



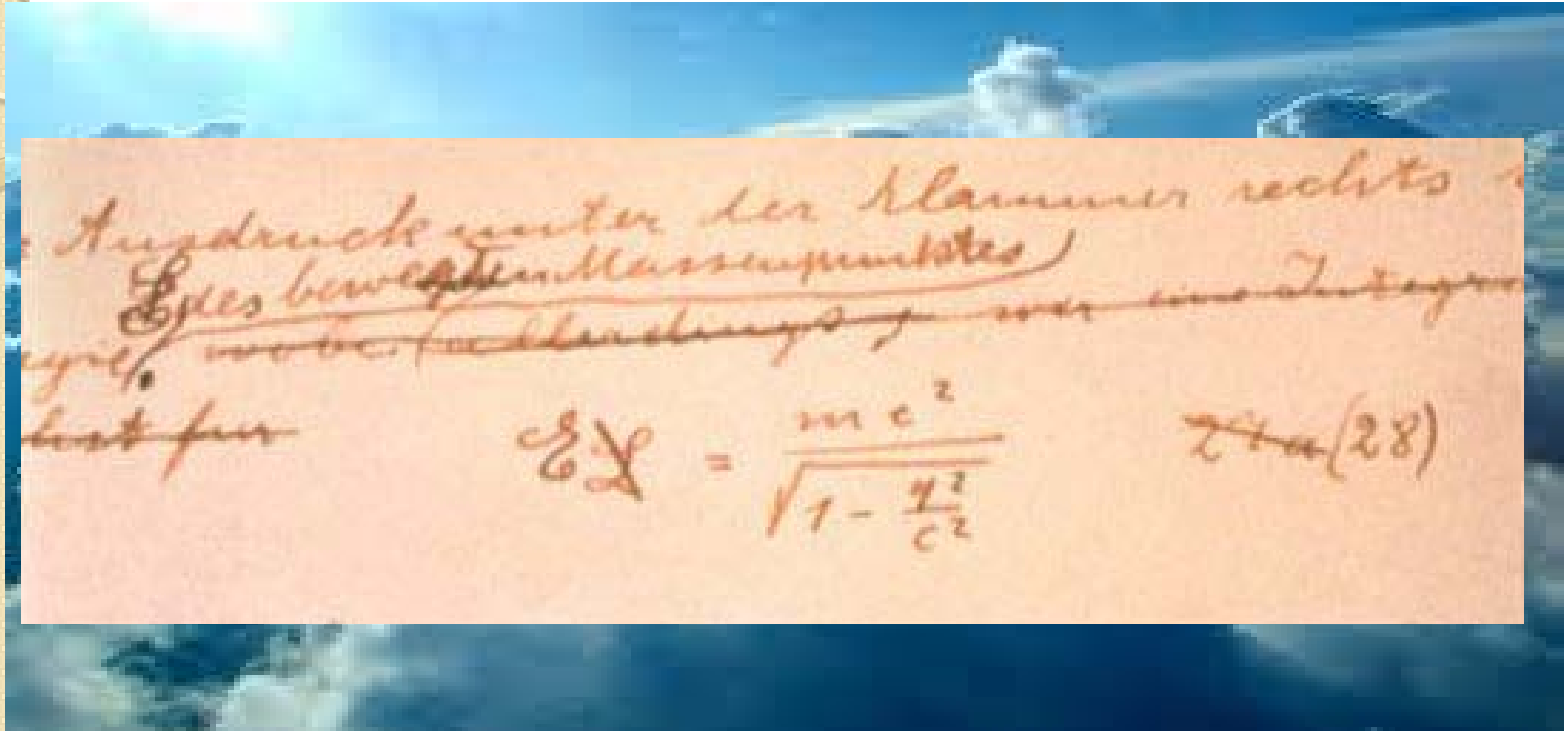
Writing on the Clouds

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UWORCS 2012, Western University

The Purpose



Describe an architecture and implementation of a cloud-based handwriting recognizer.

