- Generator output: image with content of the clear-text and style of word-samples
- GAN-discriminator
- HTR-model for content loss
- Writer-identification for style loss

Handwriting Transformer



Ankan Kumar Bhunia et al. “Handwriting Transformers”. In: *Proceedings of the IEEE/CVF International Conference on Computer Vision (ICCV)*. Oct. 2021, pp. 1086–1094

Handwriting Transformer (HWT) vs. GANwriting vs. Davis et al.

Style examples	HWT (Ours)	GANwriting	Davis et al.
<p><i>If your neighbour is a poor Christian who will not think to live in peace of soul and conscience</i></p> <p>The process has been too slow for Herr Strauss and last month he attacked Britain for being an</p> <p>These were loud cries of 'shame' from all parts of the Conservative side</p> <p>Mr. Hill appeared to be in the thoughts he said, if the Soviet Union would be prepared to reach an agreement for a zone of</p> <p>Mr. Macleod went on with the conference at Lancaster House despite the crisis which had blown</p> <p>By the end of the month he still delighted in Naples the hotel Clancany that he enjoyed it all</p>	<p>No two people can write precisely the same way just like no two people can have the same fingerprints</p> <p>No two people can write precisely the same way just like no two people can have the same fingerprints</p> <p>No two people can write precisely the same way just like no two people can have the same fingerprints</p> <p>No two people can write precisely the same way just like no two people can have the same fingerprints</p> <p>No two people can write precisely the same way just like no two people can have the same fingerprints</p> <p>No two people can write precisely the same way just like no two people can have the same fingerprints</p> <p>No two people can write precisely the same way just like no two people can have the same fingerprints</p> <p>No two people can write precisely the same way just like no two people can have the same fingerprints</p>	<p>No two people can write precise the same way just like no two people can have the same fingerp</p> <p>No two people can write precise the same way just like no two people can have the same fingerp</p> <p>No two people can write precise the same way just like no two people can have the same fingerp</p> <p>No two people can write precise the same way just like no two people can have the same fingerp</p> <p>No two people can write precise the same way just like no two people can have the same fingerp</p> <p>No two people can write precise the same way just like no two people can have the same fingerp</p> <p>No two people can write precise the same way just like no two people can have the same fingerp</p> <p>No two people can write precise the same way just like no two people can have the same fingerp</p>	<p>No two people can write precisely the same way, just like no two people can have the same fingerprints</p> <p>No two people can write precisely the same way, just like no two people can have the same fingerprints</p> <p>No two people can write precisely the same way, just like no two people can have the same fingerprints</p> <p>No two people can write precisely the same way, just like no two people can have the same fingerprints</p> <p>No two people can write precisely the same way, just like no two people can have the same fingerprints</p> <p>No two people can write precisely the same way, just like no two people can have the same fingerprints</p> <p>No two people can write precisely the same way, just like no two people can have the same fingerprints</p> <p>No two people can write precisely the same way, just like no two people can have the same fingerprints</p>

Ankan Kumar Bhunia et al. "Handwriting Transformers". In: *Proceedings of the IEEE/CVF International Conference on Computer Vision (ICCV)*. Oct. 2021, pp. 1086–1094

Defects of GANwriting



Figure: Frequently appearing artifacts in the outputs of GANwriting.

Defects of GANwriting

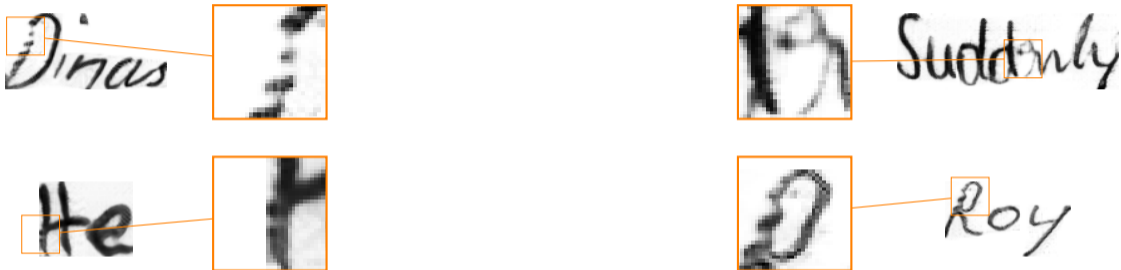


Figure: Frequently appearing artifacts in the outputs of GANwriting.

