A FISH called WANDA

WANDA: A Measurement Tool for Forensic Document Examiners

Measurement Science and Standards in Forensic Handwriting Analysis,
NIST Campus, Conference & Webcast 4./5. June 2013

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NISlab™

A FISH called WANDA, 2013

Katrin Franke, PhD, Professor

- Professor of Computer Science, 2010
  PhD in Artificial Intelligence, 2005
  MSc in Electrical Engineering, 1994
- Industrial Research and Development (19+ years)
  Financial Services and Law Enforcement Agencies
- Courses, Tutorials and post-graduate Training:
  Law Enforcement, BSc, MSc, PhD
- Chair IAPR/TC6 – Computational Forensics, 2008-2012
- IAPR Young Investigator Award, 2009
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Disclaimer

- The following slides have been published previously, i.e.

- Franke, K., Schomaker, L., Vuurpijl, L., Giesler, S. (2003). FISH-New: A common ground for computer-based forensic writer identification (Abstract). Forensic Science International, Volume 136(S1-S432) p. 84, Proc. 3rd European Academy of Forensic Science Triennial Meeting, Istanbul, Turkey.

- Franke, K. (2004). Digital image processing and pattern recognition in the forensic analysis of handwriting (Abstract). In Proc. 6th International Congress of the Gesellschaft für Forensischen Schriftenuntersuchung (GFS), Heidelberg, Germany.

- Franke, K., Rose, S. (2004). Ink-deposition model: The relation of writing and ink deposition processes. In Proc. 9th International Workshop on Frontiers in Handwriting Recognition (IWFHR), Tokyo, Japan, pp. 173-178.

FISH-new:
A Common Ground for Writer Identification

Katrin Franke,
Fraunhofer IPK,
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Lambert Schomaker,
Rijksuniversiteit Groningen,
The Netherlands

Louis Vuurpijl,
Nijmegen University,
The Netherlands

Stefan Giesler,
Freiburg, Germany

Demands in Forensic Science

- Objective measurement and classification,
- Robustness and Reproducibility of the results,
- Secure against Falsifications.

Initiation, Extension and Adaptation of Computer-based investigation methods

Method:

Combining specific Knowledge from

- Forensic handwriting examination,
- Computer vision, and
- Pattern recognition.

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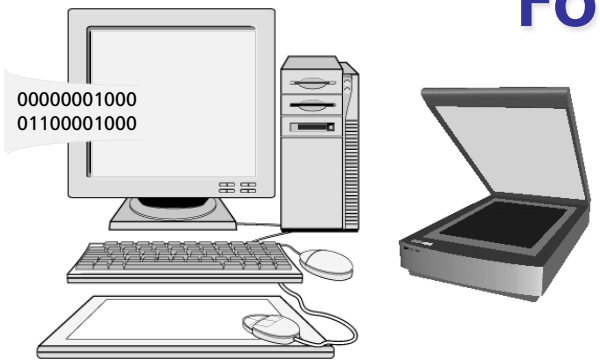
Forensic Information System Handwriting

Computer-based Forensic handwriting examination



Systems operating in forensic labs:

- SCRIPT (NIFO/TNO, Netherlands) and
- FISH (Bundeskriminalamt, Germany)

Forensic InformationSystem Handwriting

Since 1988 FISH is operating in forensic labs, handwriting is:

- Classified by shape characteristics,
- Compared with database,
- Presented according recognized similarities,
- Digitally stored, and
- Managed.

FISH Database*:

77.000 Investigation cases,
17.500 Handwritten products,
32.000 Persons,
78.000 Identifications of persons,
86.000 Documents.

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* *(31th December 1997)*

Strategic Meeting:
November 28th-29th, 2001

Initiator:
Bundeskriminalamt,
Germany,

Guests:
Netherlands
Forensic Institute,
The Netherlands,
US Secret Service, US,
FBI, US.

Fraunhofer IPK,
Gfal, Germany
Nijmegen University,
Rijksuniversiteit Groningen,
The Netherlands,

Status quo in November 2001 *

- Common Standards are lacking
- Systems become outdated
- Improvements can be expected,
  If state-of-the-art methods in
  pattern recognition are used

* Project: Vergelijk -
Comparison of the Script and the FISH system
Contracting Entity: Netherlands Forensic Institute - (2000)
Performed at: NICI - Nijmegen University,
L. Schomaker and L. Vuurpijl

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Timeline: A FISH called WANDA

- 1997
  Fraunhofer IPK project by BKA/BMI - “ESD”
  Modular system for the elimination of noisy signals in documents
- 2000
  NICI, Nijmegen University project by NFI - “Vergelijk”
  Comparison of the Script and the FISH system
- 2001
  August - Initial discussions with BKA for new FISH developments
  November, 28th-29th - Strategic meeting at BKA
- 2002
  October, 1st - Official project start
- 2003
  May, 19th – Project –result presentation at BKA
- Until 2006
  Continuous advancement and extension of WANDA modules

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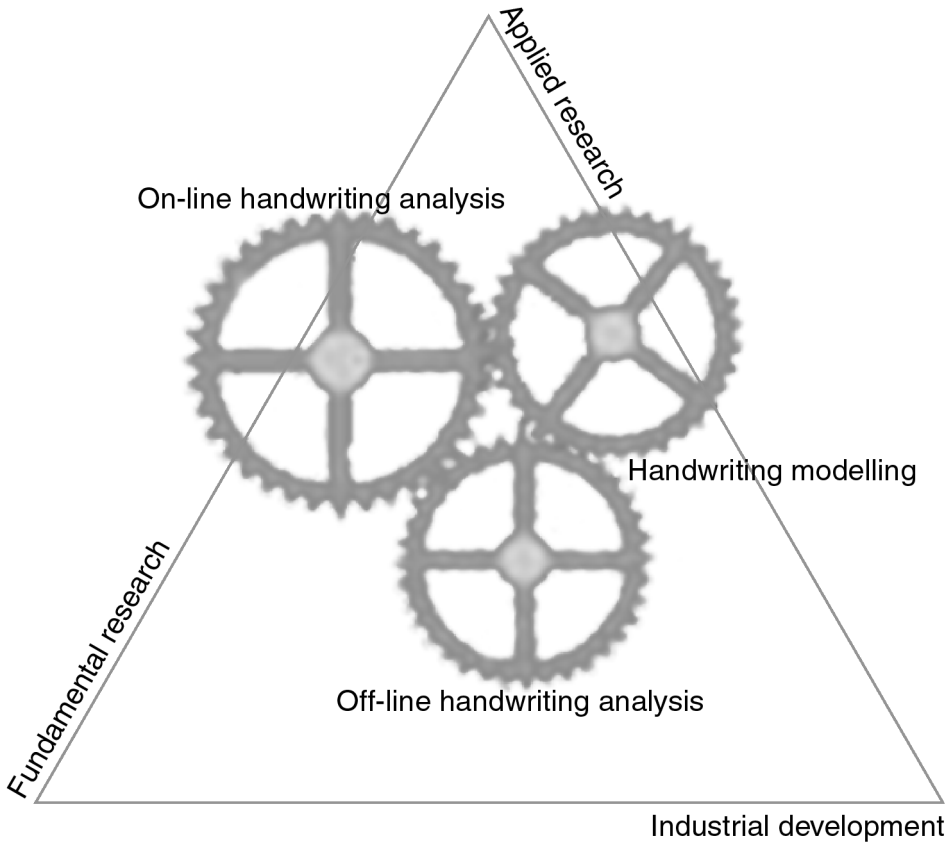
WANDA Team 2003

Fraunhofer Institut Produktionsanlagen und Konstruktionstechnik

Artificial Intelligence Institute, Rijksuniversiteit Groningen

international Unipen Foundation

nici Nijmegen Institute for Cognition and Informa
University of Nijmegen



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Project start:
16th September 2002

WANDA Team 2003

Fraunhofer Institut Produktionsanlagen und Konstruktionstechnik

Artificial Intelligence Institute, Rijksuniversiteit Groningen

international Unipen Foundation

nici Nijmegen Institute for Cognition and Information University of Nijmegen

- Off-line and on-line handwriting analysis
- Forensic signature analysis

- Motor-control theory
- Pattern recognition and Image processing
- System engineering

- Fundamental and Applied Research
- Industrial Development

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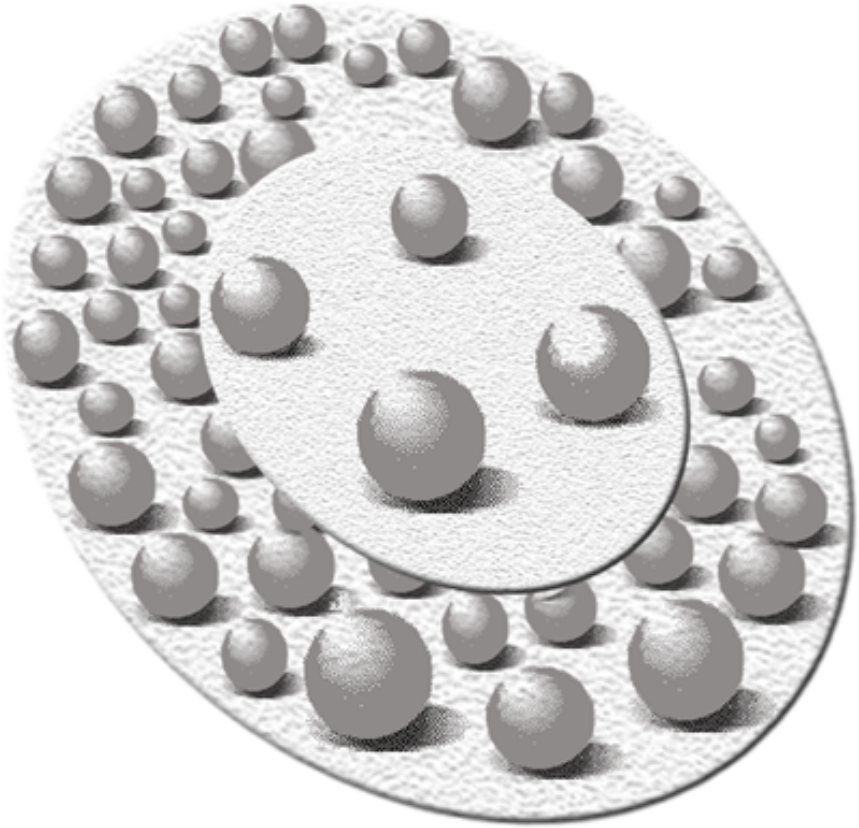
Project start:
16th September 2002

Project Participants



Fraunhofer IPK
Altug Metin
Christian Taubenheim
Christian Veenhuis
Katrin Franke
Mario Köppen
Martin Peng
Nino Palavandishvili
Ottmar Bünnemeyer
Steffen Rose
Tomas Kühn
Wolfgang Penk
Xiufen Liu

iUF / RUG
Geertie Zwarts
Isabelle Guyon
Johan Everts
Lambert Schomaker
Maarten Jacobs

NICI
Hubert Voogd
Louis Vuurpijl
Maartijn Beenders
Merijn van Erp

SWE
Stefan Giesler

Bundeskriminalamt
Werner Kuckuck
Axel Kerhoff
Manfred Philipp
Hartmut Gieschen

LKA Berlin
Gerhard Grube
Reinhard Zschach

Katrin Franke
Lambert Schomaker
Louis Vuurpijl
Stefan Giesler

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Overall idea

Standardization of the data-format,
Modularization and Extensibility in system concept,
Objectification in measurements and Replicability of results.

Usage of stable standards:

Programming language Java on clients and general server

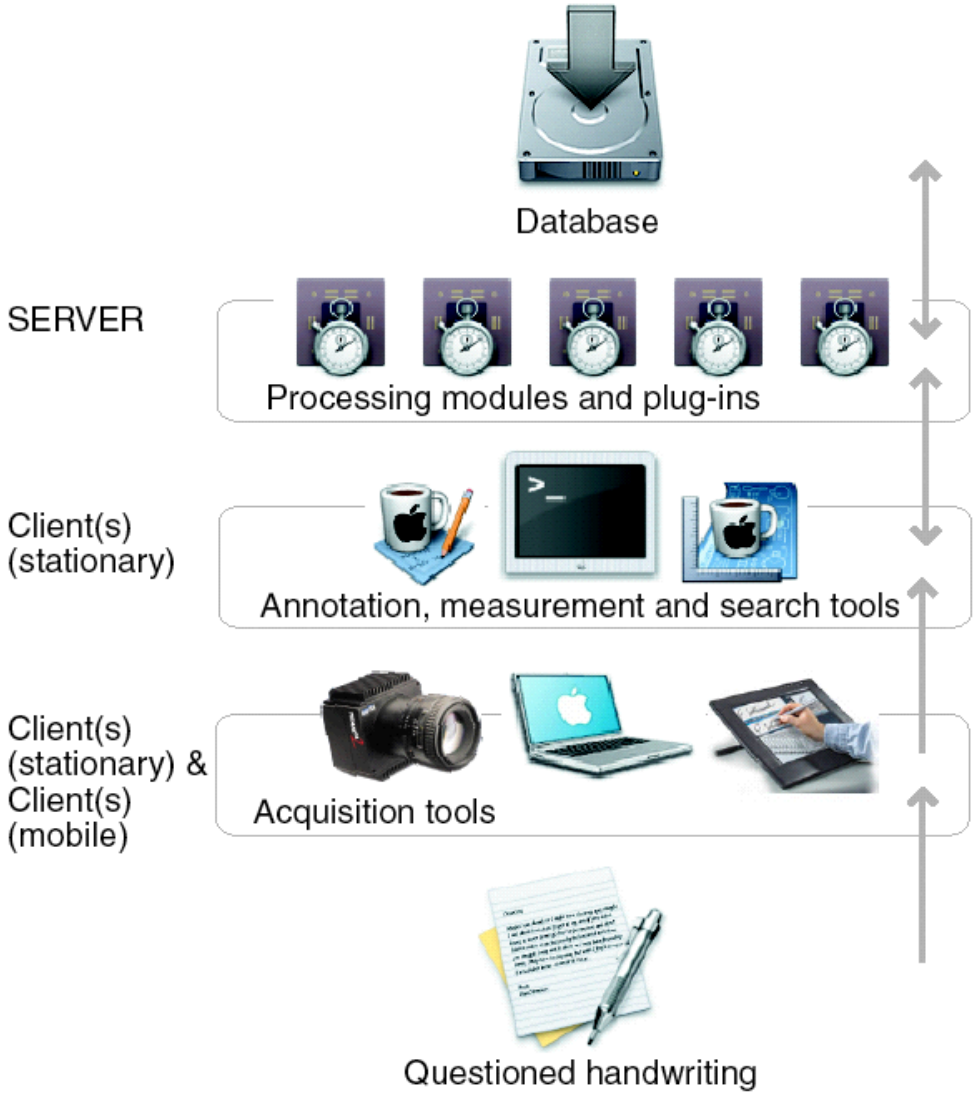
Data interchange language XML (Extensible Markup Language).

XML everywhere:

- System configuration and plug-in specification,
- Data transfer protocol,
- Data modeling and annotation, and
- Journaling of data processing.

