

Offline Handwriting Word Recognition

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Overview of the Project

Off-line handwriting recognition

- It involves the automatic conversion of text in an image into letter codes which are usable within computer and text-processing applications
- Off-line handwriting recognition is comparatively difficult, as different people have different handwriting styles

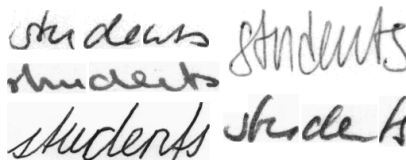


Figure: 'Students' written by different authors

Our AI Project

A lot of research has been done over the past years.

We explored the topic and implemented a full pipeline for the task.
The research touched different fields:

- Data Collection
- Image Processing
- Features extraction
- Machine Learning

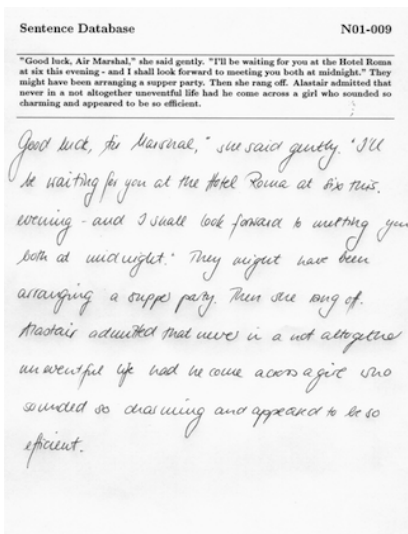
Dataset

The IAM Handwriting Database 3.0¹

- Unconstrained handwritten text (scanned at a resolution of 300dpi and saved as PNG images with 256 gray levels)
- 1'539 pages of scanned text of 657 writers
- 13'353 isolated and labeled text lines
- 115'320 isolated and labeled words