Motivation

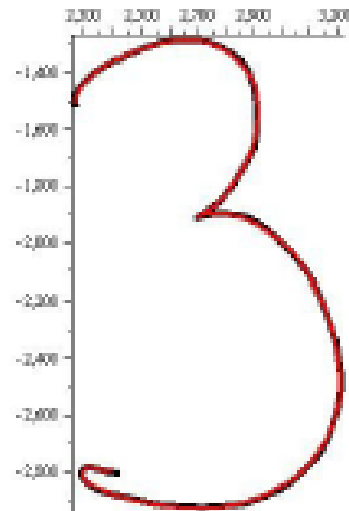
- Access from *anywhere*.
- Access from *any device*.
- Pool of *training* data.
- Pool of *corrections*.
- *Synchronization* of training data across multiple devices.

Organization of the talk

- Digital handwriting/recognition preliminaries.
- Cloud-based infrastructure for handwriting.
- Implementation.
- Experimental evaluation.

Digital *handwriting*

- Represented as a sequence of points
 $(x_0, y_0), (x_1, y_1), (x_2, y_2) \dots$
- Each point contains one value of certain channel



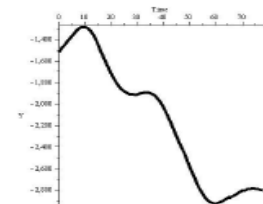
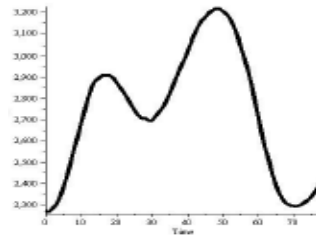
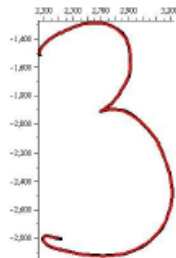
Decomposition of channels

- Consider X and Y coordinates separately, as functions, say, of time:

- Then

$Y(t)$

$X(T)$



Approximation of a character

- A function can be approximated with orthogonal polynomials P_0, P_1, \dots :

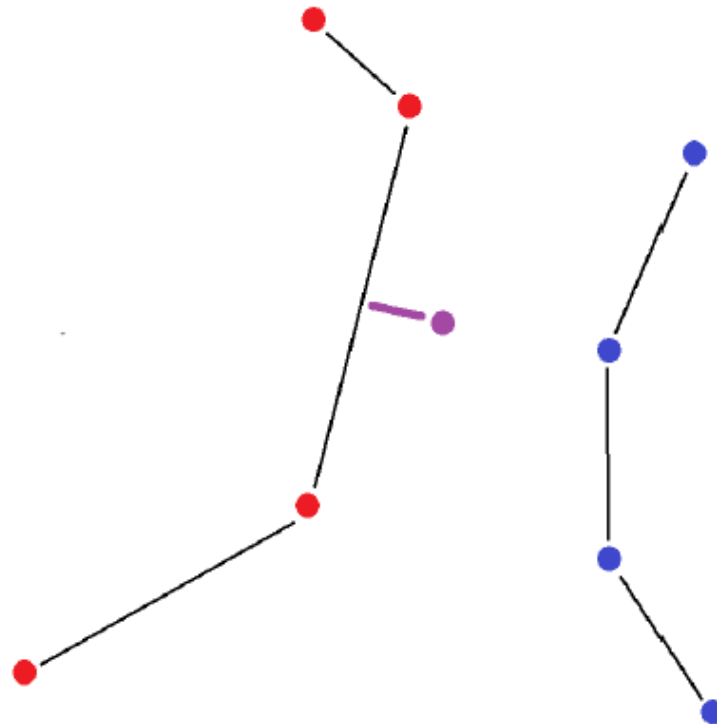
$$f(t) \approx \sum_{i=0}^d c_i P_i(t)$$

- We approximate $X(t)$ and $Y(t)$ and obtain

$$c_0^X, c_1^X, \dots, c_d^X, c_0^Y, c_1^Y, \dots, c_d^Y$$

Classification

- Classification is based on the distance to convex hulls of nearest neighbours.

