Offline Handwritten Signature Verification Using a Stream-Based Approach

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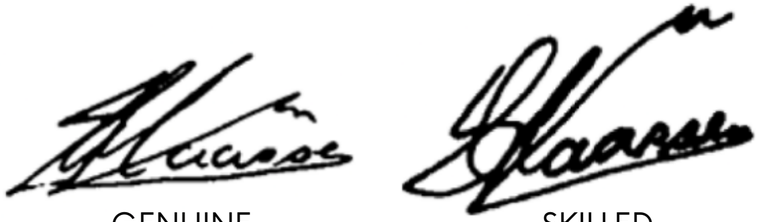
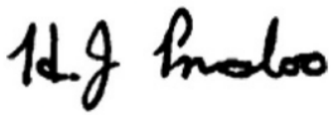
Handwritten Signature Verification (HSV)

- Distinguish genuine from forged signatures



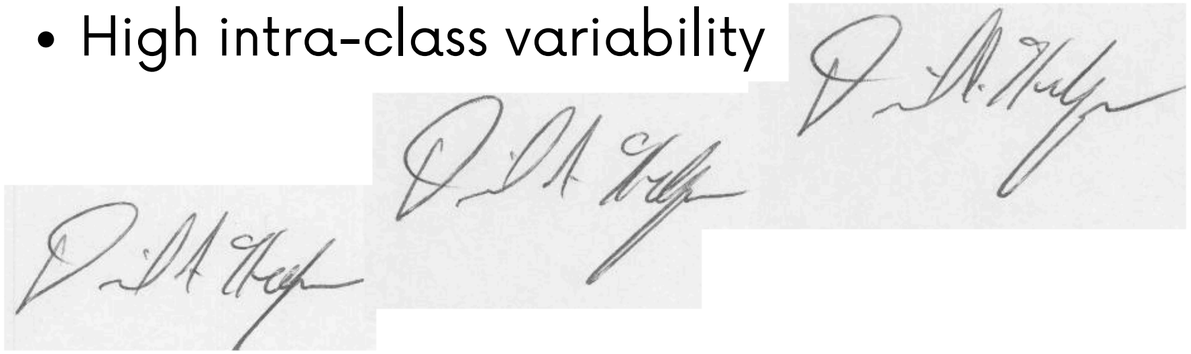
GENUINE

SKILLED FORGERY

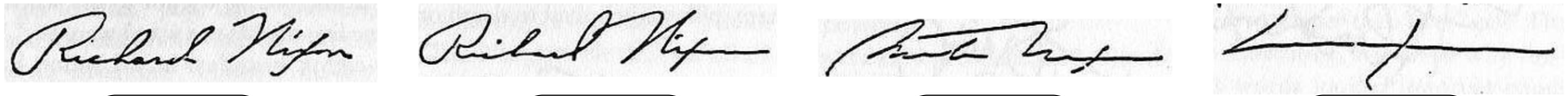


RAMDOM FORGERY

- High intra-class variability



- Changes over time



1968 1969 1973 1974

Research Problem

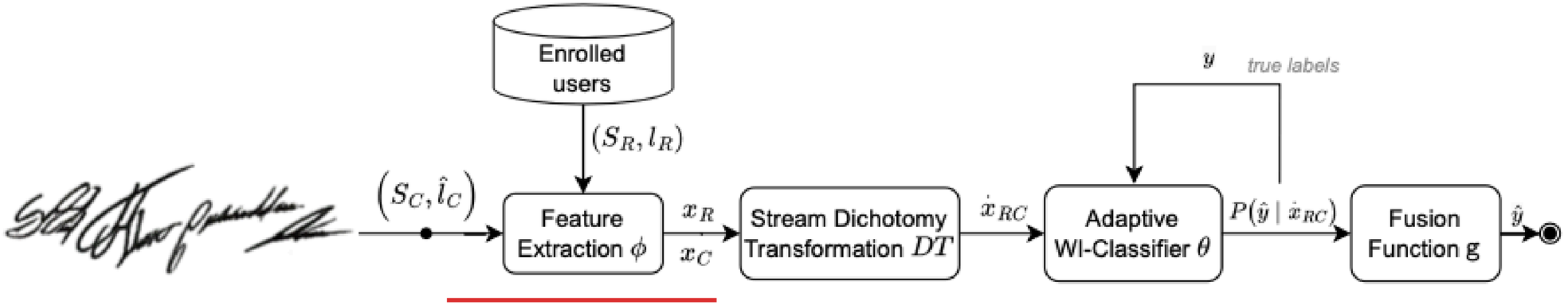
- How can an HSV system adapt to evolving signatures while coping with limited data?

