Role of Automation in the Forensic Examination of Handwritten Items

Sargur Srihari

Department of Computer Science & Engineering

University at Buffalo, The State University of New York

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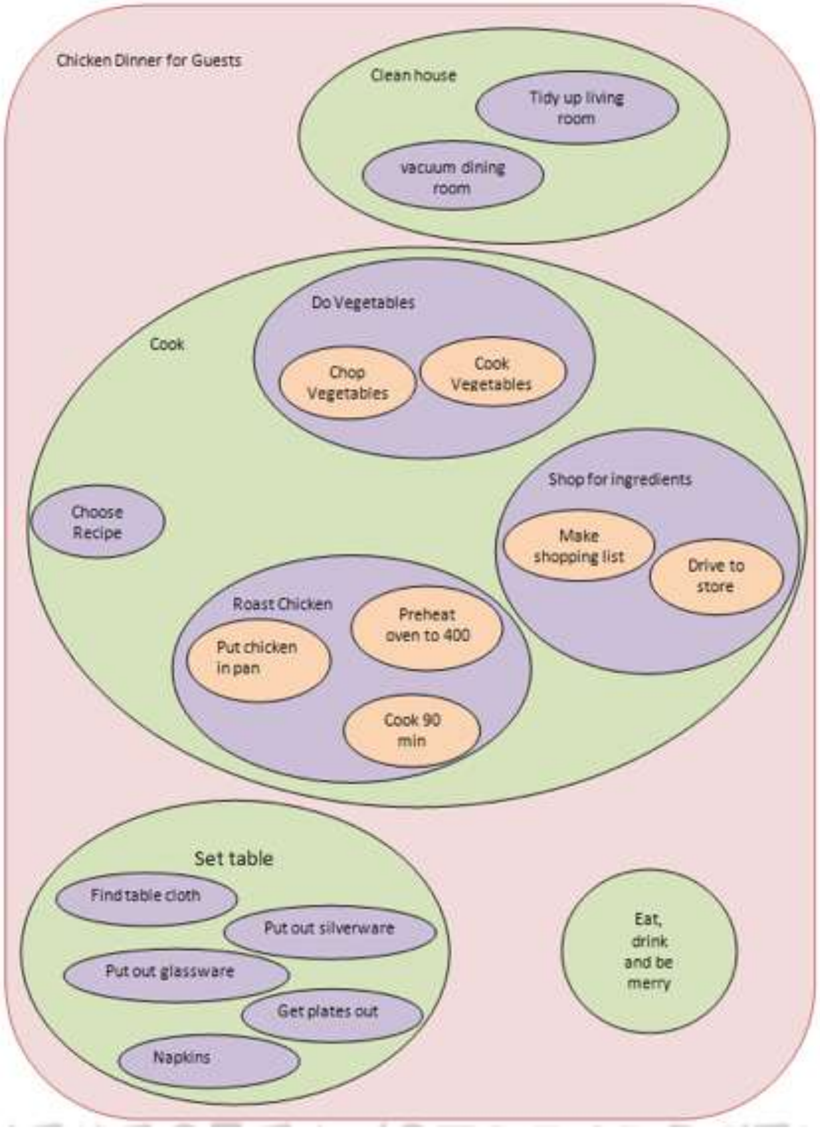
Plan of Discussion

- Computational Thinking (CT)
  - What, Why, How, Limitations
- Reverse Engineering of QDE
- Automation Tools
  - Individualizing Characteristics
  - Opinion
  - Adequacy
- Summary and Discussion

Computational Thinking (CT)

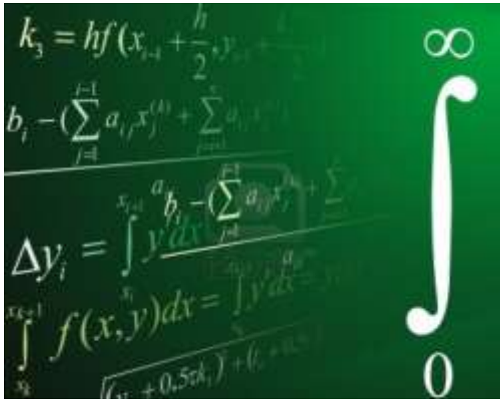
- What is it?
  - A way to solve problems, design systems, and understand human behavior
  - Draw on concepts of computer science
- Why?
  - To flourish in today's world, CT is the way to think and understand the world



S. Papert, J. Wing

How is CT done?