Framework concept

- User interacts via Java client
- Client is the front-end for accessing & processing information
- Information is distributed over and hosted by trusted servers
- Via their clients, users request services provided by the servers



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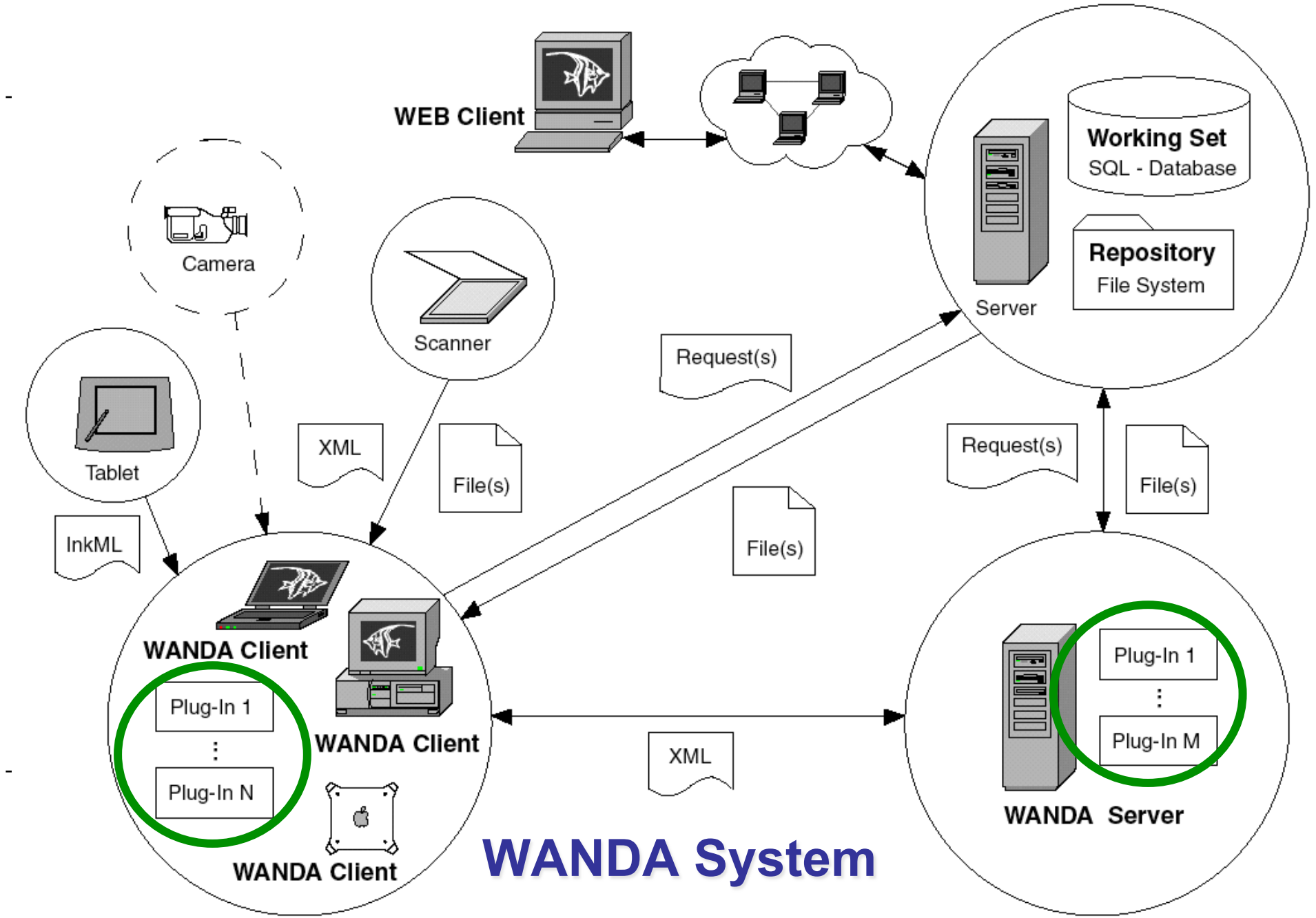
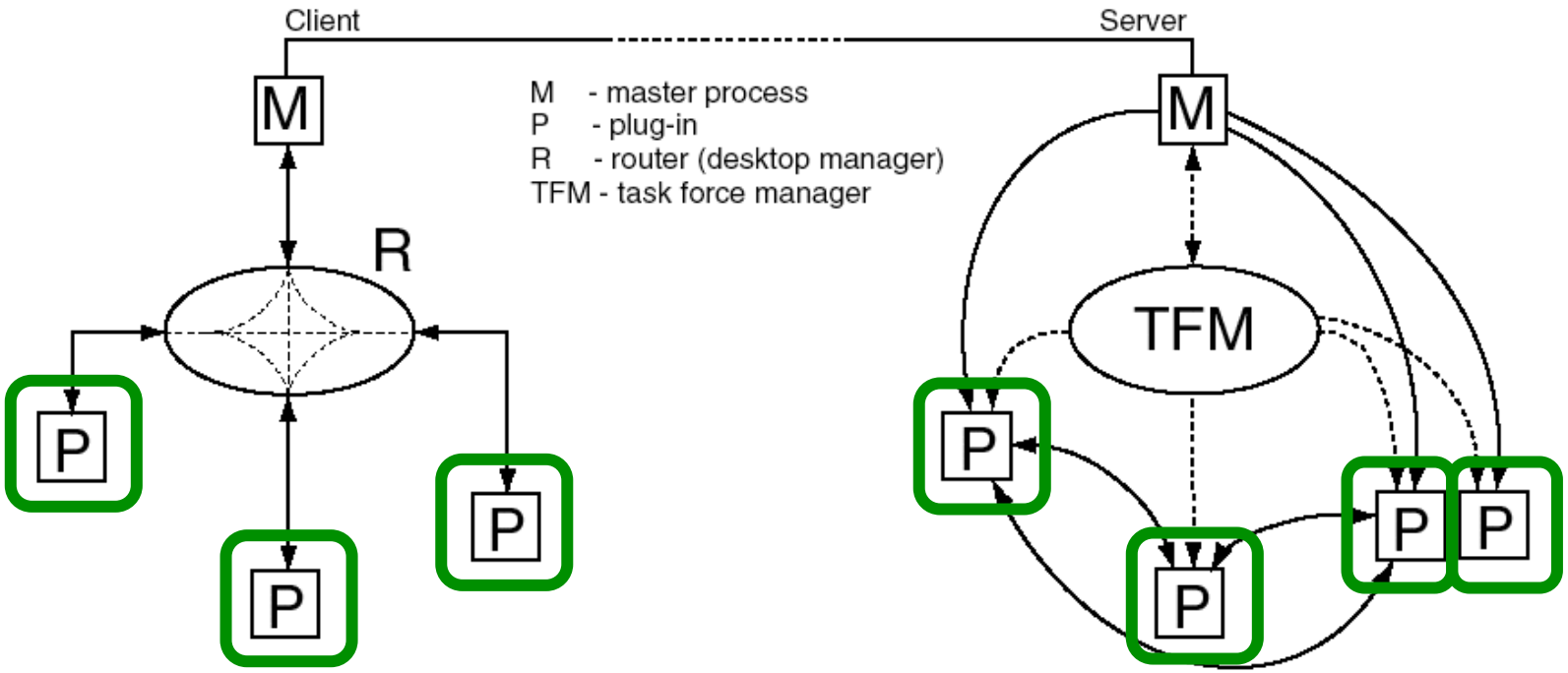

WEB Client
Working Set
SQL - Database
Repository
File System
Server
Camera
Scanner
Tablet
InkML
XML
File(s)
Request(s)
File(s)
Request(s)
File(s)
WANDA Client
Plug-In 1
Plug-In N
WANDA Client
WANDA Client
XML
Plug-In 1
Plug-In M
WANDA Server
WANDA System

Plug-In Concept I



a) Client plug-in organization - Master-slave point to point via Router

b) Server plug-in organization - Partial / Full connectivity

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```
<client_plugin
  name="wandaWriter">
  <description>
    Writer Annotation
  </description>
  <platform name="all"/>
  <module
    exec="writer.Writer"
    type="client"/>
  <lib value="writer.jar"/>
  <icon
    value="writer/writer.png"/>
  <menu
    category="annotation"
    toolbar="true"/>
  <style
    resizable="false"
    maximizable="false"
    iconifiable="true"/>
</client_plugin>
```

Plug-In Concept II

- Costumer tailored system
  Investigation Bureaus and/or Forensic Laboratories
  Signature Analysis and/or Writer Identification System
  Local Network and/or Remote Access
- Integration / Connection to systems at work
- System updates and Extension to latest developments without Framework adaptation - plug-and-play
- Standardization of Investigation Methods
- Research Platform

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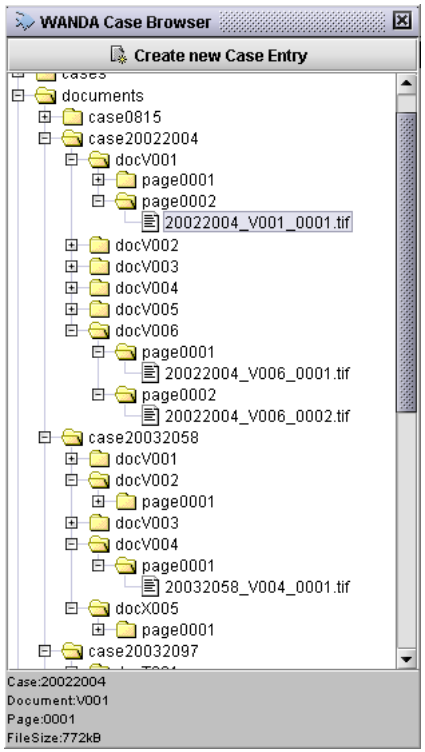
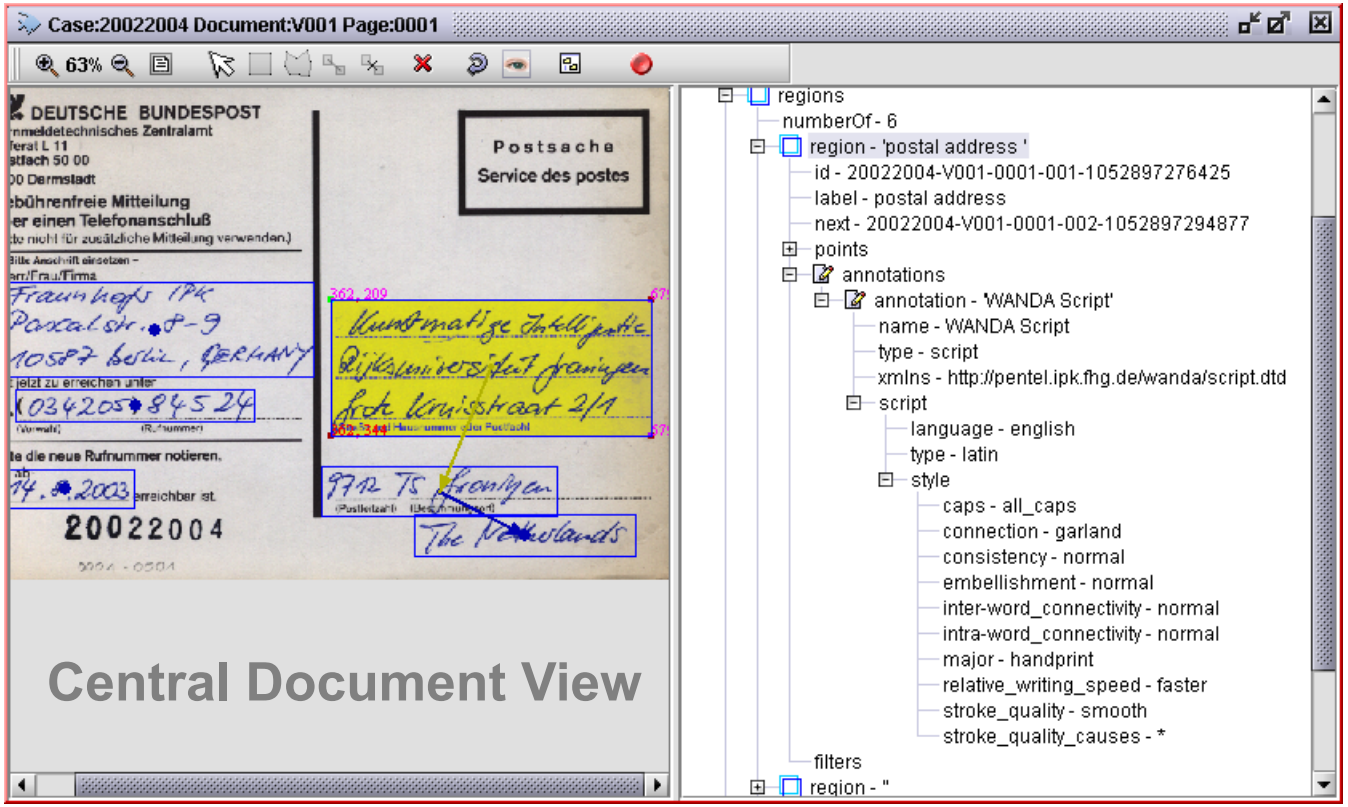
Client desktop with Plug-In modules



Case Browser



Central Document View

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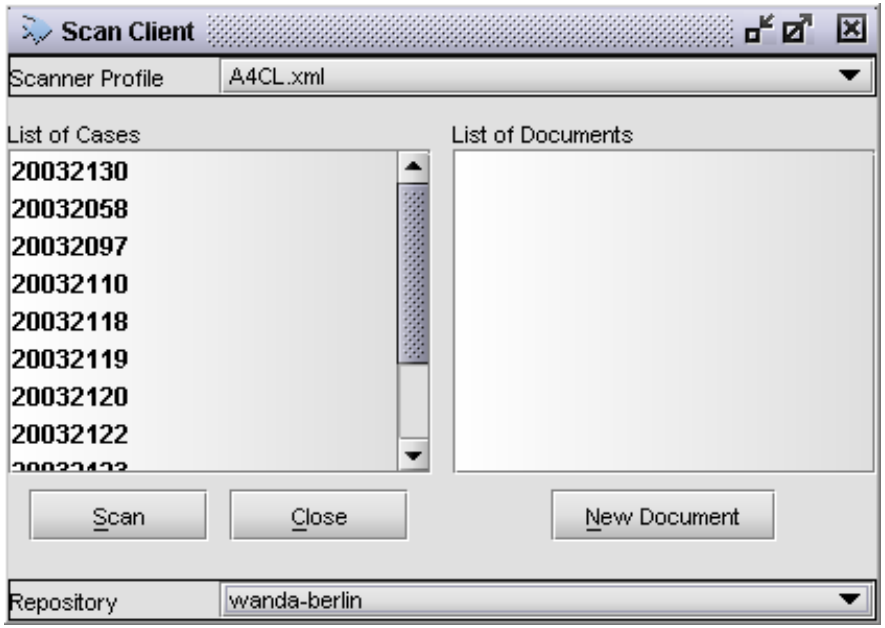
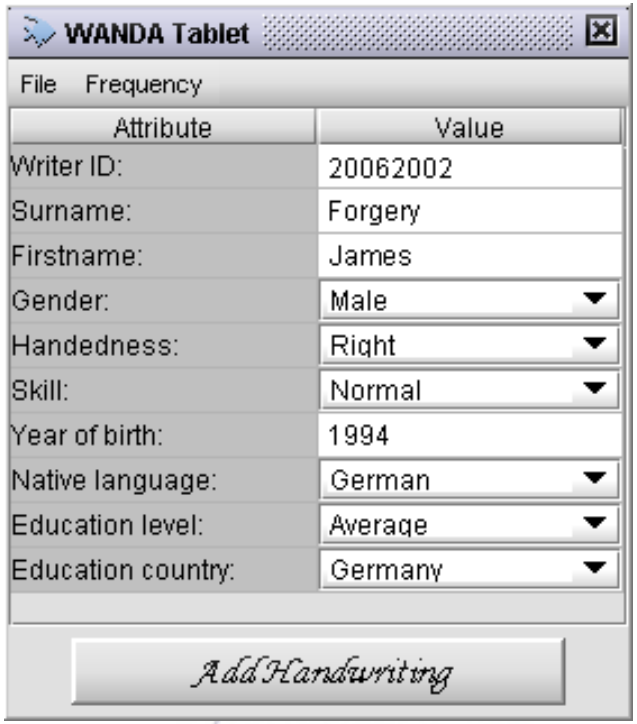
WANDA Scan and WANDA Tablet Plug-In





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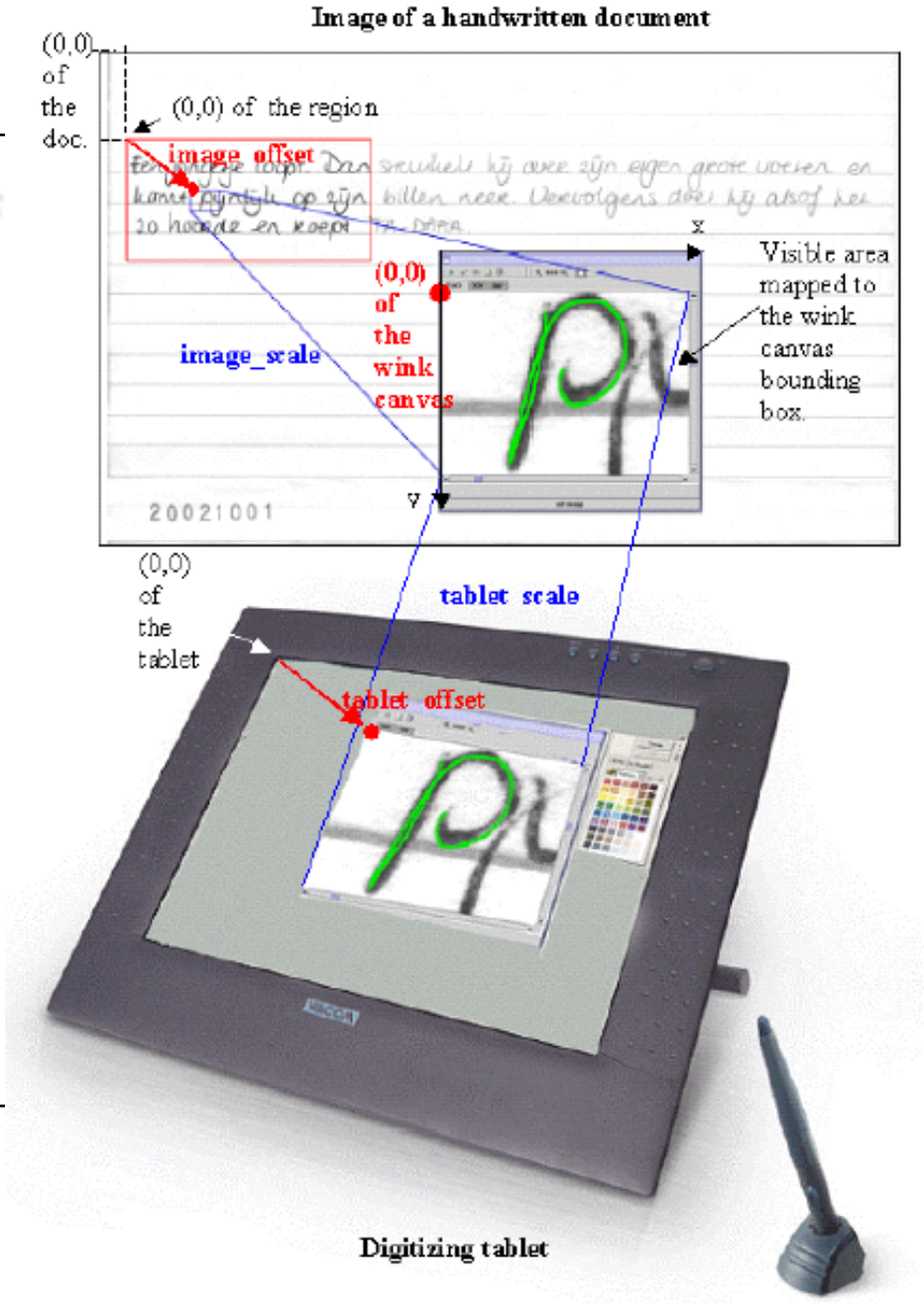
Combined processing of on- and offline data

- “Simple” reconstruction of the writing sequence
- Direct tracing of the handwritten stroke, e.g. for measurements of loop sizes, stroke width or ink deposit
- Assignment of on-line and off-line handwriting characteristics
