



From Ink to AI: Innovations and Integration in Forensic Handwriting Examination

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ICDAR Conference, Vienna, 30 August 2026

The tutorial is divided into four parts.

1

Forensic handwriting examination

2

Automatic handwriting and signature analysis

3

Differences between disciplines and their implications

4

Pathways to integration

1

Forensic handwriting examination

2

Automatic handwriting and signature analysis

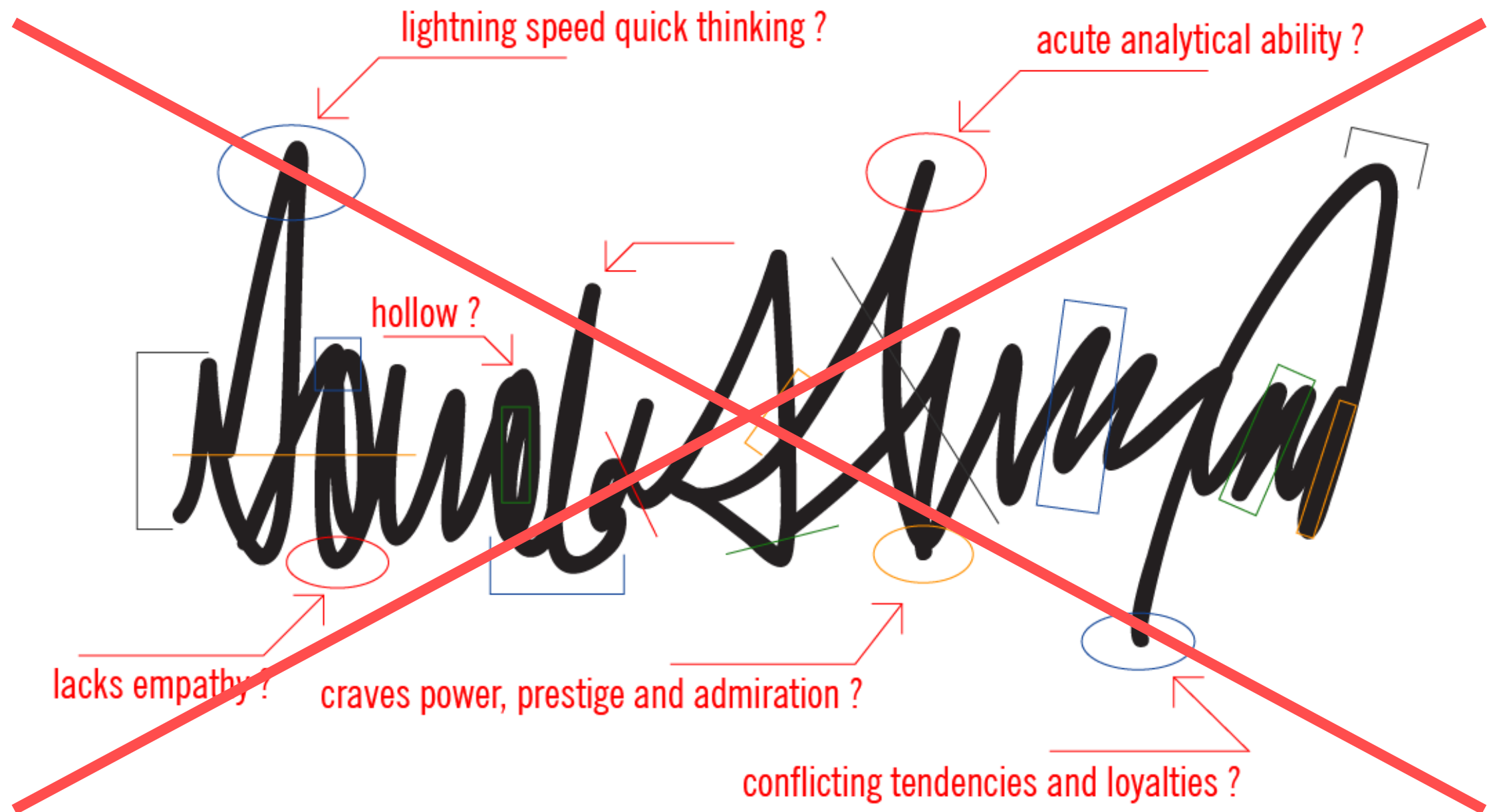
3

Differences between disciplines and their implications

4

Pathways to integration

Graphology does NOT work!



FHEs examine handwritten materials of all kinds.

Last Will and Testament
I, John Smith, being sound mind,
declare this to be my last Will
and Testament. I leave all my properties
and possessions to my daughter, Emily
Smith.
Signed this 12th day of May, 2024
John Smith

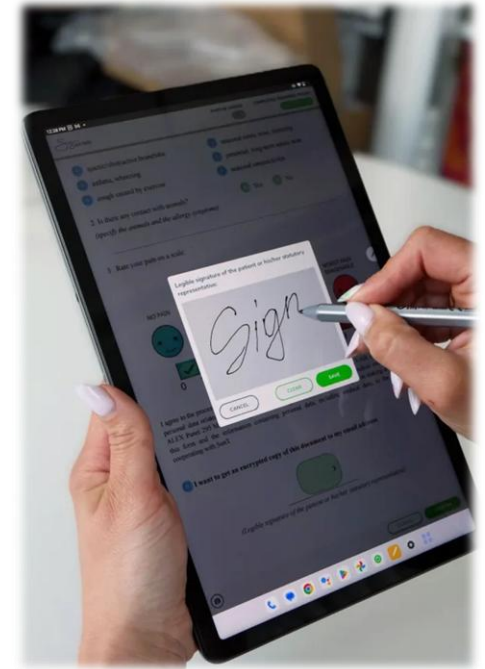
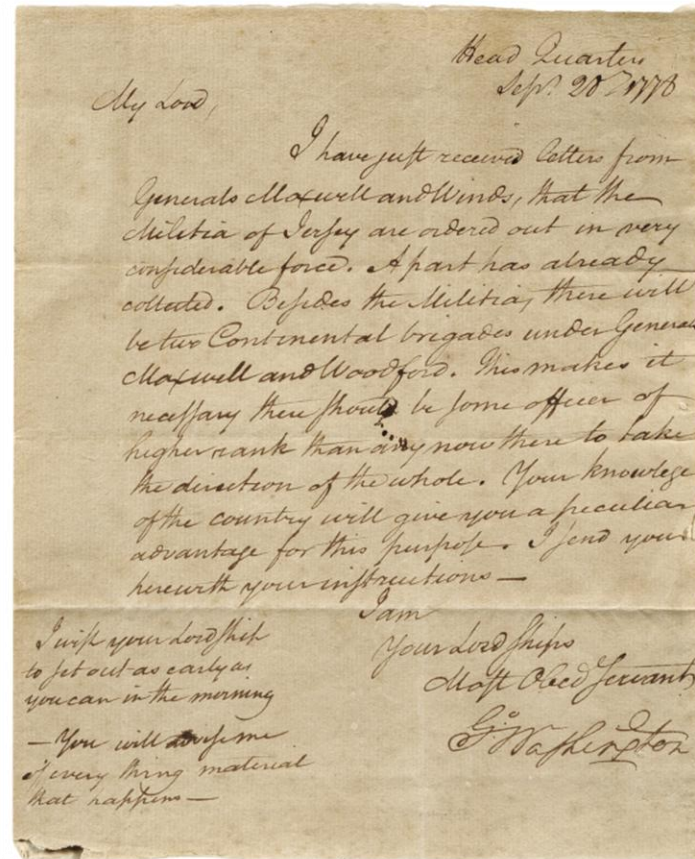
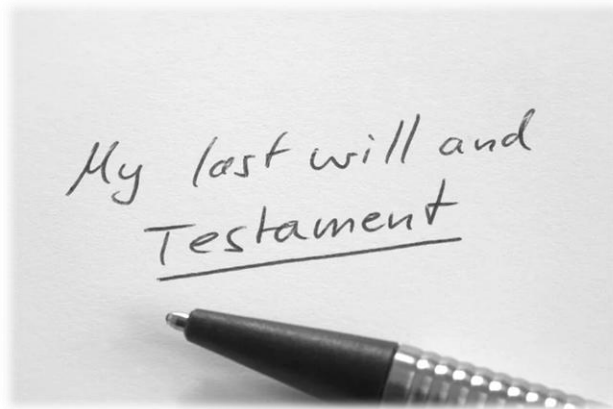
YOU SHUT
MOUTH OR
YOU BROKEN!
O

#14500

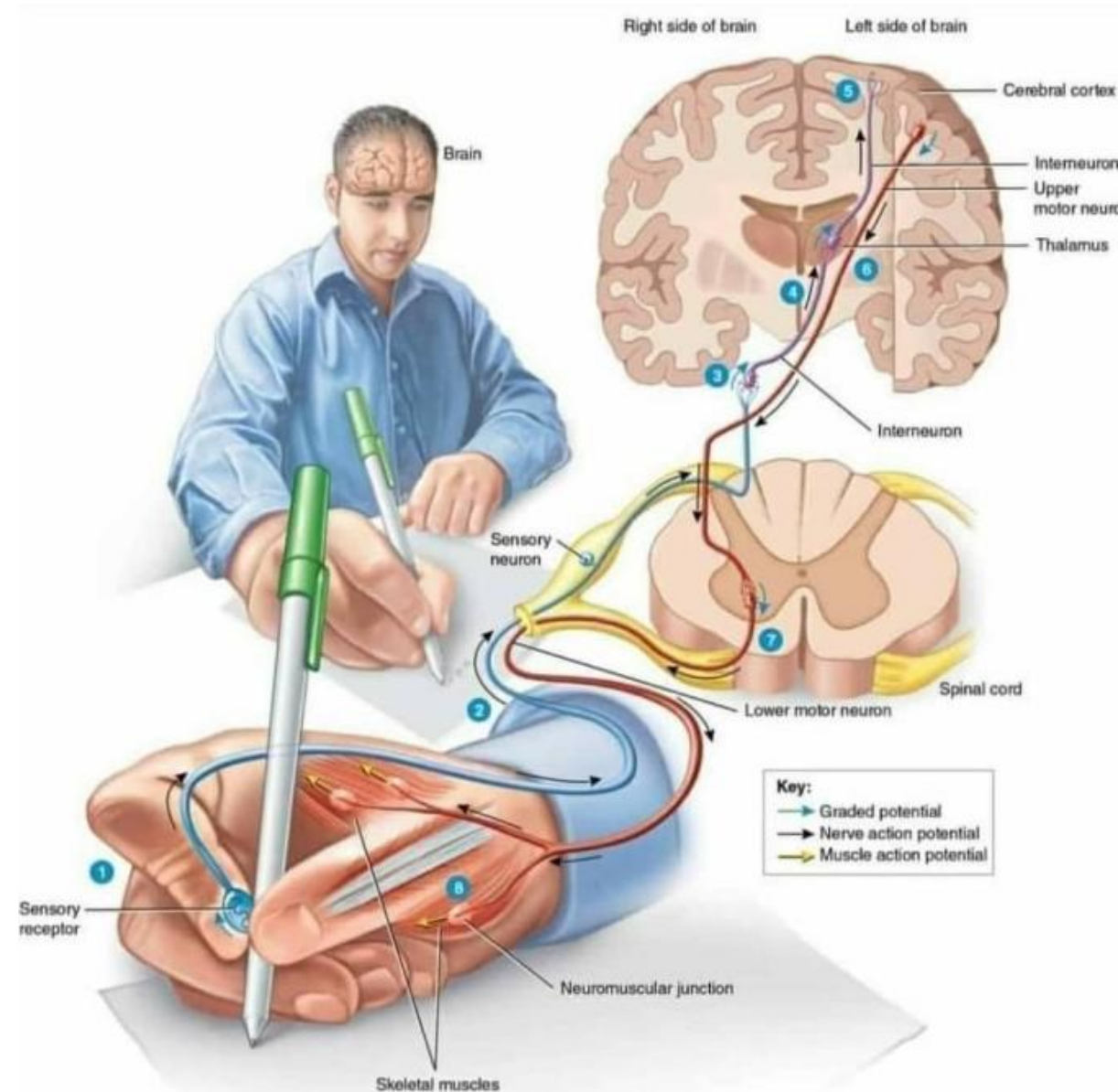
Paul



Handwriting may become less important, but forensic handwriting examination is far from dead.



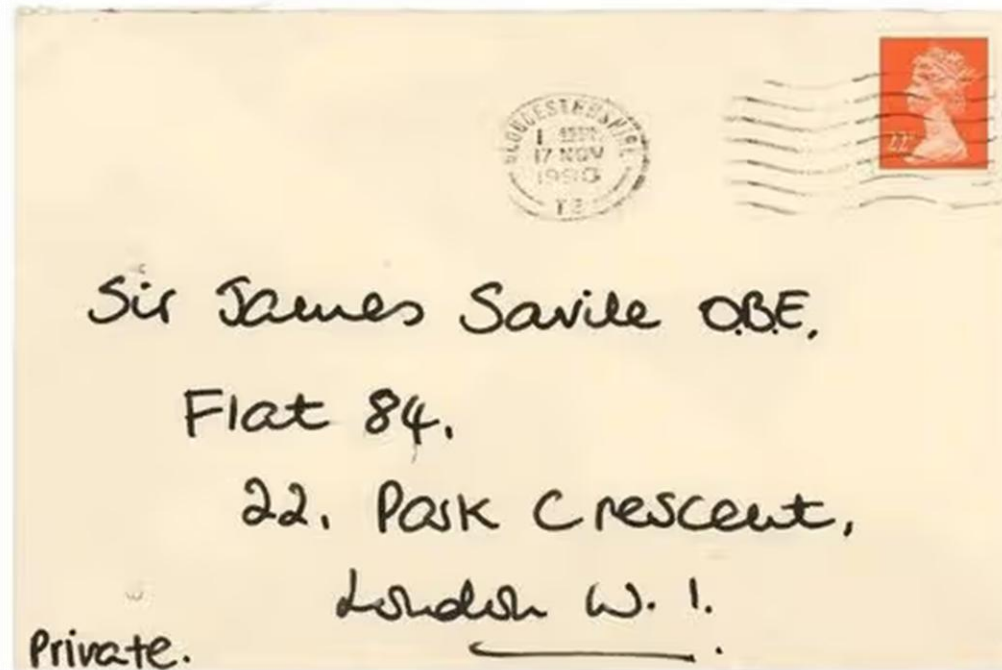
Handwriting is the result of complex psychophysiological mechanisms.



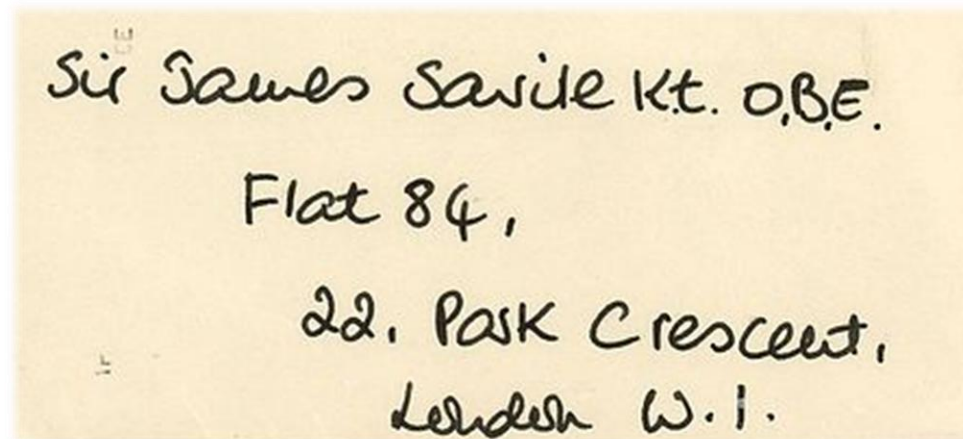
<https://www.linkedin.com/pulse/handwriting-really-brainwriting-priya-maheshwari>

Handwriting comparison is based on two assumptions.

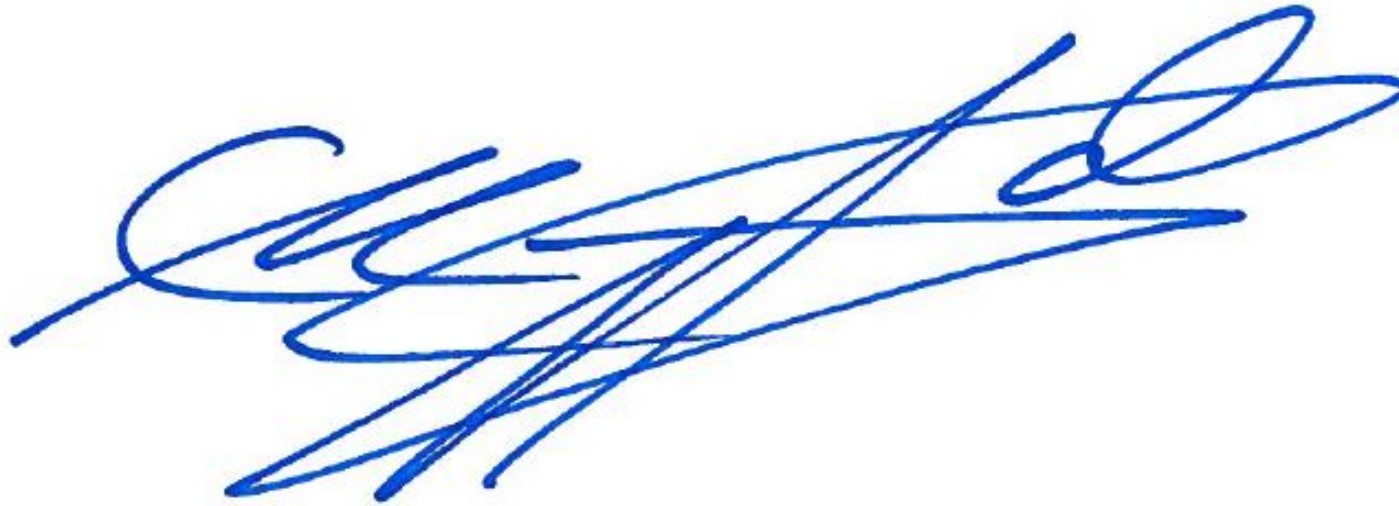
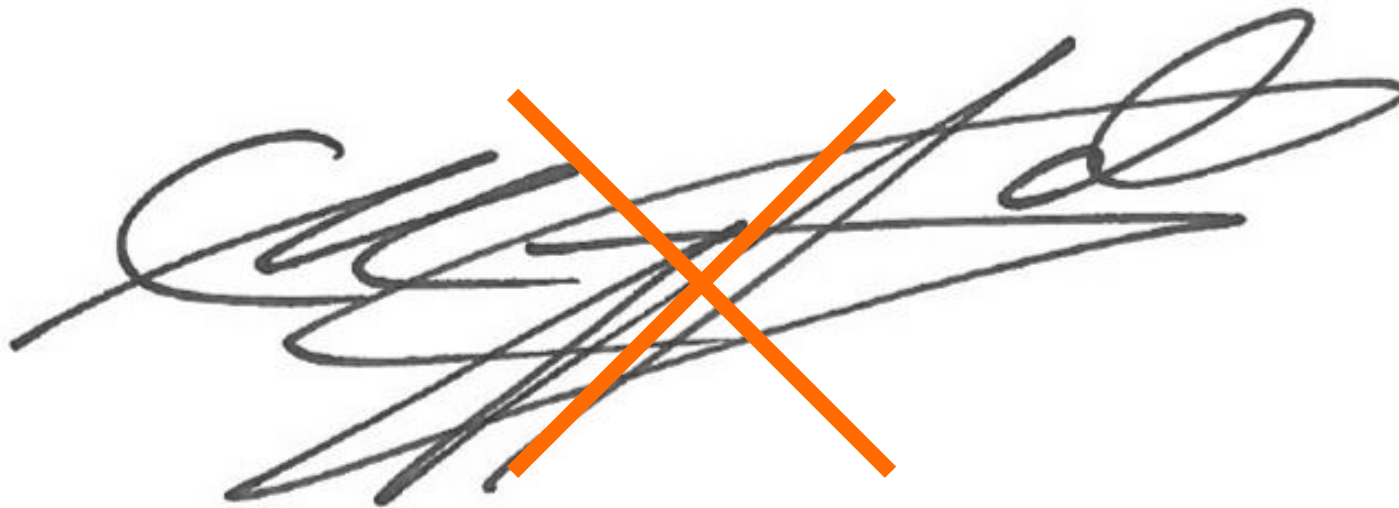
- Handwriting is unique.



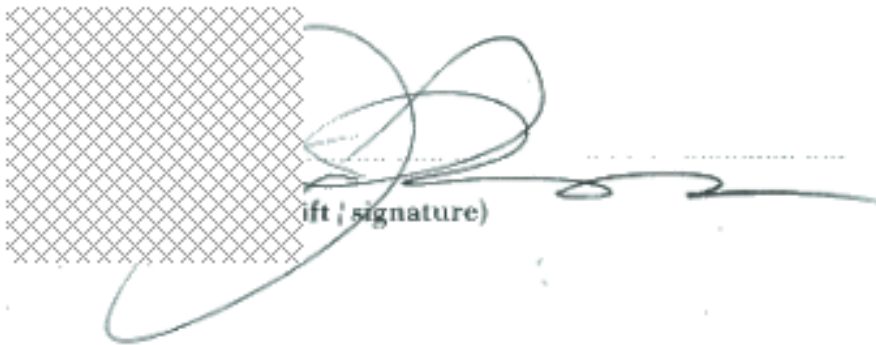
- An individual's handwriting naturally varies.