1. Abstraction
   – to understand and solve problems more effectively
2. Algorithmic Thinking and Mathematics
   – to develop efficient, fair, and secure solutions
3. Understand scale
   – Efficiency
   – Economic and social reasons



CT and Law

- Long Dream: Logical rules to automate verdict
  - Napoleonic Code (1804)

    - Minimize discretion, maximize predictability of outcome
    - Flounders: vagueness of words and variation of real world
  - Expert system replacements of judiciary
    - Poor record both of success and of uptake
- Better Inroads: Legal reasoning systems
  - Merely assist in legal decisions
    - E.g., Construct hypotheses for evidence in a crime scene
      - Remind detectives of hypotheses might have missed
- *Mind-expanding* avoids pitfalls of *mind-narrowing*

CT and Forensics

- CT useful in domains where:
  - Human judgement is involved
  - Knowledge engineering can be performed
    - Starting point for creating artificial intelligence
- Within forensics:
  - Impression evidence
    - Handwriting, latent prints, footwear marks
- Handwriting:
  - Success demonstrated in recognition

Knowledge Engineering for FDE

- CAT Principle
  - Comparability
  - Adequacy
  - Time Contemporaneous
- Characteristics
  - Class
  - Individualizing
  - Seven S's
    - Size, slant, spacing, shading, system, speed, strokes

INTERNATIONAL

Designation: E 2290 – 03

Standard Guide for
Examination of Handwritten Items[1]

INTERNATIONAL

Designation: E1658 – 08

Standard Terminology for
Expressing Conclusions of Forensic Document Examiners[1]

FDE- Exam. of HW Items (ASTM)

- Determine if Q v Q, K v K, or Q v K
- For Q and K:
  - Quality (copies?)
  - Distorted (disguised)
  - Type, Range
  - Individualizing characteristics?
- Comparable? else new K & repeat
- Differences/similarities for conclusion (5 or 9-pt)
    - Identification, Highly probable same, Probably did, Indications did , No conclusion Indications didn’t, Probably didn’t, Highly probable didn’t, Elimination

Word Cloud of ASTM Procedure

Pseudo-code for Interactive Forensic Examination (iFOX)

Algorithm 6 Comparison of handwritten items with statistical tools

```
1:  Determine Comparison Type:
2:      Q v Q (no suspect or determine no. of writers)
3:      K v K (to determine variation range)
4:      K v Q (to determine/repudiate writership)
5:  for each Q or K do
6:      Quality: determine visually or by automatic detection of noise.
7:      Distortion: detect manually or by use distortion measures.
8:      Type determination: manually or by automatic classification.
9:      Internal consistency: within document, e.g., multiple writers.
10:     Determine range of variation: compare subgroups.
11:     Identify individualizing characteristics: those with low probability.
12: end for
13: for each Comparison do
14:     Comparability: Both of same Type (Step 8).
15:     Comparison: Determine likelihood ratio (LR) based on characteristics and adequacy.
16:     Form Opinion: by quantizing LR or probability of identification.
17: end for
```