- Off-line specimens synthesis



K. Franke, L. Schomaker, W. Penk 2003.

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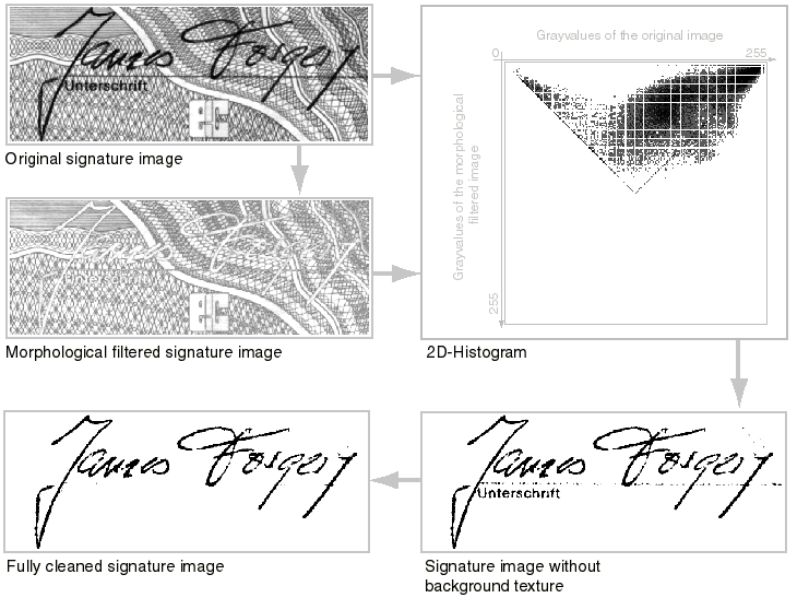
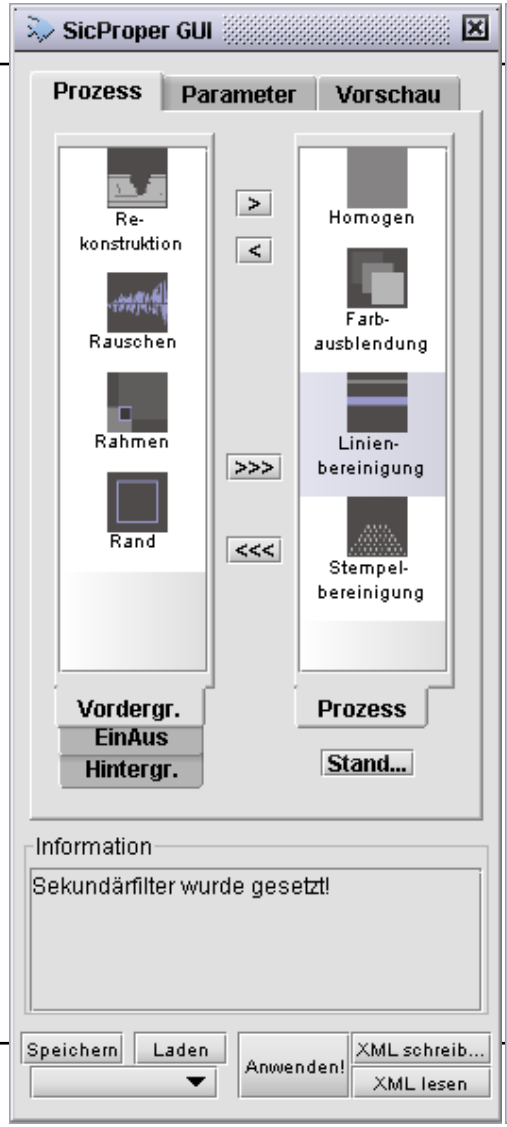
WANDA Clean Plug-In



K. Franke & M. Köppen 1999.



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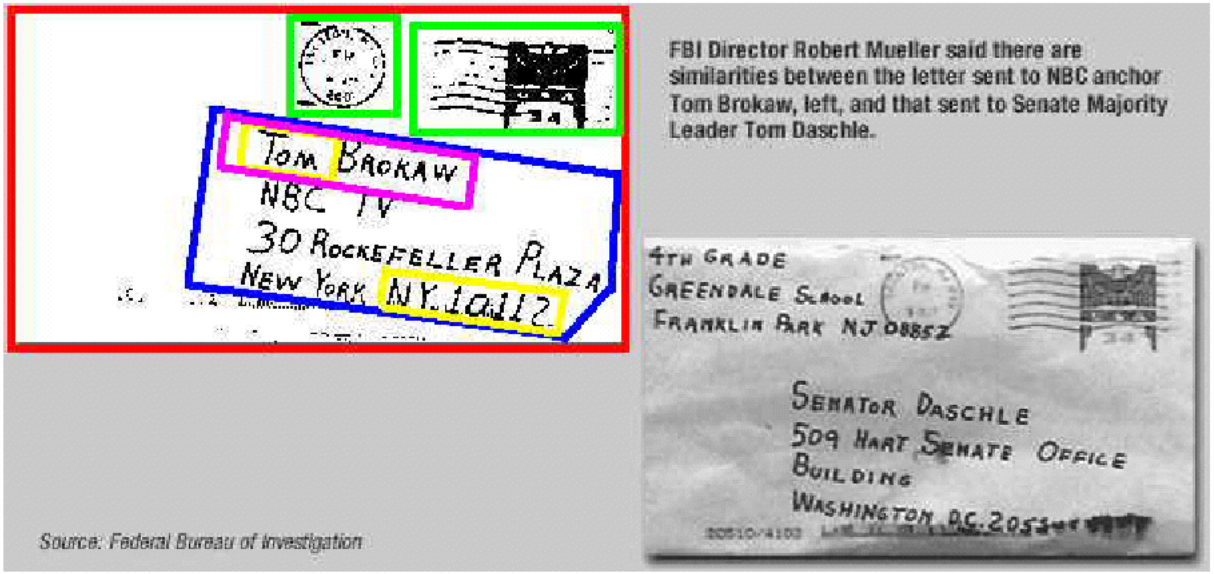
WANDA Annotation Plug-Ins

Concept for the Description of Handwriting Characteristics.

- Script
- Writer
- Content
- Material



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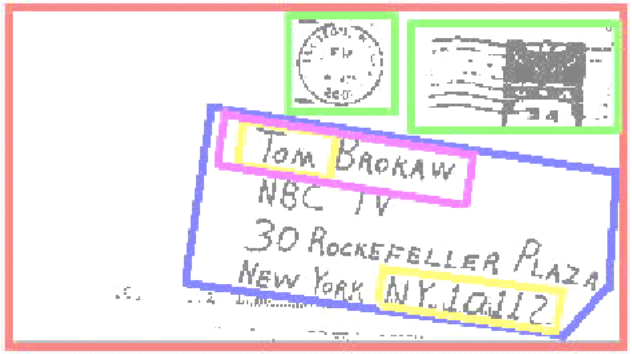
Script

- Usage of established categories
- Usage of unambiguous level
  - low
  - medium
  - high



Script Annotation

Attribute	Value
Script	
Type	Latin
Language	English
Style	
Type	Handprint
Caps	All Caps
Connection	Garland
Consistency	*
Embellishment	*
Stroke Quality	Smooth
Stroke Quality Causes	Pen Defect
Inter-word Connectivity	*
Intra-word Connectivity	*
Relative Writing Speed	Normal

Accept Cancel

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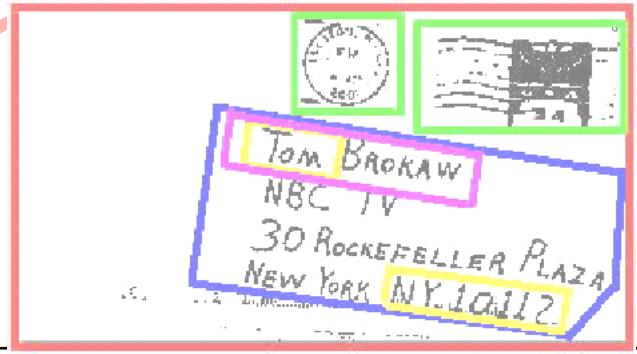
Content - Verbatim

Content Annotation

Attribute	Value
Document	
Type	Greeting Card
Intent	Public
Textblock	
Type	Addressee Address Block
Length	Paragraph
Textblock - Properties	
Tone	Kind
Grammar	Ok
Spelling	Ok
Textblock - Verbatim	
Verbatim	! Enter Below !
Miscblock	
Type	*

TOM BROKAW
NBC TV
30 ROCKEFELLER PLAZA
NEW YORK NY.10112

Amount of Handwriting
Bridges to Linguistic
Plain text for further usage



Writer

Consideration of
Characteristics that may provide
Clues on handwritings individuality.

Others -> Cases Management

Writer Annotation

Attribute	Value
Writer ID	
ID	20022006
Person	
Firstname	James
Surname	Forgery
Gender	Male
Year of Birth	1994
Properties	
Handedness	Right
Skill	Ok
Educations	
Level	Medium
Country	Germany
Language	
Nativ	German

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Material Annotation

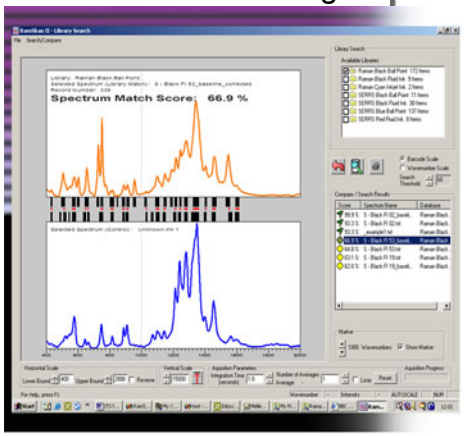
Attribute	Value
Pen	
Type	Ball Point Pen
Product	
Pen - Tip	
Type	Ball Pen
Material	Metal
Diameter	0.5
Flexibility	Low
Pen - Ink	
Viscosity	Normal
Transparence	Opaque
Color	Blue
Product	
Paper	
Type	Bleached
Size	A6
Material	*
Weight	*
Product	
Absorbency	*
Pad	
Type	*
Hardness	Normal
Surface	Even

Material

- Writing instrument
  - Pen tip
  - Ink
- Paper
- Writing pad

Currently only verbal description !

XML-based data storage?!



http://www.fosterfreeman.co.uk