Variability: No two signatures are identical.

A blue ink signature, appearing to be 'C. G. L. d.', written in a cursive style.A grey ink signature, identical to the one above, but with a large orange 'X' drawn over it, indicating it is not identical or is being rejected.

The degree of variability differs between individuals.



The degree of variability is influenced by several factors, including time.

23.02.1998

Drift H.P. [redacted] hler

27.11.2000

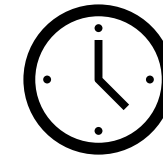
H.P. [redacted]

27.02.2010

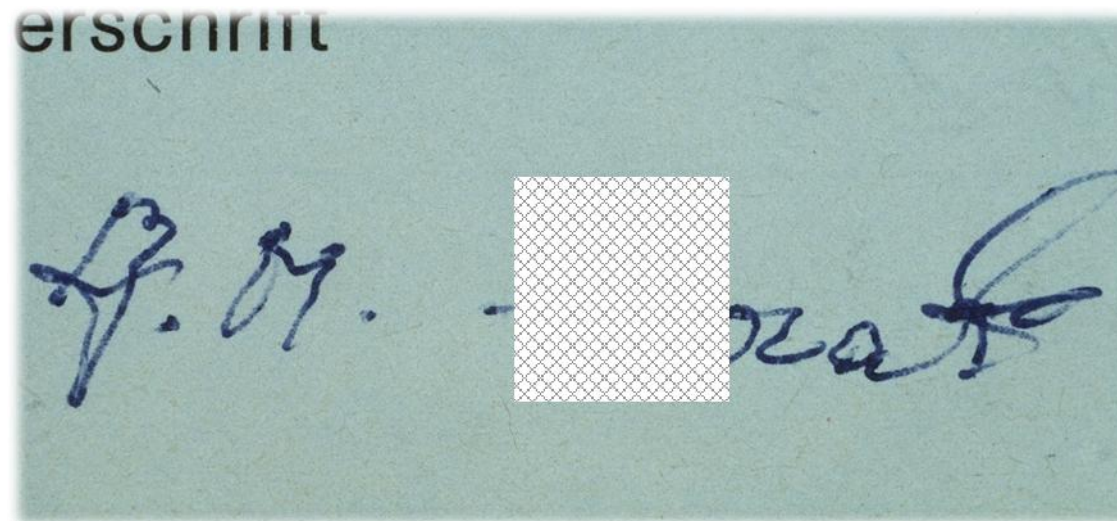
[redacted]

16.06.2015

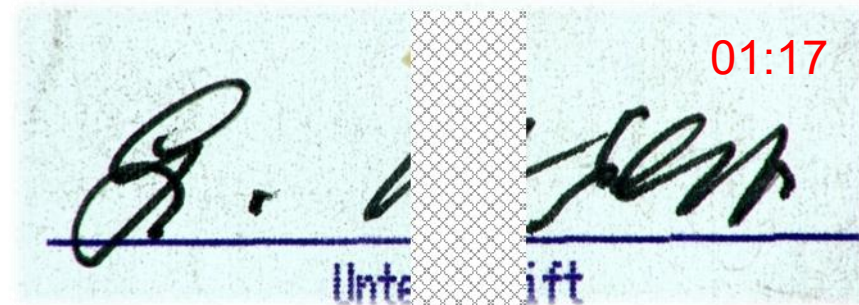
[redacted]



The degree of variability is influenced by several factors, including health (often linked to age).



The degree of variability is influenced by several factors, including alcohol.



The degree of variability is influenced by several factors, including the writing hand.

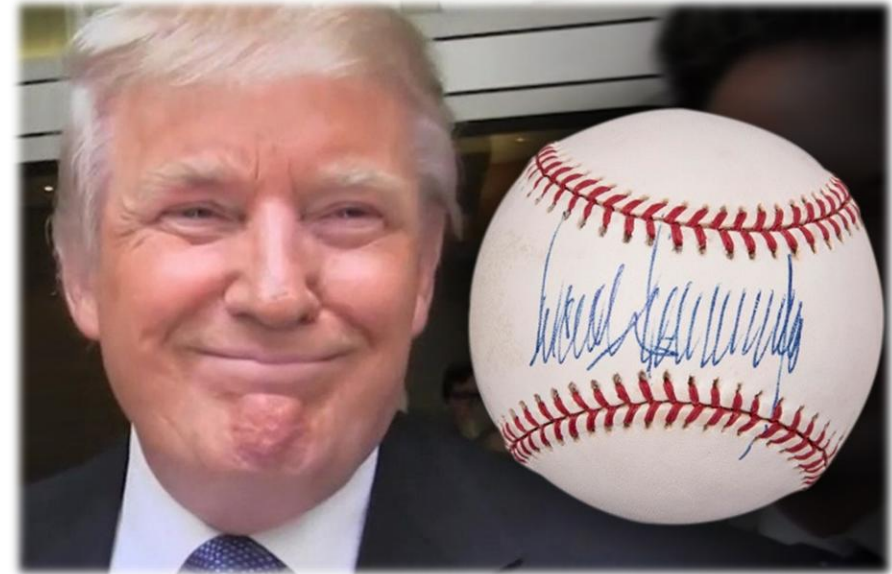
Die Anzeige für die Ferienwohnung haben wir übers Internet gefunden.
Die Adresse lautet: Otto-Hagen-Straße 5 in Etting.
Telefonnummer: 0748-15889



die Anzeige für die Ferienwohnung haben wir übers Internet gefunden.
Die Adresse lautet: Otto-Hagen-Straße 5 in Etting.
Telefonnummer: 0748-15889



The degree of variability is influenced by several factors, including the writing position.



The degree of variability is influenced by several factors, including disguise-strategies

WE ALL KNOW THAT WHAT YOU STAND FOR, WITH YOUR BRAINWASHED TROOPS AND MARTYRS, WILL BE THE DOWNFALL OF THIS COMMUNITY.

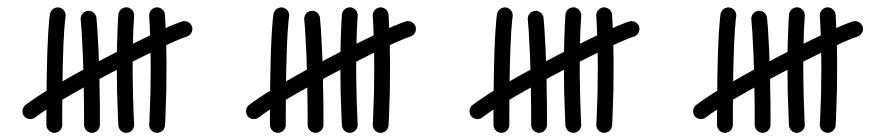
WE ALL KNOW THAT WHAT YOU STAND FOR, WITH YOUR BRAINWASHED TROOPS AND MARTYRS, WILL BE THE DOWNFALL OF THIS COMMUNITY.

BAW
-57R
8870 287R757

E N I L H T I N
Z G E X A C
I N C A N A D A
E N I N A L L I
M I T L I N E

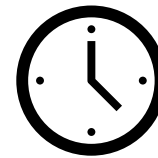
Because of this variability, high standards are required for comparison material.

- Enough samples produced in different situations



- Produced under conditions similar to those of the questioned writing

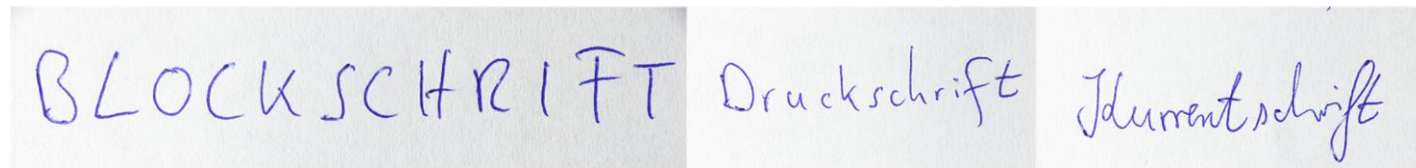
- Temporal proximity to the questioned writing



- Availability of originals



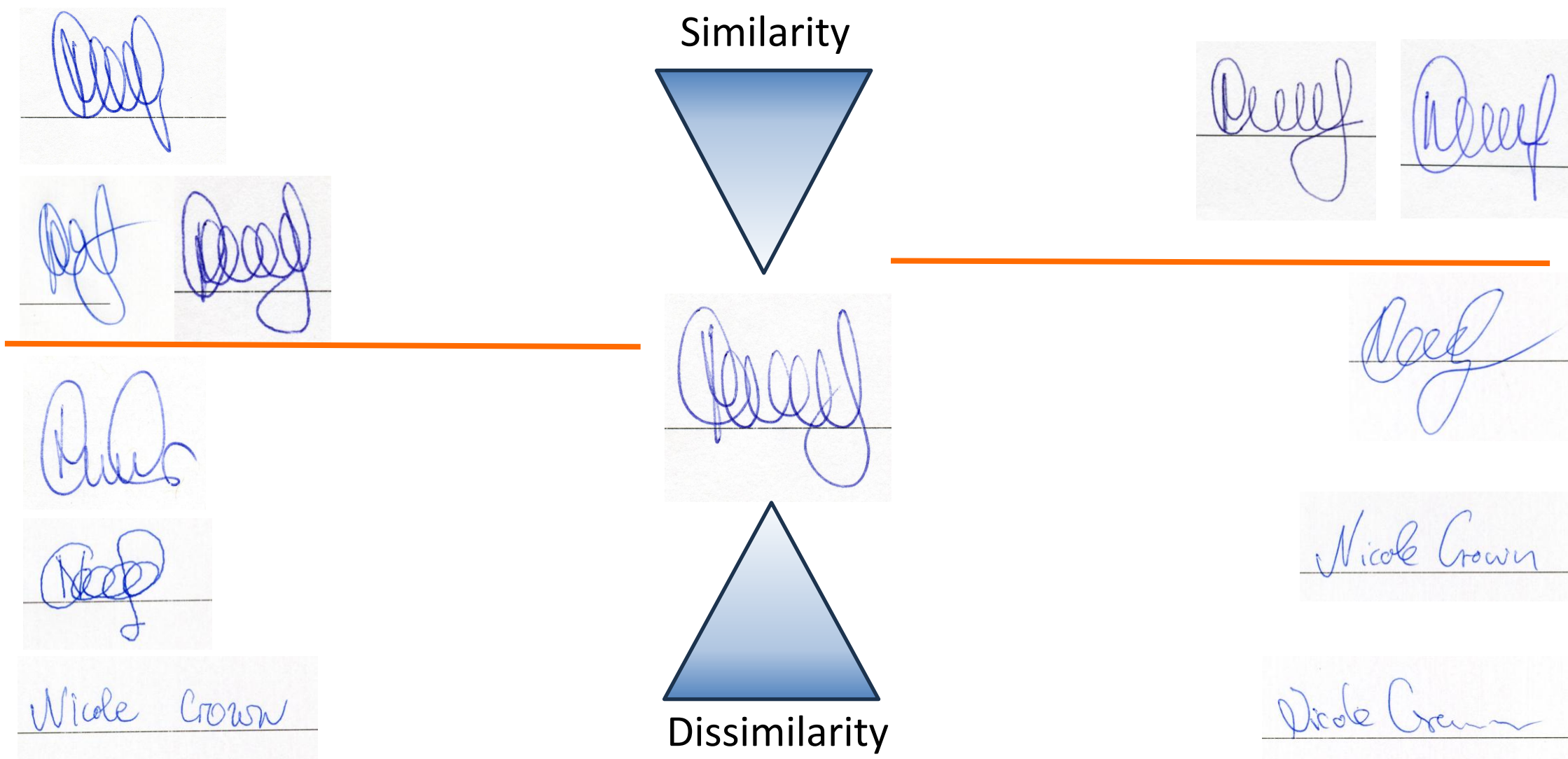
- Similar writing style and characters



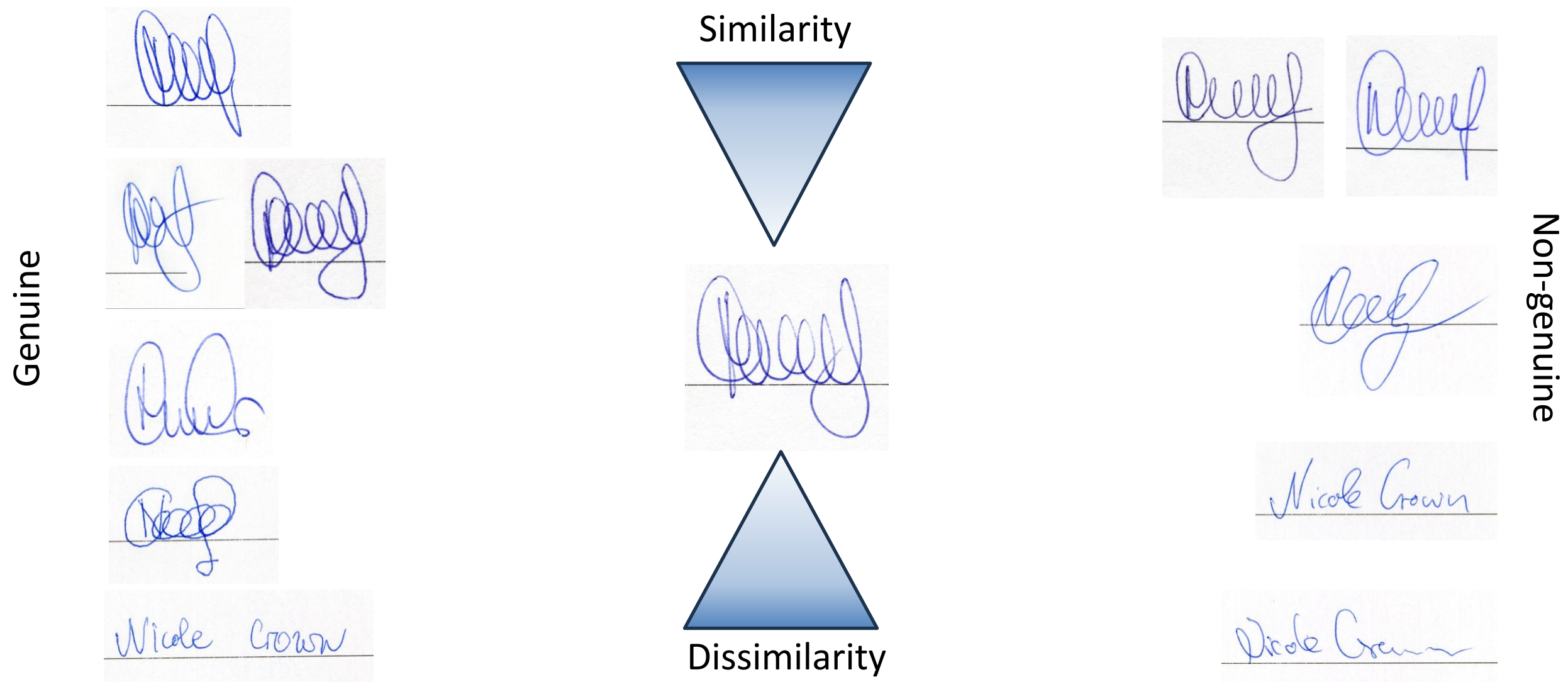
- Reliable attribution to the comparison writer



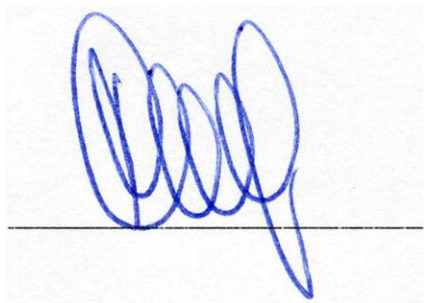
The variability also makes the examination of signatures complex.



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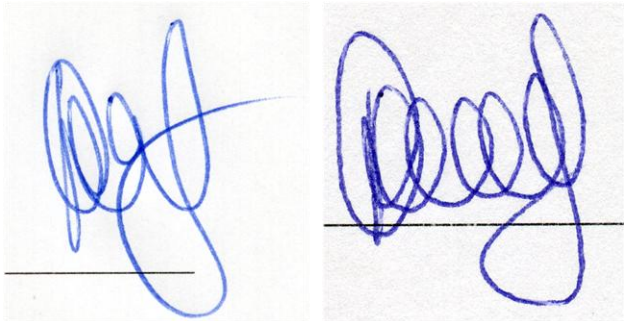
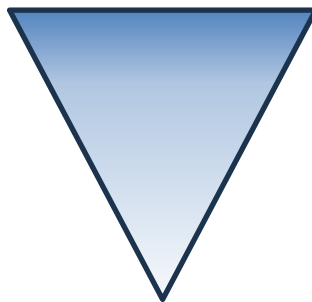


Genuine

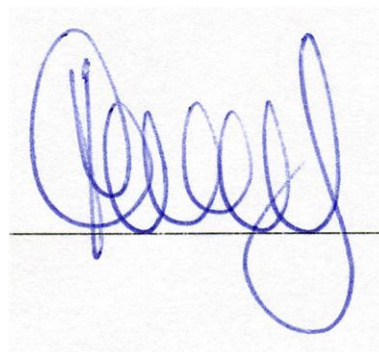


“Normal”
signature

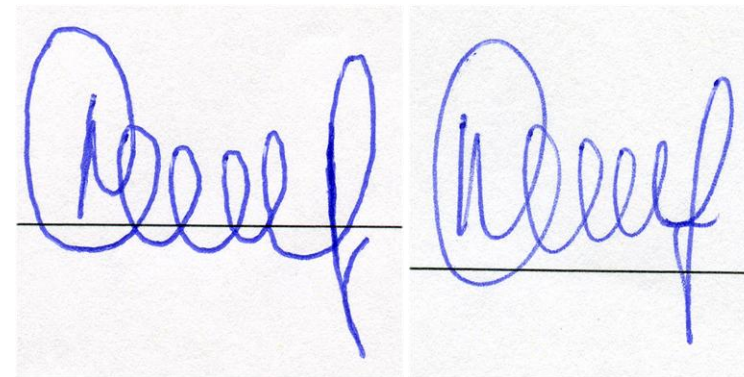
Similarity



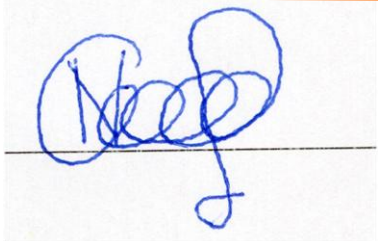
Unconsciously
altered



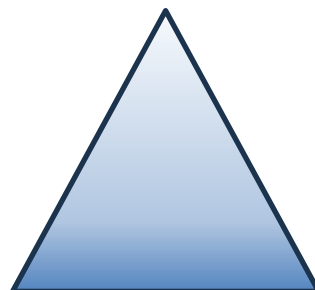
Simulated



Non-genuine

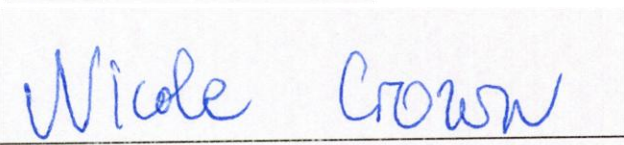
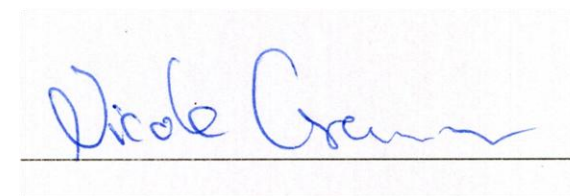
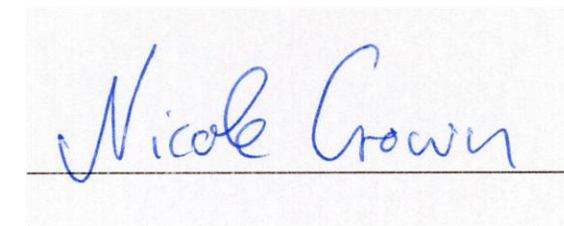


Consciously
altered



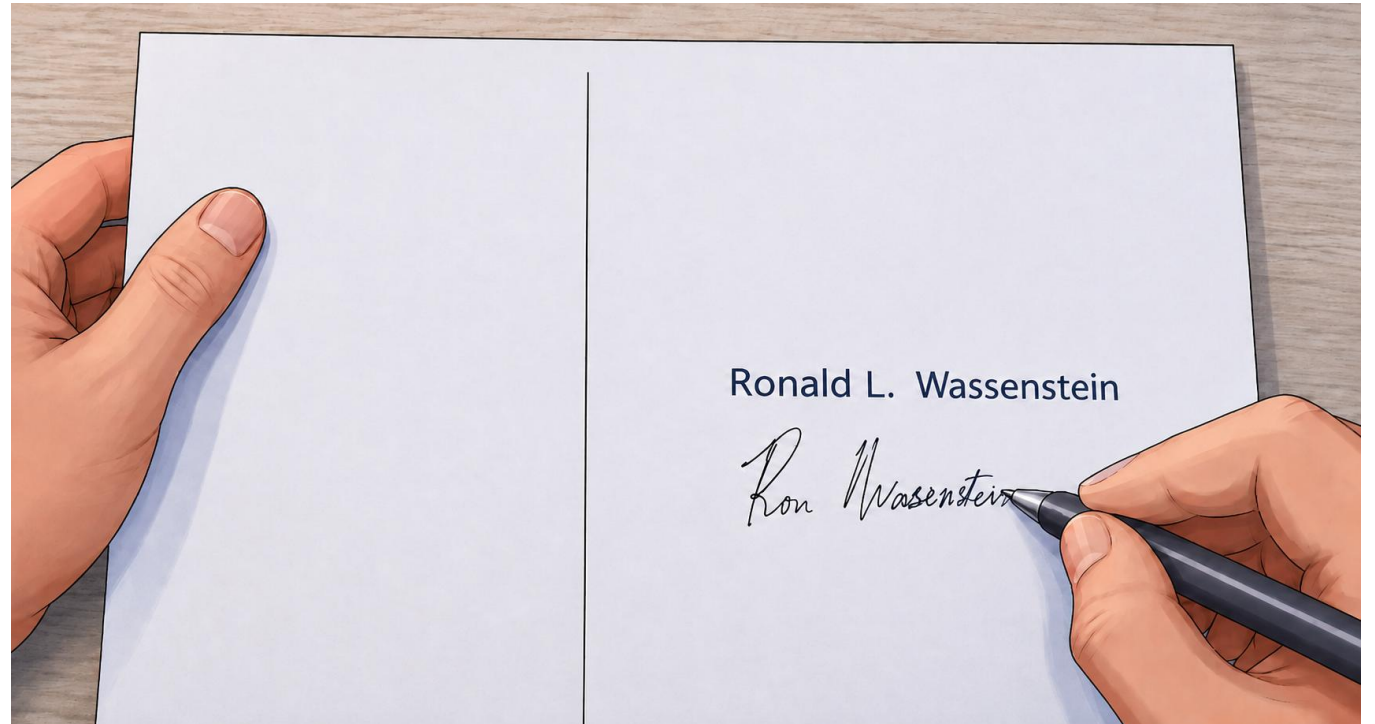
Dissimilarity

Non-
simulated



A forger can use different approaches, for example:

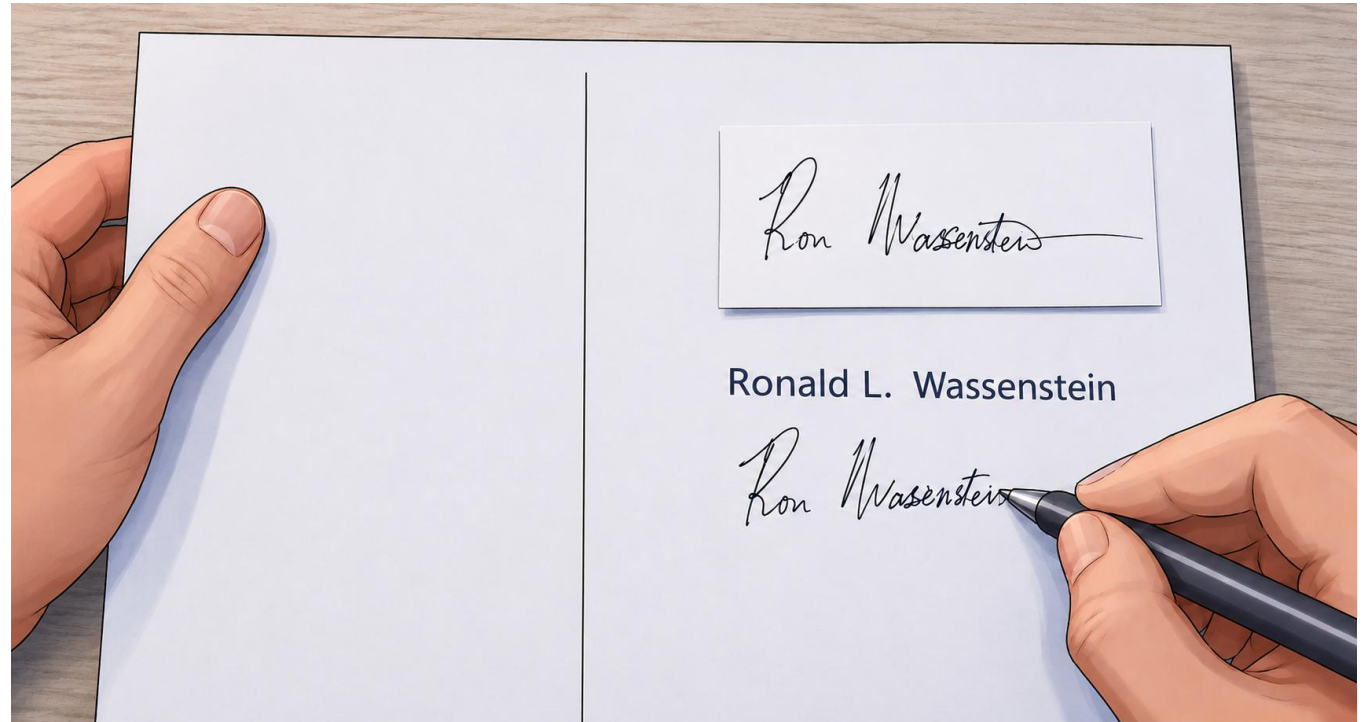
- Writing in their own handwriting (non-simulated)



A forger can use different approaches, for example:

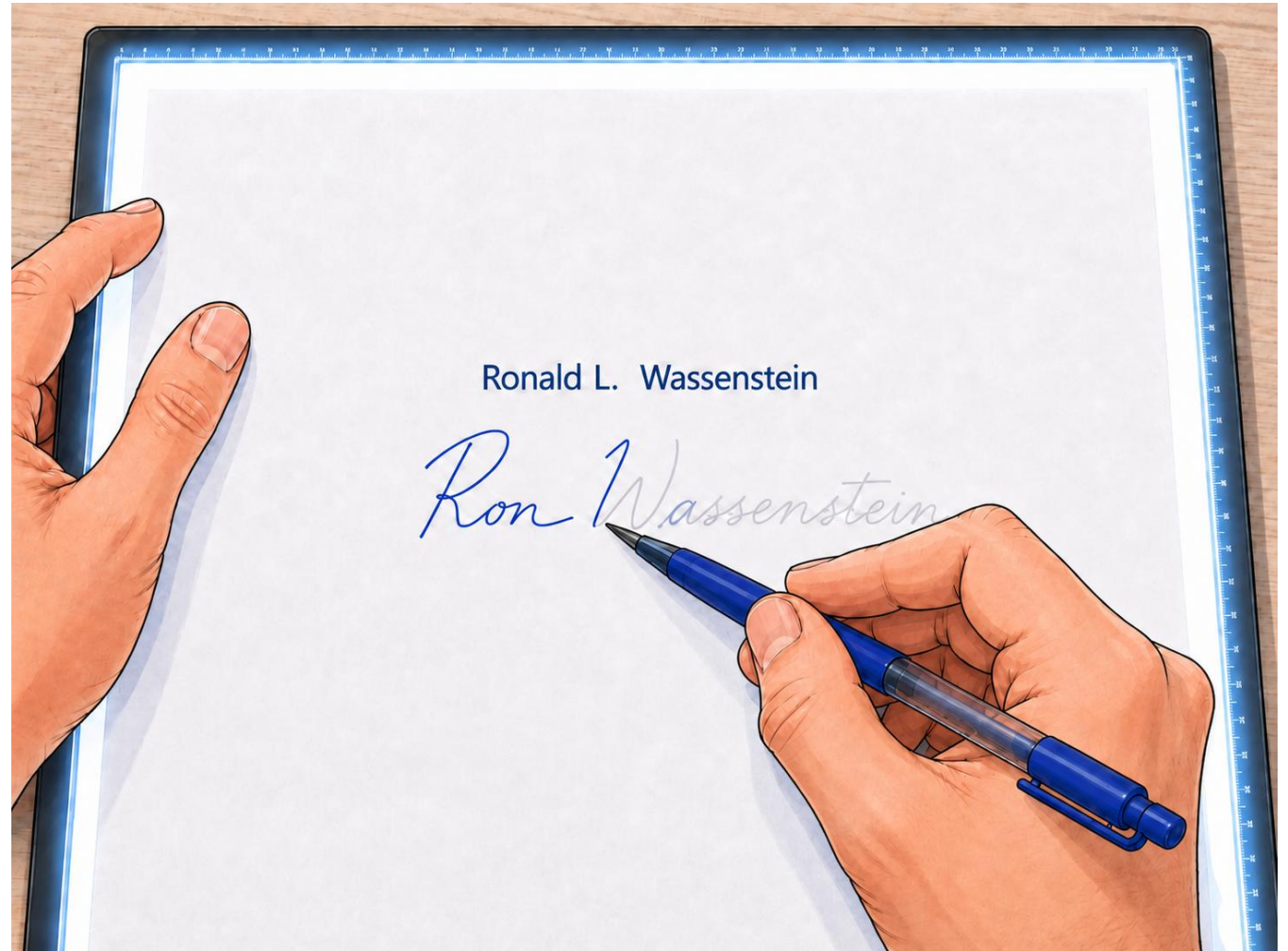
- Writing in their own handwriting

- Freehand simulation



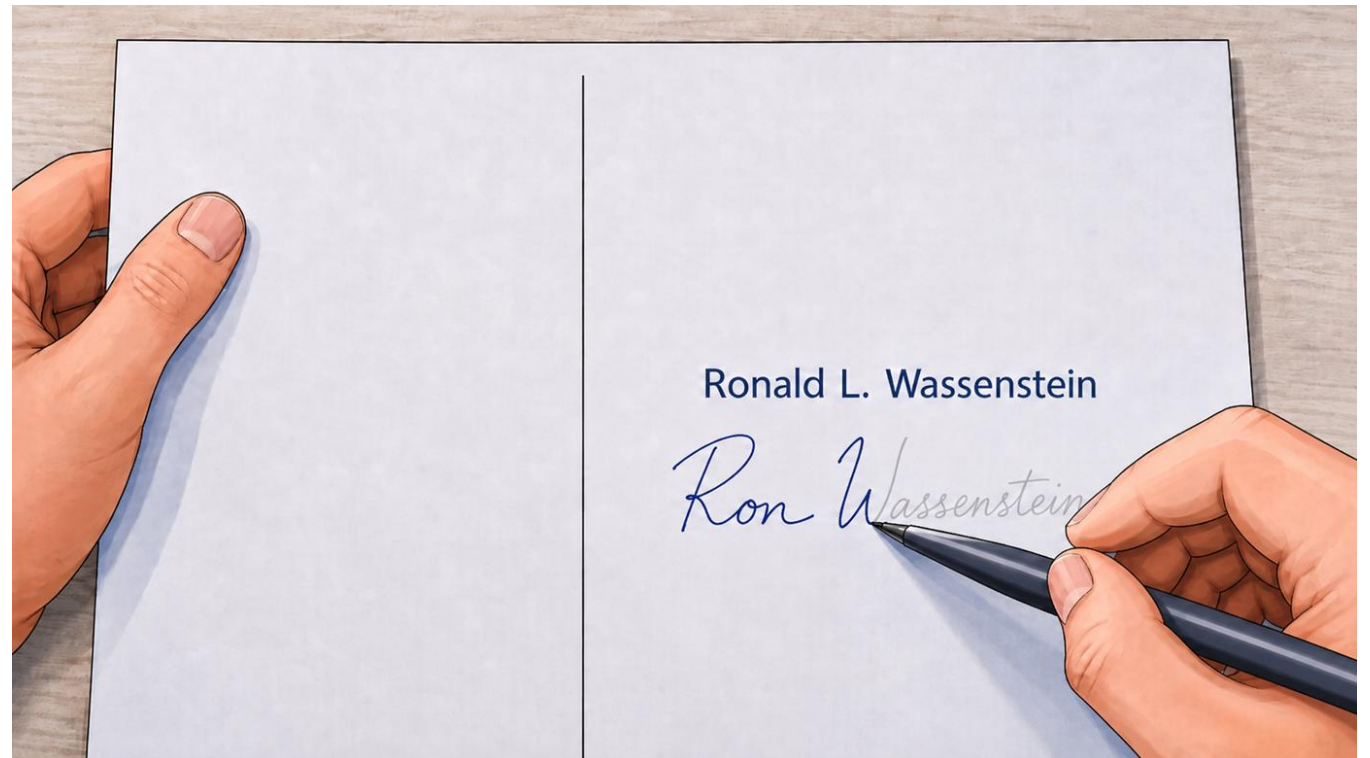
A forger can use different approaches, for example:

- Writing in their own handwriting
- Freehand simulation
- Direct tracing



A forger can use different approaches, for example:

- Writing in their own handwriting
- Freehand simulation
- Direct tracing
- Indirect tracing



Various factors influence the quality of a forgery, for example factors related to the forger:

- Perceptual abilities, visual memory, graphic skill

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journal homepage: www.elsevier.com/locate/forsciint



Are expert penmen better than lay people at producing simulations of a model signature?

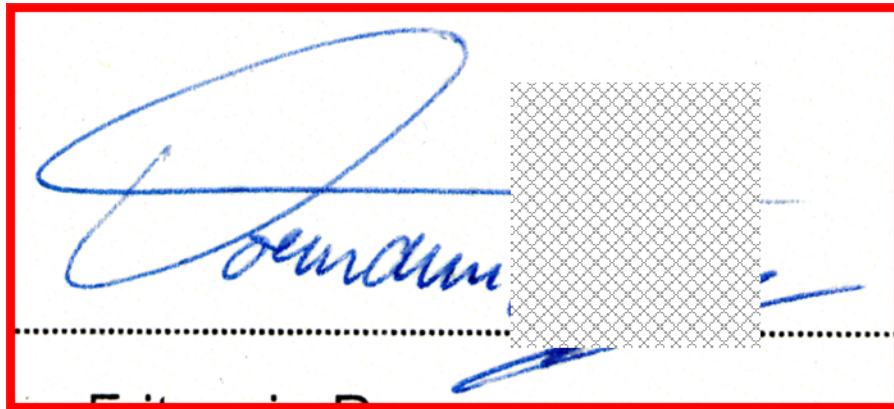
Tahnee Dewhurst^{a,b}, Bryan Found^{a,b,*}, Doug Rogers^b

^aDocument Examination Unit, Digital and Documents Evidence Branch, Victoria Police Forensic Services Department, Macleod, Victoria 3085, Australia

^bHandwriting Analysis and Research Laboratory, School of Human Biosciences, La Trobe University, Victoria 3086, Australia

Various factors influence the quality of a forgery, for example factors related to the forger:

- Perceptual abilities, visual memory, graphic skill
- Handwriting similarity (e.g. due to chance or family-related similarities)



Various factors influence the quality of a forgery, for example factors related to the situation:

- Quality and quantity of available genuine signature specimens
- Opportunity to practice
- Choice of writing instrument
- Presence of other people who are unaware of the forgery
- Ability to reproduce the target document and select the best simulation
- Number of signatures to be forged



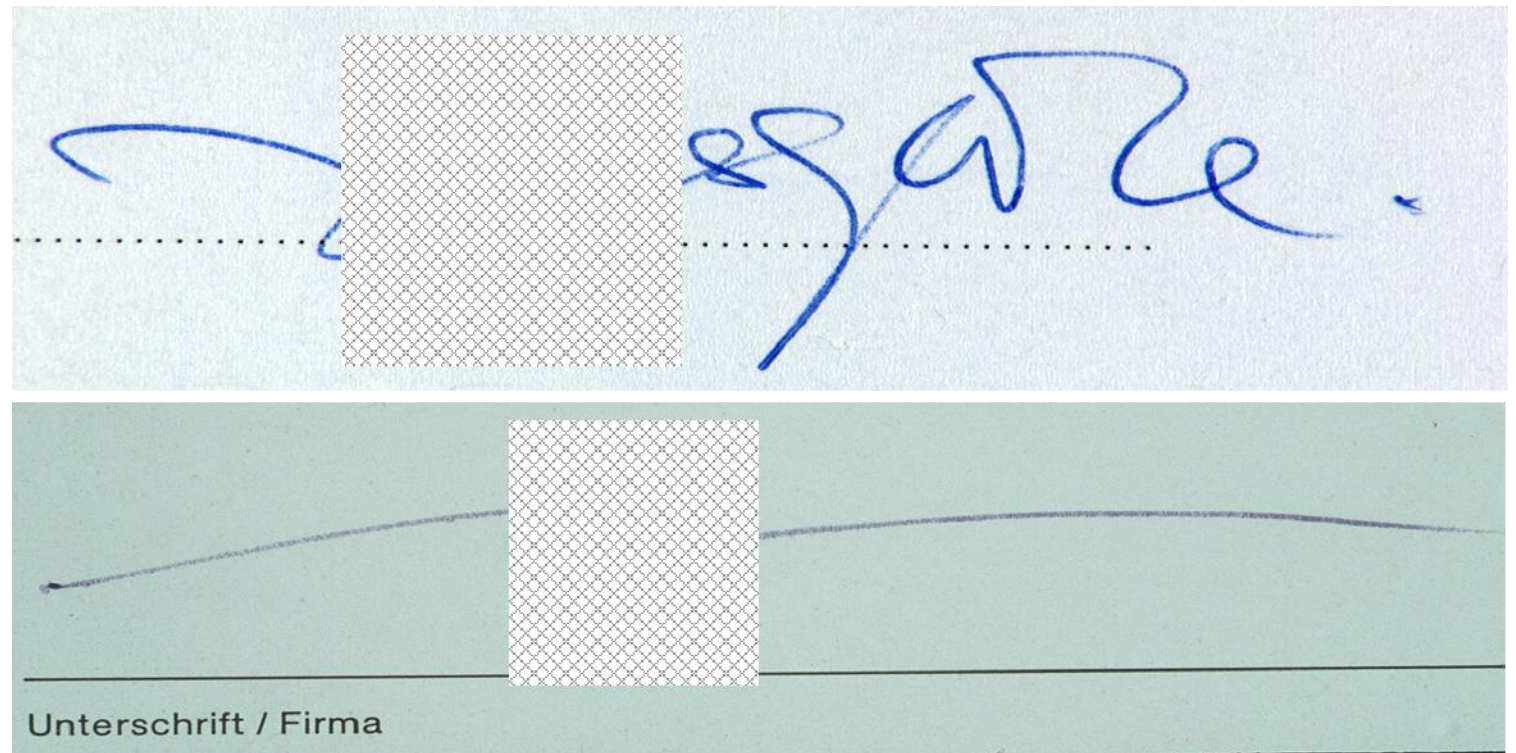
Various factors influence the quality of a forgery, for example factors related to the signatures of the “target person”:

- Range of variation

- “Graphic information content”

- Complexity

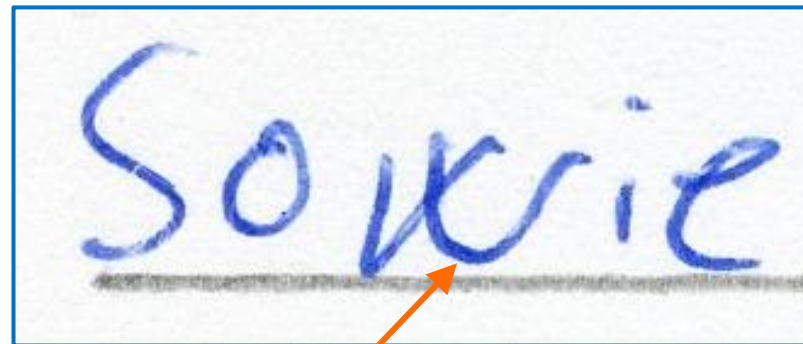
Variations of complexity



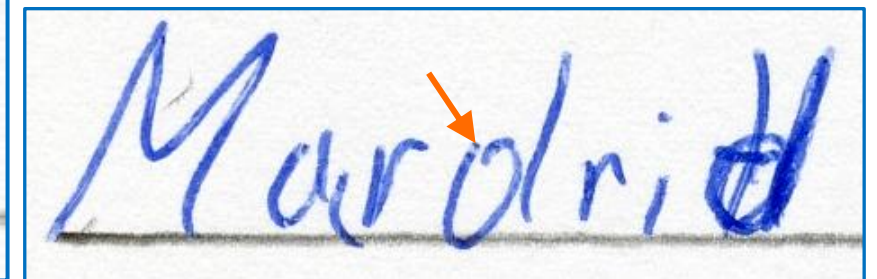
Various factors influence the quality of a forgery, for example factors related to the signatures of the “target person”:

- Range of variation
- “Graphic information content”
 - Complexity
 - Degree of individuality

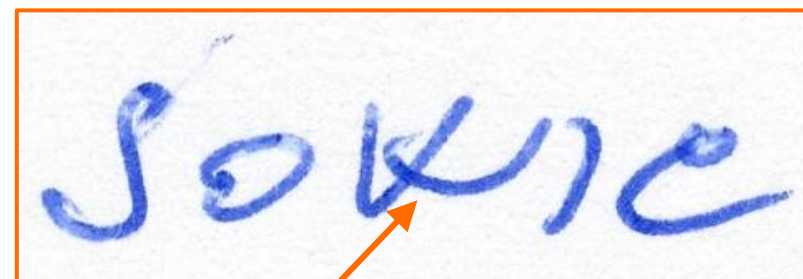
Two writers from Kosovo



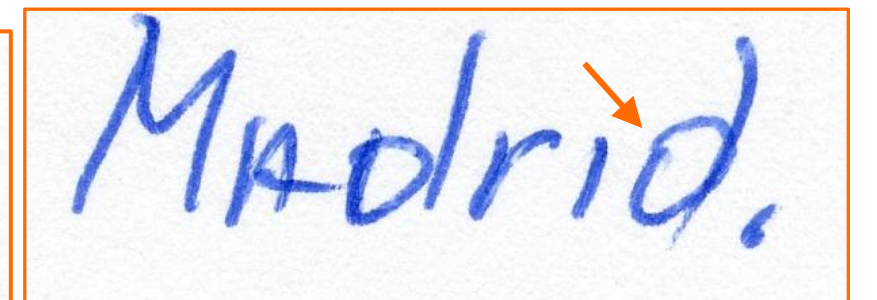
Sokrie



Madrid



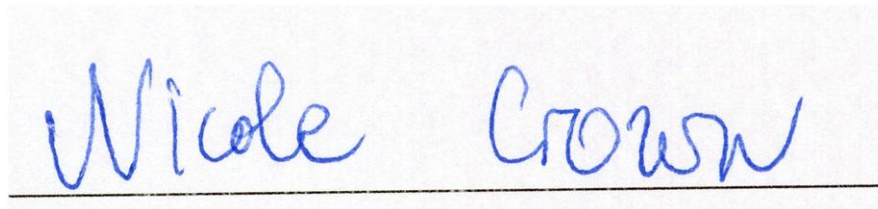
Sokrie



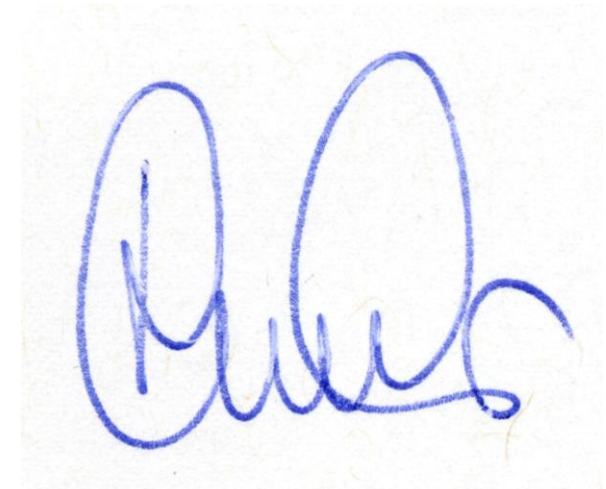
Madrid.