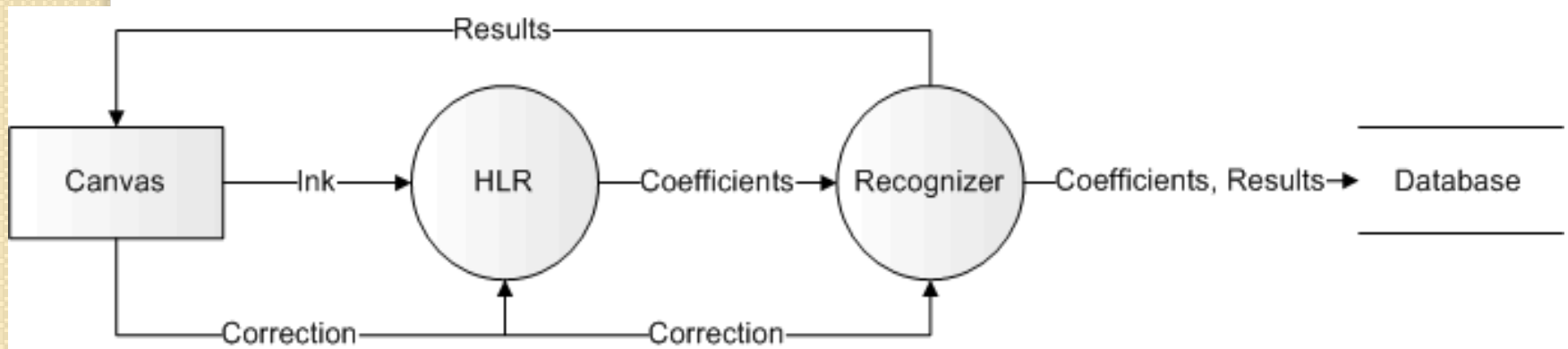


Cloud computing

- Allows remote, distributed storage and execution.
- Relieves clients from software maintenance.
- Facilitates service provider with easy development and update.

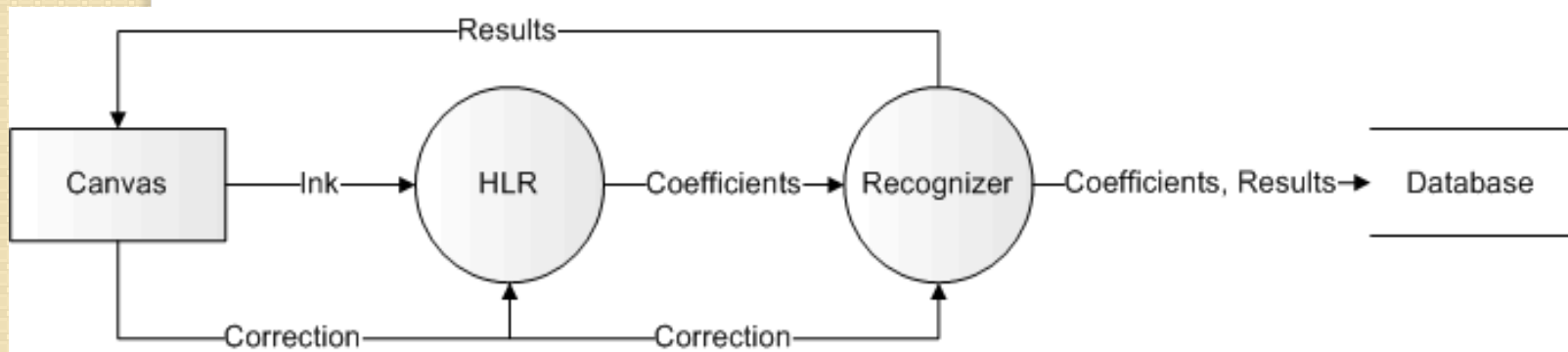
System Overview

- Canvas
- HLR (High-Level Recognizer).
- Recognizer.
- Database.