```
#document
  page - 'Telephone Note'
    id -
    label - Telephone Note
    next -
    regions
      numberOf - 1
      region - 'Richard ... Forgery'
        id - 20022004-V005-0001-001-1053289251429
        label - Richard ... Forgery
        next -
        points
        annotations
          annotation - 'WANDA Material'
          annotation - 'WANDA Content'
          annotation - 'WANDA Script'
        filters
          filter - 'WANDA Clean'
    annotations
      annotation -
    filters
```

ESDA

Spectral

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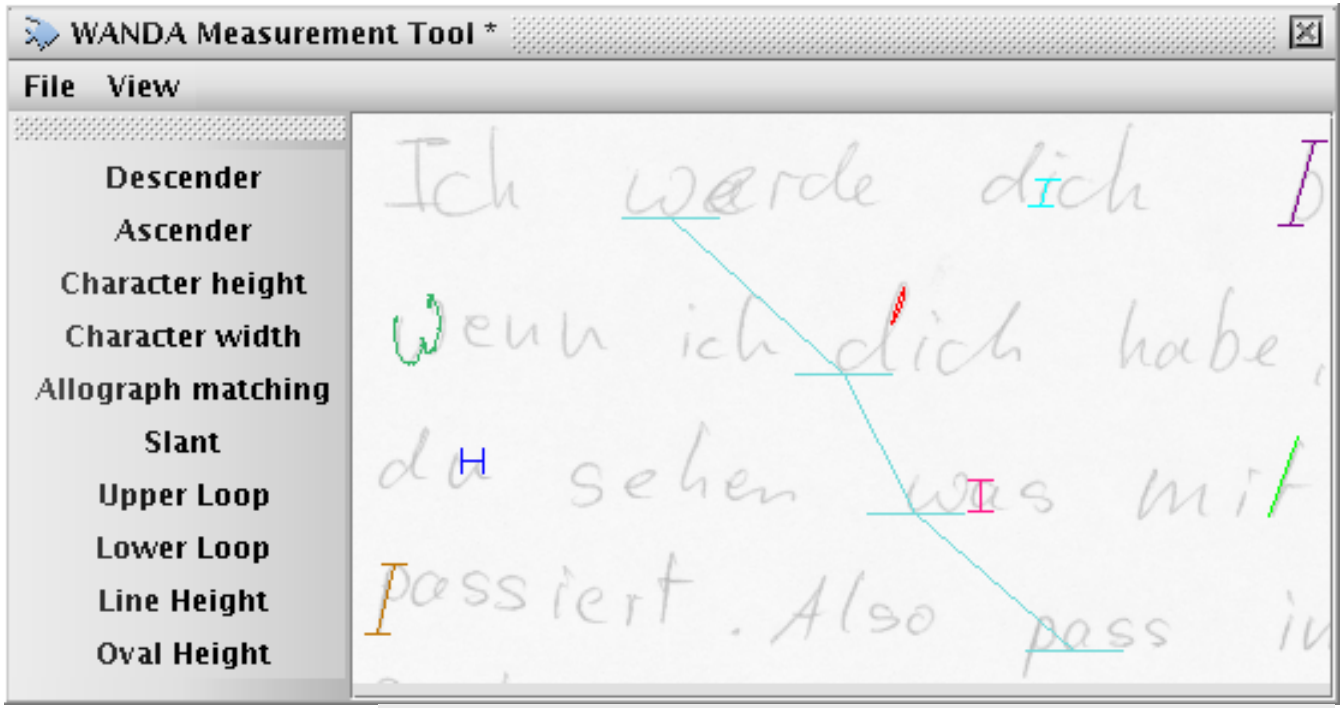
WANDA Measurement Plug-In

WMP



van Erp, Vuurpijl, Franke, Schomaker 2003

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Concepts of the WMP

Measurement	Fish	Script	WMP
Ascender/Descender heights	√	√	√
Corpus heights	√	√	√
Letter widths	√	√	√
Slant	√	√	√
Upper/lower loops	√		√
Line distance		√	√
Word width		√	
Isolate characters	√		√ **(implicit)**
Follow characters	√		√ **(implicit)**
Allograph matching			√

The WMP measures all interactive FISH features and employs the WAM

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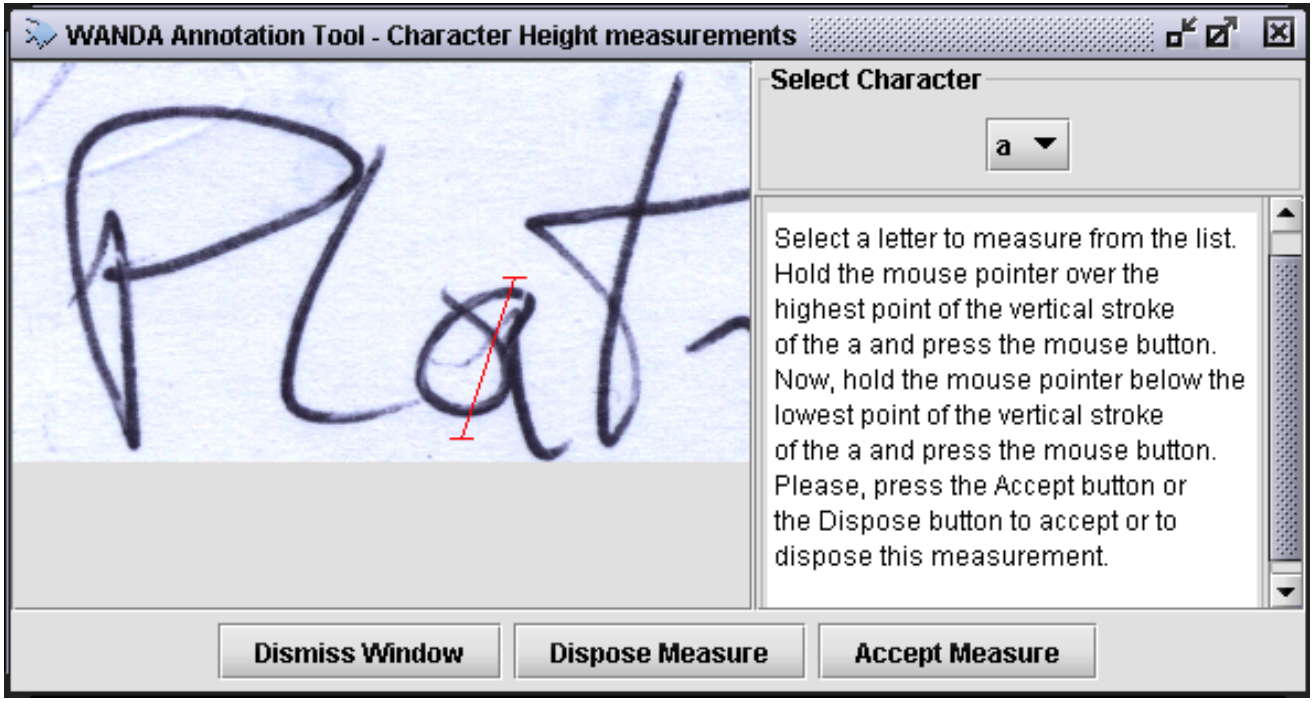
How to use WMP

Interactive selection
Automatic measurement

Online help for novice
Hotkeys for experts



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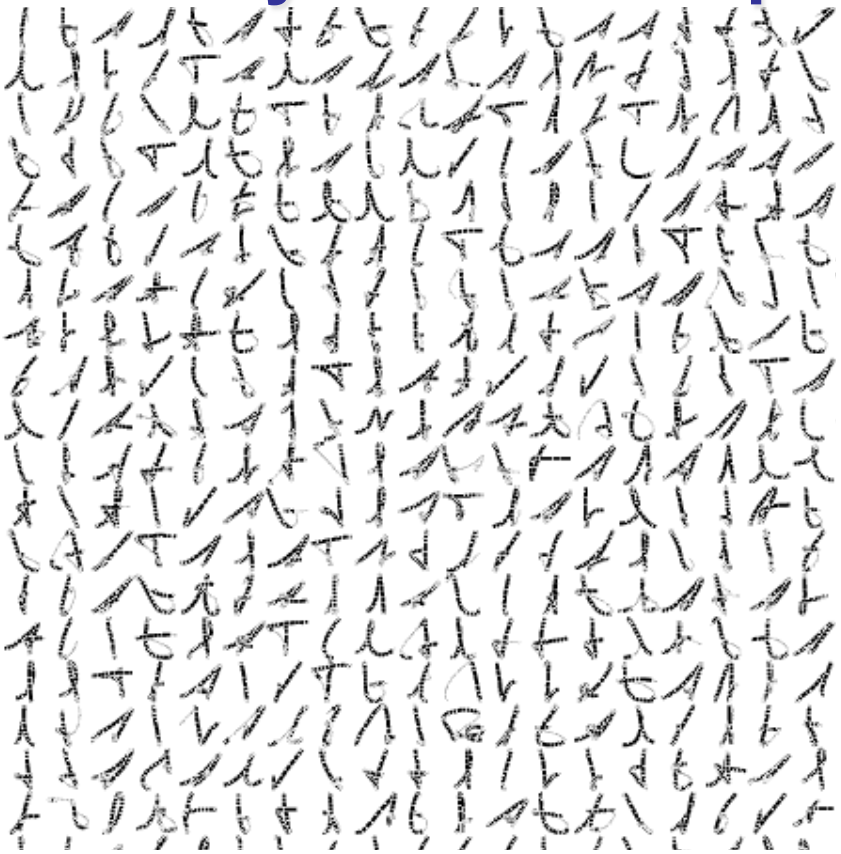
Diversity in letter shapes….



Within and between writer variation:

Exemplars of the character ‘t’

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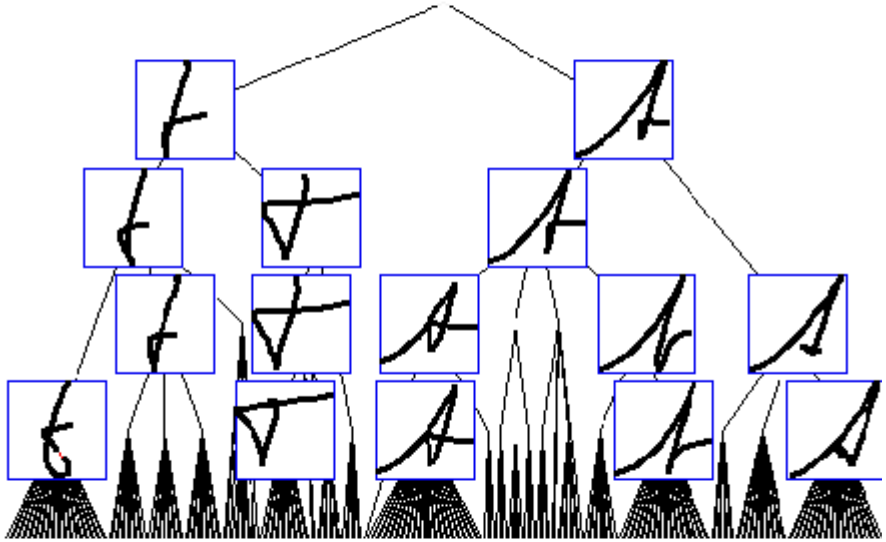
…… and structure through allographs

Finding structure in diversity by use of “n-ary” hierarchical clustering

Vuurpijl & Schomaker 1997



Considered handwritings of
6600 writers from Europe and the US

WAM: Wanda Allograph Matcher

- The document examiner copy-draws the trajectory of a specific character
- Use pattern recognition to match this to the database of prototypical allographs
- Index (annotate) the document as containing an example of this particular allograph
- Allowing for automated writer search
- And uniform labeling of documents

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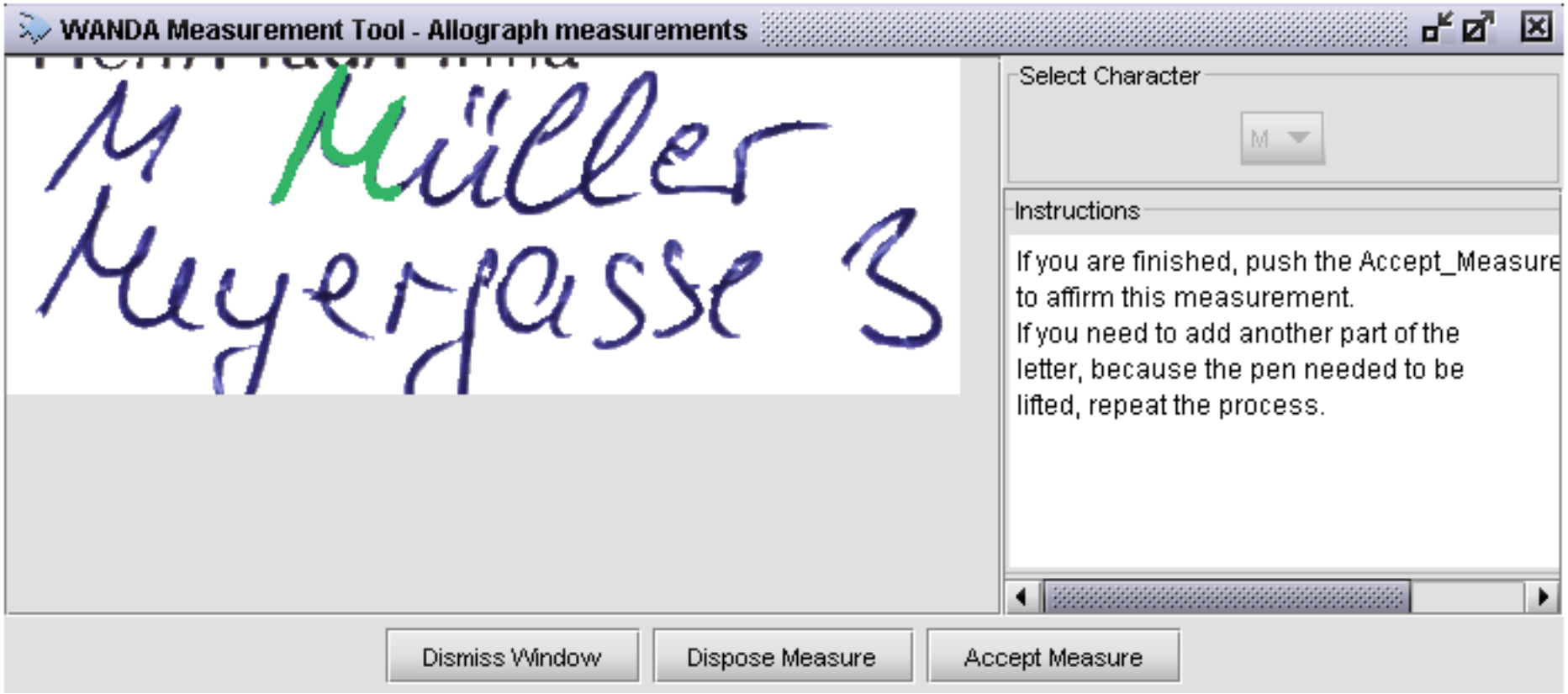
How to use the WAM - Step 1



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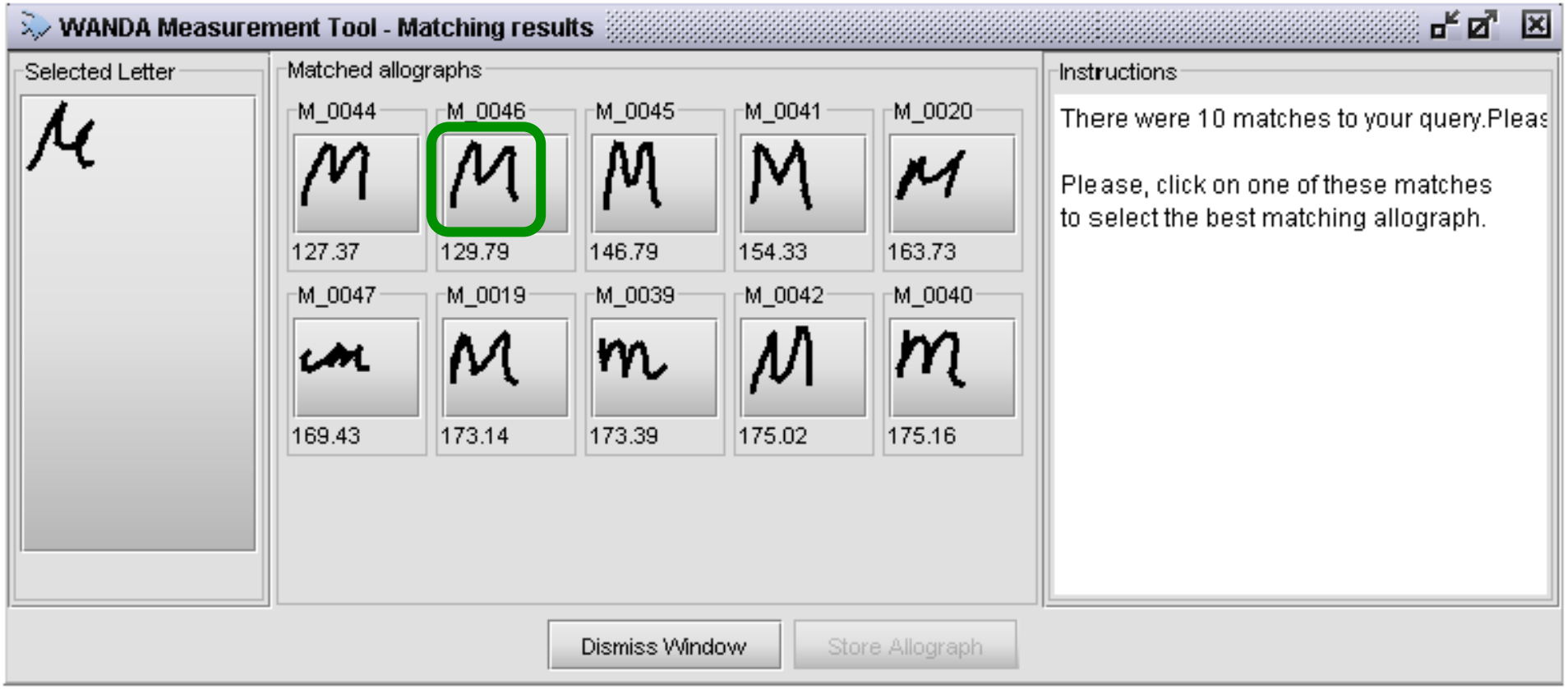
How to use the WAM - Step 2



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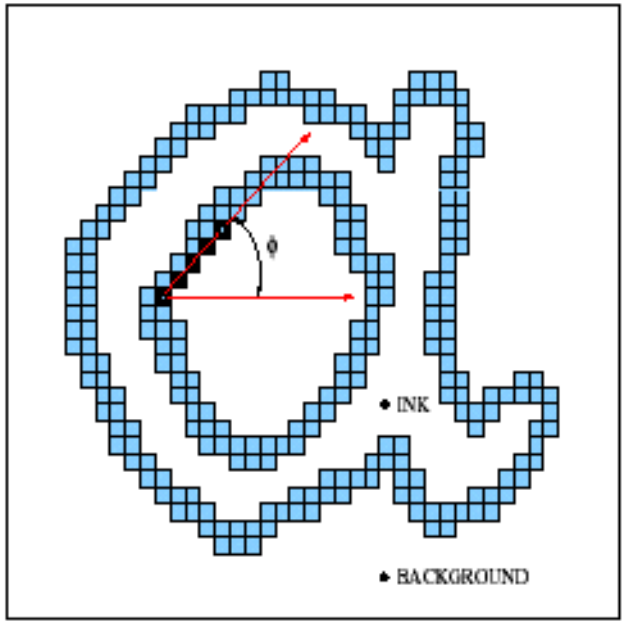
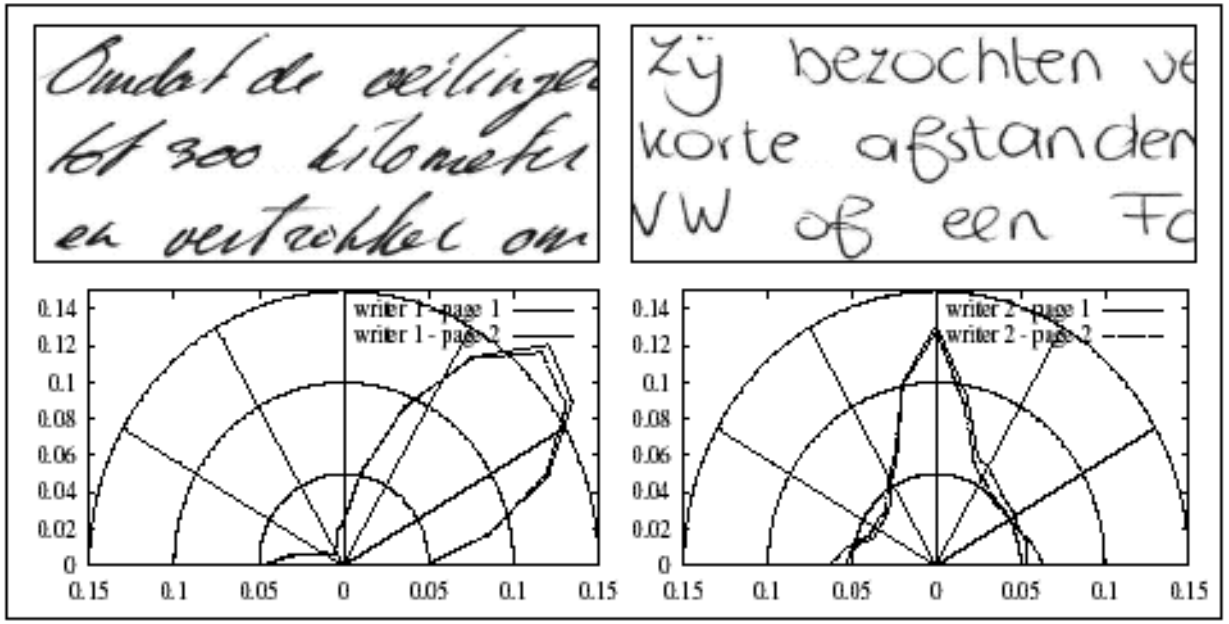
Automatic extracted features - 2003

	Feature	Explanation	Dim.	$\Delta(\vec{u}, \vec{v})$