- “stepping” artifacts

Defects of GANwriting



Figure: Frequently appearing artifacts in the outputs of GANwriting.

- “stepping” artifacts
- thin lines

Defects of GANwriting



Figure: Frequently appearing artifacts in the outputs of GANwriting.

- “stepping” artifacts
- thin lines
- smudged lines

Defects of GANwriting

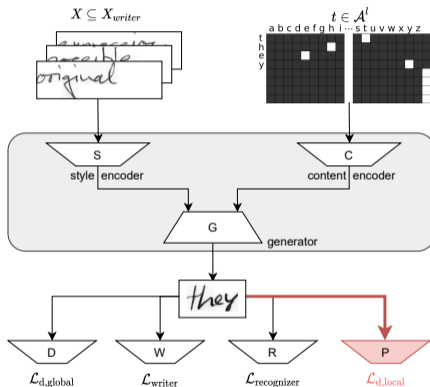


Figure: Frequently appearing artifacts in the outputs of GANwriting.

- “stepping” artifacts
- thin lines
- smudged lines
- unsteady lines

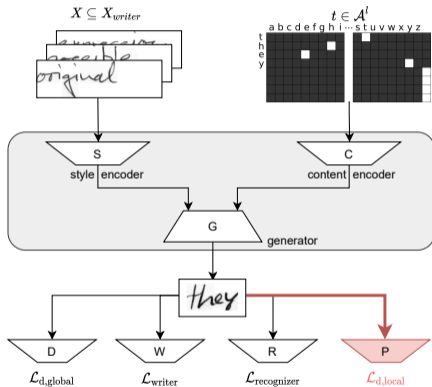
SmartPatch

SmartPatch



Alexander Mattick et al. "SmartPatch: Improving Handwritten Word Imitation with Patch Discriminators". In: *Document Analysis and Recognition – ICDAR 2021*. Ed. by Josep Lladós, Daniel Lopresti, and Seiichi Uchida. Cham: Springer International Publishing, 2021, pp. 268–283

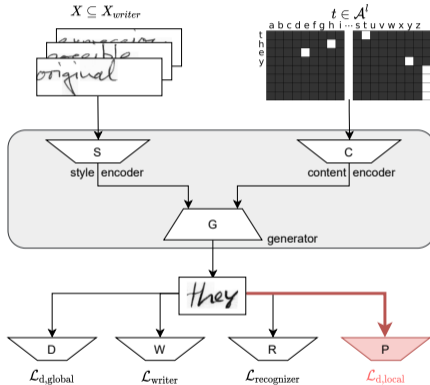
SmartPatch



- Dedicated discriminator for character level

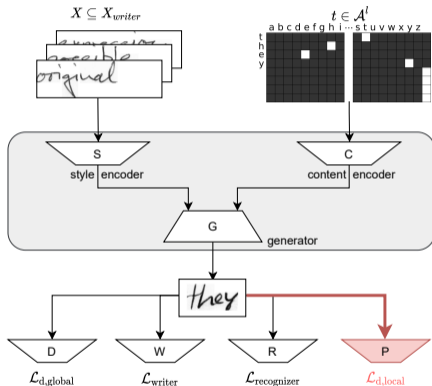
Alexander Mattick et al. "SmartPatch: Improving Handwritten Word Imitation with Patch Discriminators". In: *Document Analysis and Recognition – ICDAR 2021*. Ed. by Josep Lladós, Daniel Lopresti, and Seiichi Uchida. Cham: Springer International Publishing, 2021, pp. 268–283