Recognition Flow

- Ink is sent to HLR.
- Coefficients are sent to the recognizer.
- Recognition results are returned to the canvas.
- The recognition engine can be implemented as a web service.



SOAP message with coefficients

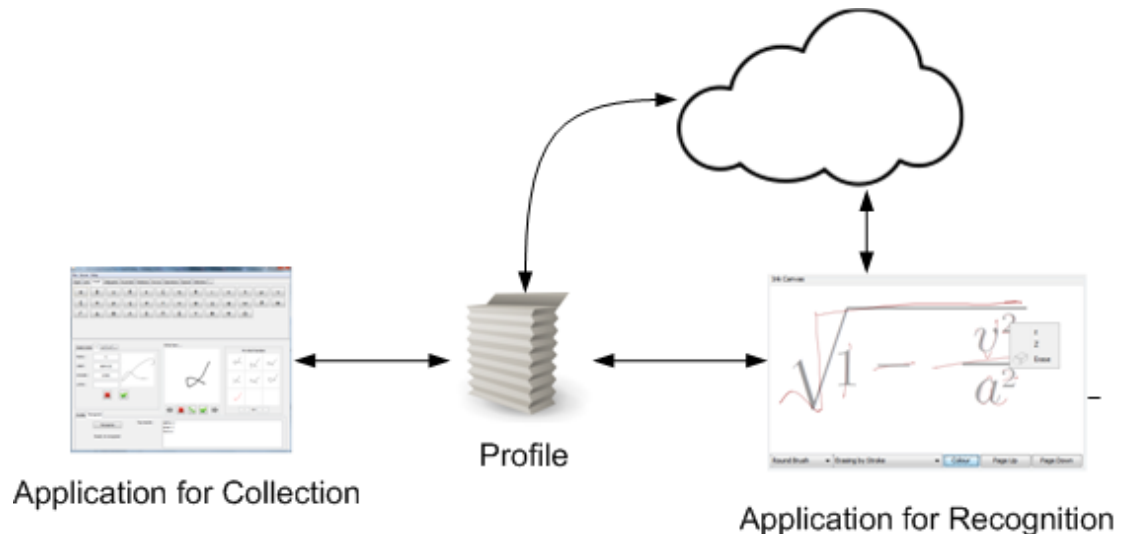
```
...  
<soap:Body xmlns:m="http://www.inkml.org/processing">  
  <m:Process>  
    <m:mt>0.005;94;-91;11;2;-14;64;-70;  
      -18;1;-75;14;14;8;4;-2;4;0;-9;5;10;-11;5;</m:mt>  
  </m:Process>  
</soap:Body>  
...
```

SOAP message with recognition results

```
...  
<soap:Body xmlns:m="http://www.inkml.org/processing">  
  <m:ProcessResponse>  
    <m:Unicode>0030, 004F, 006F</m:Unicode>  
  </m:ProcessResponse>  
</soap:Body>  
...
```