f1	ACF	Autocorrelation in horizontal raster	100	Euclid.
f2	VrunB	PDF of vertical run lengths of ink	100	χ^2
f3	HrunW	PDF of horizontal run length of 'white'	100	χ^2
f4	Brush	Ink-density PDF at stroke endings	225	χ^2
f5	$p(\phi)$	Edge-direction PDF	16	Euclid.
f6	$p(\phi_1, \phi_2)$	Hinge angle combination PDF	464	χ^2
f7	$p(\phi_1, \phi_3)$	Horiz. edge-angle co-occurrence	512	χ^2
f8	WR	Writer: handedness, sex, age, style	16	Euclid.

Schomaker, Bulacu, van Erp 2003

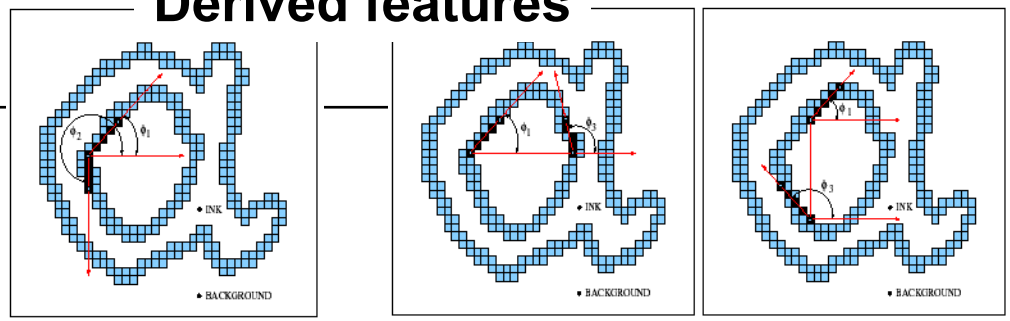
Edge-direction features





Bulacu, Schomaker, Vuurpijl 2003

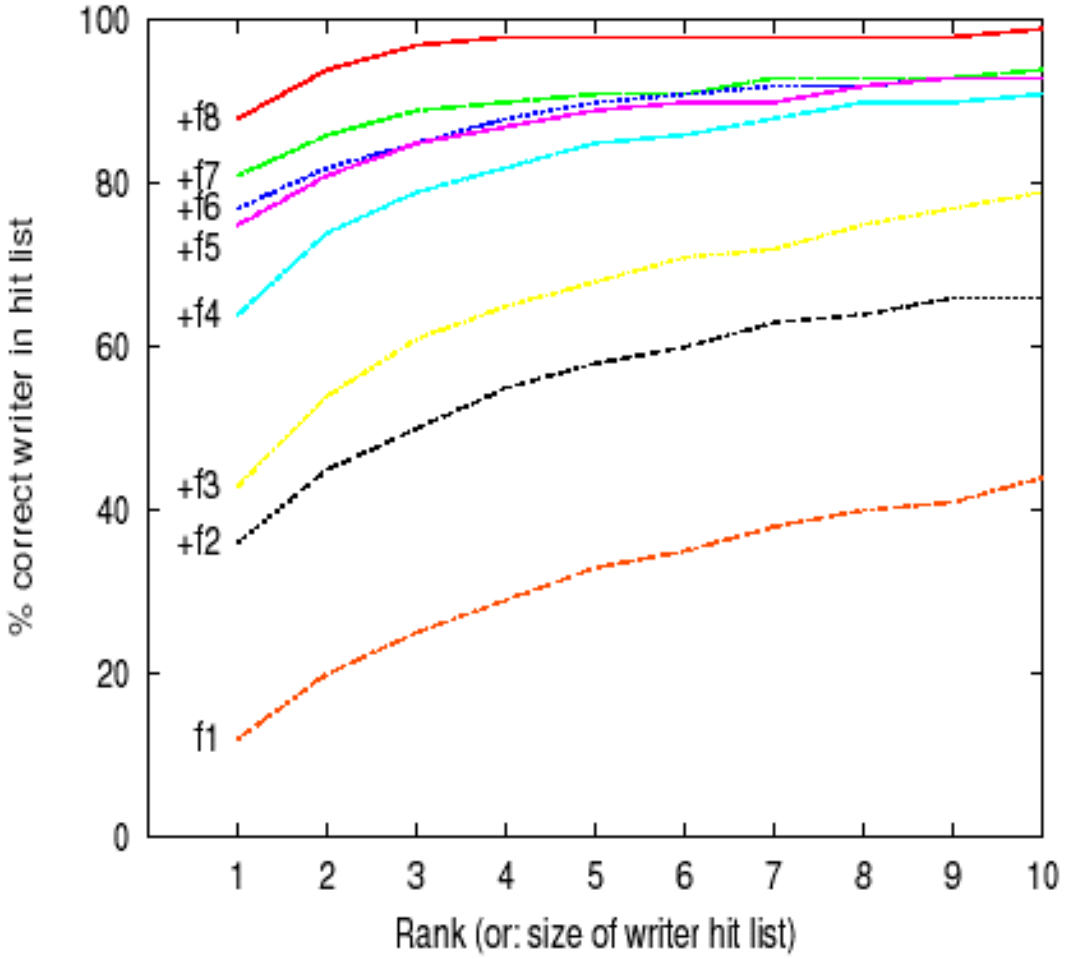
Derived features



Results I

For a query sample,
the set *W* will contain
one matching sample of
the same writer and
500 distractor samples by
250 other writers.

Schomaker, Bulacu, van Erp 2003



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Results II

	Feature
f1	ACF
f2	VrunB
f3	HrunW
f4	Brush
f5	$p(\phi)$
f6	$p(\phi_1, \phi_2)$
f7	$p(\phi_1, \phi_3)$
f8	WR

Same documents of 100 writers were processed with the two systems working in forensic labs and our currently available version

	TOP1	(TOP10)	
System A:	34%	(90%)	
System B:	65%	(90%)	
Latest results:	79%	(95%)	Bulacu & Schomaker 2003

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Forensic Information System Handwriting

References

2004: WANDA: A common ground for forensic handwriting examination and writer identification
K Franke, L Schomaker, C Veenhuis, L Vuurpijl, M van Erp, I Guyon
ENFHEX news-Bulletin of the European Network of Forensic Handwriting Experts

2004: The WANDAML markup language for digital document annotation
K Franke, I Guyon, L Schomaker, L Vuurpijl, Frontiers in Handwriting Recognition, 2004. IWFHR-9 2004. Ninth ...

2003, WANDA: A generic framework applied in forensic handwriting analysis and writer identification
K Franke, L Schomaker, C Veenhuis, C Taubenheim, I Guyon, L Vuurpijl, M van …
Proc. 3rd International Conference on Hybrid Intelligent Systems, 927-938

2003, The WANDA measurement tool for forensic document examination
M Erp, LG Vuurpijl, K Franke, LRB Schomaker, Nijmegen: Nijmegen Institute for Cognition and Information

2004: Automatic writer identification using connected-component contours and edge-based features of uppercase western script
L Schomaker, M Bulacu, Pattern Analysis and Machine Intelligence, IEEE Transactions on 26 (6), 787-798

2007: Text-independent writer identification and verification using textural and allographic features
M Bulacu, L Schomaker, Pattern Analysis and Machine Intelligence, IEEE Transactions on 29 (4), 701-717