Various factors influence the quality of a forgery, for example factors related to the signatures of the “target person”:

- Range of variation
- “Graphic information content”
 - Complexity
 - Degree of individuality
 - Writing dynamics
 - Connections between characters / elements
 - Legibility



Nicole Crown



P. Müller

ACE-V is a common procedure in forensic science.

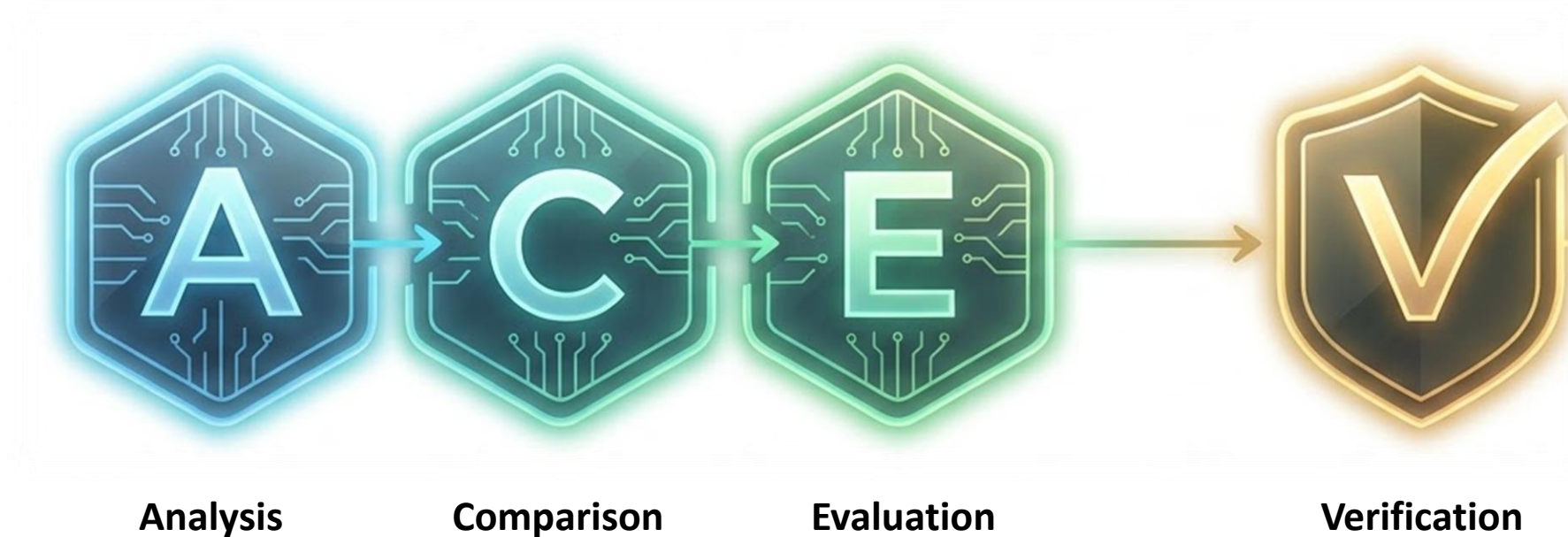


Image AI generated

ACE-V is at the core of forensic examinations.

Pre-assessment

- Adequacy of material and mandate questions
- Potential strength of evidence?

Technical examinations

- Image processing
- Spectral analysis
- Electrostatic examination
- Microscopy

Analysis

- Separate analysis of characteristics in questioned (Q) and known (K) material

Comparison

- Comparison of characteristics in Q and K
→ **Findings (similar / dissimilar)**

Evaluation of findings

- Assessment of the probability of the findings under each proposition
→ **Likelihood Ratio (evidential strength)**

Verification

- Independent repetition of **ACE** by another examiner (quality check)

Technical examinations are non-destructive.

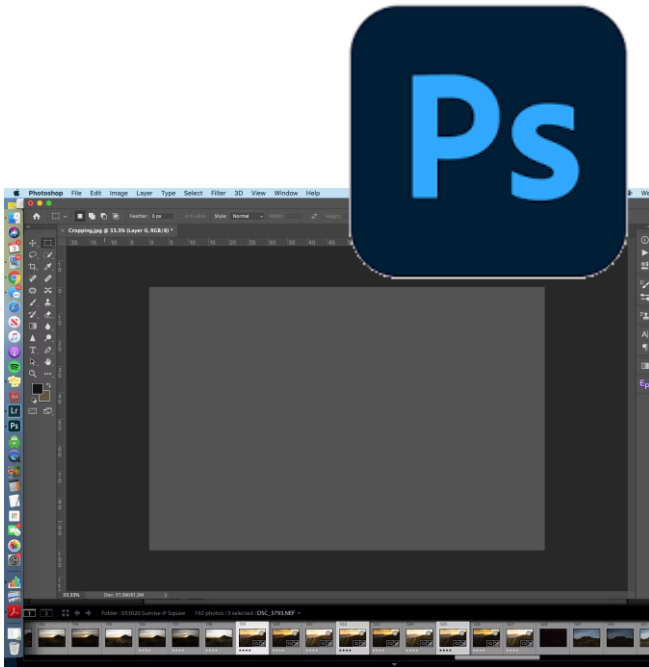


Image processing



Spectral analysis

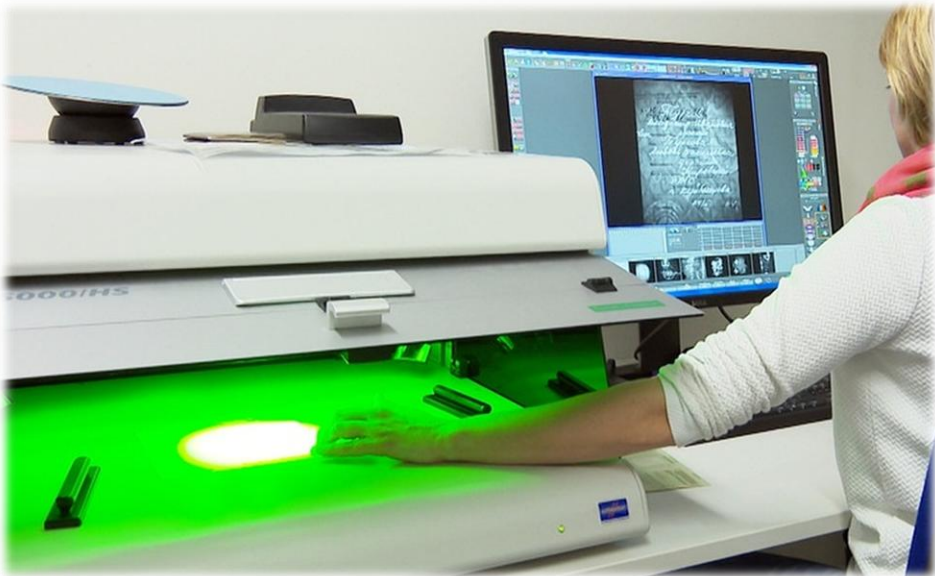


Electrostatic examination



Microscopy

Spectral analysis can reveal differences in ink composition.

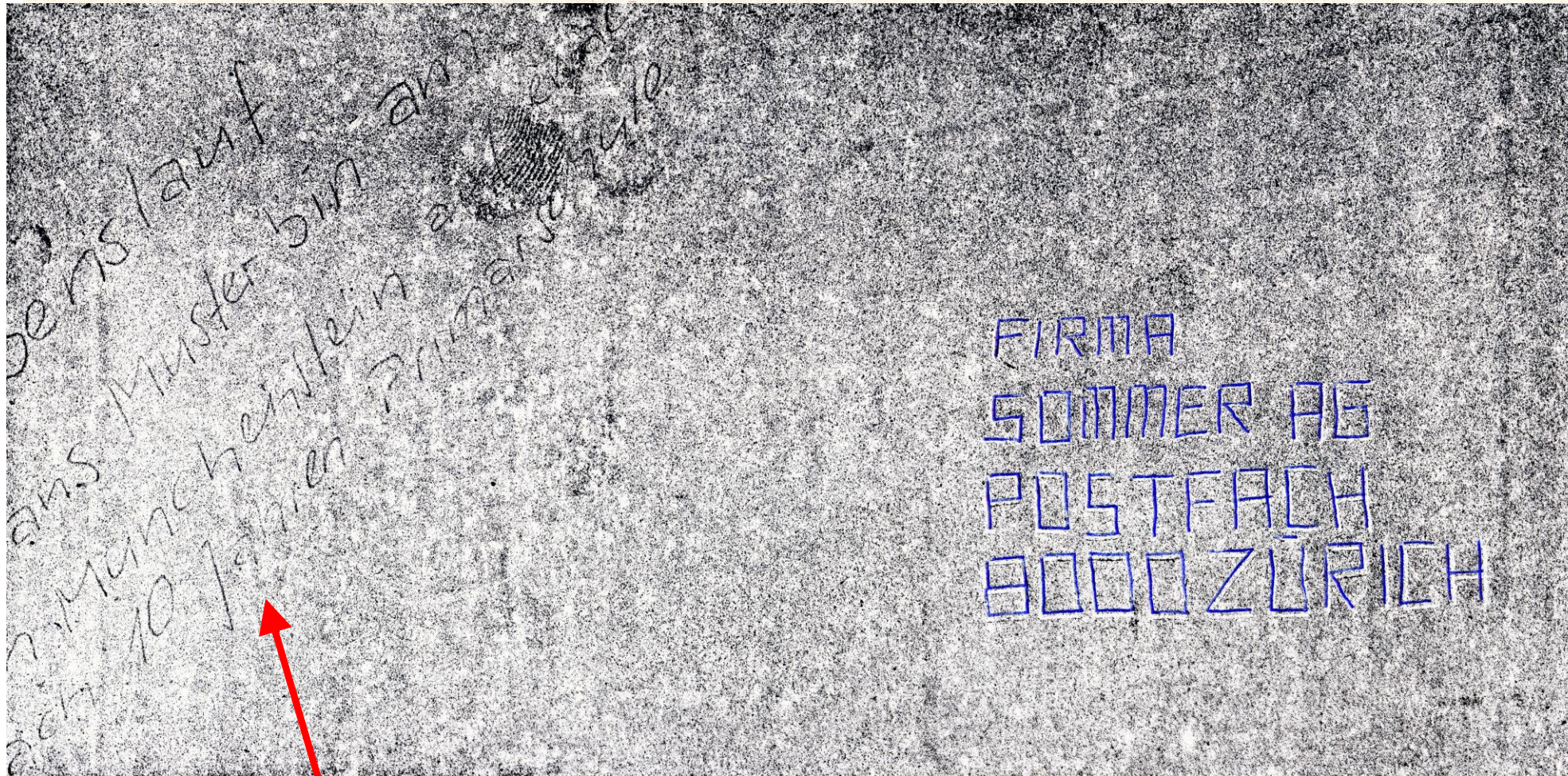


different ink types

The Electrostatic Detection Apparatus (ESDA) can reveal indented writing impressions.



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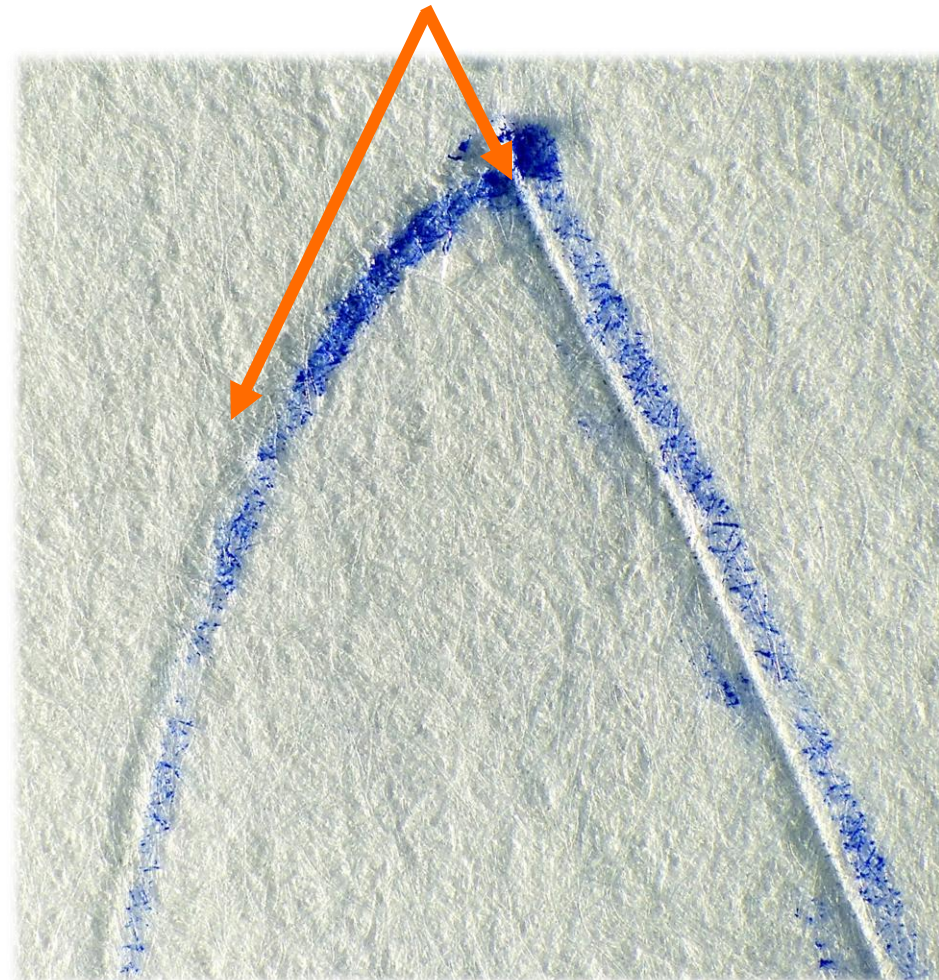
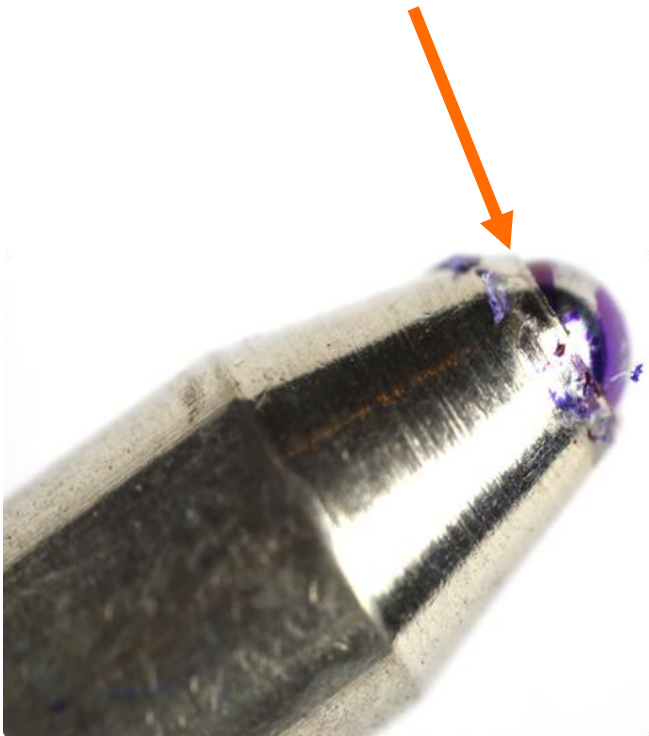


Indented writing impressions

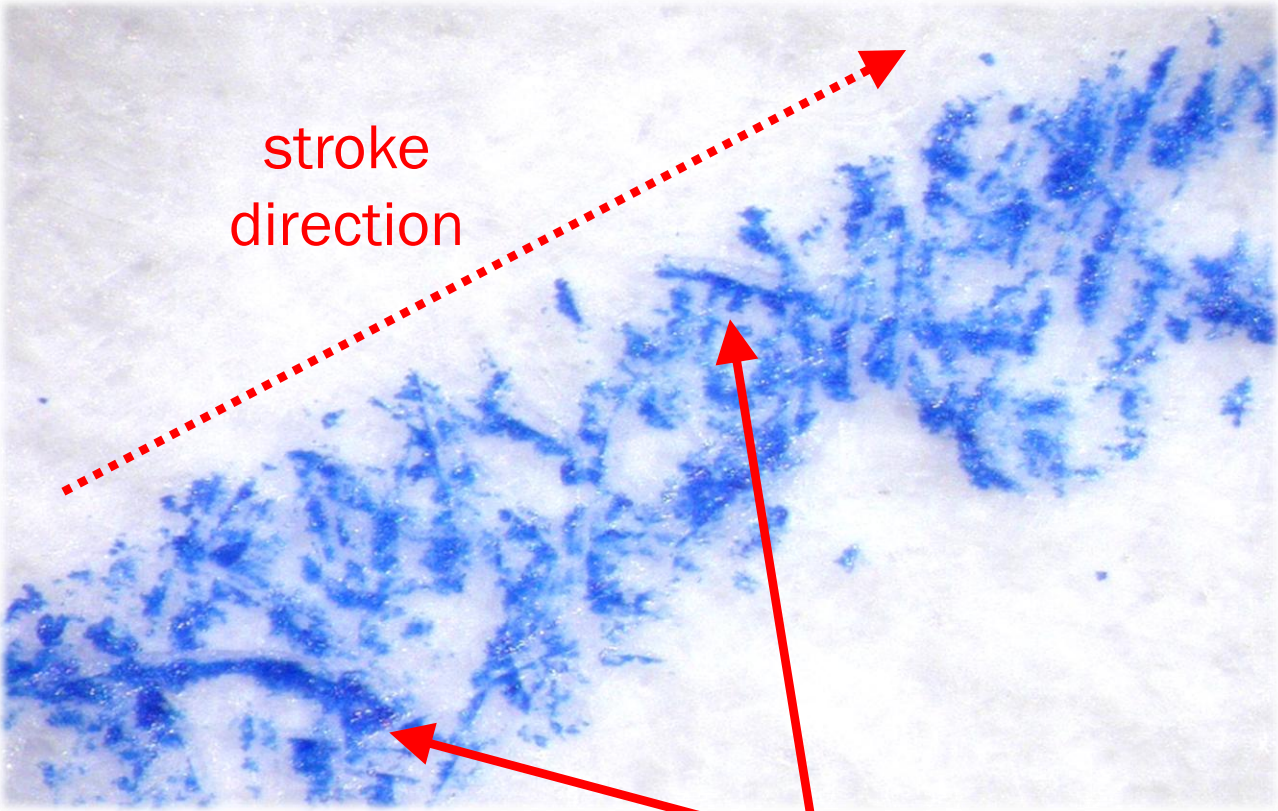
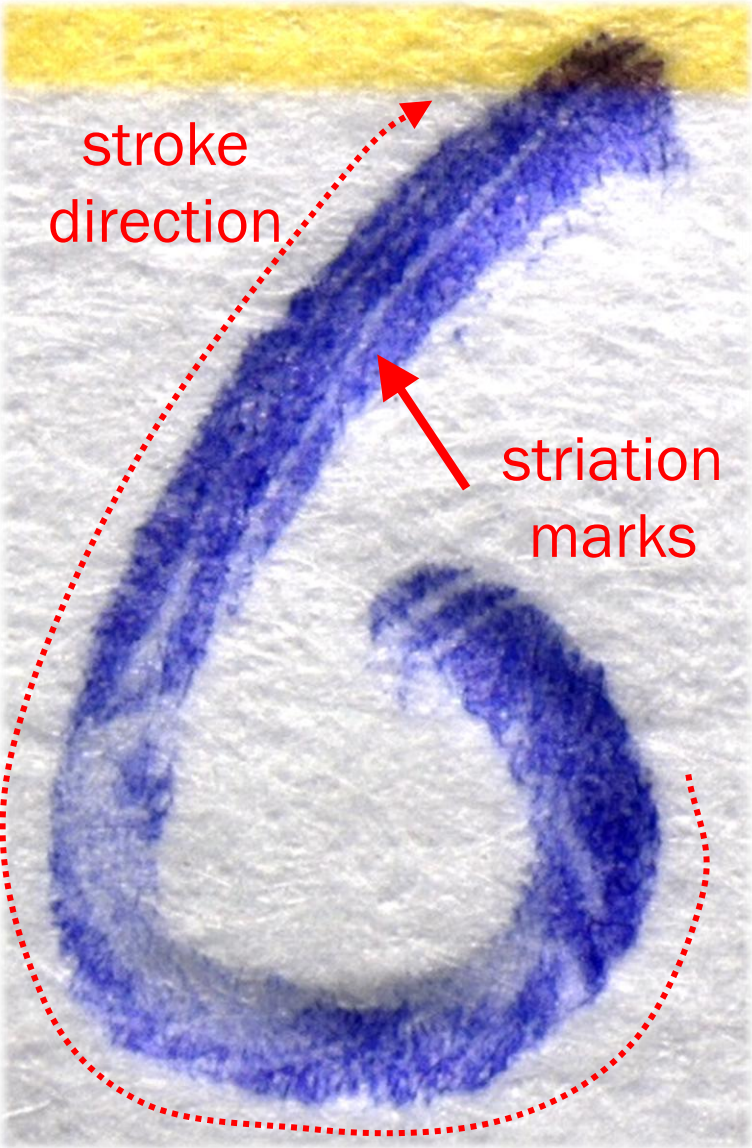
Microscopy can help determine the pen angle during writing.