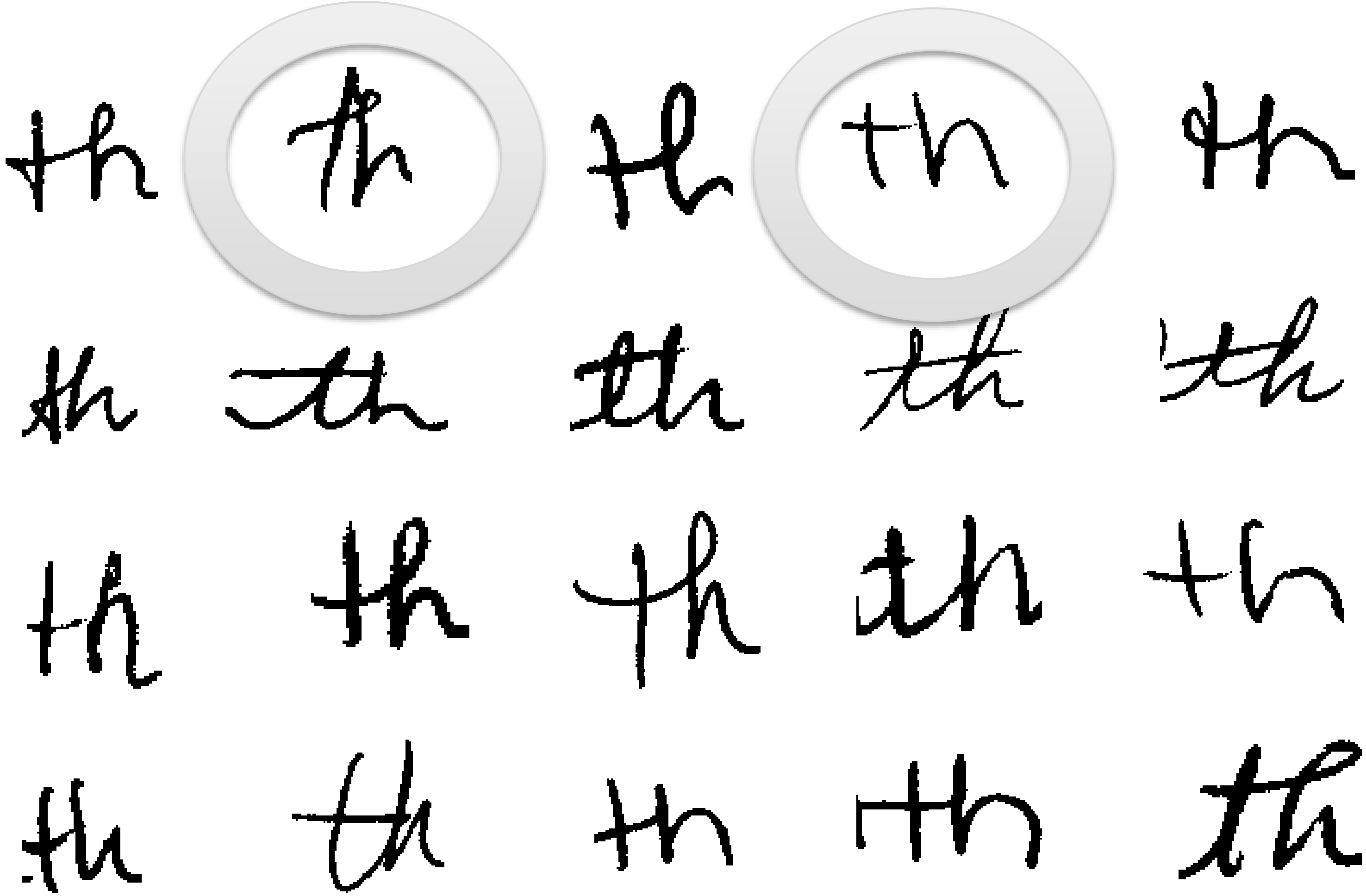
Tools for Steps in FDE Procedure

- Quality
- Distortion
- Range

1. Individualizing characteristics
2. Comparability (Type)
3. Comparison (Opinion)
4. Adequacy

Details Next

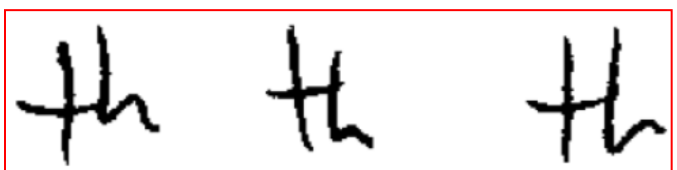
Individualizing Characteristics?



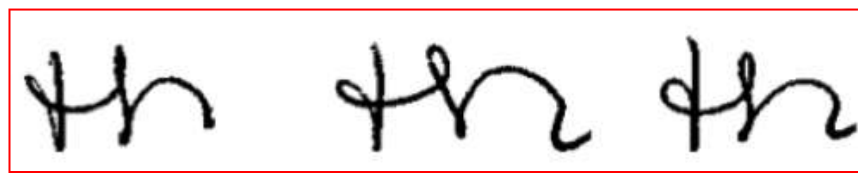
Characteristics of ``th’’