2005: Robotic writing trace synthesis and its application in the study of signature line quality.
K Franke, LRB Schomaker, Journal of Forensic Document Examination 16

2005: The influence of physical and biomechanical processes on the ink trace: Methodological foundations for the forensic analysis of signatures
K Franke, Rijksuniversiteit Groningen

2010: Computational forensics: An overview
K Franke, SN Srihari, Computational Forensics, 1-10

Ink-Deposition Model: the relation of writing and ink deposition processes

Katrin Franke, Steffen Rose

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Production Systems and Design Technologies
Department of Pattern Recognition
Berlin, Germany

Challenges in Forensic Applications

- Working with **residual ink traces**
- Reduced writer-specific information, e.g. clues about writing behavior are highly degraded
- Numerous **physical** and **biomechanical effects** on the ink trace
- Optical **Inspection of** the inner ink trace characteristics, so-called **stroke morphology**

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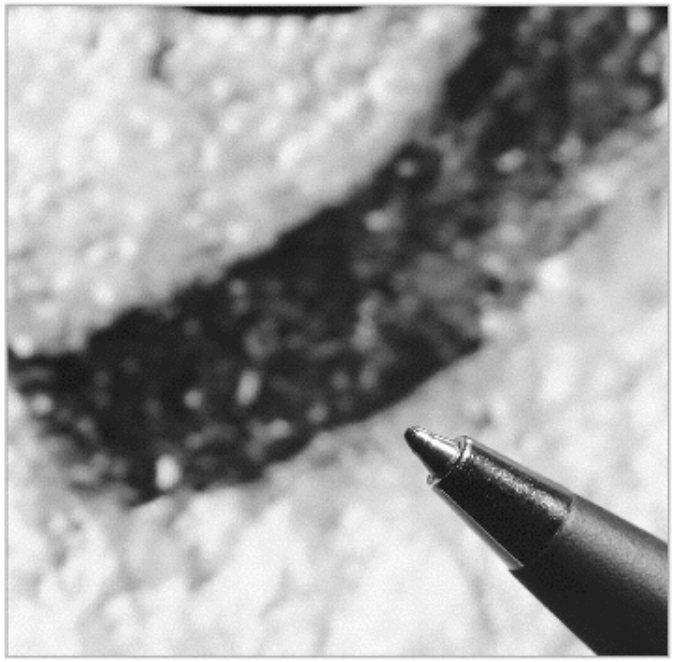
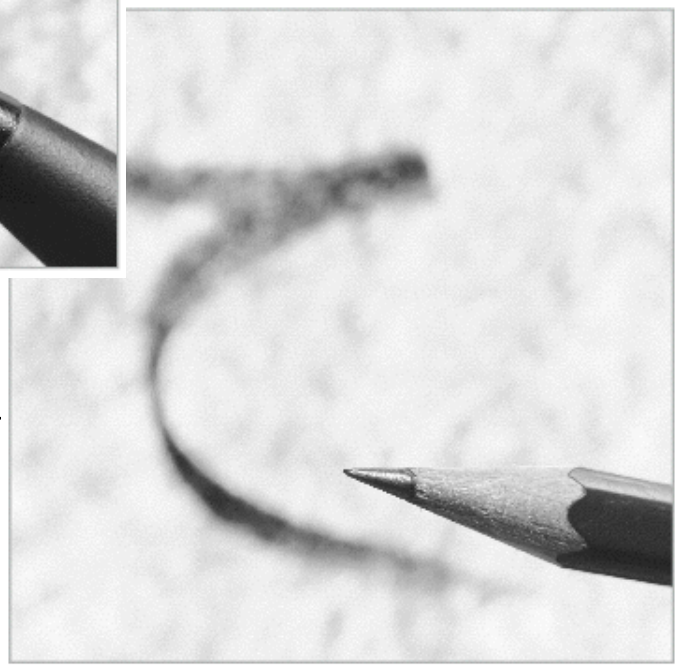
Focus on the influence of pen used

Fluid ink type
Fountain, Fine-line,
Roller pen etc.



Viscous ink type
Ballpoint pen

Solid ink type
(Mechanical) Pencil



Franke, Bünnemeyer & Sy
IWFHR'2002

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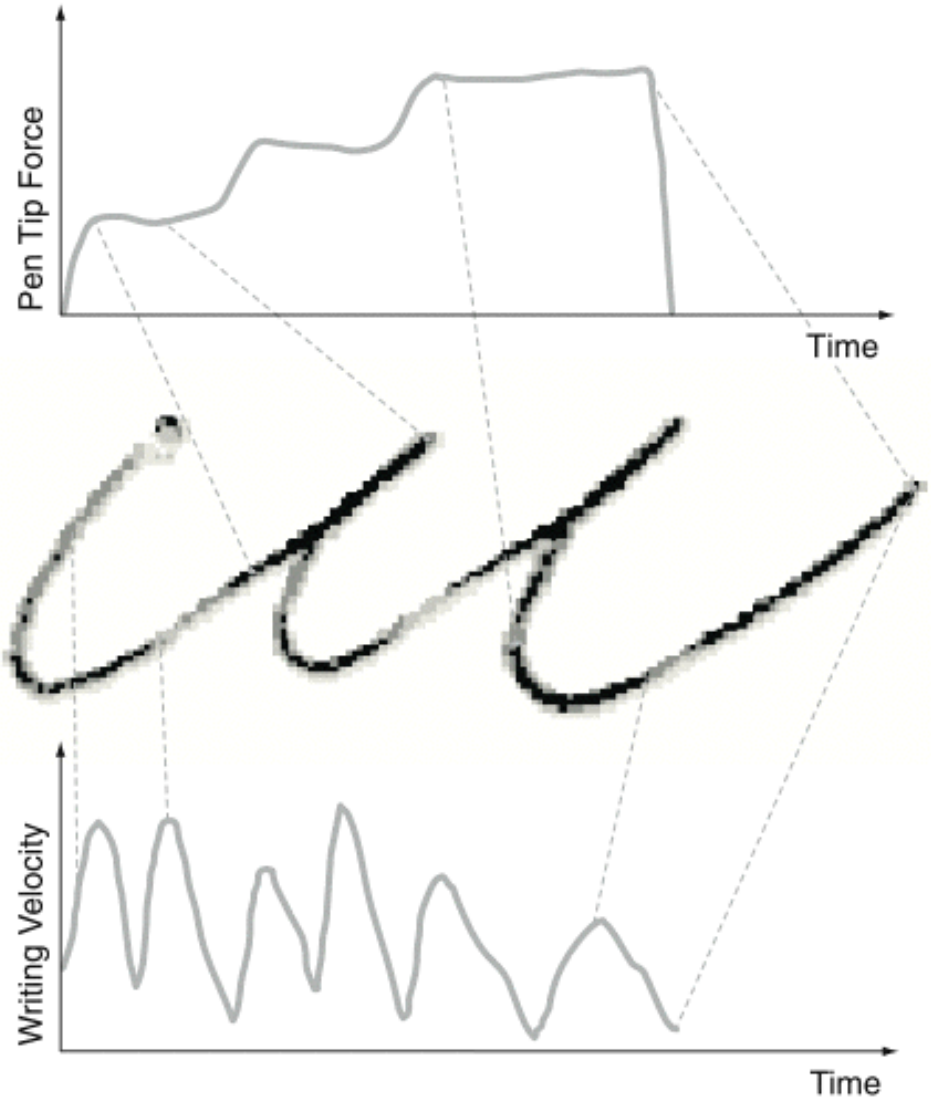
Major research questions

- **What are the interactions** between evoked writing instrument and writing behaviors?
- Can **ink-deposition** characteristics be exploited in order **to recover individual characteristics** of a handwritten signature?
- How can **disturbing material influences be neutralized** during a computer-based analysis procedure?

Relation Writing Behaviors to Ink-Trace Characteristics

Demanded studies:

Extraction of ink traces
- Normalization of ink deposit
- Validating of ink deposit stability
- **Modeling of relative ink intensity**



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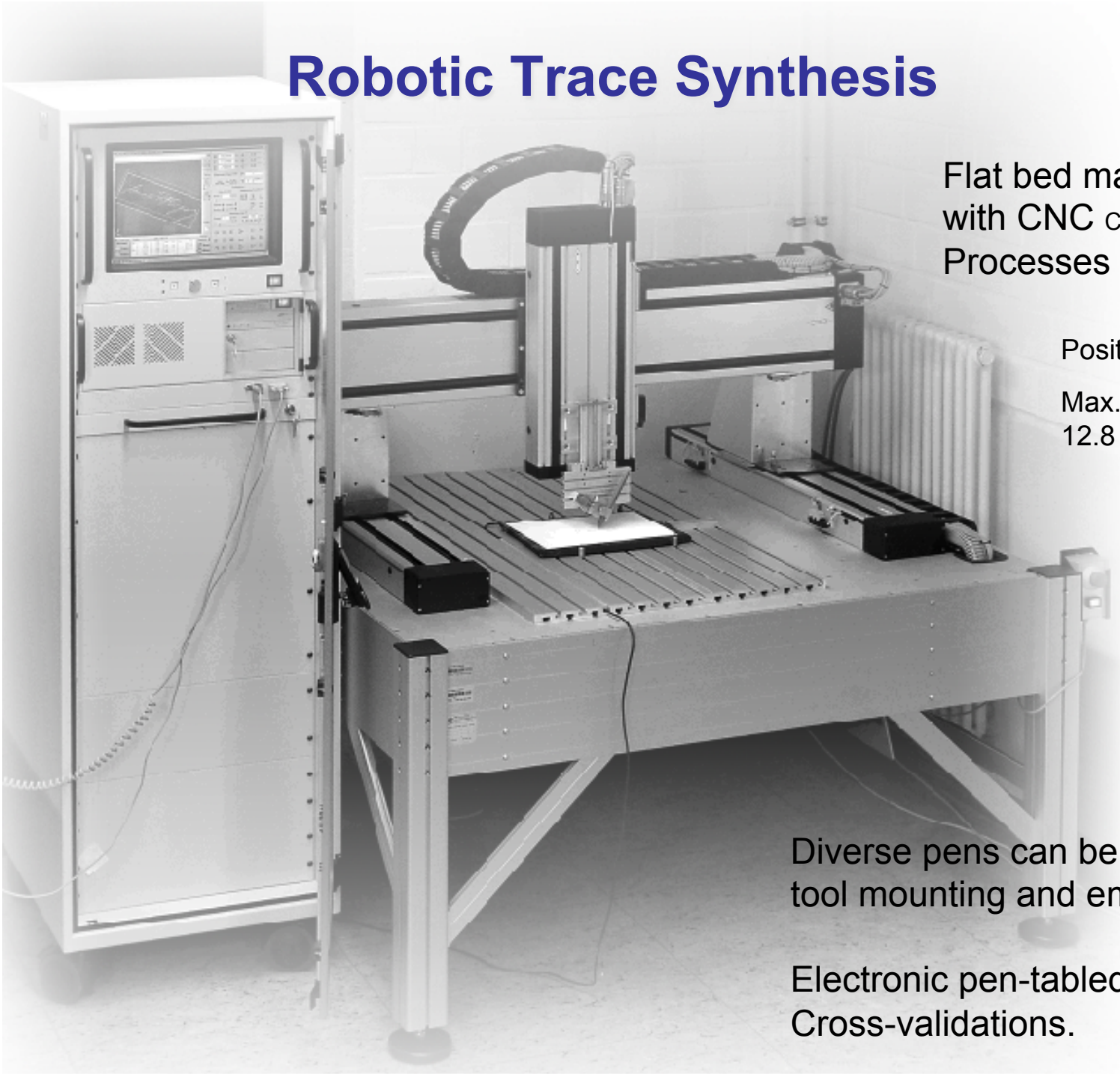
Robotic Trace Synthesis



Flat bed machine (GFV-SW)
with CNC Computer Numerical Control.
Processes NC-program code.

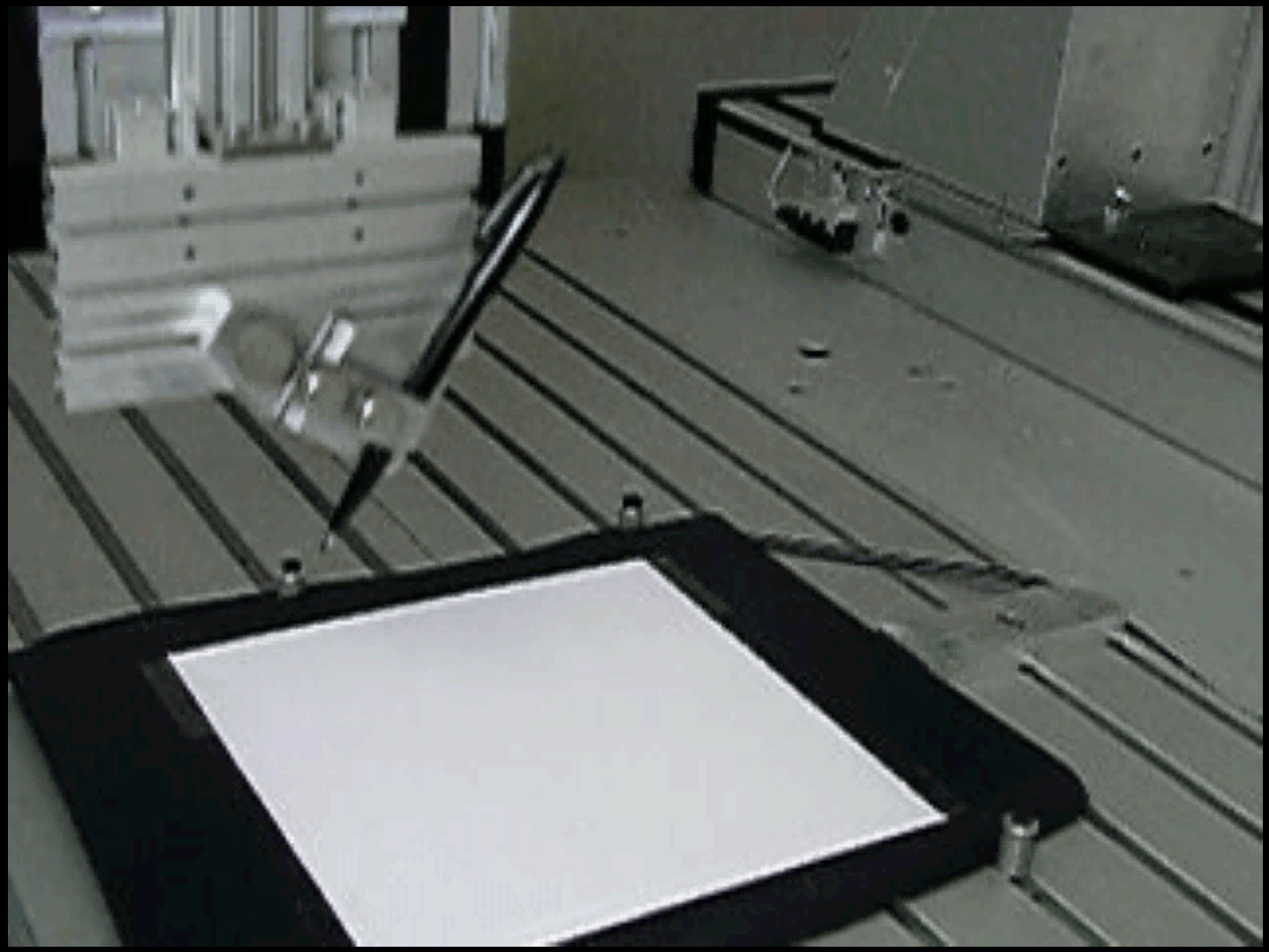
Position accuracy of 1 μm

Max. movement velocity of
12.8 m/min (214 mm/s)

Diverse pens can be plugged in the
tool mounting and employed for writing.

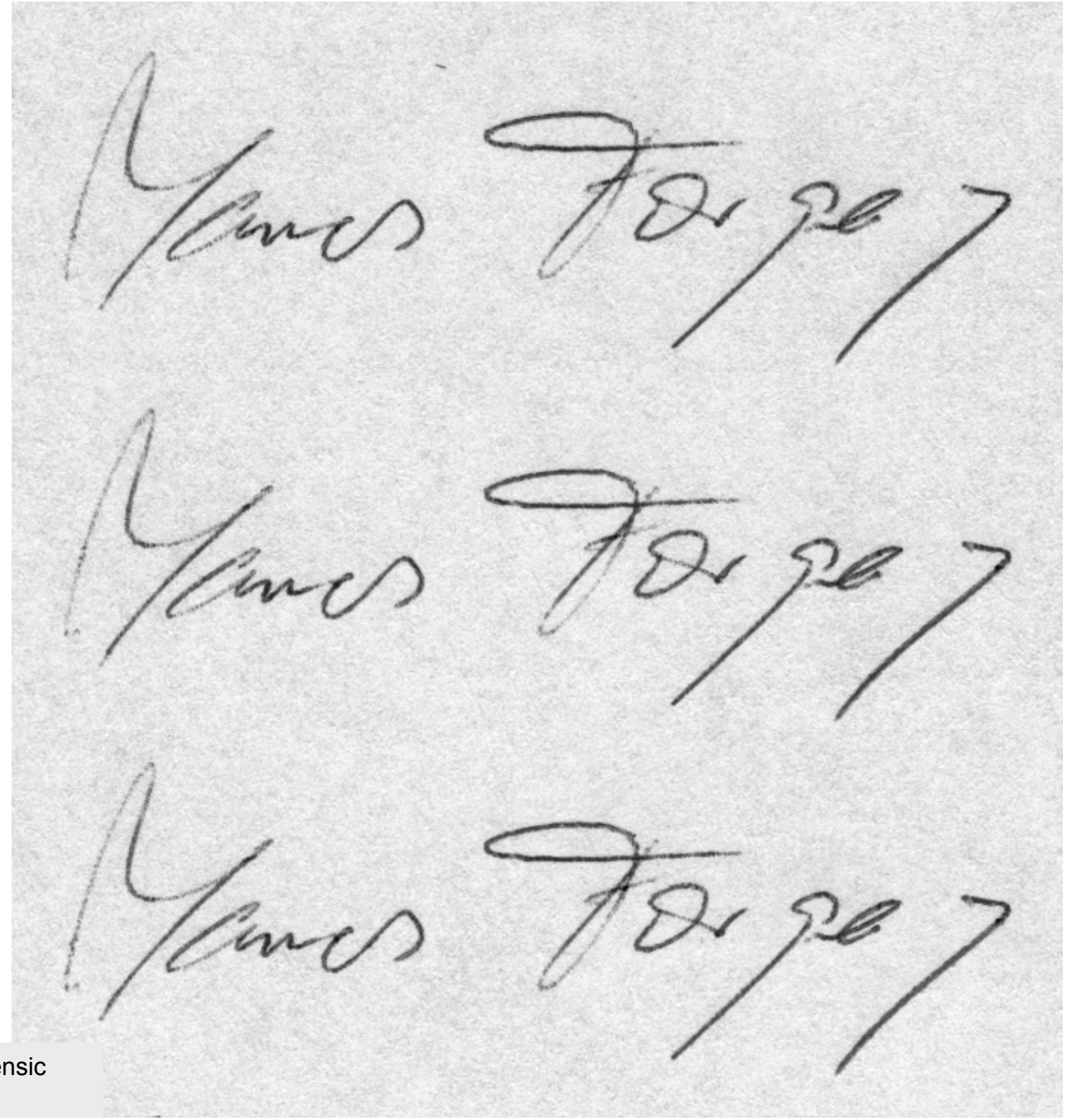
Electronic pen-tabled is used for
Cross-validations.

Writing Robot in Action



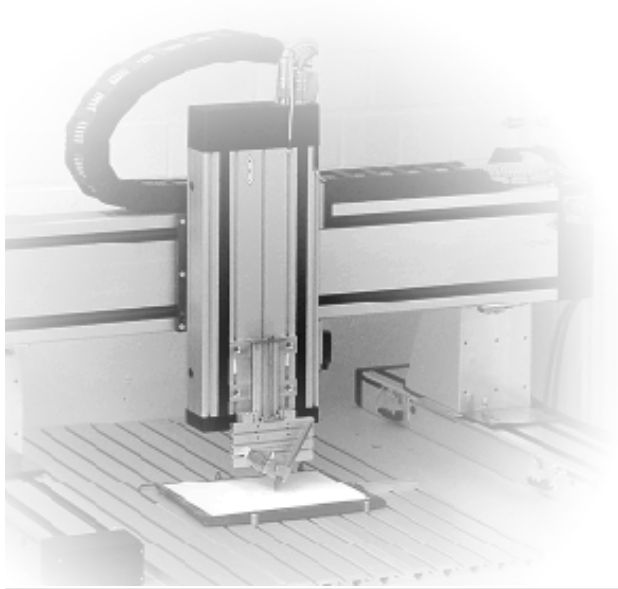
Signatures written by the Robot