Sister lines

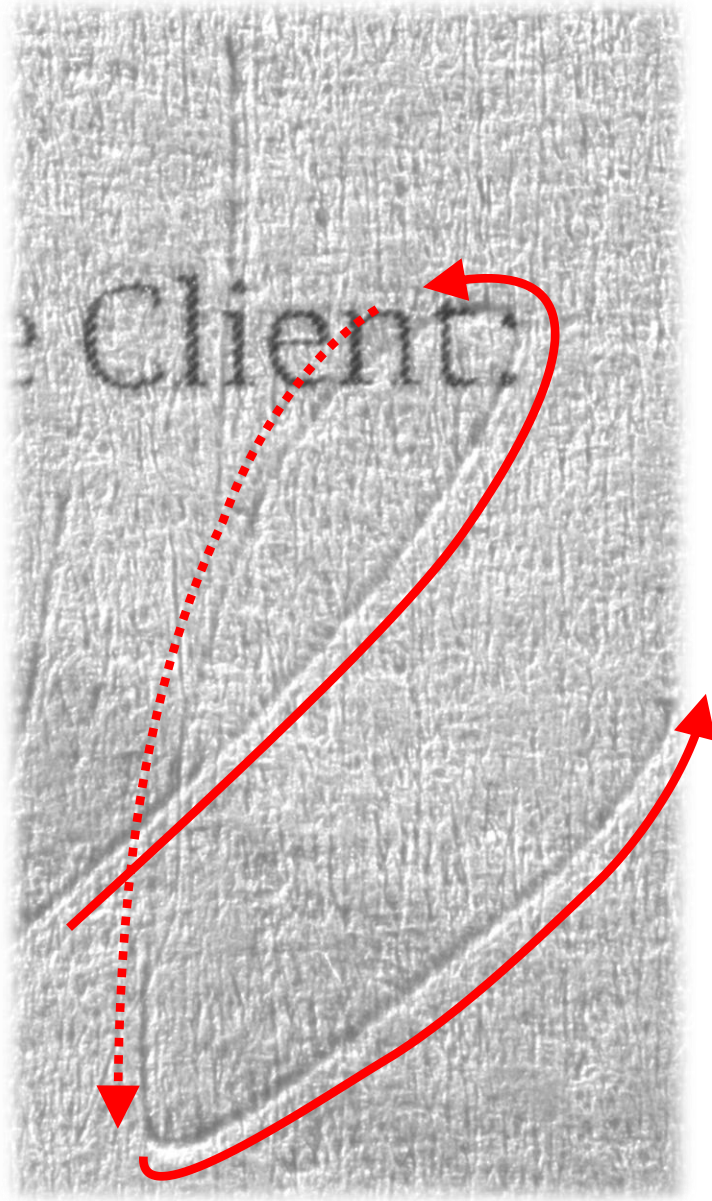
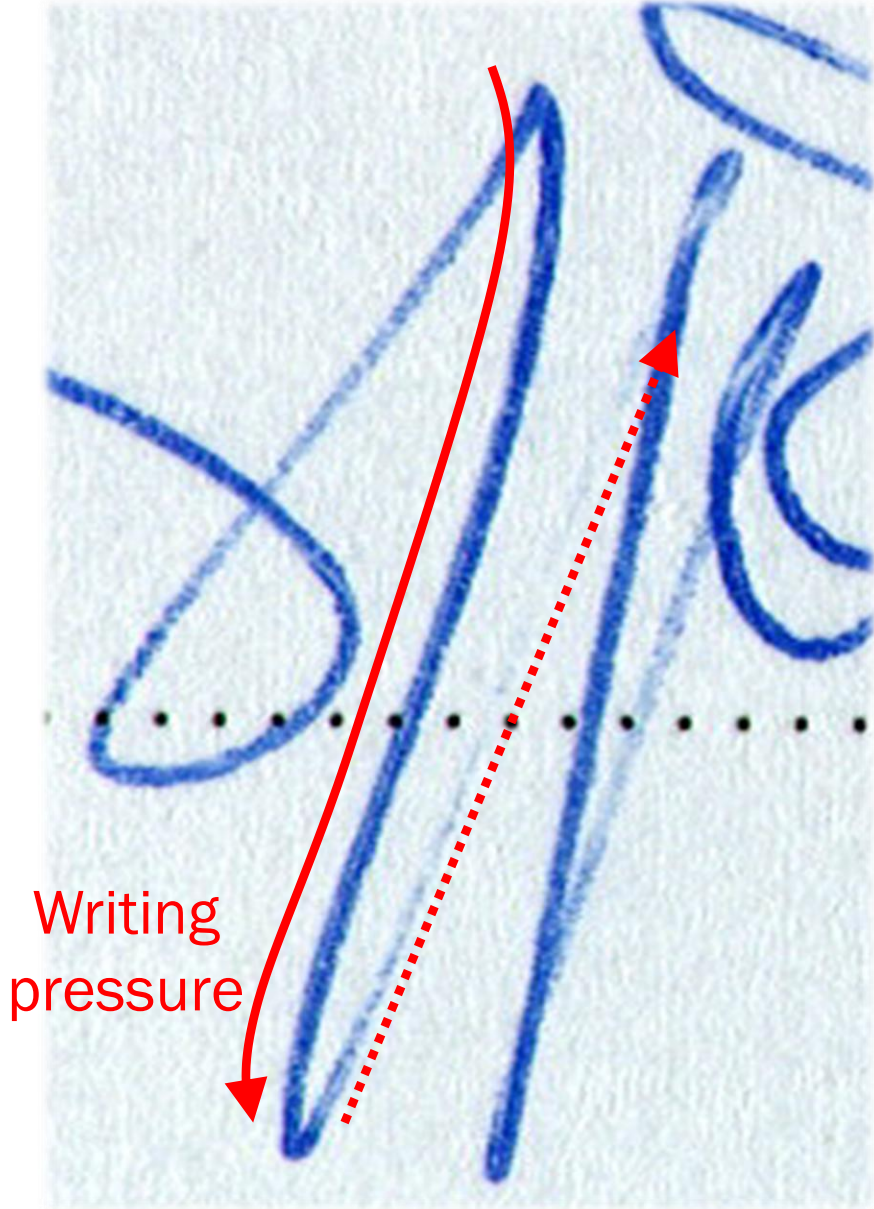


Microscopy can help reconstruct how the stroke direction.



ink deposits on left of fibres

Microscopy helps to observe writing pressure variation.

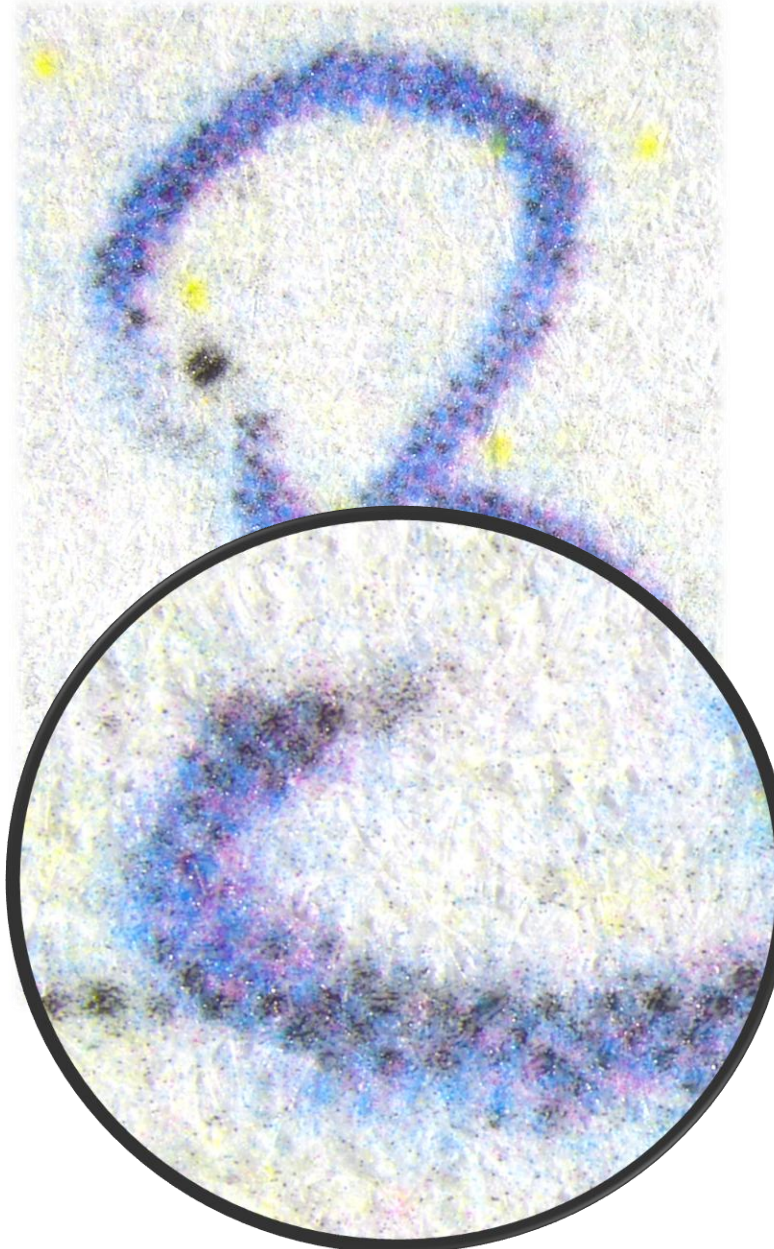
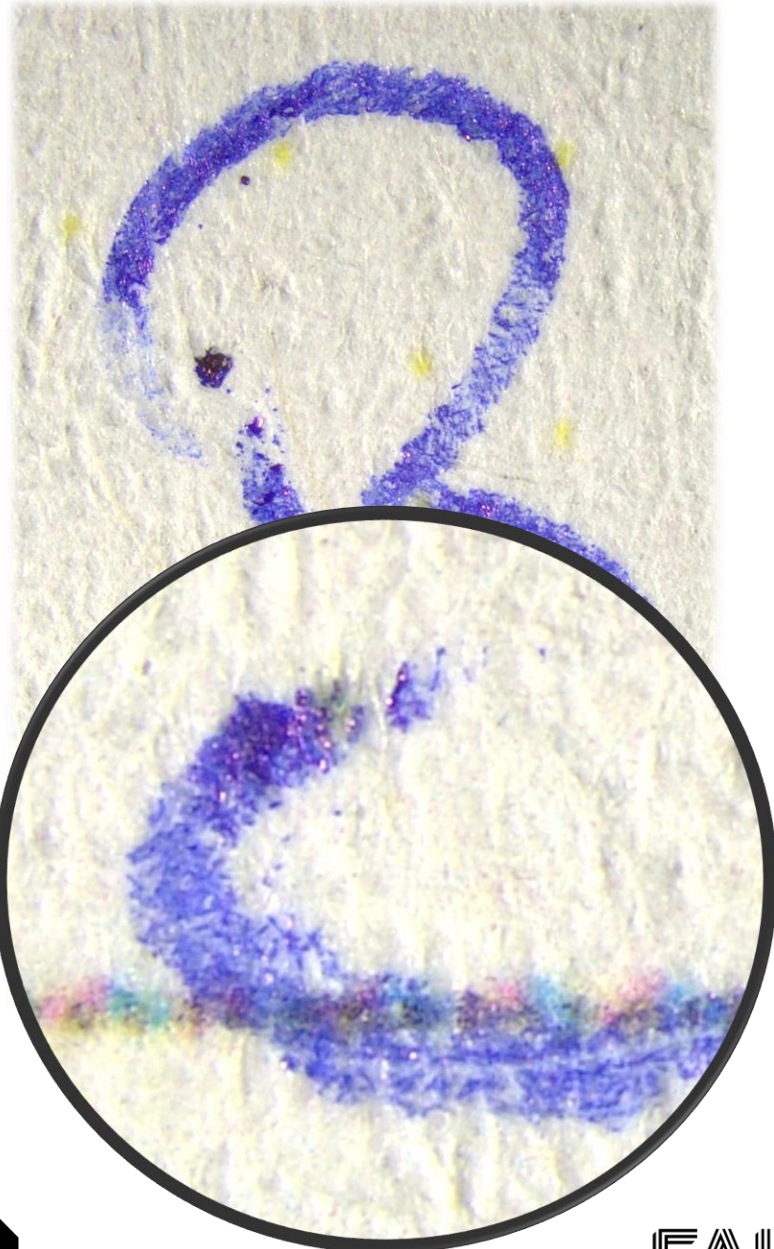


Microscopy can help to distinguish originals from non-originals.

Original (ballpoint pen)

Colour copy

Black-and-white copy



In copies, “strawberries” (Erdbeeren) can become “heirs” (Erben).

Jonathan Heckeroth
Beispielweg 456
54321 Beispielstadt

Lieber Jonathan,
nach meinem Test bin ich allein nach Irland
verreist. Die Erdbeeren in meinem Garten sind
bestimmt schon reif. Du darfst sie gerne pflücken.
Schnapp Dir auch ruhig meine Instrumente. Ich
rufe demnächst mal an.

Bis bald

Max Müller

Erdbeeren

Testament

Ich bestimme Jonathan Heckeroth

als meinen alleinigen Erben

Max Müller

Erben

Graphical features can be classified as general or specific characteristics.



General characteristics

- Assessed in entire text/words
- Overall appearance
- Can be compared between different words/letters
→ global assessment

Specific characteristics

- Assessed in single characters
- Shape/details
- Only same or very similar characters can be compared
→ local assessment

General features refer to different components of handwriting.



Spacing

- Layout, positioning on document
- Distances between words and between lines

Size/Proportions

- Vertical proportions
- Emphasis (e.g. large capitals)

Fluency

- Connectivity (between letters) / pen lifts
- Writing speed

Movement characteristics

- Slope
- Initiating / terminal strokes

Writing pressure

- Pressure strength
- Pressure rhythm/variation

Line quality

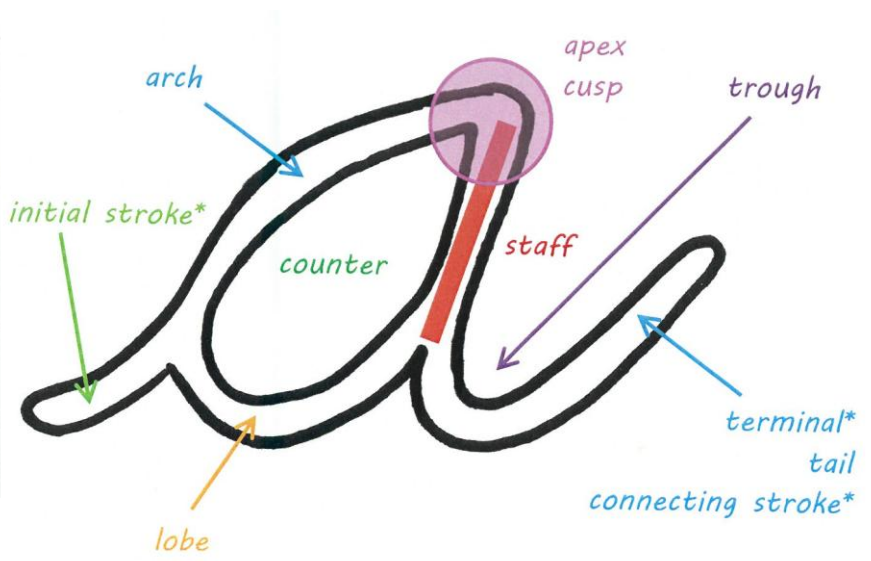
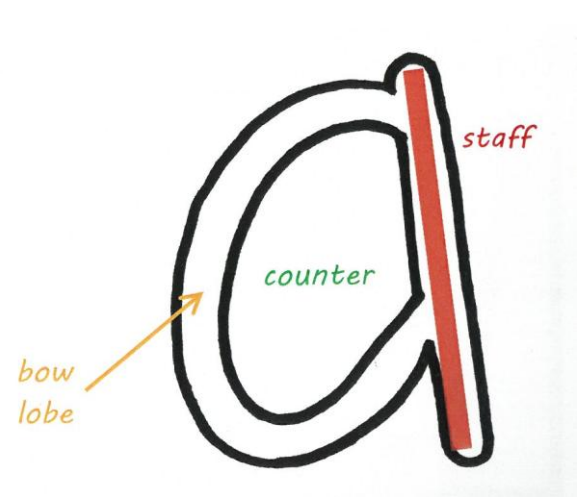
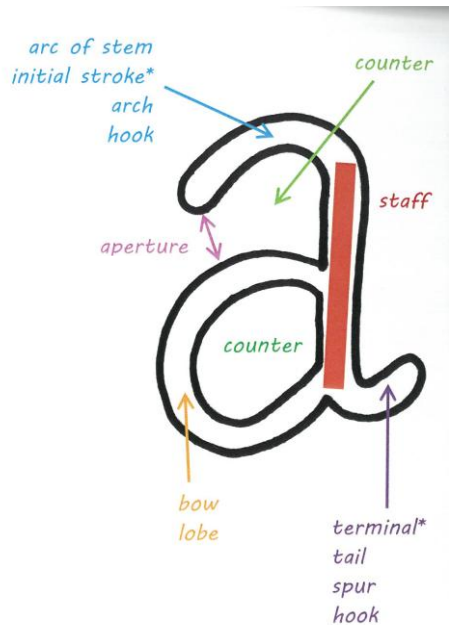
- Characteristics of writing direction & velocity
- Characteristics of pen grip

All characters are systematically analysed and compared.