Contributions

- Proposed a stream-based HSV framework.
- Developed a Stream Dichotomy Transformation.
- Created a Signature Stream Generation method for evaluation.

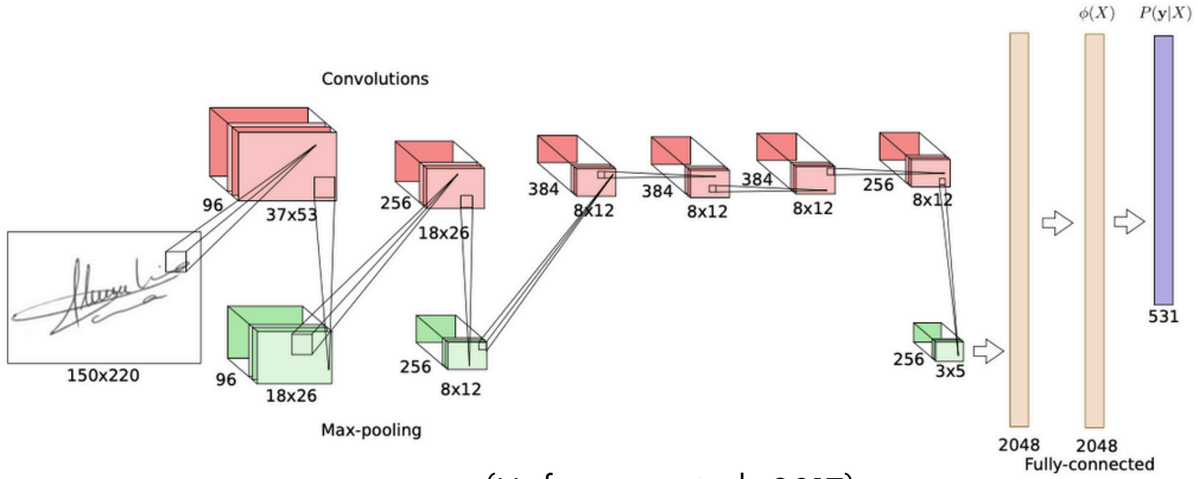
Stream HSV Framework

Feature Extraction



SigNet (Hafemann, et al., 2017)
Data: GPDS 960 Graylevel

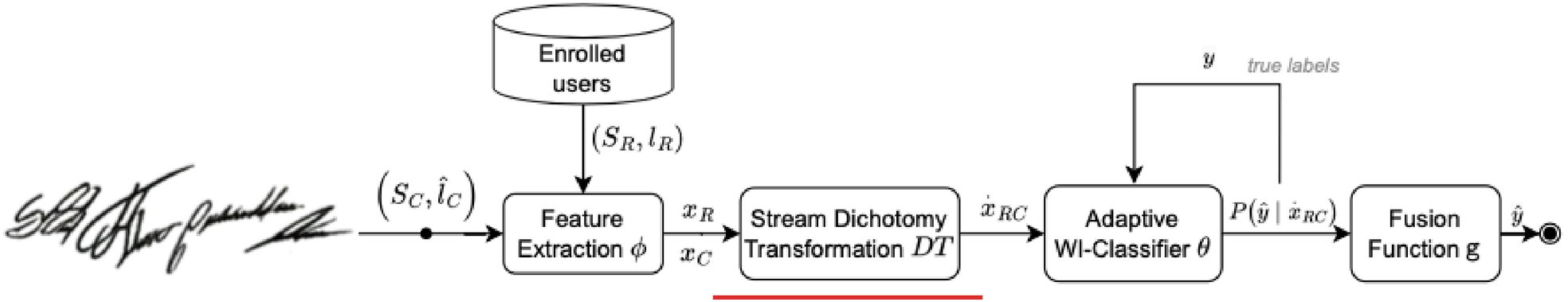
SigNet-S (Viana, et al., 2023)
Data: GPDS Synthetic