R = Height Relationship of t to h	L = Shape of Loop of h	A = Shape of Arch of h	C = Height of Cross on t staff	B = Baseline of h	S = Shape of t
r^0 = t shorter than h	l^0 = retraced	a^0 = rounded arch	c^0 = upper half of staff	b^0 = slanting upward	s^0 = tented
r^1 = t even with h	l^1 = curved right side and straight left side	a^1 = pointed	c^1 = lower half of staff	b^1 = slanting downward	s^1 = single stroke
r^2 = t taller than h	l^2 = curved left side and straight right side	a^2 =no set pattern	c^2 = above staff	b^2 = baseline even	s^2 = looped
r^3 = no set pattern	l^3 = both sides curved		c^3 = no fixed pattern	b^3 = no set pattern	s^3 = closed
	l^4 = no fixed pattern				s^4 = mixture of shapes

R. J. Muehlberger, K. W. Newman, J. Regent and J. G. Wichmann, A Statistical Examination of Selected Handwriting Characteristics, *Journal of Forensic Sciences*, 1977: 206-210.

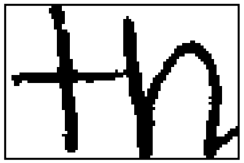


$r^1, l^0, a^0, c^3, b^1, s^2$



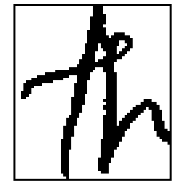
$r^2, l^2, a^0, c^1, b^0, s^2$

Rarity: measure of Individualization



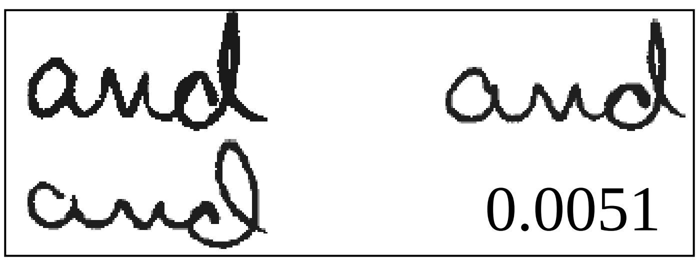
0.0304

High Probability

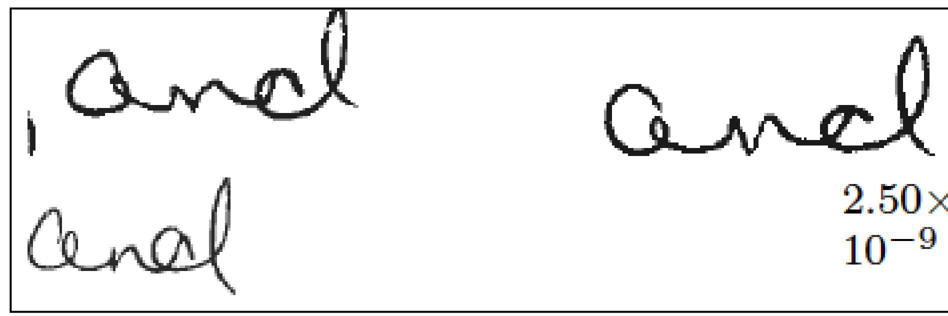


7.2×10^{-8}

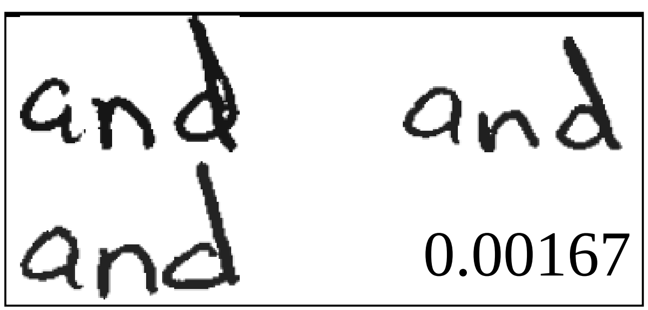
Low Probability



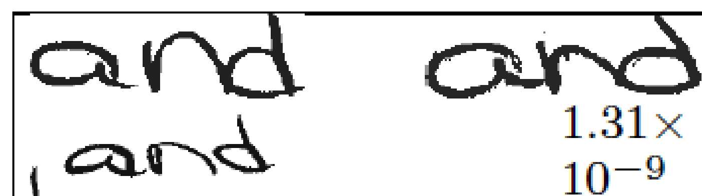
0.0051



2.50×10^{-9}

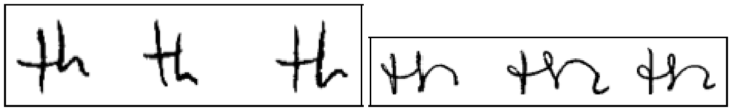


0.00167



1.31×10^{-9}

Statistical Models of Characteristics



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Probabilities for full joint distribution= 4,799