SmartPatch



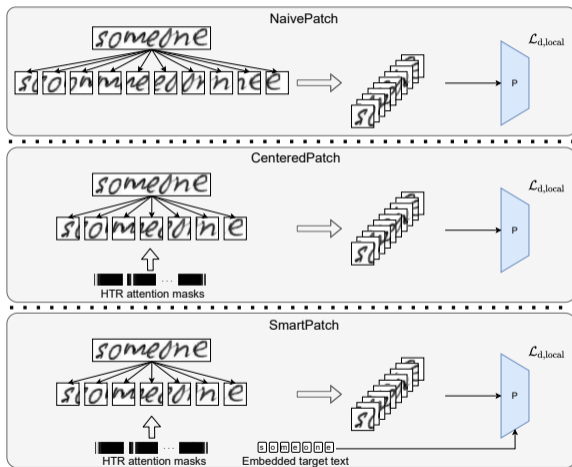
- Dedicated discriminator for character level
- Rolling patches: 64×64 patches with stride 32

SmartPatch



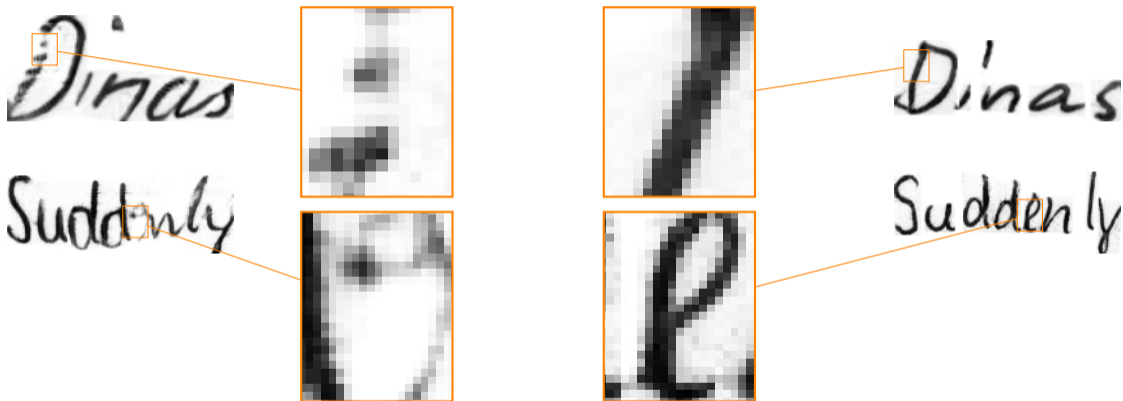
- Dedicated discriminator for character level
- Rolling patches: 64×64 patches with stride 32
- Discriminator: small pix2pix 70×70 receptive field

SmartPatch - Discriminator Designs



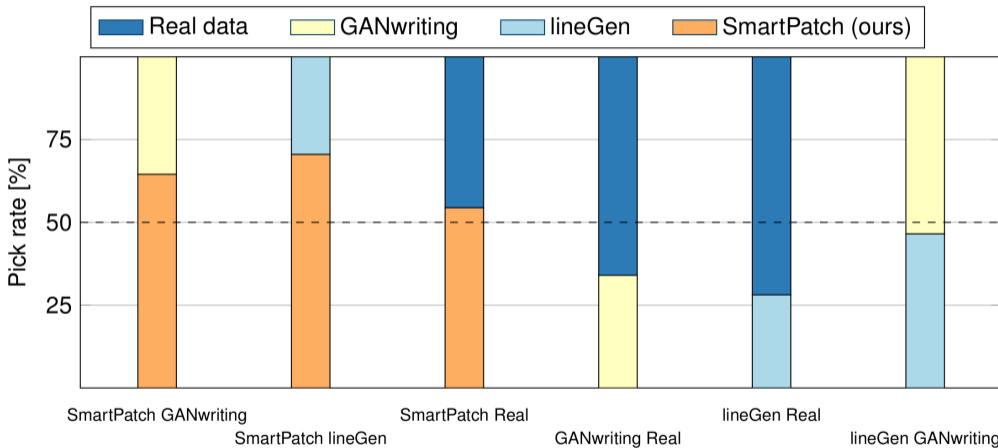
Alexander Mattick et al. "SmartPatch: Improving Handwritten Word Imitation with Patch Discriminators". In: *Document Analysis and Recognition – ICDAR 2021*. Ed. by Josep Lladós, Daniel Lopresti, and Seichi Uchida. Cham: Springer International Publishing, 2021, pp. 268–283