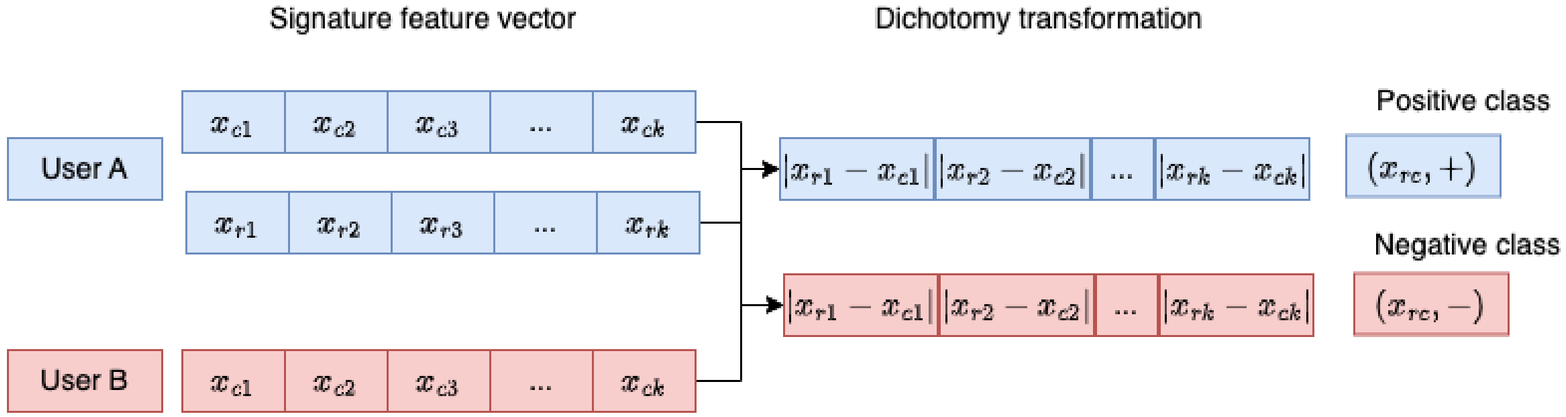
(Hafemann, et al., 2017)