No. of Parameters if we assume independence= 19

itial roke of orma- on of ***a*** **1)**	**Formation of staff of** ***a*** **(x_2)**	**Number of arches of** ***n*** **(x_3)**	**Shape of arches of** ***n*** **(x_4)**	**Location of mid-point of** ***n*** **(x_5)**	**Formation of staff of** ***d*** **(x_6)**	**Formation of initial stroke of** ***d*** **(x_7)**	**Formation of terminal stroke of** ***d*** **(x_8)**	**Symbo in pla of t word** ***and*** **(x_9**
ight of aff (0)	Tented (0)	One (0)	Pointed (0)	Above baseline (0)	Tented (0)	Overhand (0)	Curved up (0)	Formati (0)
eft of aff (1)	Retraced (1)	Two (1)	Rounded (1)	Below baseline (1)	Retraced (1)	Underhand (1)	Straight accross (1)	Symbol (1)
enter of aff (2)	Looped (2)	No fixed pattern (2)	Retraced (2)	At base-line (2)	Looped (2)	Straight accross (2)	Curved down (2)	None (2
o fixed attern)	No staff (3)		Combination (3)	No fixed pattern (3)	No fixed pattern (3)	No fixed pattern (3)	No obvious ending stroke (3)	
	No fixed pattern (4)		No fixed pattern (4)				No fixed pattern (4)	

Probabilities=

287,999 (cursive)

809,999 (hand-print)

What if we assume independence?

True Joint Probabilities: Prob (height,weight)

P(a,b)	**b^0 (heavy)**	**b^1 (light)**	**P(a) (height)**
a^0 (tall)	0.6	0.05	0.65
a^1 (short)	0.05	0.3	0.35
P(b) (weight)	0.65	0.35	

P(tall, light) < P(short,light) 0.05<0.3

Short & light six times more probable than tall and light: Correct!

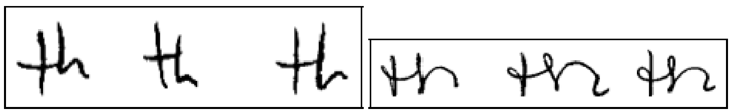
Assuming Independence

P(a,b)	**b^0 (heavy)**	**b^1 (light)**	**P(a) (height)**
a^0 (tall)	0.42	0.23	0.65
a^1 (short)	0.23	0.12	0.35
P(b) (weight)	0.65	0.35	

P(tall,light) > P(short,light) 0.23 >0.12

Tall & light, twice probability of short & light: Wrong!

Compromise Solution: PGMs



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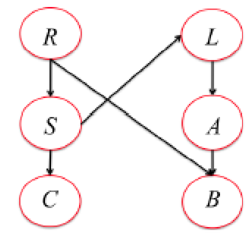
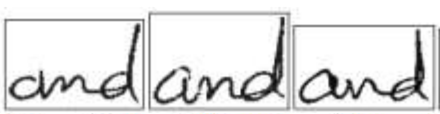


$$P(X) = P(R)P(L|S)P(A|L)P(C|S)P(B|R,A)P(S|R)$$

100 parameters



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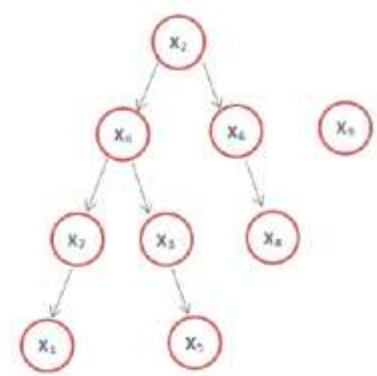


99 parameters (cursive)

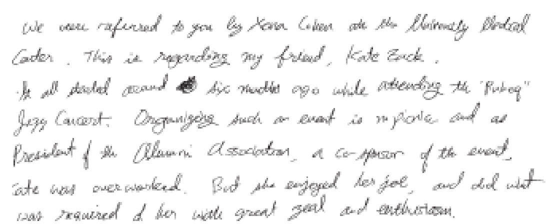
77 parameters (hand-print)