GANwriting vs. SmartPatch



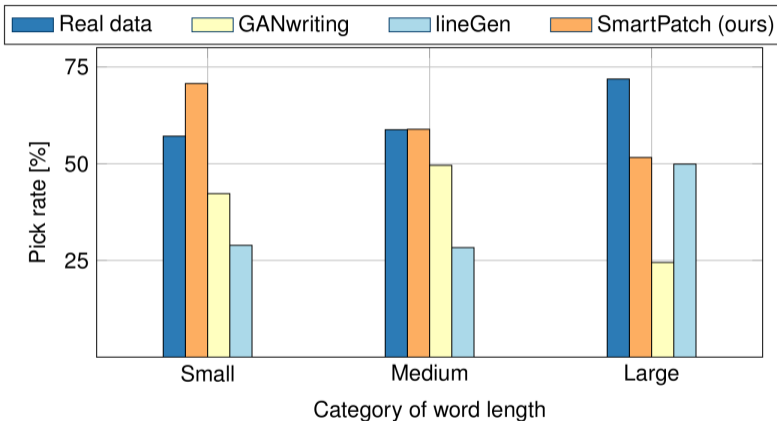
Lei Kang et al. "GANwriting: Content-Conditioned Generation of Styled Handwritten Word Images". In: *Computer Vision – ECCV 2020*. Ed. by Andrea Vedaldi et al. Cham: Springer International Publishing, 2020, pp. 273–289; Alexander Mattick et al. "SmartPatch: Improving Handwritten Word Imitation with Patch Discriminators". In: *Document Analysis and Recognition – ICDAR 2021*. Ed. by Josep Lladós, Daniel Lopresti, and Seiichi Uchida. Cham: Springer International Publishing, 2021, pp. 268–283

Results



Alexander Mattick et al. "SmartPatch: Improving Handwritten Word Imitation with Patch Discriminators". In: *Document Analysis and Recognition – ICDAR 2021*. Ed. by Josep Lladós, Daniel Lopresti, and Seiichi Uchida. Cham: Springer International Publishing, 2021, pp. 268–283

Results



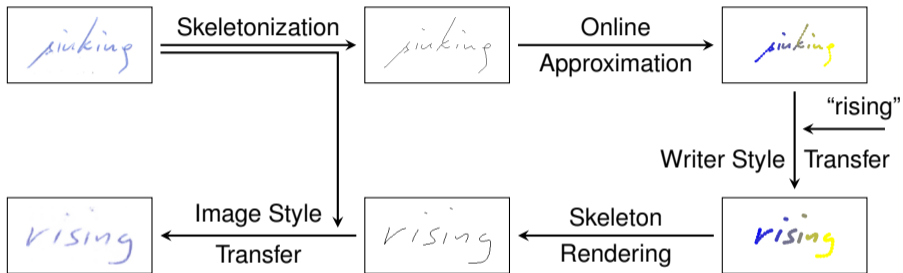
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Full-Line Generation



Spatio-Temporal Handwriting Imitation

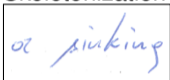
Overview



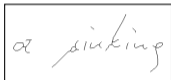
Spatio-Temporal Handwriting Imitation

From Offline to Online Data

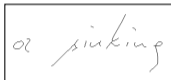
1. Skeletonization



Input

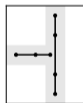
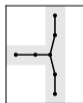
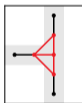
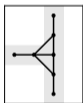
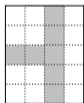