Stream HSV Framework

Stream Dichotomy Transformation

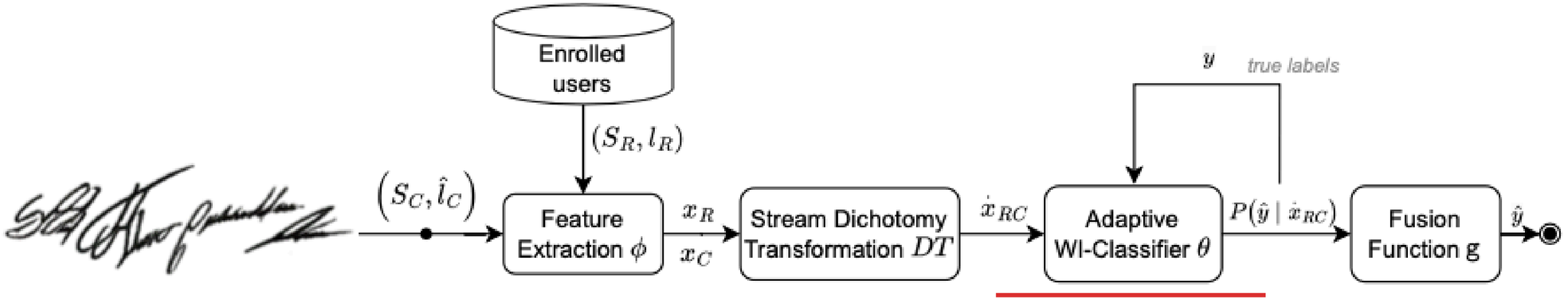


- N-classes to 2-class
- WI implementation: one single model for all users



Stream HSV Framework

Adaptive WI-Classifier

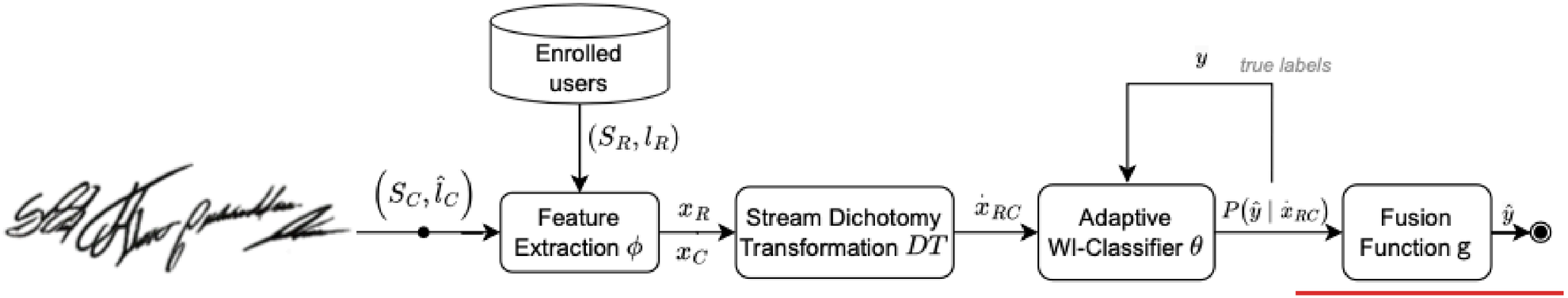


- Support Vector Machines (SVM) are a popular choice for the verification step
- Adaptive classifier requirement
- Solution: Stochastic Gradient Descent (SGD) classifier with a Hinge loss function

$$\min_{\mathbf{w},b} \quad \frac{C}{2}||\mathbf{w}||^2 + \frac{1}{N}\sum_{i=1}^{N}\max(0, 1 - y_i(\mathbf{w}\cdot\mathbf{x}_i + b))$$

Stream HSV Framework

Fusion Function



- Maximum fusion function on classifier decisions

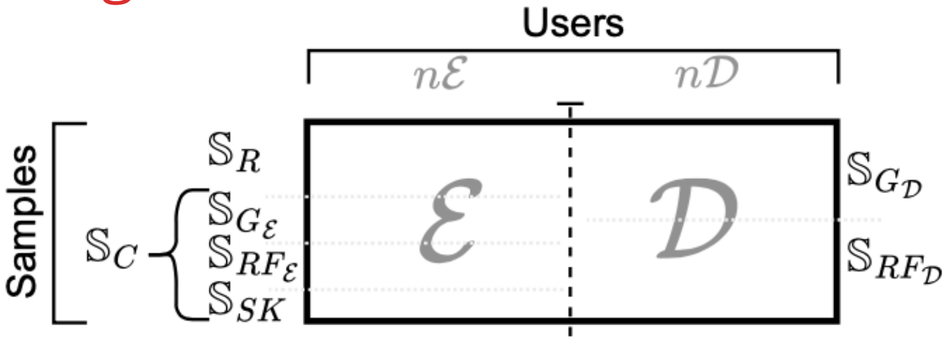
	Classifier decisions			
	Reference S_{R_1}	Reference S_{R_2}	Reference S_{R_3}	Max fusion function
Input signature (S_c)	d_1	d_2	d_3	$max(d_1, d_2, d_3)$

Experimental Setup

Datasets

Ref	Dataset Name	Language	Users	Genuine signatures	Forgeries
[9]	CEDAR	Western	55	24	24
[3]	GPDS Synthetic	Western	10000	24	30
[11]	MCYT-75	Western	75	15	15

Segmentation



Data generation for batch settings

Development Set

Positive set:

$$\dot{\mathbb{X}}^i_{\mathcal{D}+} = \bigcup_{k=1}^{n\mathcal{D}_G-1} \bigcup_{j=k+1}^{n\mathcal{D}_G} DT(\phi(S^{i,k}_G), \phi(S^{i,j}_G))$$