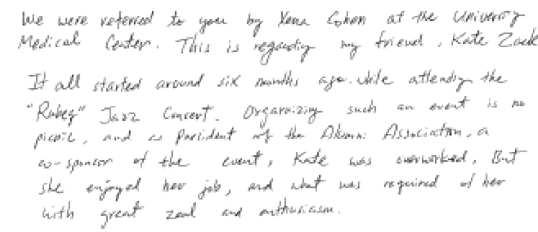
Learning PGMs from Data

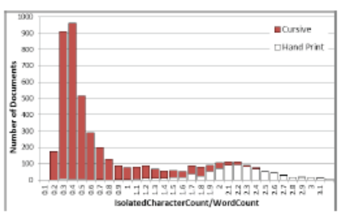
- Bayesian Networks (directed graphs)
- Markov Networks (undirected graphs)
- Learning algorithms:
  - Determine pairwise independences using chi-squared tests
  - Determine quality of model using log-loss
  - Problem is NP-hard
    - use approximate solutions

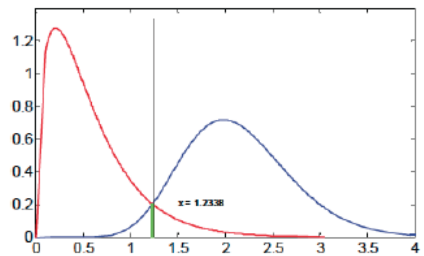
Type Determination

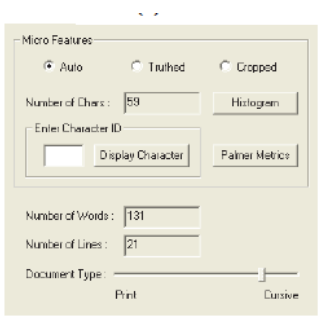
- Cursive vs. Handprint

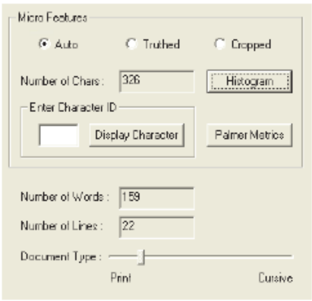












f_1: Discreteness

Ratio of isolated character count(ICC) to word count (WC)

f_2: Loopiness

Ratio of interior to exterior contours

Opinion

$$LR_J = LR(\mathbf{k}, \mathbf{q}) = \frac{P(\mathbf{k}, \mathbf{q}|h^0)}{P(\mathbf{k}, \mathbf{q}|h^1)}$$

$$LR_D = \frac{P(D(\mathbf{k},\mathbf{q})|h^0)}{P(D(\mathbf{k},\mathbf{q})|h^1)}$$

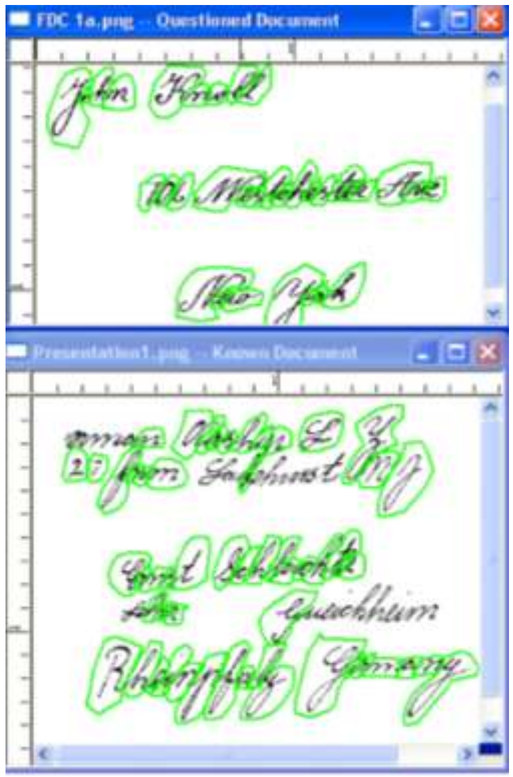
$$P(h^0|F) = \frac{P(h^0) \cdot \prod_i LR(f_i)}{P(h^1) + P(h^0) \cdot \prod_i LR(f_i)}$$