¹<http://www.iam.unibe.ch/fki/databases/iam-handwriting-database>

Example of a page of scanned text



Implementation Details

Pipeline

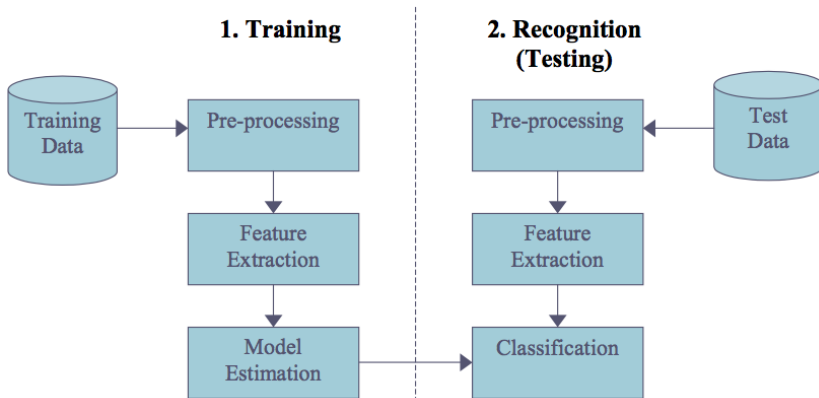


Figure: Pipeline of a word recognition system

Implementation Details

Pre-Processing

Pre-processing

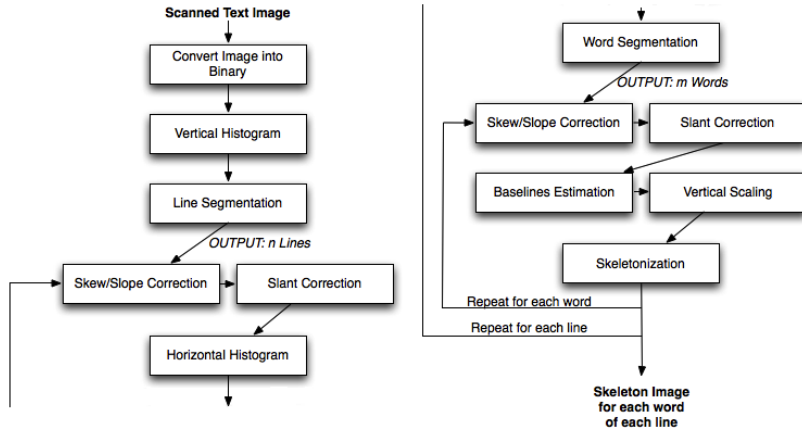
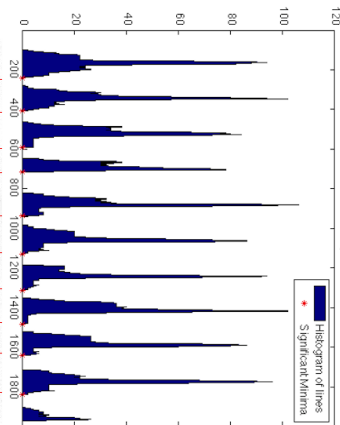


Figure: Pipeline for the pre-processing/normalization step

Line Segmentation

Tough they may gather some left-wing support, a large majority of Labour MPs are likely to turn down the Foot-Griffiths resolution. The Foot's line will be that as Labour MPs opposed the Government Bill which brought life peers into existence, they should not now put forward nominees. He believes that the House of Lords should be abolished and that Labour should not take any steps which would appear to "prop up" an out-dated institution.



Original image segmented in lines

Vertical histograms and significant minima

Figure: Example of line segmentation

Skew and Slope Correction

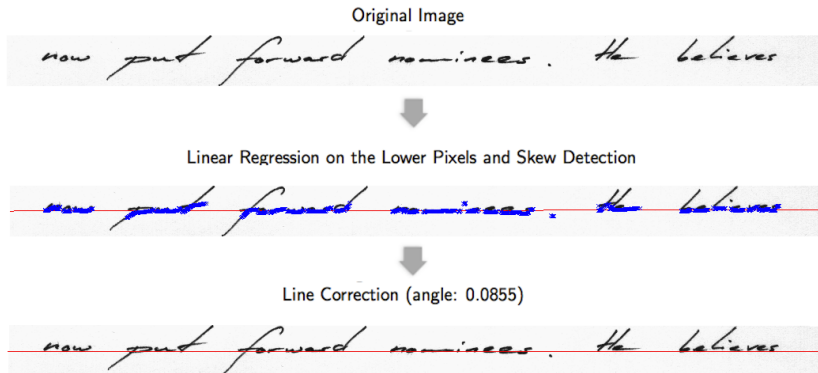


Figure: Skew detection and correction pipeline

Slant Correction

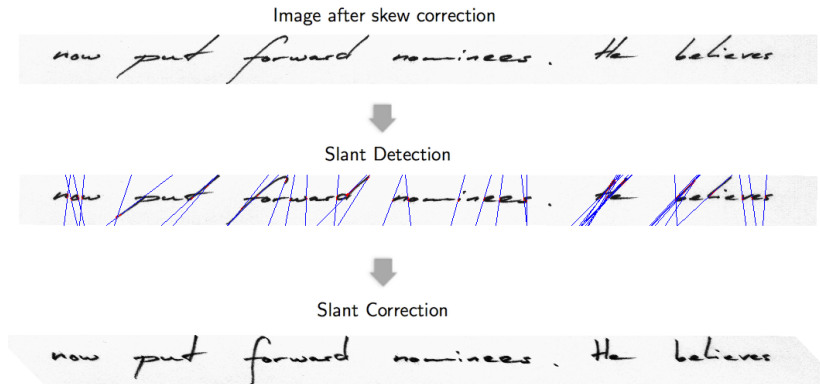
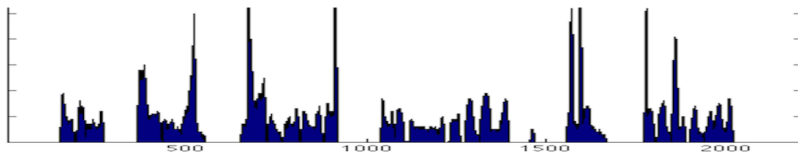