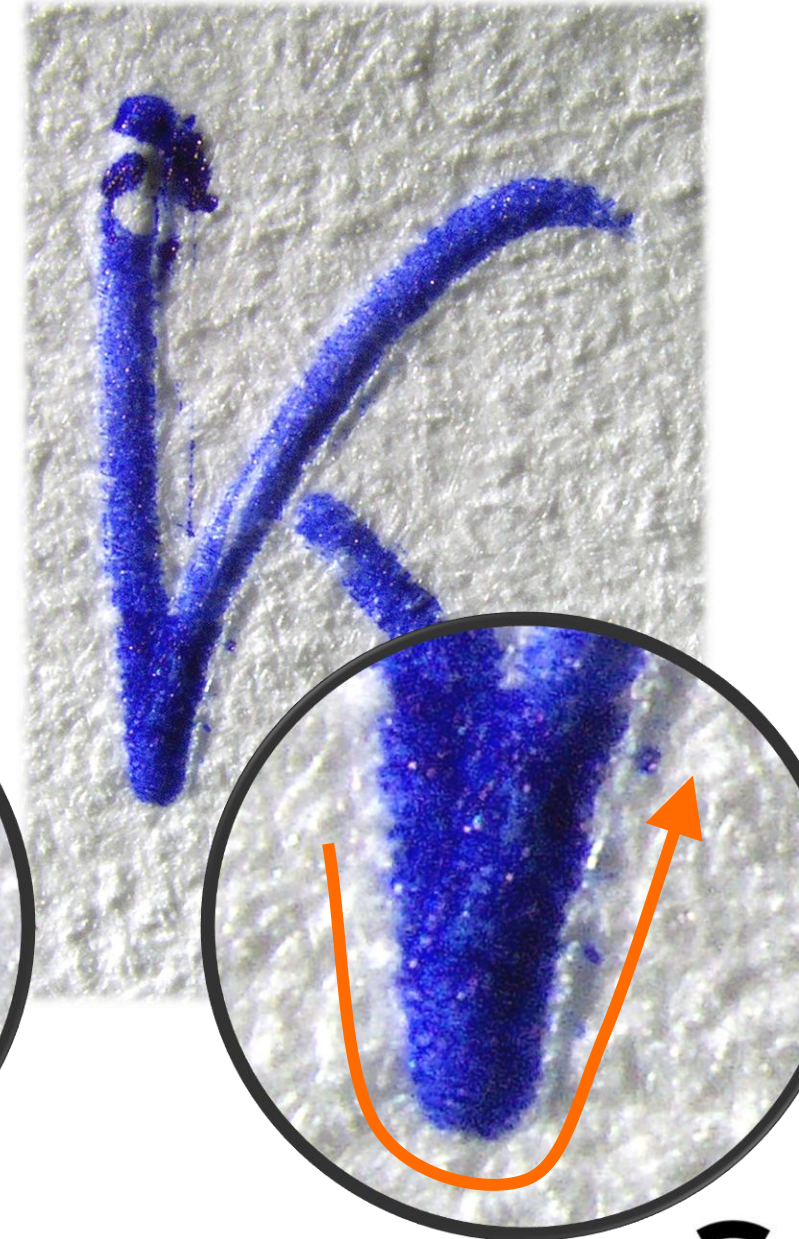
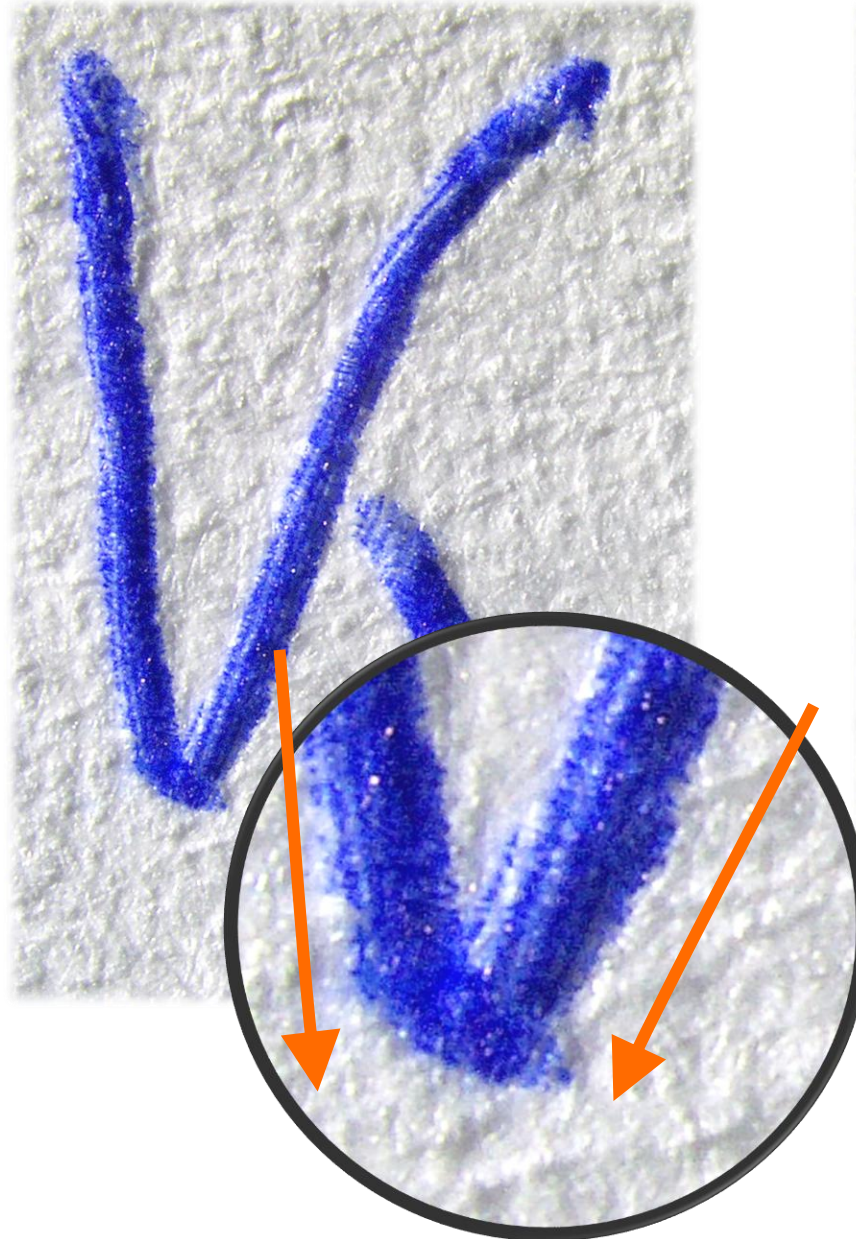
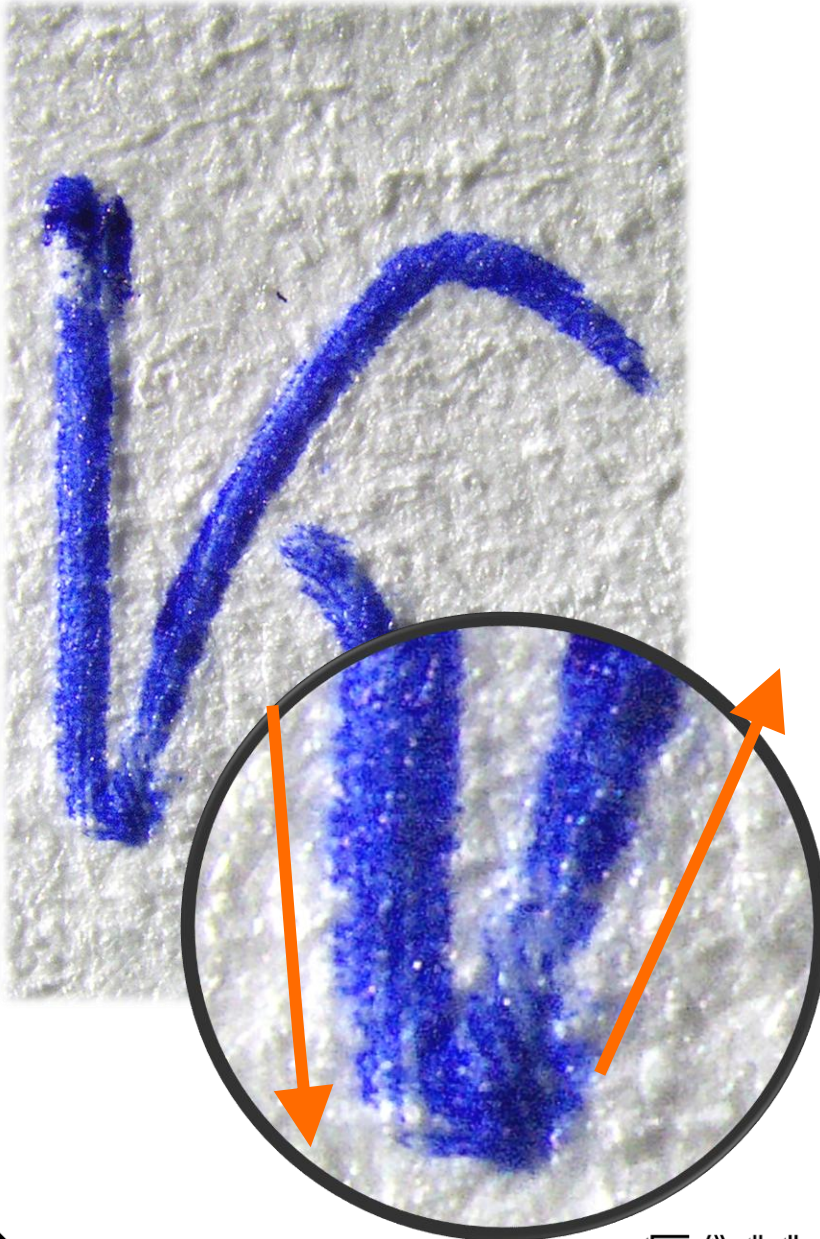
	Fragliche Schrift (XT1 / XN1)	Vergleichsschriften	
Aa	a xar A a la A a a	<u>A</u> S2 a N2Z3 <u>a</u> W5	+ +
Bb	b b	b N2Z2 b L5	+ +
Cc	ich ich	ich W2	(+) +
Dd	d d	d N2Z2	+ +
Ee	e le e eu el er e ie er e	<u>e</u> S2 e N2Z5	+ +
Ee	e e e le e e e e e		
Ff	fi if f Fei	Fe V1 fü N2 ff S2 if L5	+ +
Gg	g	s L5	(+) +
Hh	hc it hi ch hi	H V1 h N2Z1 hi N2Z5 h	(+) +

Each character can be written in numerous different ways.

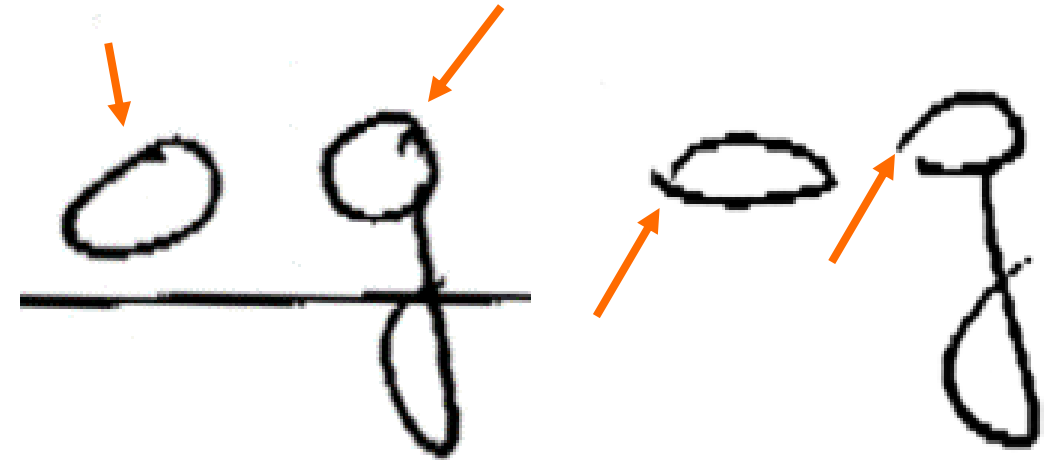
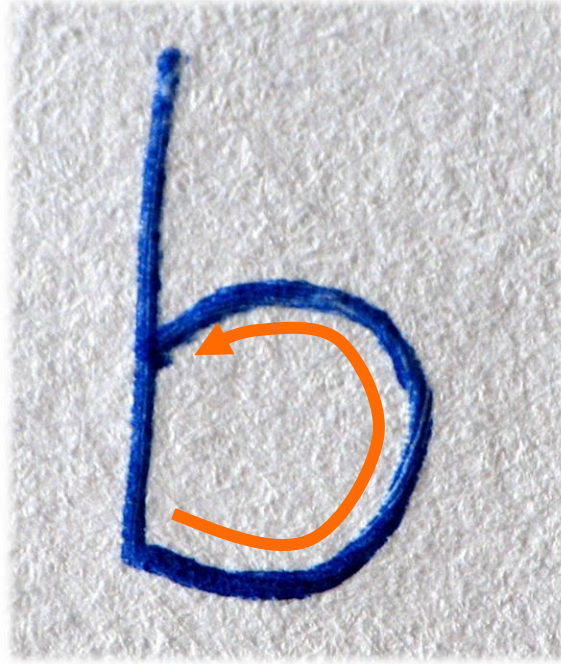
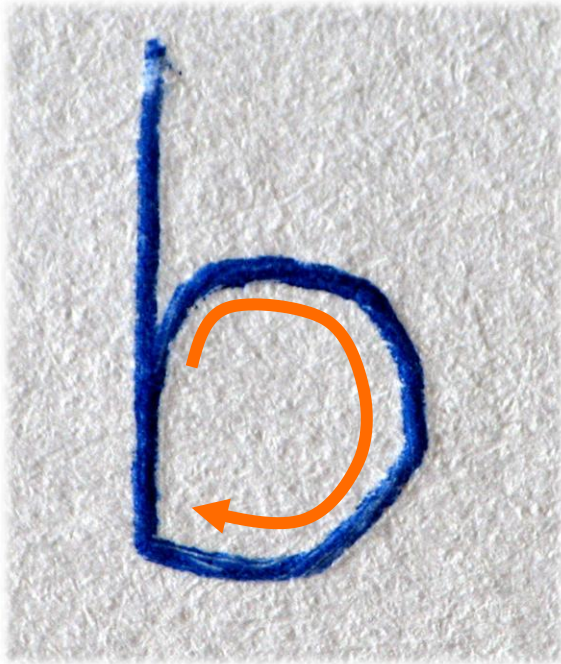


Images by Gina Hunter

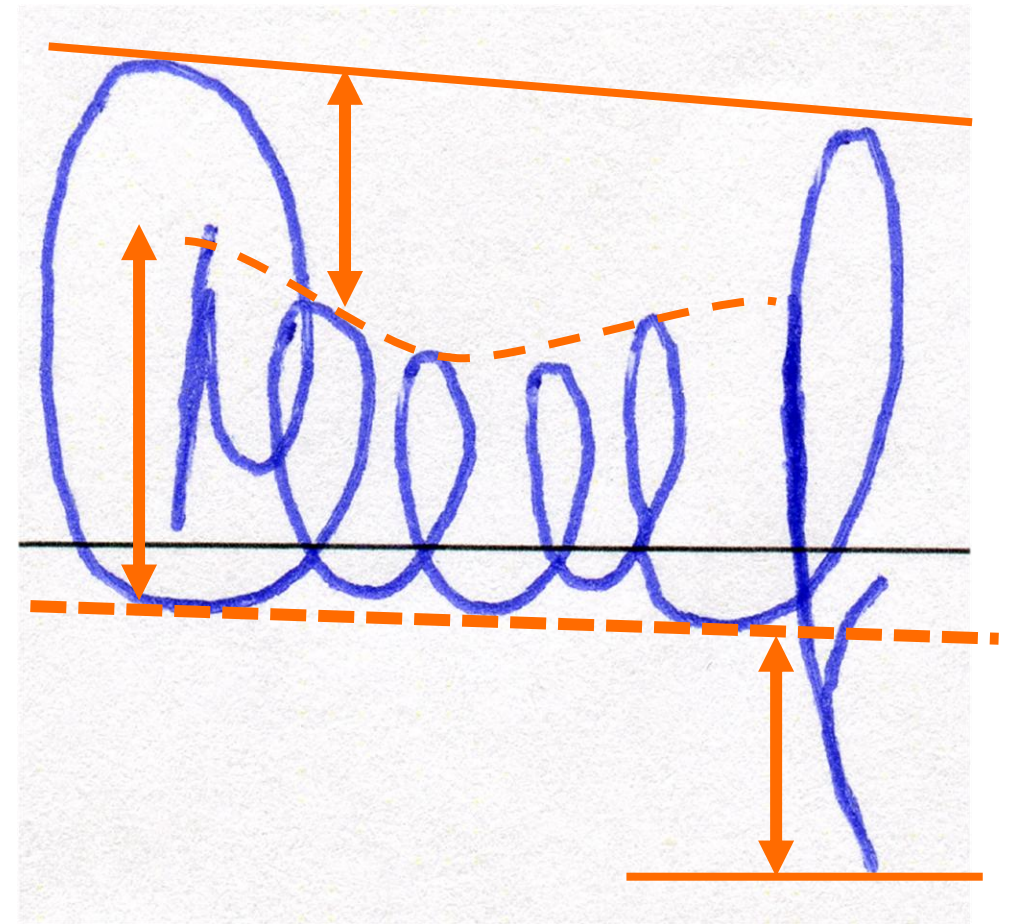
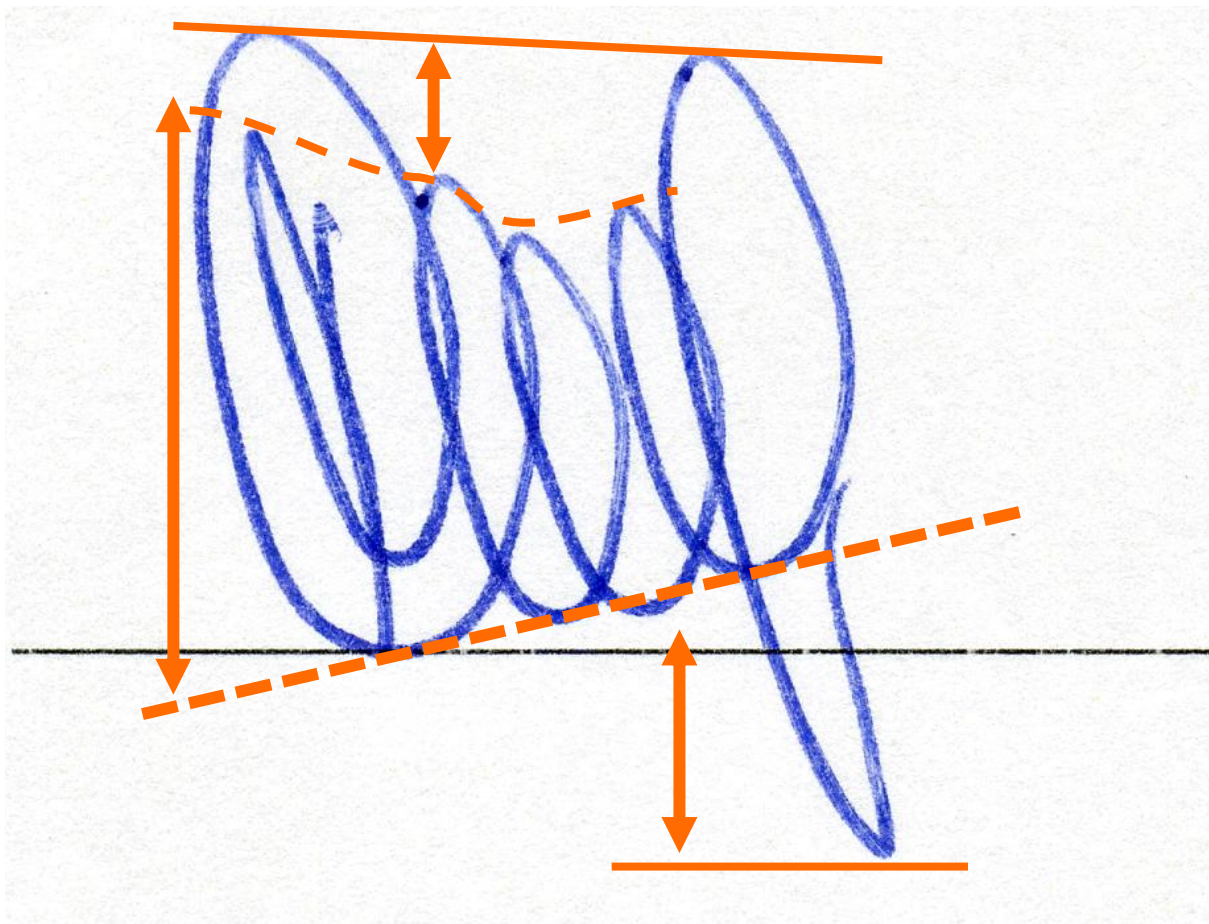
Details in construction: Characters can show different connectivity.