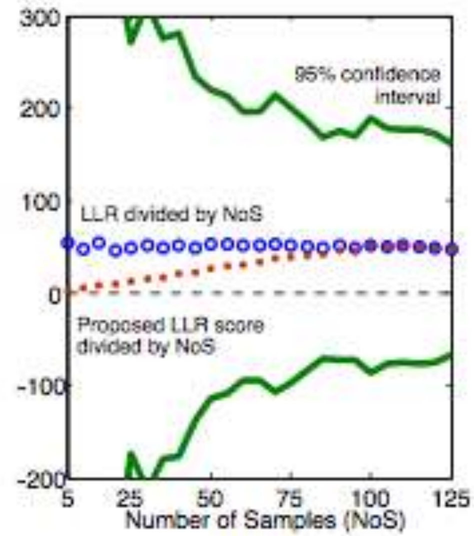
Information $\mathcal{I}$	Content $\mathcal{C}$	Sys. Accuracy	Min.LLR	Max.LLR
Line	Same Different	86.40% 62.98%	-93.82 -72.14	115.57 11.05
Multiple lines	Same Different	93.81%	-105.02	96.83
Half page	Same Different	93.08% 94.78%	-322.59 -111.83	698.64 172.28
Full page	Same	95.75%	-90.1	67.93

Scale	Opinions for same	P^S_{ic}
1	Identified as same	$0.00 \sim 22.21$
2	Highly probably same	$22.22 \sim 44.43$
3	Probably same	$44.44 \sim 66.65$
4	Indicating same	$66.66 \sim 88.87$
5	No conclusion	$88.88 \sim 100.00$

Scale	Opinions for different	P^{Di}_{ic}
5	No conclusion	$88.88 \sim 100.00$
6	Indicating different	$66.66 \sim 88.87$
7	Probably different	$44.44 \sim 66.65$
8	Highly probable different	$22.22 \sim 44.43$
9	Identified as different	$0.00 \sim 22.21$

Adequacy





(b)

1. A single feature $F = f_1$ with $LR(f_1) = 96$.
2. Nine features $F = \{f_i\}_{i=1}^{9}$ with $\{LR(f_i), i = 1, .., 9\} = \{3, 4, 2, \frac{1}{4}, 2, 2, \frac{1}{3}, 6, 2\}$

Availability of Automation Tools

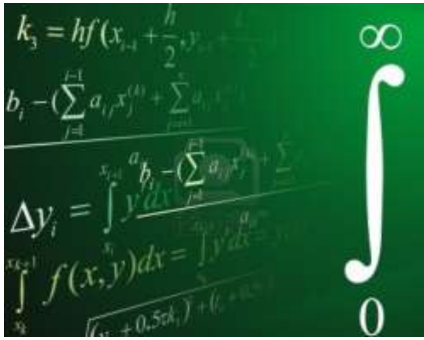
- Interactive tools rather than automation
- Incorporate CT
  - Abstraction: Aids to organize thought process
  - Algorithms and Mathematics
  - Scalability
    - Potential of Large quantities quickly analyzed
- Mind Expanding
  - Probability allows considering characteristics otherwise ignored, or discounting identified ones
  - Value of small amounts of information

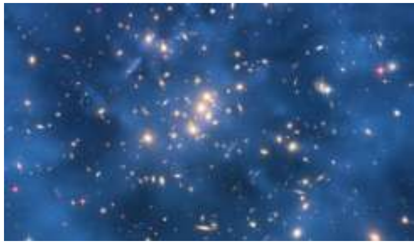
Status of Automation Tools

- Interactive tools rather than automation
- Work in Progress
  - Characteristics
    - Data needs to be collected
  - Learning statistical models
    - Learning PGMs is current topic in ML
  - Inference algorithms
  - Type determination
  - Opinion Mapping

Summary

- Computational Thinking + Forensics = Computational Forensics
- Solve using
  - Abstraction
  - Algorithms
  - Mathematics
  - Scale





Summary

- Reverse engineering of QDE
  - Available in ASTM standards, other QD literature
- Steps amenable to automation tools
  - Data Collection
  - Modeling distribution of characteristics
  - Type determination
  - Likelihood Ratios (Opinion)
  - Confidence Intervals (Adequacy)

How does this fit with fully Automated Systems?

- Systems such as FISH, CEDAR-FOX and FLASH-ID narrow down possibilities
- Interactive systems (iFOX) will assist the document examiner in going the last mile
  - E.g., associate probabilities with their observations