Implementation

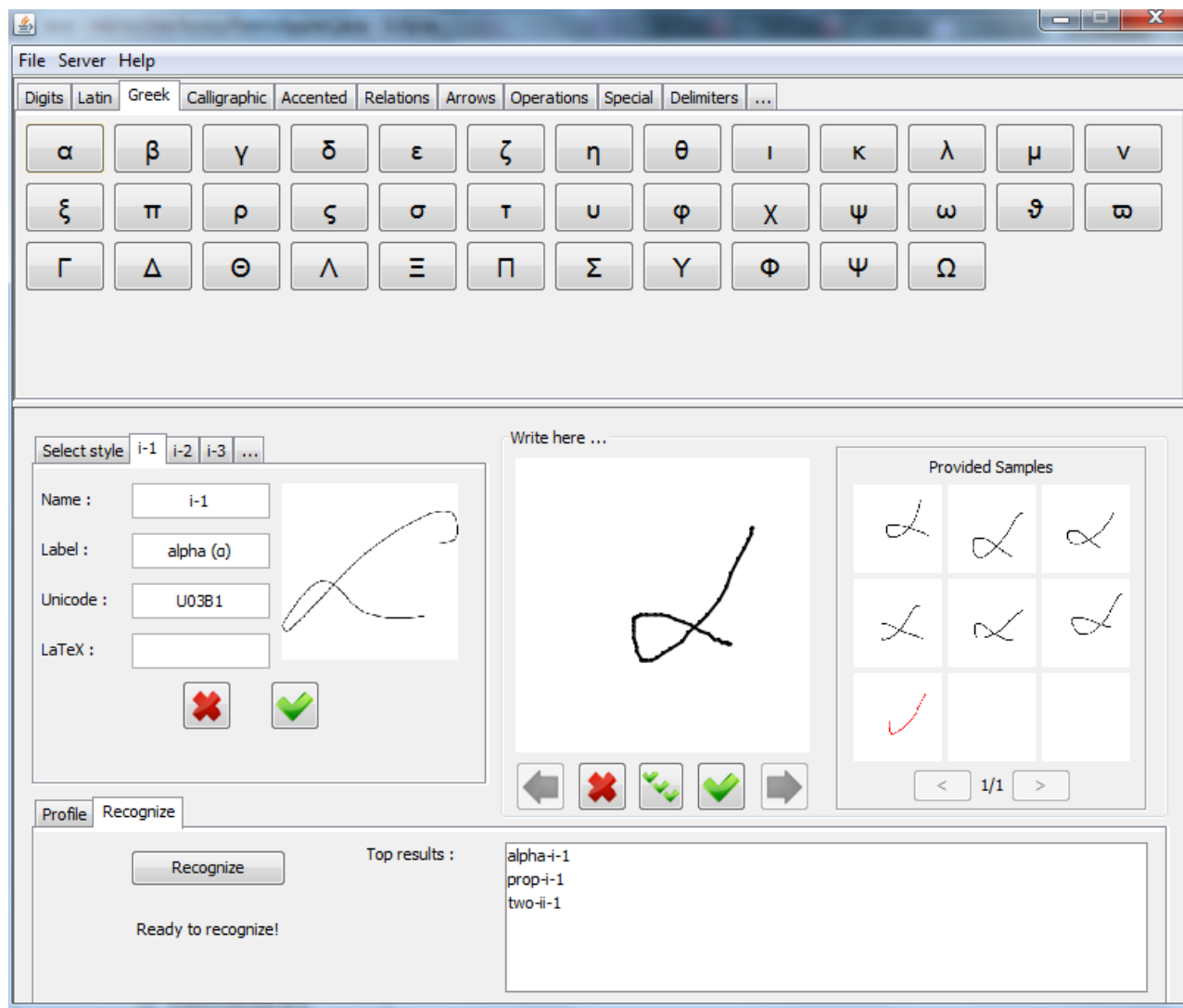
- The implementation contains the following parts
 - A user interface for training.
 - A user interface for recognition (ink canvas, HLR and recognizer).
 - A cloud.