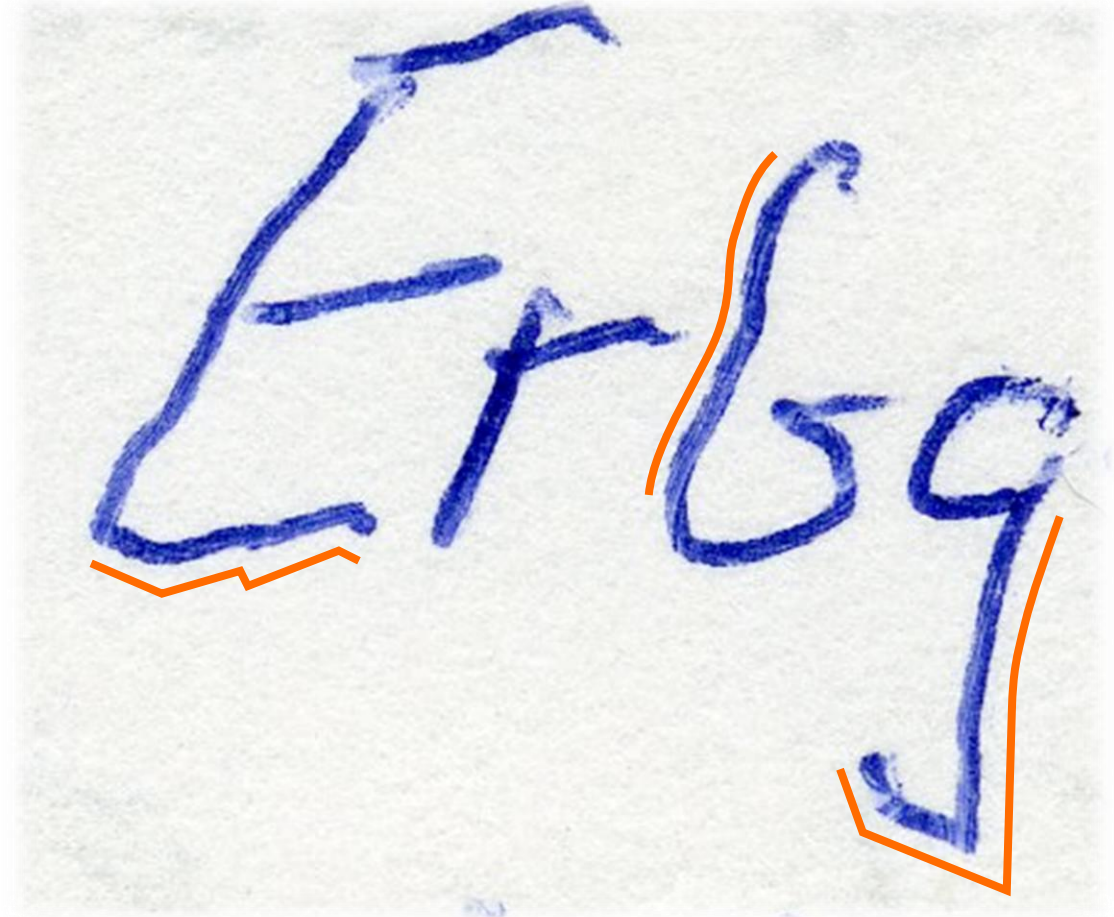
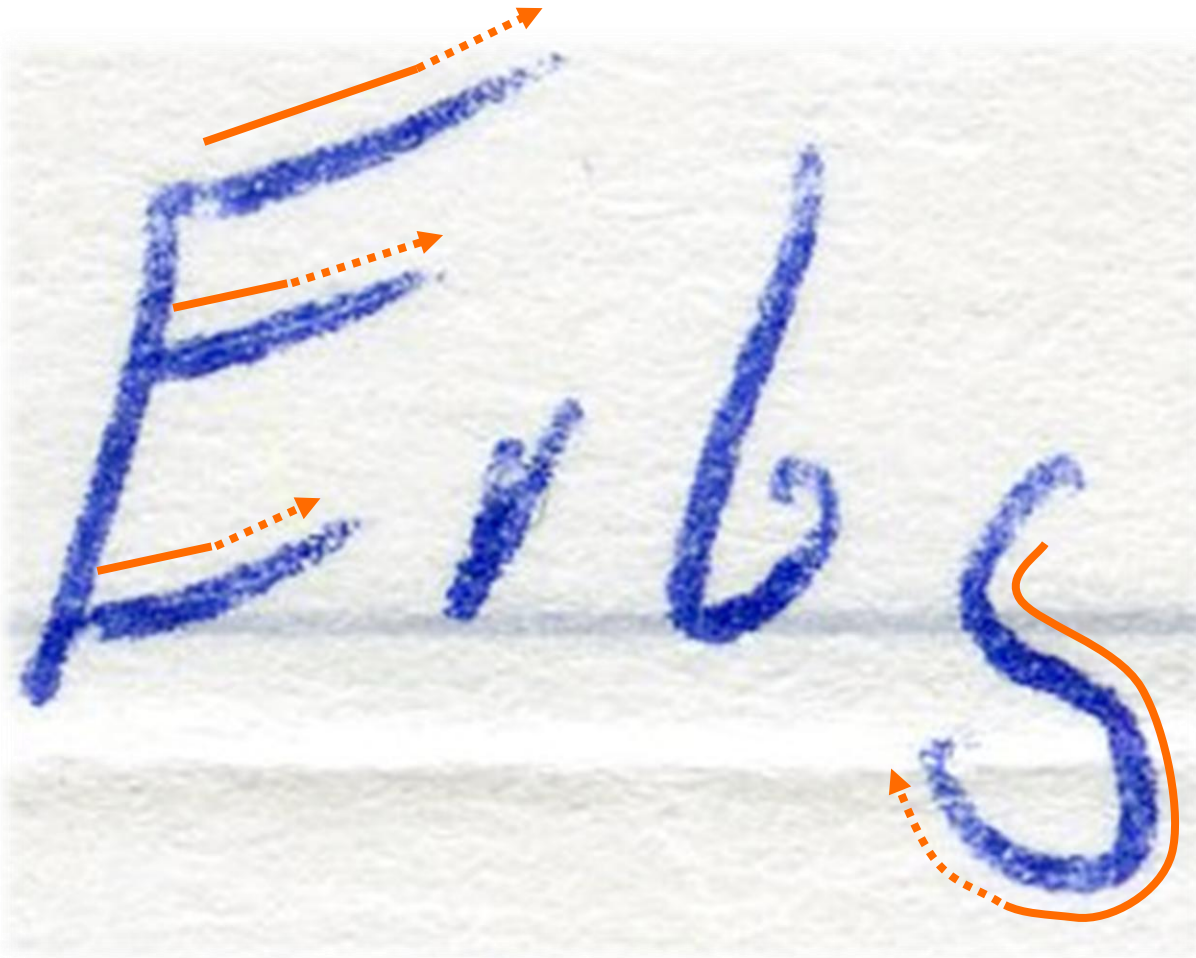
Details in construction: Similarly shaped ovals, can show different stroke direction or different start/end positions.



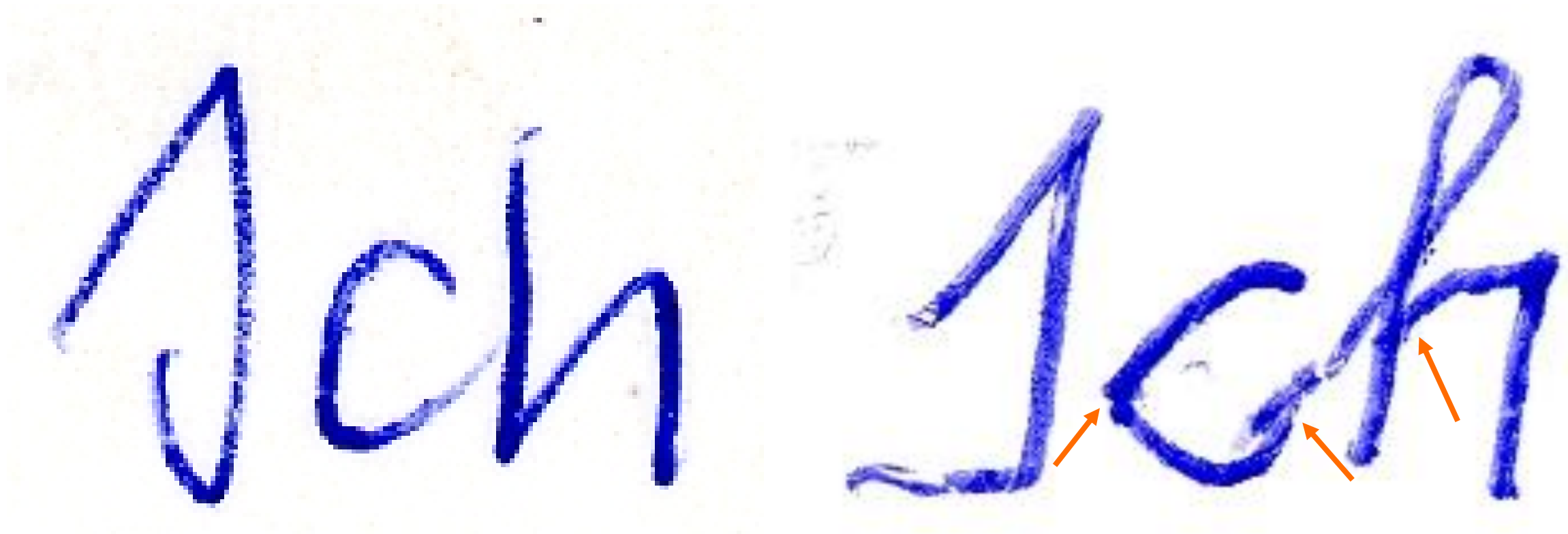
Proportions: Differences in the baseline alignment and in vertical proportions.



Line quality: Slowly executed simulation often show line disturbances and monotonous writing pressure.



Pen lifts and wrong sequence of movements may indicate lack of automatization and accompany simulations.



All findings are evaluated in light of competing propositions.



For example:

H_1 : The signature was written
by Mr. X, the named signatory.

GENUINE

H_2 : The signature was written
by someone other than Mr. X.

FORGED

Forensic evaluation is not hypothesis testing!

Bayes' theorem is fundamental in forensic science.



Regular Bayes's formula about conditional probabilities:

$$P(H_1|E) = \frac{P(E|H_1) \times P(H_1)}{P(E)}$$

E: evidence / forensic findings

H₁: "same writer" proposition

GENUINE

H₂: "different writer" proposition

FORGED

Transformation into odds form with H₁ over H₂:

$$\frac{\text{GENUINE}}{\text{FORGED}} \times \frac{P(H_1)}{P(H_2)} \times \frac{P(E|H_1)}{P(E|H_2)} = \frac{P(H_1|E)}{P(H_2|E)}$$

$$\text{Odds}(a \text{ priori}) \times LR = \text{Odds}(a \text{ posteriori})$$

LR: Likelihood Ratio

(ratio of conditional probabilities)

Bayes' theorem explains the role of the forensic examiner.

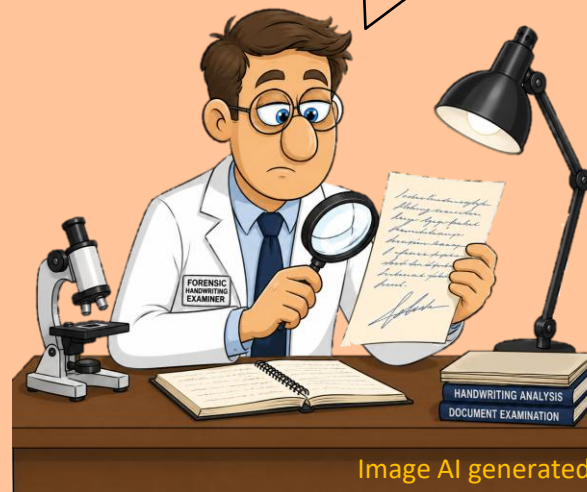


$$\frac{P(H_1)}{P(H_2)} \times \frac{P(E|H_1)}{P(E|H_2)} = \frac{P(H_1|E)}{P(H_2|E)}$$

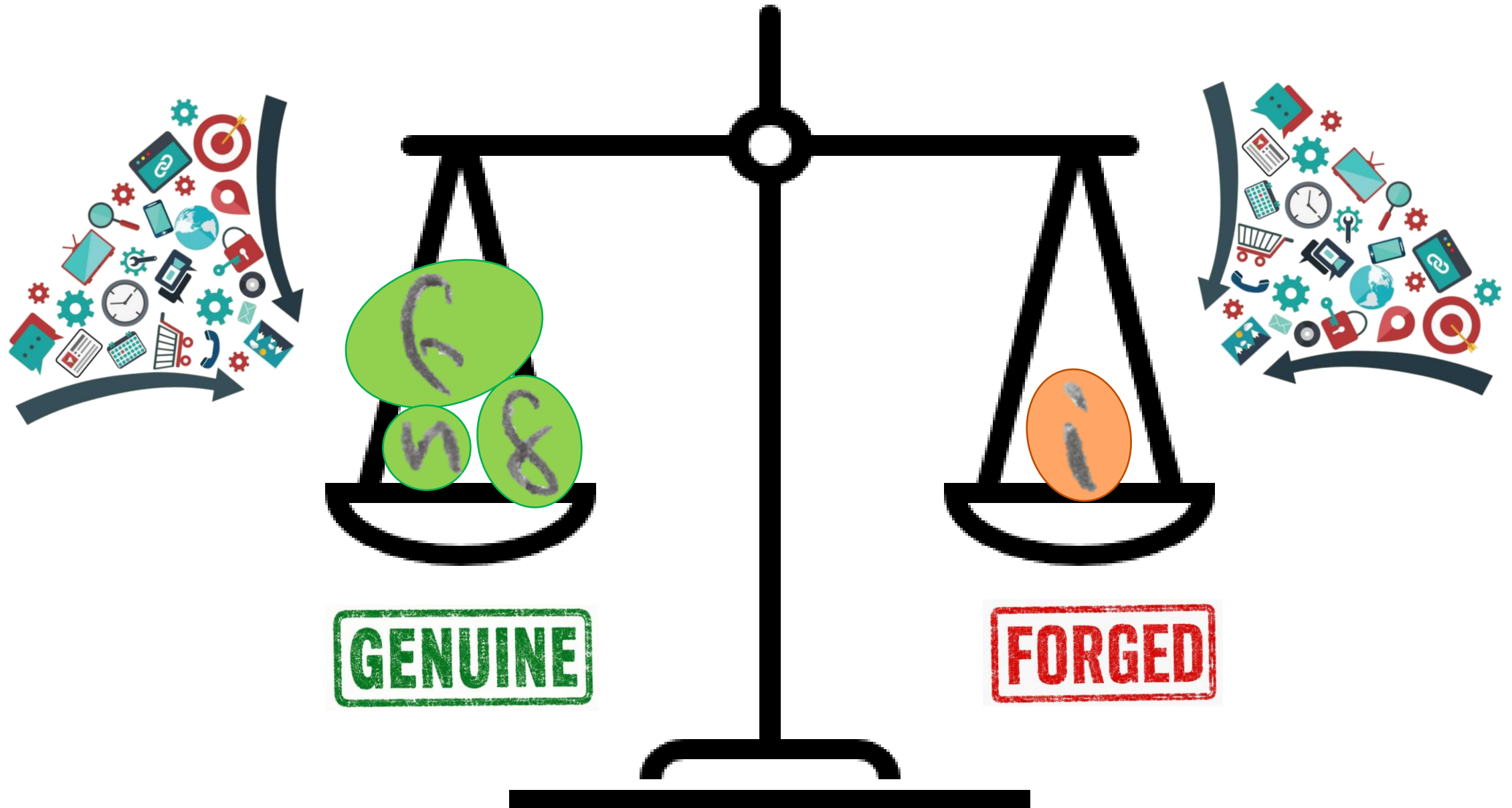
Case circumstances,
case file,
witness statements
→ Prior probabilities

Expert Report:
Findings
→ **Evidential value**
(Likelihood Ratio)

Adjustment of
personal beliefs
→ **Posterior**
probabilities

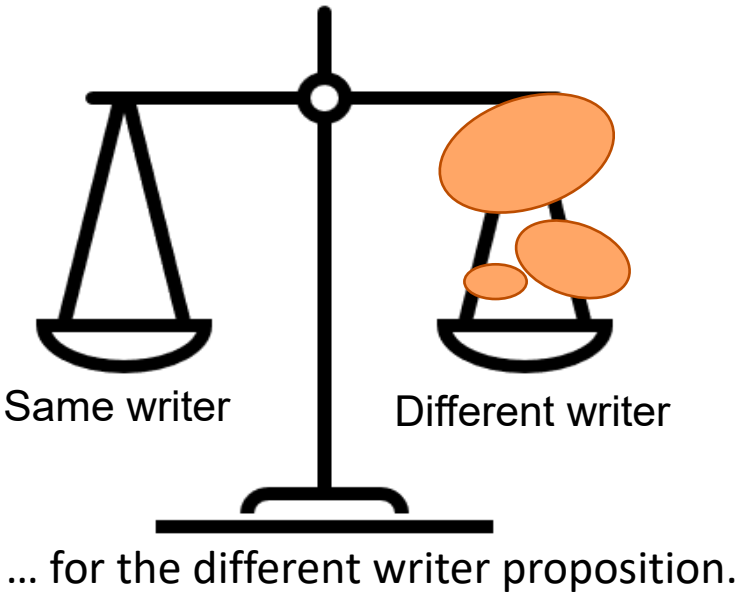
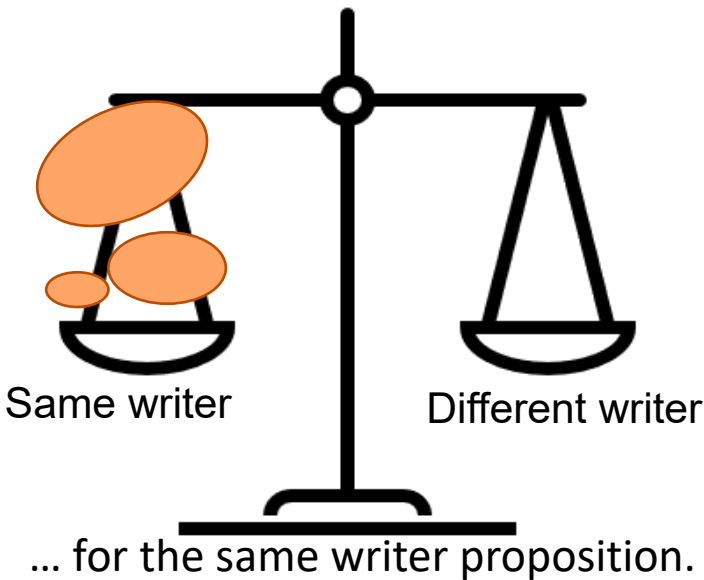
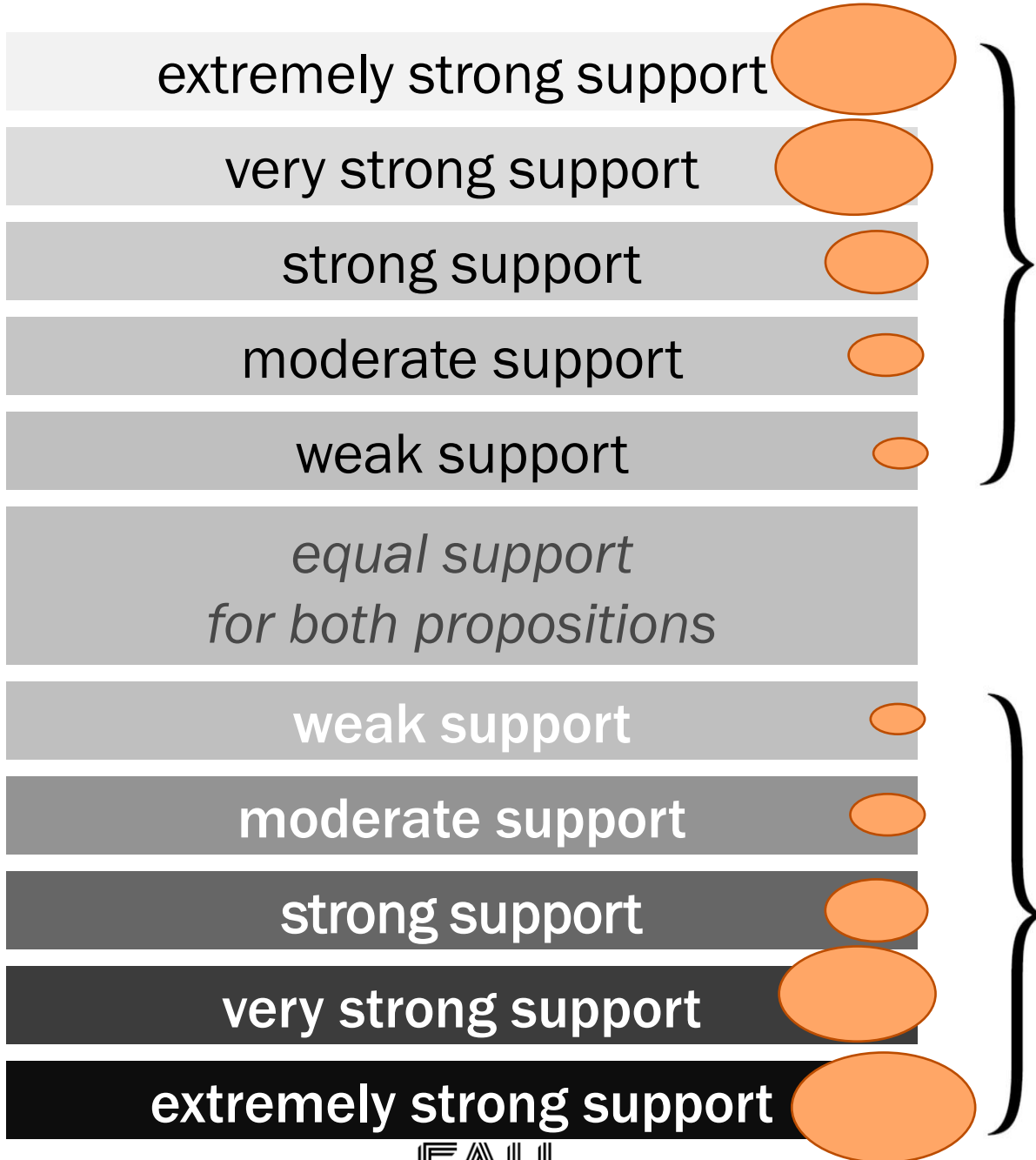


Findings are evaluated considering their value and taking into account known or alleged case information.



Conclusions are often expressed using a verbal likelihood ratio scale.

The findings provide ...



FHEs examine handwritten materials of all kinds.