Primitive

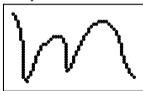


Learned

2. Skeletons \rightarrow strokes



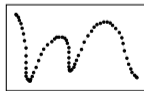
3. Importance sampling



None



Constant



Maximum acceleration

Writer Style Transfer

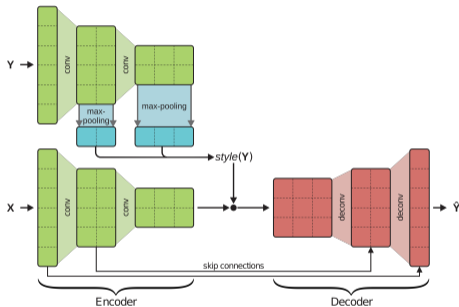
Online Handwriting Synthesis¹

Style Input	Output
<i>spireless!" "You think you could</i>	<i>I am a synthetic sample</i>
<i>Michael Coxton The father</i>	<i>I am a synthetic sample</i>
<i>they get'em. We've been alert</i>	<i>I am a synthetic sample</i>
<i>one for me?" Jesus did so, and</i>	<i>I am a synthetic sample</i>
<i>any better? You know it was! He</i>	<i>I am a synthetic sample</i>
<i>and change the money</i>	<i>I am a synthetic sample</i>

¹Alex Graves. *Generating Sequences With Recurrent Neural Networks*. Aug. 2013. arXiv: 1308.0850 [cs.NE].

Image/Pen Style Transfer

- Extract style information of the input image
- Remove spatial information of style
- Add to generated image



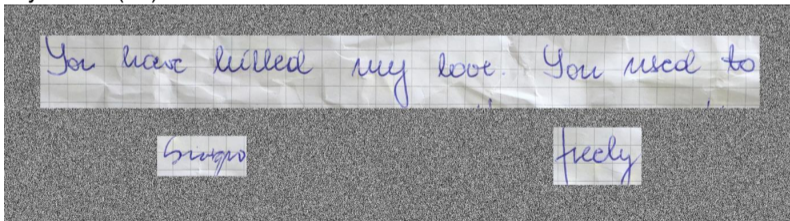
Results – User Study

- Turing task (32): Fake or Real?



straight

- Style task (64):

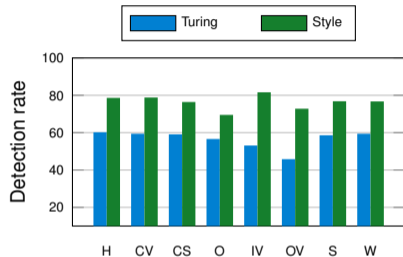


Results – User Study

- 59 participants
- Accuracy Turing task: 58.7 %
- Accuracy Style task: 76.8 %

Results – User Study

- 59 participants
- Accuracy Turing task: 58.7 %
- Accuracy Style task: 76.8 %
- Humanities (H) have best performance (vs. CV, CS, O)
- Out-of-Vocabulary (OV) better imitated than in vocabulary (IV)
- No impact of synthetic background (S vs. W)



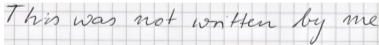
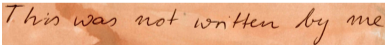
Qualitative Results

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

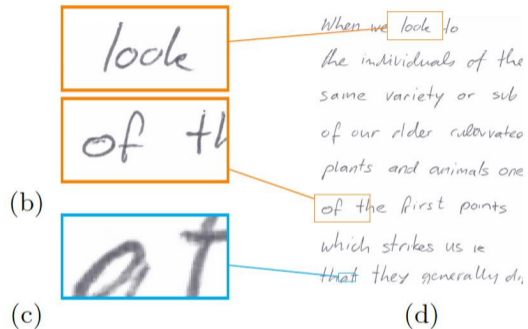
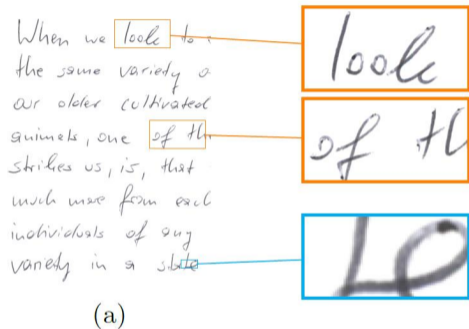
(b) when we look to the individuals of the same variety
 Assembly Higher colored