Negative set:

$$\dot{\mathbb{X}}^i_{\mathcal{D}-} = \bigcup_{k=1}^{n\mathcal{D}_G-1} \bigcup_{j=1}^{n\mathcal{D}_G/2} DT(\phi(S^{i,k}_G), \phi(S^{i,j}_{RF}))$$

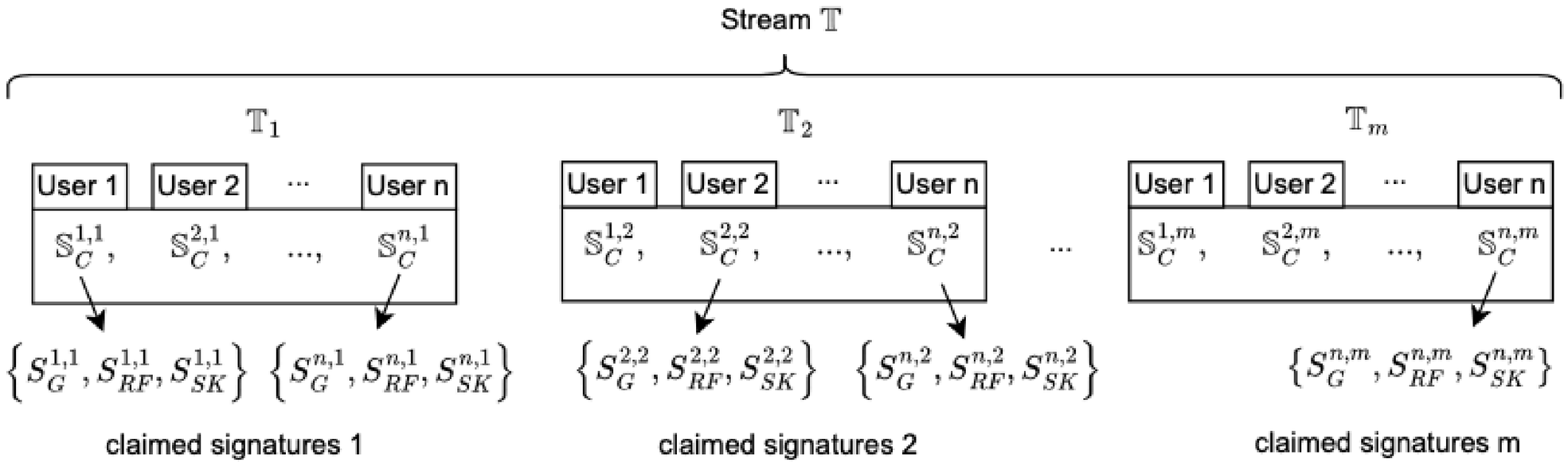
Exploitation Set

$$\dot{\mathbb{X}}^i_{\mathcal{E}} = \bigcup_{k=1}^{n\mathcal{E}_R} \bigcup_{j=1}^{n\mathcal{E}_C} \{\dot{\mathbf{x}}^{i,k,j}_G, \dot{\mathbf{x}}^{i,k,j}_{RF}, \dot{\mathbf{x}}^{i,k,j}_{SK}\}$$

$$\dot{\mathbb{X}}_{\mathcal{E}} = \bigcup_{i=1}^{n\mathcal{E}} \dot{\mathbb{X}}^i_{\mathcal{E}}$$

Experimental Setup

Stream Generation



$$\dot{\mathbb{T}}_j = \bigcup_{i=1}^{n\mathcal{E}} \{\dot{\mathbb{X}}_G^{i,j}, \dot{\mathbb{X}}_{RF}^{i,j}, \dot{\mathbb{X}}_{SF}^{i,j}\} \qquad \dot{\mathbb{T}} = \bigcup_{j=1}^{n\mathcal{E}_C} \dot{\mathbb{T}}_j$$