```
%
G17 G90
G0 Z-70
F0.6
G1 X0.566 Y8.316 Z-80.000
G1 X0.338 Y8.039 Z-80.000
F1.2
G1 X0.125 Y7.934 Z-80.000
F1.6
G1 X0.000 Y8.173 Z-81.000
F1.8
G1 X0.027 Y8.890 Z-81.000
F1.9
G1 X0.250 Y10.151 Z-81.000
G1 X3.174 Y18.506 Z-81.000
G1 X4.051 Y20.026 Z-81.000
F1.8
. . .
G1 X47.949 Y6.301 Z-75.000
F1.3
G1 X49.104 Y6.730 Z-75.000
F1.0
G1 X49.974 Y7.028 Z-75.000
G0 Z0
G0 X0 Y0
M30
```



Franke & Schomaker, Journal of Forensic Document Examination (in Press)

Our Approach: Analysis by Synthesis



- Synthesize simple ink traces
  - → Employ different pen
  - → Vary “writing behavior”
- Analyze produced ink traces
  - → Consider general ink intensity distribution
  - → Inspect changes

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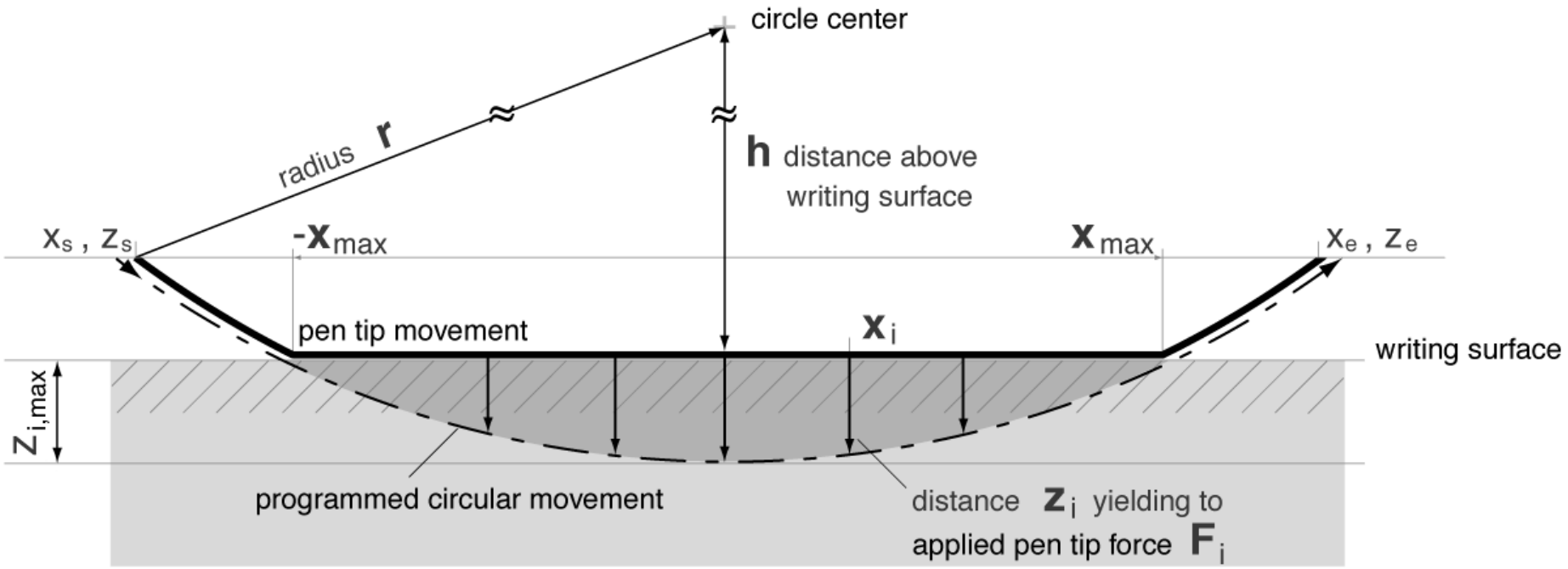
Synthesis of ballistic trajectories and ink traces



$$F_i = z_i \cdot \bar{F}_W\big|_{\Delta z = 1\,\mathrm{mm}}$$

$$z_i = \sqrt{r^2 - x_i^2} - h \quad (-x_{\max} < x_i < x_{\max})$$

$$x_{\max} = \sqrt{r^2 - h^2}$$

Physical ink deposition processes

Solid ink type - (Mechanical) Pencil

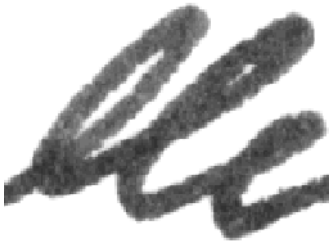
File effect

Paper fibers sticking out of the fiber-mat are colorized.

Viscous ink type - Ballpoint pen

Unrolling and squeezing effect

deposits the viscous paste onto the paper surface.



Fluid ink type - Fountain, Fine-line, Roller pen etc.

Capillary effect

Paper fibers are soaked with water-based ink.

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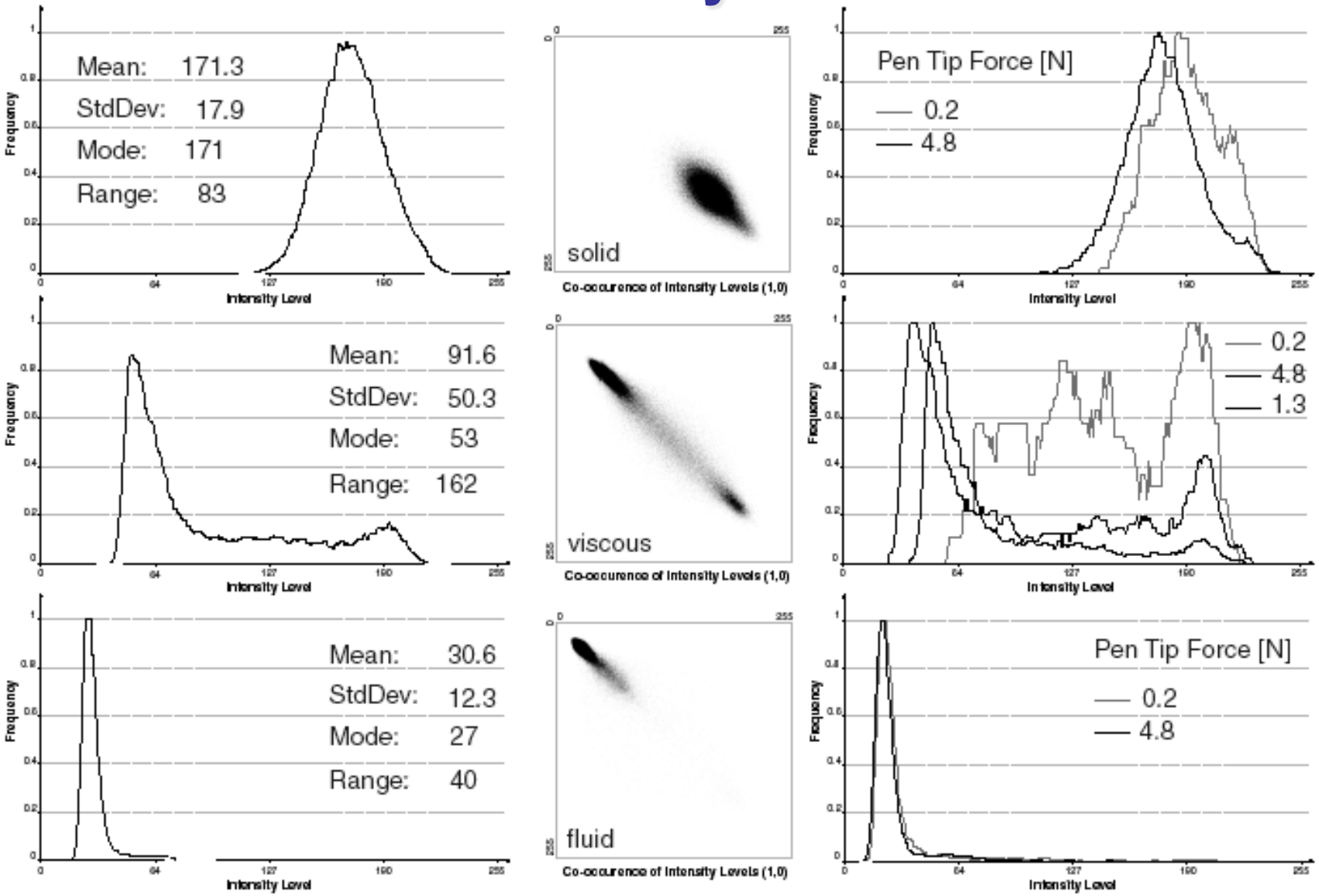
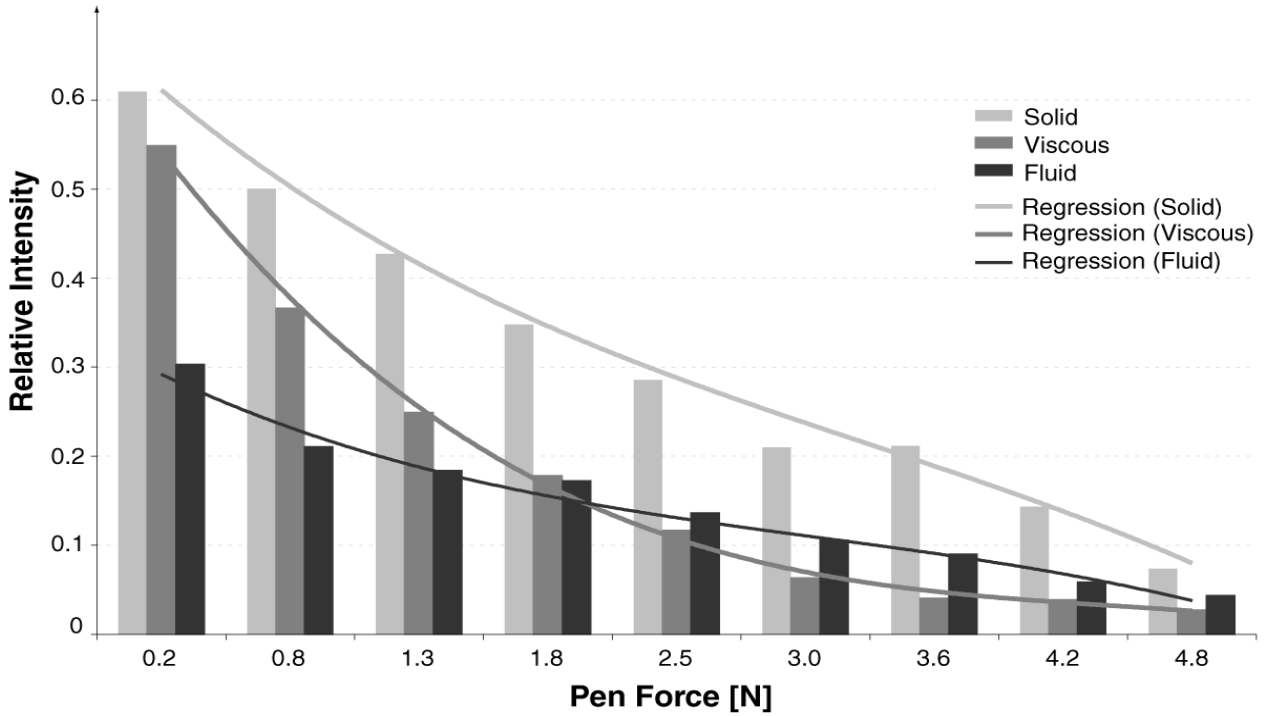
Franke & Rose,
IWFHR‘2004

2004-10-27

Variations in ink-intensity distribution



Regressions of intensity profile plots



Ink Deposition Model

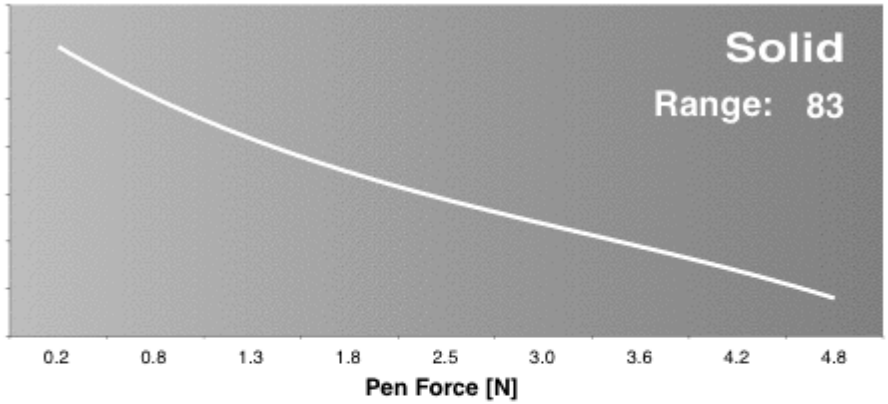
Relationship of applied pen tip force and relative ink intensity

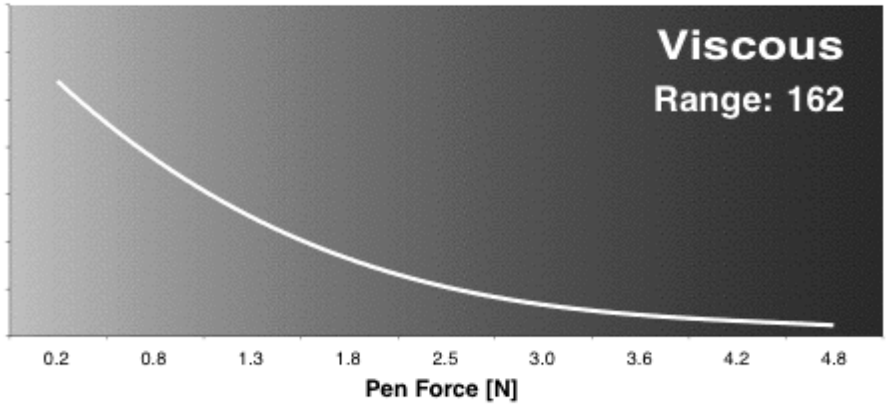
$$
\begin{aligned}
i_{\text{solid}} &= -0.0008f^3 + 0.0157f^2 - 0.1498f + 0.7462 \\
i_{\text{visco}} &= -0.0011f^3 + 0.0027f^2 - 0.2376f + 0.7537 \\
i_{\text{fluid}} &= -0.0006f^3 + 0.0116f^2 - 0.0902f + 0.3713
\end{aligned}
$$

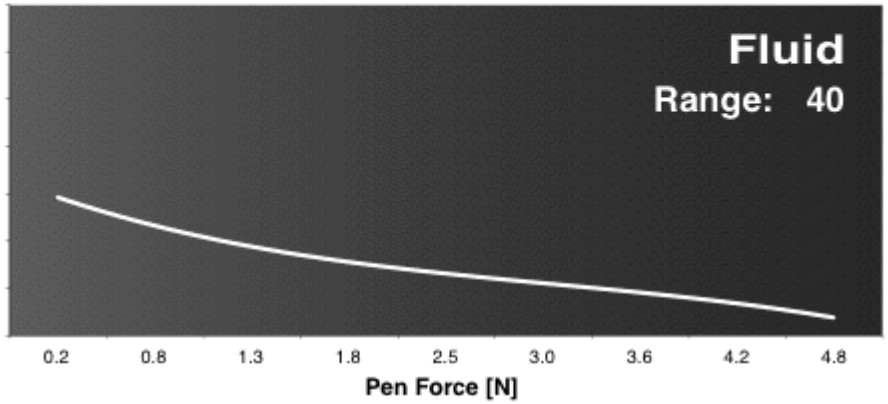
Ink Deposition Models

Gray-ragtime considers particular
Ink Deposition Model + average ink-intensity range

$$
\begin{aligned}
i_{\text{solid}} &= -0.0008\,f^3 + 0.0157\,f^2 - 0.1498\,f + 0.7462 \\
i_{\text{visco}} &= -0.0011\,f^3 + 0.0027\,f^2 - 0.2376\,f + 0.7537 \\
i_{\text{fluid}} &= -0.0006\,f^3 + 0.0116\,f^2 - 0.0902\,f + 0.3713
\end{aligned}
$$







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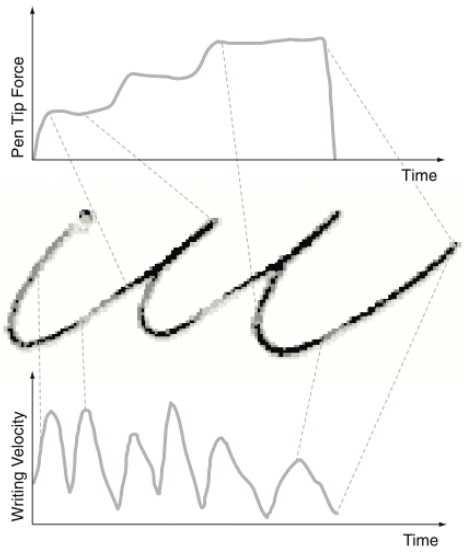

IDM Applications ➞ Next Steps

- Signature Processing Control
  Ink distribution and/or stroke width analysis
- Normalization of ink traces
  Relative ink distribution being pen/ink independent
- Soft-Synthesis of off-line specimen from on-line data (brushing function)
- Assignment to temporal characteristics

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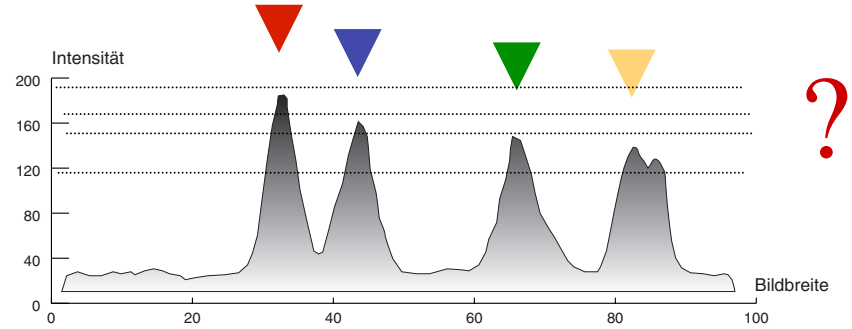
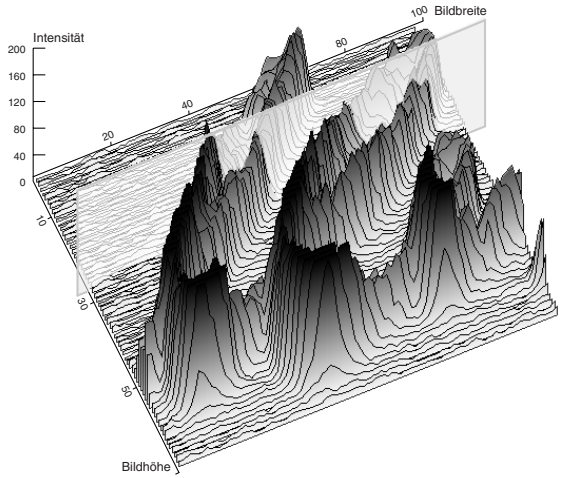
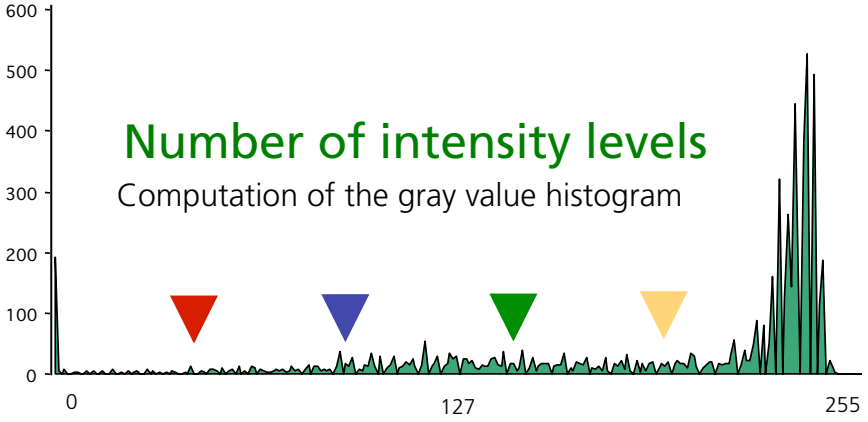
Digital Densitron



Intensity profile of an image row

Intensity profile of the whole image





Number of intensity levels

Computation of the gray value histogram

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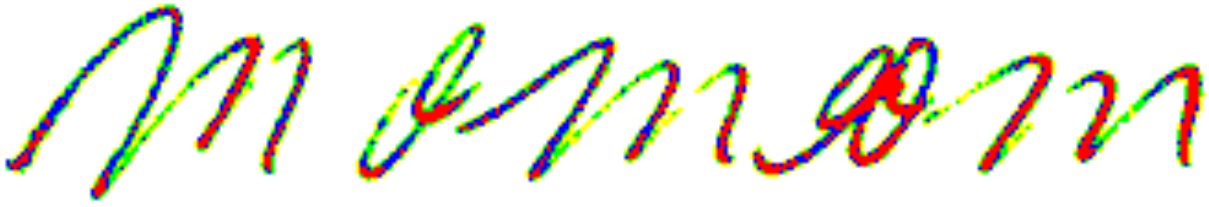
Franke & Grube, JFDE‘1998
Franke, Mannheimer Hefte‘2004

2004-10-27

ISU.Samples - Densitron I



Generated Signatures Specimens

Ball-point Pen Tip

- Genuine signatures of **10 different writers**