Figure: Slant detection and correction pipeline

Word segmentation

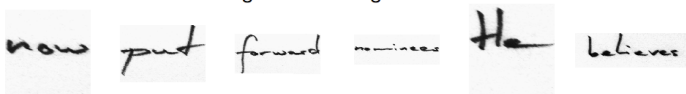
Horizontal Histogram



White Spaces Distribution



Clustering and Words Segmentation

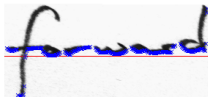


Baseline Estimation

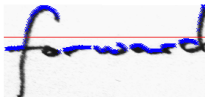
forward



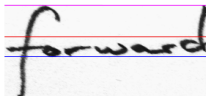
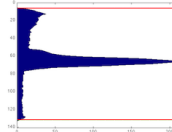
Lower Baseline



Upper Baseline

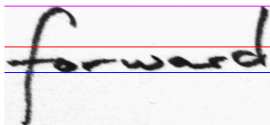


Ascender and Descender Baselines



Vertical Scaling

Words with baselines



Normalization to fixed height and fixed baselines

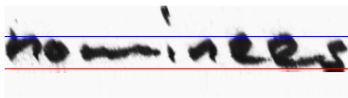
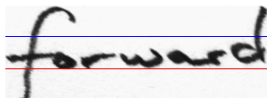


Figure: Examples of vertical scaling process

Skeletonization

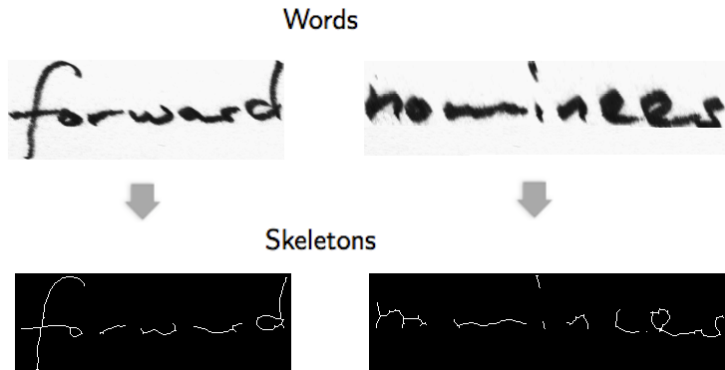
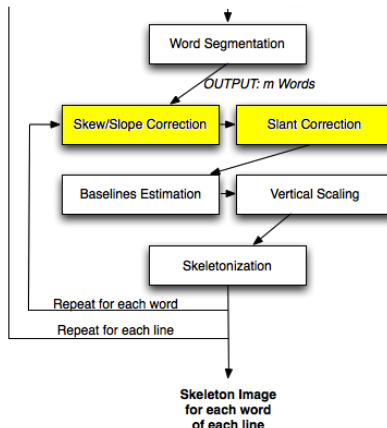
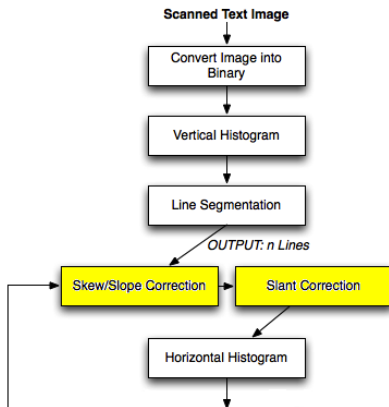


Figure: Skeletonization process

Remembering the entire pipeline....