Last Will and Testament
I, John Smith, being sound mind,
declare this to be my last Will
and Testament. I leave all my properties
and possessions to my daughter, Emily
Smith.
Signed this 12th day of May, 2024
John Smith

YOU SHUT
MOUTH OR
YOU BROKEN!
O

#14500

Paul

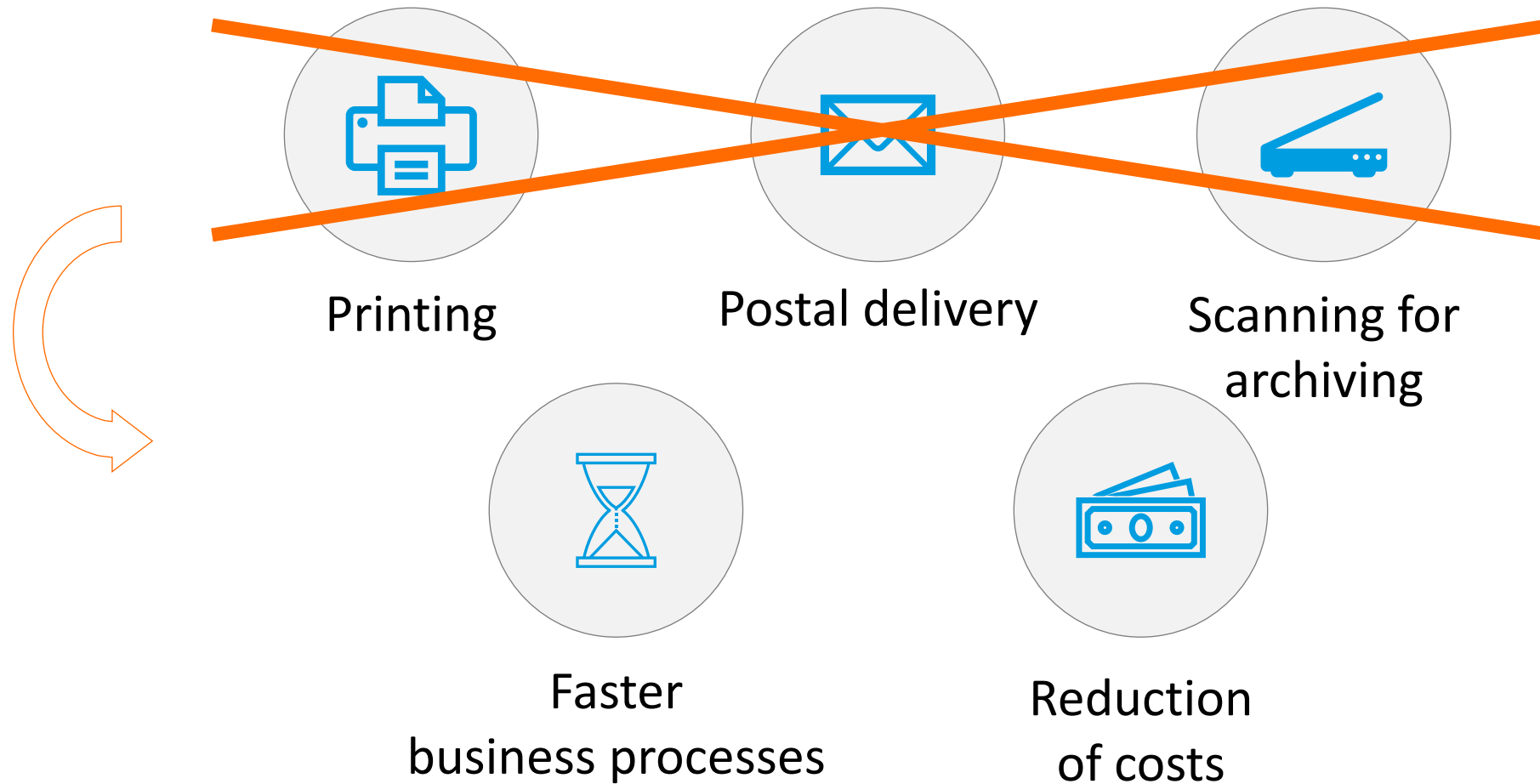


A digitally captured signature (DCS) differs from a scanned or photographed signature.

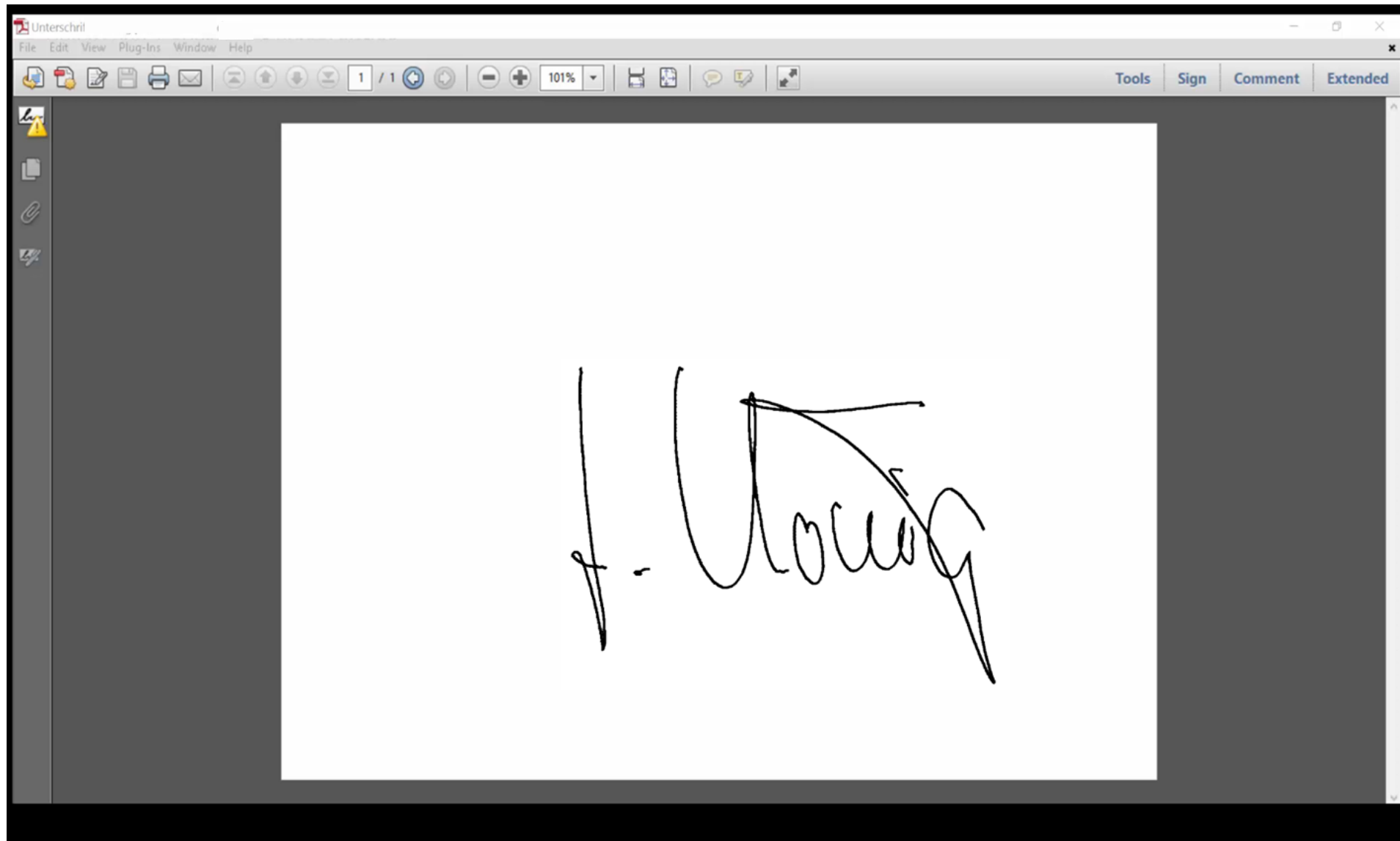
DCS = a handwritten signature digitised during the writing process



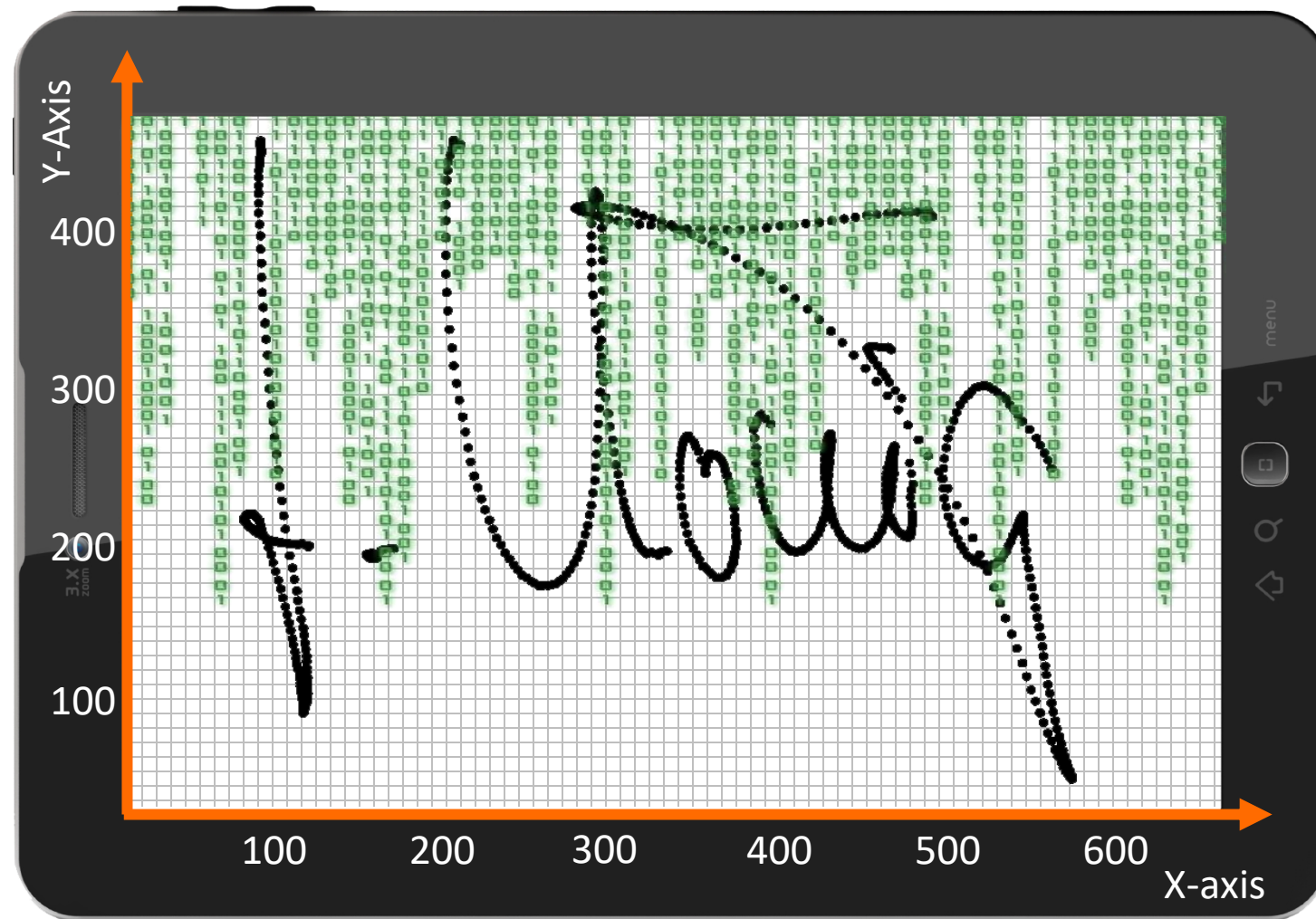
Paperless signing facilitates business processes.



A DCS is more than just an image, as displayed in a PDF file.



A DCS is more than just an image, as displayed in a PDF file.



Numerical data form the core of a DCS.



X-coordinates	Y-coordinates	Force values	Time in ms
629	1418	532	0
634	1414	657	5
637	1407	681	10
632	1401	695	15
...	...	...	...

A DCS can be displayed in various ways:
Signature shown as points



Stefan Buchner

A DCS can be displayed in various ways:
Signature shown as lines with points



The image shows a handwritten signature, 'Stefan Buchner', where each stroke is composed of a sequence of small black dots connected by thin, straight lines. This visual representation is used to demonstrate how a Digital Cursive Signature (DCS) can be displayed as a series of points and lines.

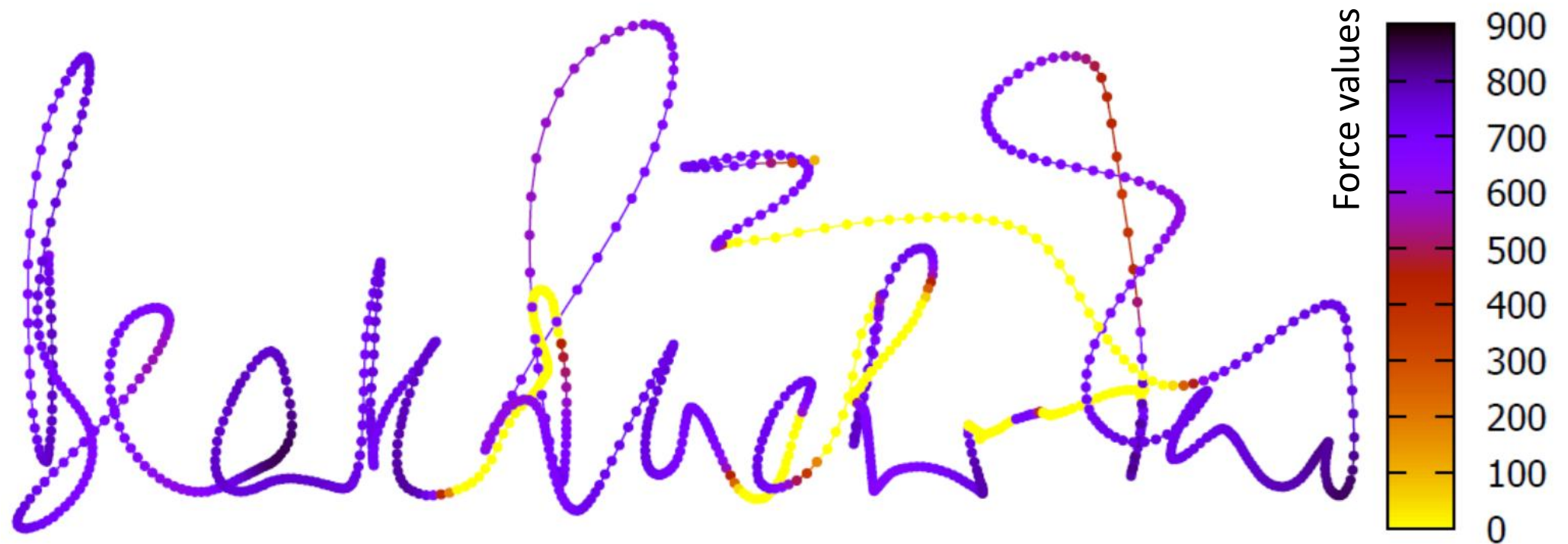
**A DCS can be displayed in various ways:
Signature shown as lines**

A stylized signature, likely 'Stefan Buchner', rendered as continuous black lines. The signature is written in a cursive, flowing style with large loops and a prominent horizontal line across the middle.

**A DCS can be displayed in various ways:
Signature shown as lines with in-air-movements illustrated in red**

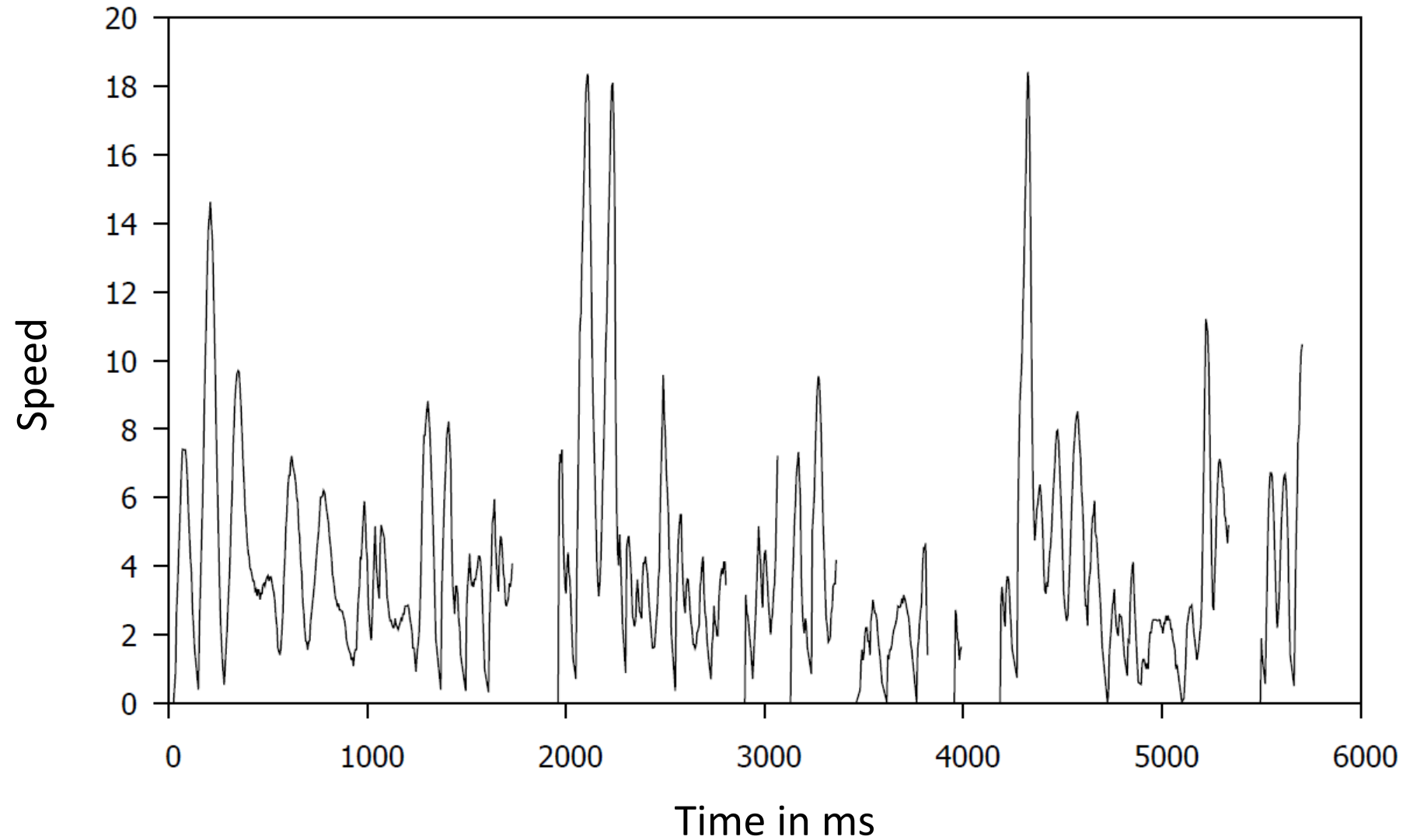
A handwritten signature in black ink, with red lines overlaid to show in-air movements. The signature appears to be 'Stefan Weber'. The red lines highlight the pen lifts and the start of new strokes, such as the beginning of the 'S', the 'W', and the final flourish.

A DCS can be displayed in various ways:
Signature points with force values illustrated by color

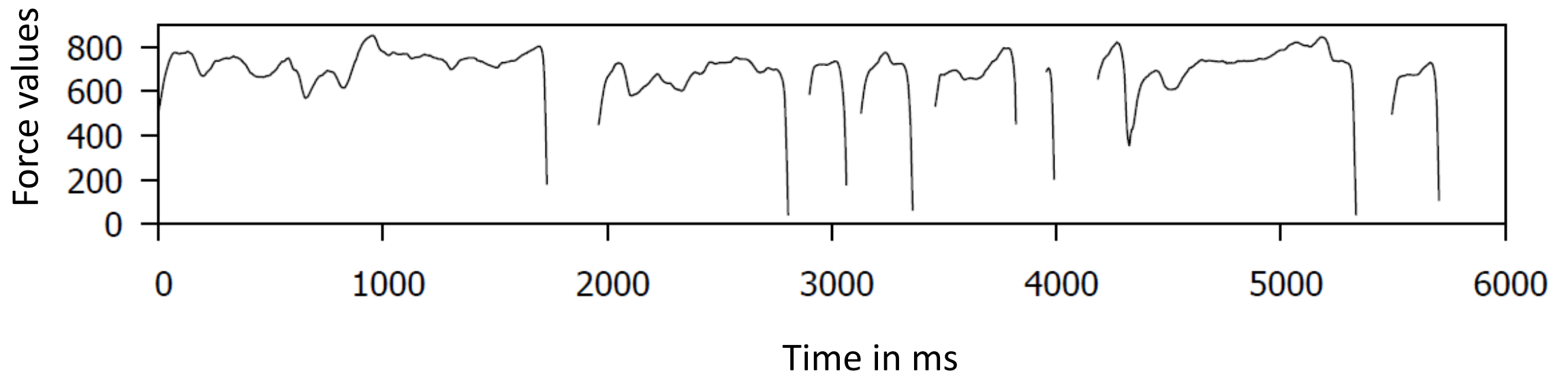


A DCS can be displayed in various ways:

Speed as a function of time



A DCS can be displayed in various ways: Force values as a function of time



**What do you think:
Is the signature outlined in red genuine or simulated?**



Genuine reference signatures



Questioned signature

What do you think now:
Is the signature outlined in red genuine or simulated?

A cursive signature in black ink, consisting of a series of loops and a long horizontal stroke at the end.

2.0 s

A second cursive signature in black ink, very similar to the first one, with a long horizontal stroke at the end.

2.0 s

Genuine reference signatures

A cursive signature in black ink, identical in appearance to the reference signatures, but enclosed within a red rectangular border. The signature has a long horizontal stroke at the end.

5.1 s

Questioned signature

Summary

- Forensic handwriting examination $\neq$ graphology
- Handwriting of a person varies
- Writing conditions can increase variation
- Handwriting is more than a static 2d-image
- “Genuine vs. forged” $\neq$ “similar vs. dissimilar”
- Examination is conducted in the context of case-specific hypotheses
- Evaluation is subjective (without algorithms)
- Evaluation considers both the whole configuration of findings and the conditions imposed by the available material and case circumstances
- Conclusions in expert reports are expressed as verbal likelihood ratio (LR) statements

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Forensic handwriting examination

2

Automatic handwriting and signature analysis

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Differences between disciplines and their implications

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Pathways to integration

1

Forensic handwriting examination

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Differences between disciplines and their implications

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Pathways to integration