3-Tier Implementation

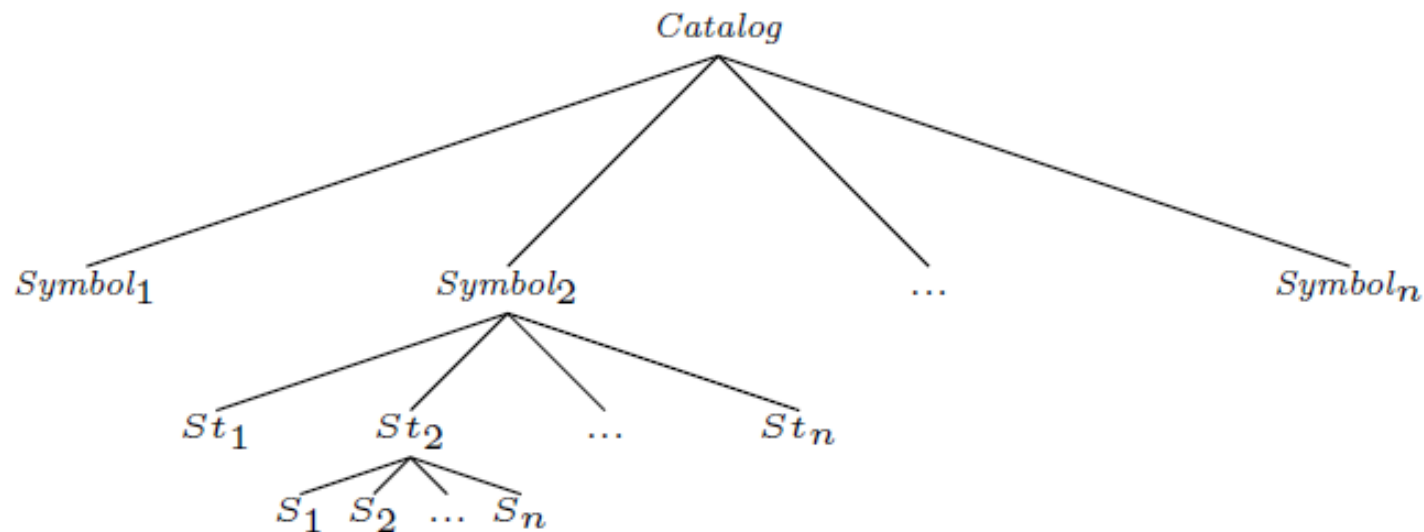
- The client applications for collection, recognition and the application server have been developed in Java.
- Requests to the application server are routed through a web server.

Client Application for Collection of Characters



Profile (dataset of samples)