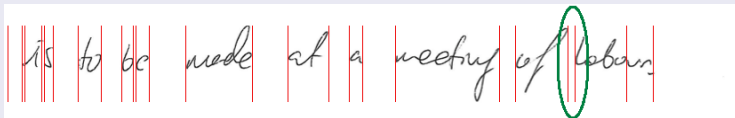
Why repeating skew and slant correction twice?



The normalizations are necessary for:

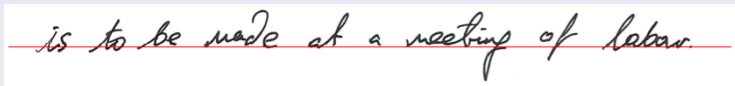
First

Words segmentation



Second

Not all the words have the same slope, slant and lower baseline



Implementation Details

Feature Extraction

Features

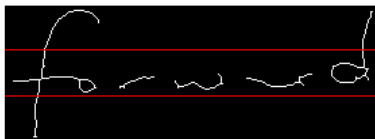
Extracted from the skeleton of the words.

Mainly 2 types:

- Statistical
- Morphological

Statistical Features

Percentage of white pixels in the 3 zones of the word:



Upper Zone: 0.0124 %

Middle Zone: 0.0338 %

Lower Zone: 0.0033 %

Figure: Example

Morphological Features

Obtained by **connected component analysis**.

- A connected component it is a subgraph in which any two vertices are connected to each other by paths, and which is connected to no additional vertices.

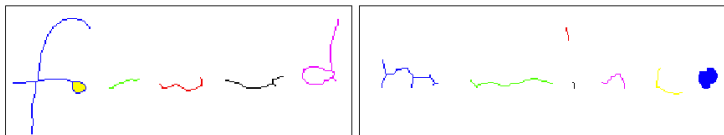
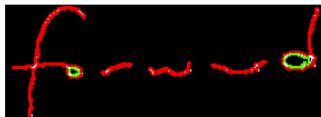


Figure: Example of words divided in different components (colors)

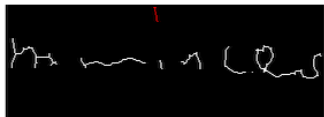
Morphological Features

We extract:

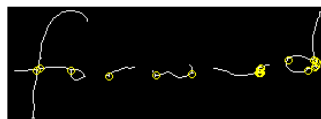
Loops



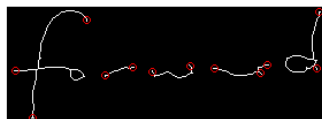
Dots



Junctions



Endpoints



Sliding window

We use a sliding window over the words and at every shift of the window we extract features.



Sliding window

We use a sliding window over the words and at every shift of the window we extract features.



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Sliding window

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Implementation Details

Hidden-Markov Model for Word Recognition

HMM

- A set of N states $S = (s_1, s_2, \dots, s_N)$, where the state of the system at time t is denoted q_t
- A set of priors $\pi = (\pi_1, \pi_2, \dots, \pi_N)$, providing the probability $P(q_1 = s_i)$.
- A transition function \mathbf{A} , where $a_{ij} = P(q_{t+1} = s_j | q_t = s_i)$.
- An observation function \mathbf{B} , mapping each observation at every state to a probability $b_i(\mathbf{o}_t) = P(\mathbf{o}_t | q_t = s_i, \lambda)$, where λ denotes the model parameters.

The model is trained to estimate the posterior probability $P(\mathbf{O} | \lambda)$ of an observation sequence \mathbf{O} , with D -dimensional observation vectors $\mathbf{o}_t = (o_1, o_2, \dots, o_D)$.