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

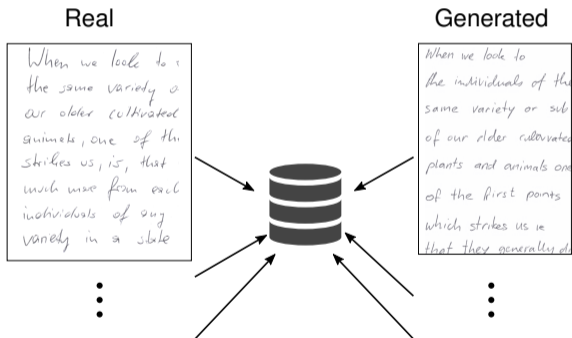
(d) you have killed my love. you used to stir my plants and animals one

(e)  

Qualitative Results



Results – Writer Identification



DB	mAP %	Acc. %
OV	29.66	14.82
IV	37.13	25.92

Source: <https://iconscout.com/icons/database>

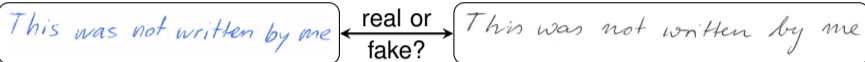
Writer Identification in Generated Images

→ A new layer for writer identification

Summary & Outlook



Summary & Outlook



Summary

- Rapidly improving results on word and line level
- Can be used for improving HTRs

Outlook

- Handwriting imitation of whole images

Questions?

Missed something? Please let us know!

References



References I

- [Bhu+21] Ankan Kumar Bhunia, Salman Khan, Hisham Cholakkal, Rao Muhammad Anwer, Fahad Shahbaz Khan, and Mubarak Shah. “Handwriting Transformers”. In: *Proceedings of the IEEE/CVF International Conference on Computer Vision (ICCV)*. Oct. 2021, pp. 1086–1094.
- [Dav+20] Brian Davis, Chris Tensmeyer, Brian Price, Curtis Wigington, Bryan Morse, and Rajiv Jain. “Text and Style Conditioned GAN for Generation of Offline Handwriting Lines”. In: *British Machine Vision Conference (BMVC)*. 2020. arXiv: 2009.00678 [cs.CV].
- [Fog+20] Sharon Fogel, Hadar Averbuch-Elor, Sarel Cohen, Shai Mazor, and Roei Litman. “ScrabbleGAN: Semi-Supervised Varying Length Handwritten Text Generation”. In: *Proceedings of the IEEE/CVF Conference on Computer Vision and Pattern Recognition (CVPR)*. June 2020.
- [Gra13] Alex Graves. *Generating Sequences With Recurrent Neural Networks*. Aug. 2013. arXiv: 1308.0850 [cs.NE].

References II

- [Kan+20] Lei Kang, Pau Riba, Yaxing Wang, Marçal Rusiñol, Alicia Fornés, and Mauricio Villegas. “GANwriting: Content-Conditioned Generation of Styled Handwritten Word Images”. In: *Computer Vision – ECCV 2020*. Cham: Springer International Publishing, 2020, pp. 273–289.
- [Mat+21] Alexander Mattick, Martin Mayr, Mathias Seuret, Andreas Maier, and Vincent Christlein. “SmartPatch: Improving Handwritten Word Imitation with Patch Discriminators”. In: *Document Analysis and Recognition – ICDAR 2021*. Cham: Springer International Publishing, 2021, pp. 268–283.
- [May+20] Martin Mayr, Martin Stumpf, Anguelos Nicolaou, Mathias Seuret, Andreas Maier, and Vincent Christlein. “Spatio-Temporal Handwriting Imitation”. In: *Computer Vision – ECCV 2020 Workshops*. 2020, pp. 528–543.