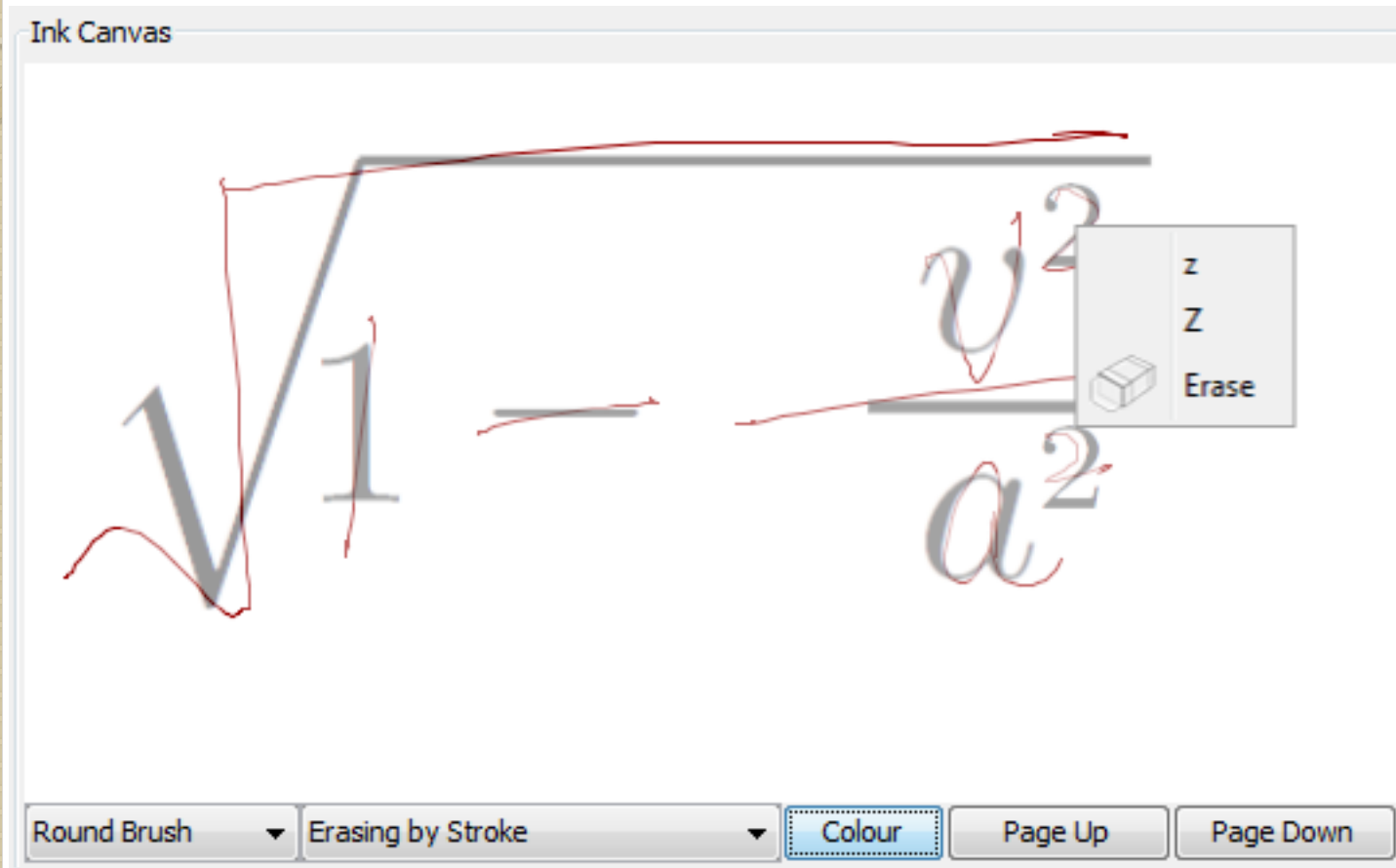
- Training samples form profiles.
- A profile is a hierarchical container of
 - Catalogs, Symbols, Styles, and Samples



Profile, cont.

- Each user can have several profiles.
- *System* profiles can be also available.
- Profiles are saved in XML documents.
- A coefficient can be substituted with $[127c]$, where $[x]$ is rounding of x to an integer