HMM

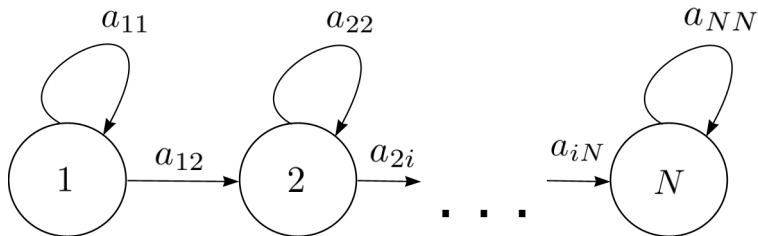


Figure: Left-to-right HMM with N states

Main problems in an HMM

- 1 The probability of an observation sequence, given the model, $P(\mathbf{O}|\lambda)$.
- 2 The most likely parameters of the model $\lambda^* = \max P(X|\lambda)$, given a training set of M observation sequences $X = (\mathbf{O}_1, \mathbf{O}_2, \dots, \mathbf{O}_M)$.
- 3 The most likely state sequence, underlying a given observation sequence and the model, $Q^* = \max P(Q|\mathbf{O}, \lambda)$.

Main problems in an HMM

- 1 The probability of an observation sequence, given the model, $P(\mathbf{O}|\lambda)$.

Sum-product algorithm: forward-backward algorithm

- 2 The most likely parameters of the model $\lambda^* = \max P(X|\lambda)$, given a training set of M observation sequences $X = (\mathbf{O}_1, \mathbf{O}_2, \dots, \mathbf{O}_M)$.

EM-algorithm: Baum-Welch reestimation

- 3 The most likely state sequence, underlying a given observation sequence and the model, $Q^* = \max P(Q|\mathbf{O}, \lambda)$.

Dynamic programming: Viterbi algorithm

Updating the parameters

Comparison with GMM:

| Model: | GMM | HMM |
|---------------------|------------------------------|--|
| Model parameters: | $\lambda = \pi, \mu, \Sigma$ | $\lambda = \pi, \mathbf{A}, \mathbf{B}$ |
| Hyper parameters: | Number of components | Topology (states, transitions), observation function |
| Observed variables: | Data points | Observations |
| Latent variables: | Priors of a component | State sequence |

Updating parameters

| Model: | GMM | HMM |
|---------|---|---|
| E-step: | Estimate the probability of a component, given the data and current parameters. | Estimate the probability of being in a state at a timestep and the probability of transferring from a state to another state. |
| M-step: | Maximise π , μ and Σ . | Maximise π , A and B |

Problems we ran into

Singularities. Consider the following observation:

$$\mathbf{O} = \begin{pmatrix} -1 & 0 \\ 2 & 0 \\ 1 & 0 \\ -2 & 0 \end{pmatrix}$$

$$\Sigma = \begin{pmatrix} 3\frac{1}{3} & 0 \\ 0 & 0 \end{pmatrix}$$

Problems we ran into

Singularities

$$\mathbf{O} = \begin{pmatrix} -1 & 0 \\ 2 & 0 \\ 1 & 0 \\ -2 & 0 \end{pmatrix}$$

$$\Sigma = \begin{pmatrix} 3\frac{1}{3} & 0 \\ 0 & 0 \end{pmatrix}$$

$$|\Sigma| = 0$$

Possible solution: Add some random noise.

Problems we ran into

Length of the word. Short words seem to be harder to find.

Possible causes:

- During the testing, the model does not execute a complete sequence, e.g. when looking for 'the' in 'therefore' it might end before 'r'.
- Short words may be more difficult to recognise as they are more sensible to inter-writer variations.

Possible solutions:

- Force the model to end the observations sequence in the final state.
- Use a more complex observation model. E.g., a MOG.