  using an electronic ink pen and an electronic writing tablet
  10 samples per writer = 100 synthesized signatures

- One signature sample
  using **24 different ball-point pens**
  10 samples per pen = 240 synthesized signatures

Questioned to be answered:

1. How accurate are synthesized on-line signatures ?
2. How stable are stroke morphology characteristics ?

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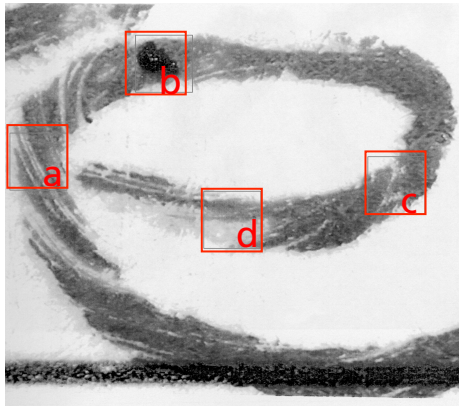
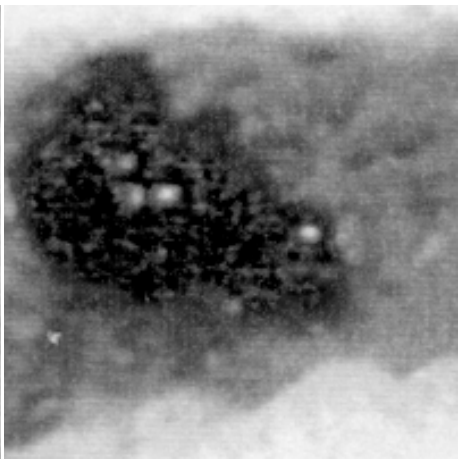
Studied stroke morphology characteristics



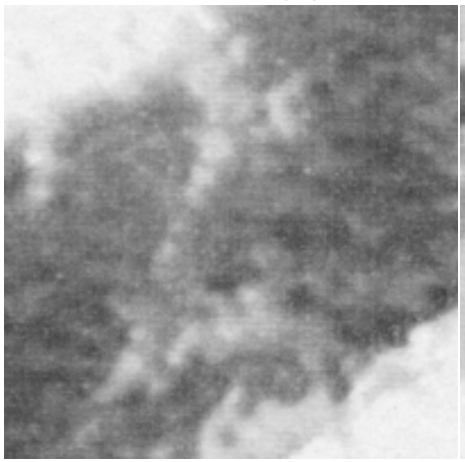
- Relative Ink Distribution
- Stroke Phenomena

a) Striations

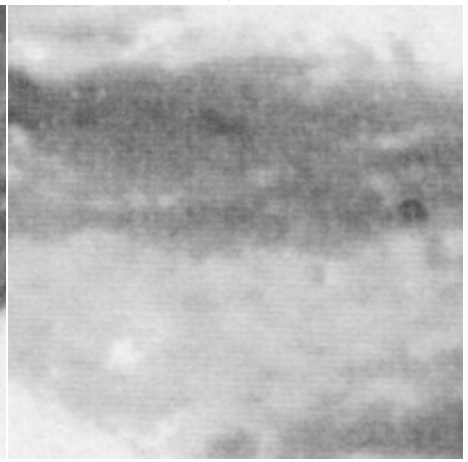
b) Ink drops, ink depots



c) Ink depositing gaps,

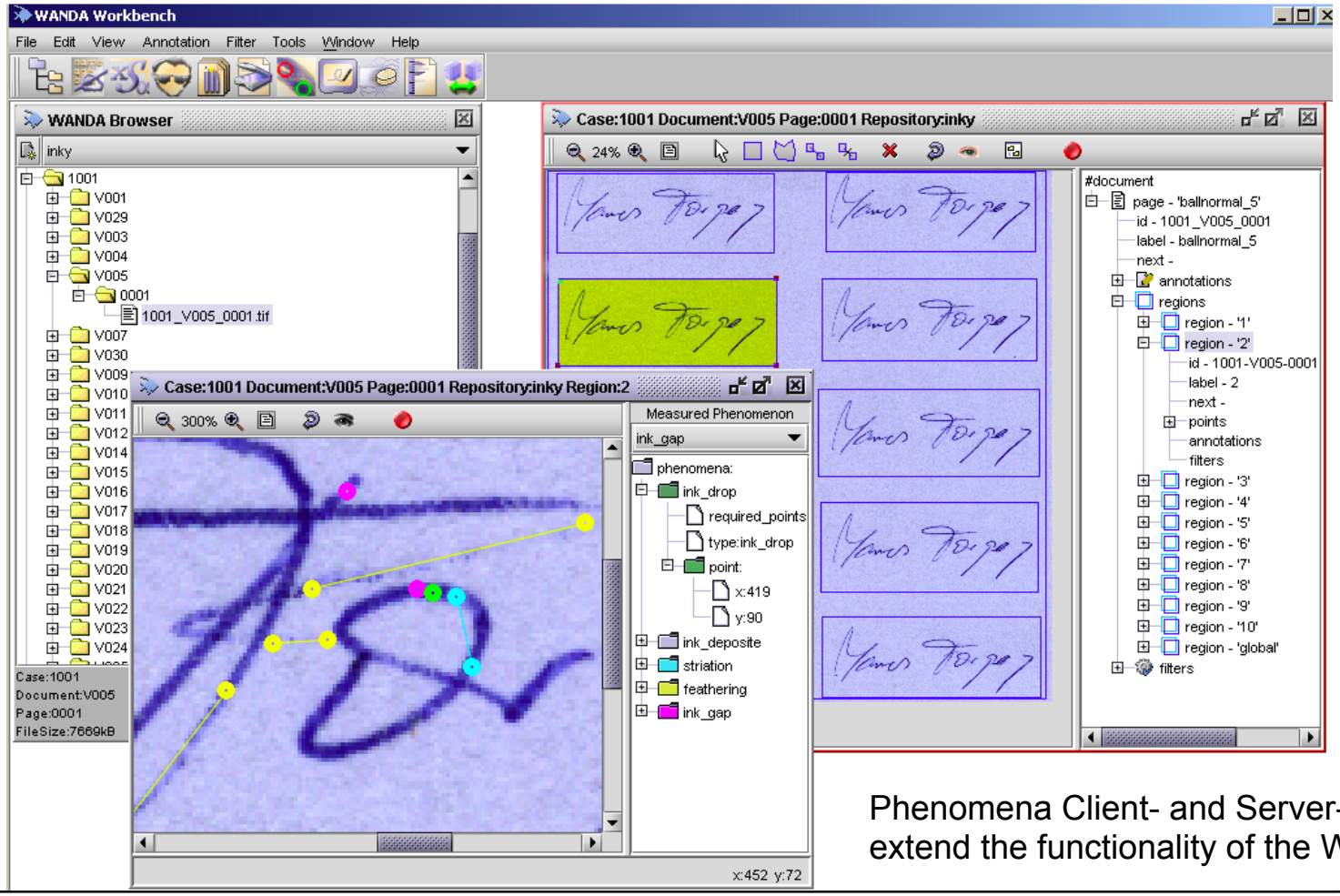


d) Feathering



Source: Widmer, 1996

Interactive Labeling of Stroke Phenomena using WANDA



Phenomena Client- and Server-Plug-In, which extend the functionality of the WANDA Workbench

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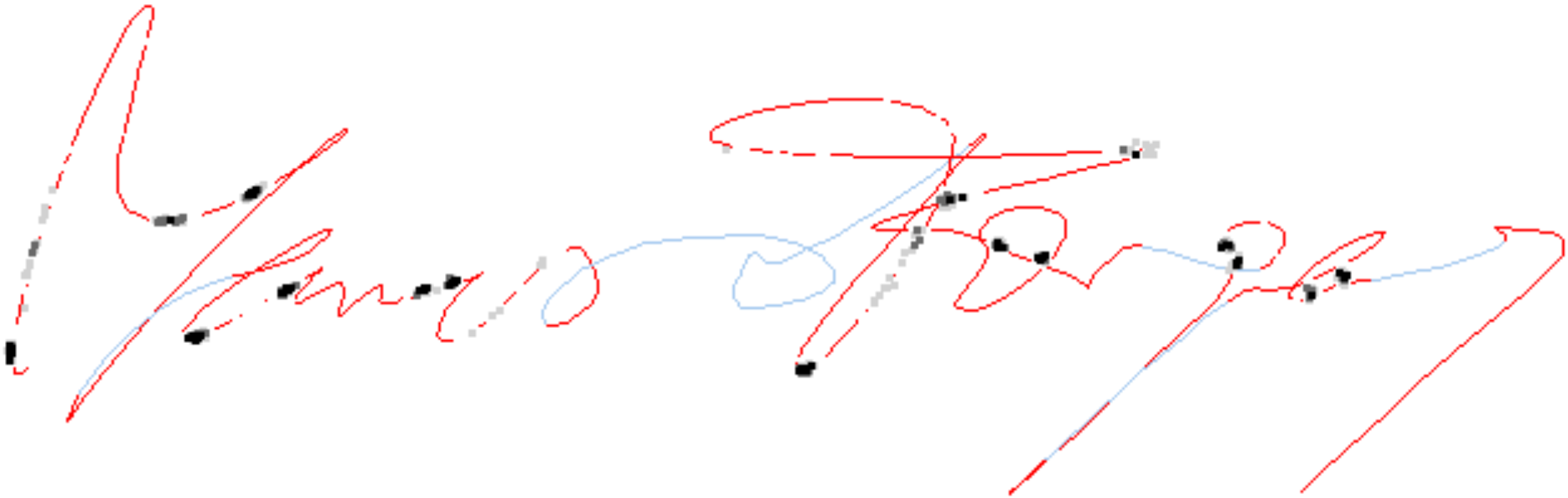
Super-imposed Labeled Phenomena: 1 - Ink drop

Super-imposed Labeled Phenomena: 2 - Ink deposit

Super-imposed Labeled Phenomena: 3 - Feathering



Super-imposed Labeled Phenomena: 4 - Striations

Super-imposed Labeled Phenomena: 5 - Ink gap

Methode evaluation I
- Stroke phenomena -

Allowed Tolerances:
10° Rotation
10 Pixel Translation
for 300 dpi scan

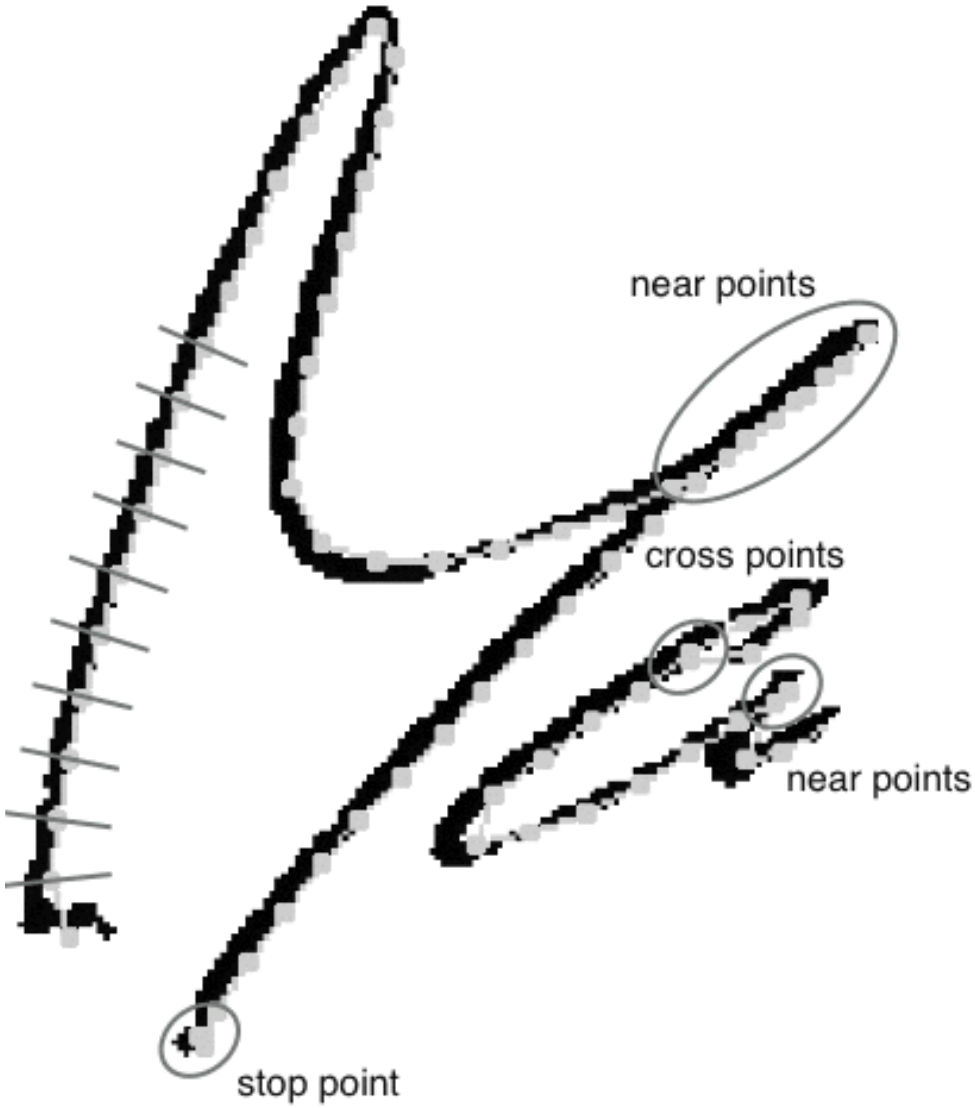
Tolerance due to
Human Labeling
5 Pixel Translation

match_Result = correct_pheno_labels / total_pheno_lables * 100	Complete Phenomena set	Reduced Phenomena set (Fusion of feathering, striation and ink gap)
Intra-group Comparison (for reach ball-point pen separately - 10 samples)	96.0 %	96.7 %
Inter-group Comparison (cross-validation over all 240 samples)	91.8%	94.7 %
Validation with Ideal reference pattern	94.6 %	96.5 %

Method evaluation II
- Ink Distribution -

	Ink	
	intra-group	inter-group
MW	97.46	88.44
Stdv	8.55	13.92
Median	100.00	93.20
Quantil 03	100.00	88.80
Min	30.00	16.00

26 Ballpoint pen, 10 Samples each



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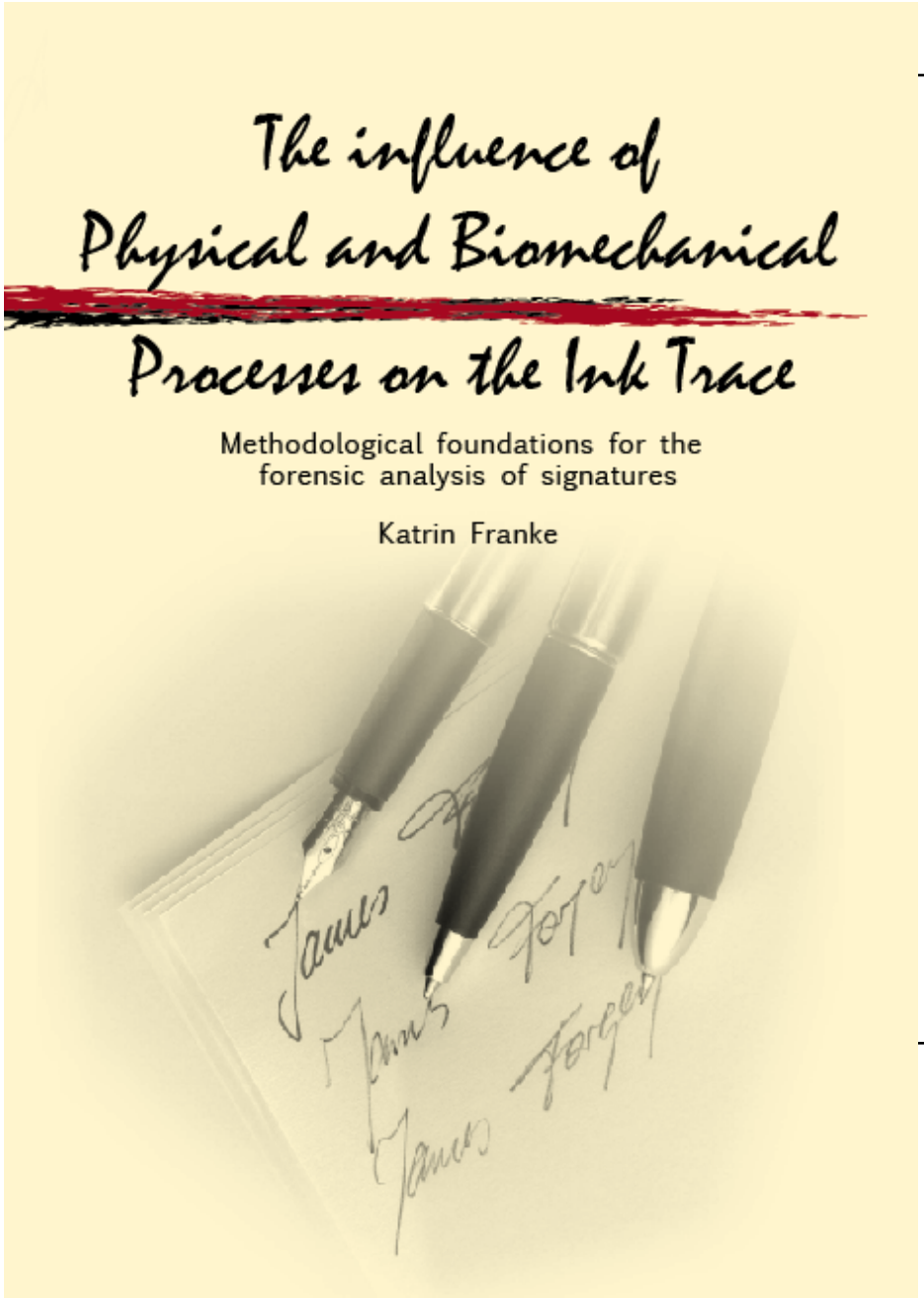

Lessons Learned

- The Influence of Physical and Biomechanical Processes on the Ink Trace -
  Methodological foundations for the forensic analysis of signatures.

- University of Groningen,
  Artificial Intelligence Institute,
  Faculty of Mathematics and Natural Sciences, The Netherlands, 2005.

- Online available via
  http://www.kyfranke.com

- 255 pages, 118 figures, 31 tables,
  321 references

Current Affiliation

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NISlab™

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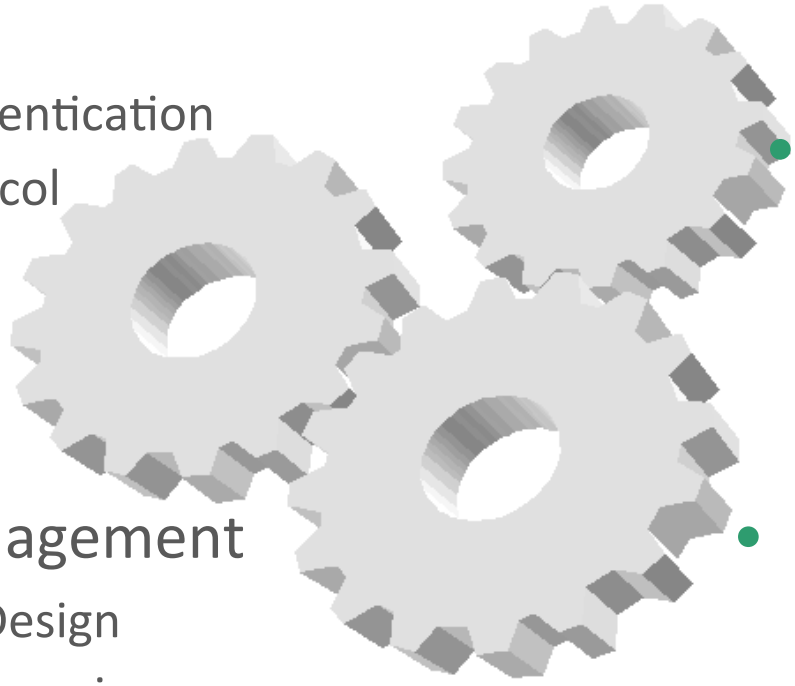
P.O. Box 191, N-2802 Gjøvik, Norway.

NISlab – Working Areas

- Biometrics
  - User Authentication
  - BTA Protocol



- Forensics
  - Forensic Readiness
  - Incidence Response
  - Investigation/Analysis

- Security Management
  - Risk-based Design
  - Security Economics
  - System/Adversary Modeling
  - Human Factors, Policies

- Security Technology
  - Software Security
  - System Administration
  - Network and Critical Infrastructure Protection

Testimon (lat. evidence)
Computational & Digital Forensics:
Fraud Detection, Analysis and Prevention

Computational Forensics:

Adding Efficiency and Intelligence to BIG DATA Investigation

NISlab™

Thank you for your consideration of comments!

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