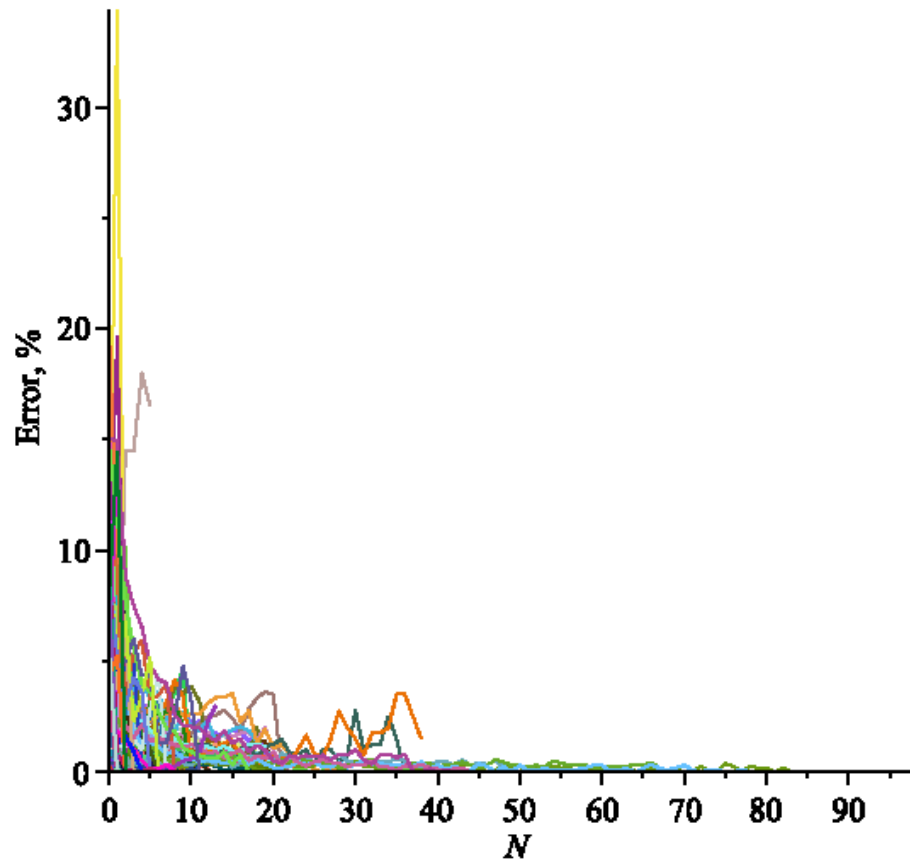
Client Application for recognition



Experimental Evaluation

- Simulation of decrease in the classification error depending on a user's input size.
- The application is initially trained with a default dataset.
- After recognition the sample is added to the training set.

Results



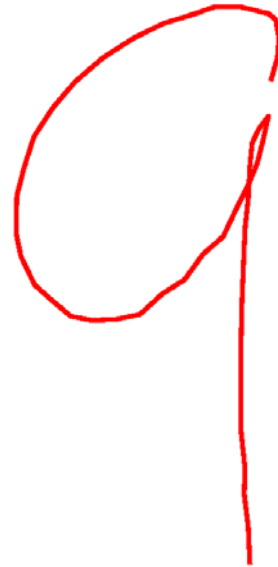
The average recognition error of the $(N+1)$ -th sample in a class among all classes by an author. All authors are shown in the plot.

Case studies: Manipulation of Clouds

- Classes of characters form clouds in high dimensional space.
- Set theory and computational geometry become applicable for different operations on the clouds of characters.

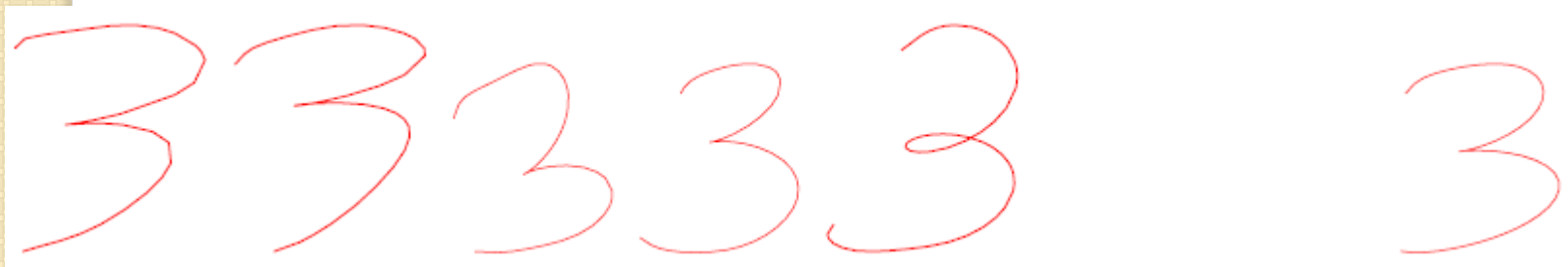
Manipulation of Clouds: Example 1

- An intersection of sets will produce samples written in an ambiguous way, e.g. a sample from the intersection of “9” and “q”:



Manipulation of Clouds: Example 2

- Computing the "average" character, as the center of mass of samples in a cluster, and using the character in calligraphic rendering of recognized samples



Conclusion

- We presented a cloud-based framework for recognition of handwriting.
- The framework can be extended to other machine-learning models (voice-/image-analysis).
- Experimental results demonstrate the framework to be highly effective.

Thank you!