Mixture of Gaussians

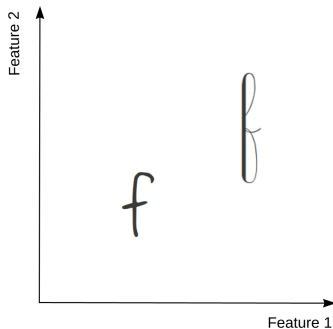


Figure: Two letters plotted in a two dimensional feature space

Mixture of Gaussians

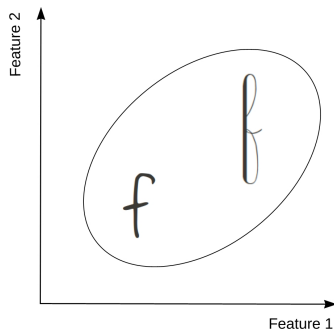


Figure: Two letters plotted in a two dimensional feature space

Mixture of Gaussians

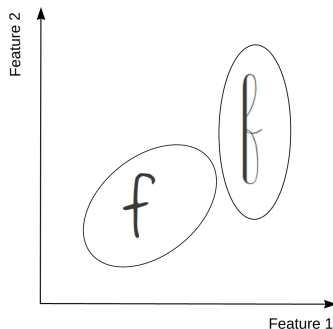


Figure: Two letters plotted in a two dimensional feature space

Experiments and Results

Experiments

We run 2 type of experiments:

- 1 vs 1 word recognition
 - We build models for 2 words and we test both models for new instances of the 2 words from novel authors
 - *GOAL*: Test how much the likelihoods of the 2 words differ
- all vs all words recognition
 - We build models for every word and for every word in the test set we rank all the models by loglikelihood
 - *GOAL*: Compute general accuracy for a small dataset

For both experiments the model of a word is built using 30 samples from 30 authors of the word.

Experiment 1 - Typewritten words

- Done to check the correctness of the pipeline.
- Only used intensity features.
- Used words 'Letter' and 'Number' (same length)

Table: Results averaged over 40 runs

| Word | Letter | Number | Difference |
|----------------------------------|---------|---------|------------|
| LL Intensity N=6 K=1 | 121.68 | 106.36 | 15.32 |
| LL All features N=6 K=1 | 795.45 | 14.08 | 781.37 |
| LL All features N=1 K=1 | 602.22 | -90.02 | 692.22 |
| LL All features N=6 K=3 | 226.96 | -820.30 | $1.04e^3$ |
| LL ALL , N=6, K=1, diagonal cov | 871.16 | 531.27 | 487.75 |
| LL ALL , N=6, K=1, isotropic cov | -179.00 | -272.23 | 197.35 |
| ... | ... | ... | ... |

Experiment 1 - Handwritten Words (same length)

- Used words 'Before' and 'People' (same length)

Table: Results for simple handwritten words, avg over 40 runs

| Word | Before | People | Difference |
|-------------------------|--------------|----------------|------------|
| LL All features N=6 K=1 | $1.17e + 03$ | $1.19e + 03$ | 480.16 |
| LL All features N=1 K=1 | 699.56 | $1.0124e + 03$ | 422.78 |
| LL All features N=6 K=3 | 226.96 | -820.30 | $1.04e^3$ |

Experiment 1 - Handwritten Words (short vs long)

Experiments 2

- Used a small dataset of 100 words
- Tested on 200 words of novel authors

| Num. States | Num. Gaussian Comp. | Accuracy 1 ² | Accuracy 2 ³ |
|-------------|---------------------|-------------------------|-------------------------|
| lengthWord | 1 | 0.2400 | 0.3400 |
| 1 | 1 | 0.2000 | 0.3600 |
| 1 | 5 | 0.0800 | 0.1800 |
| lengthWord | 5 | 0.1200 | 0.3000 |

²Correct if in 1st position of the ranked list

³Correct if in 1st or 2nd position of the ranked list

Evaluation

- short vs long...
- More GMM components seems to decrease the accuracy because of

Conclusions

Conclusions about the AI project

- The full pipeline is working, however a lot of improvements are possible:
 - Extract more features
 - Eventually apply PCA to the feature vector
 - Optimize the parameters of the HMM (i.e. using a validation set).
- Built models for letters instead of models for words (it requires letters segmentation)
- Use a language model

Personal Evaluation

- We built a full working pipeline
- We read and learnt a lot about a new topic
- We had the chance to apply a lot of techniques that we had only been studied in theory
- We improved our skills in programming

Questions?