Experimental Setup

Evaluation

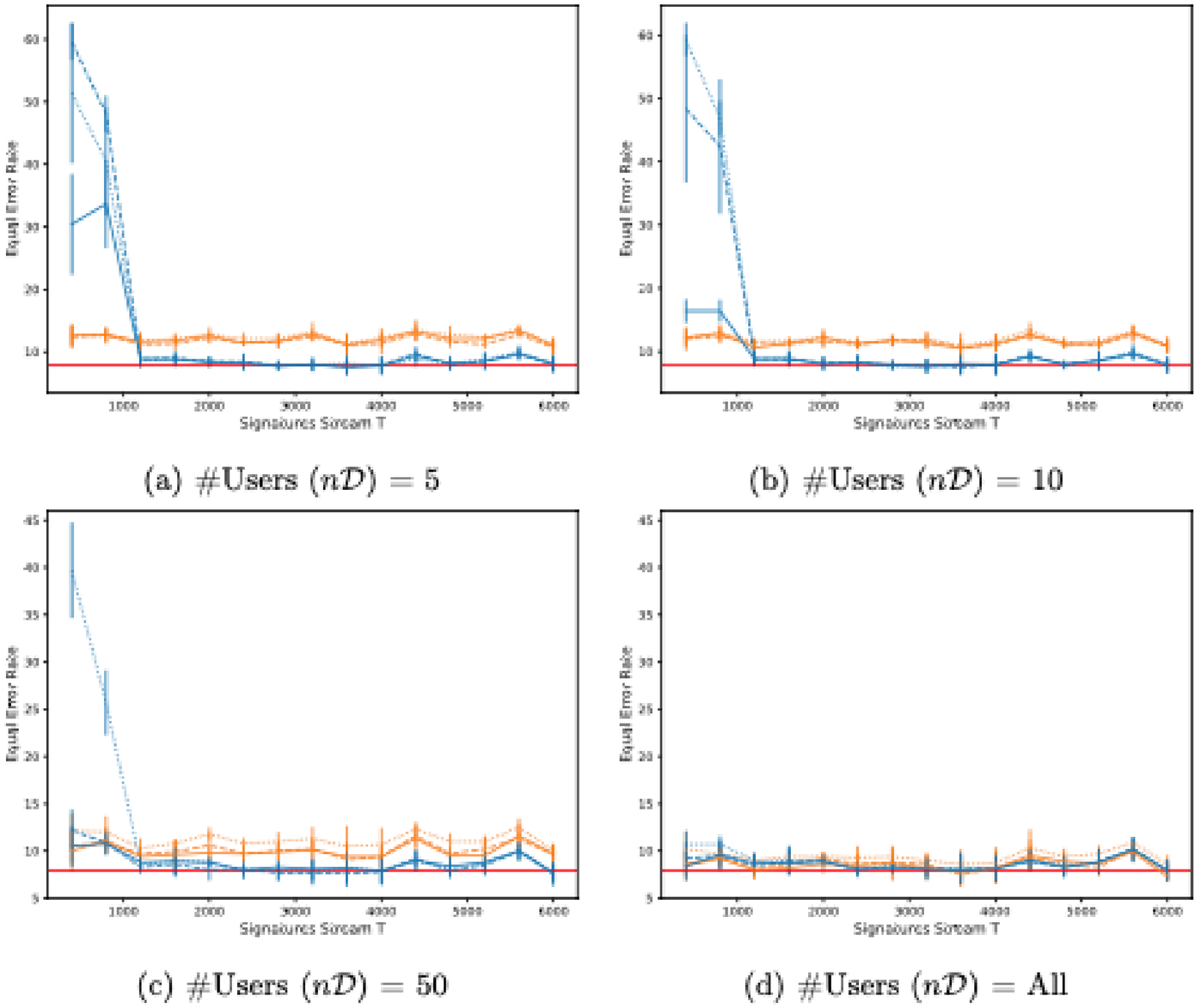
- **Method**: Prequential evaluation (test-then-train) for continuous updates.
- **Metric**: Equal Error Rate using a global threshold.
- The experiments are repeated five times, and the average results and standard deviation are computed

Table 4: Stream evaluation.

Stream	Chunk size		Window size and step
	Test	Training	
GPDS-S	900 ($n\mathcal{E} \cdot 3$)	600 ($n\mathcal{E} \cdot 2$)	400
CEDAR + MCYT	300	200	200
Type of sig.:	G, RF, and SK	G and RF	G and SK

Results

Performance on stream-based settings



Results

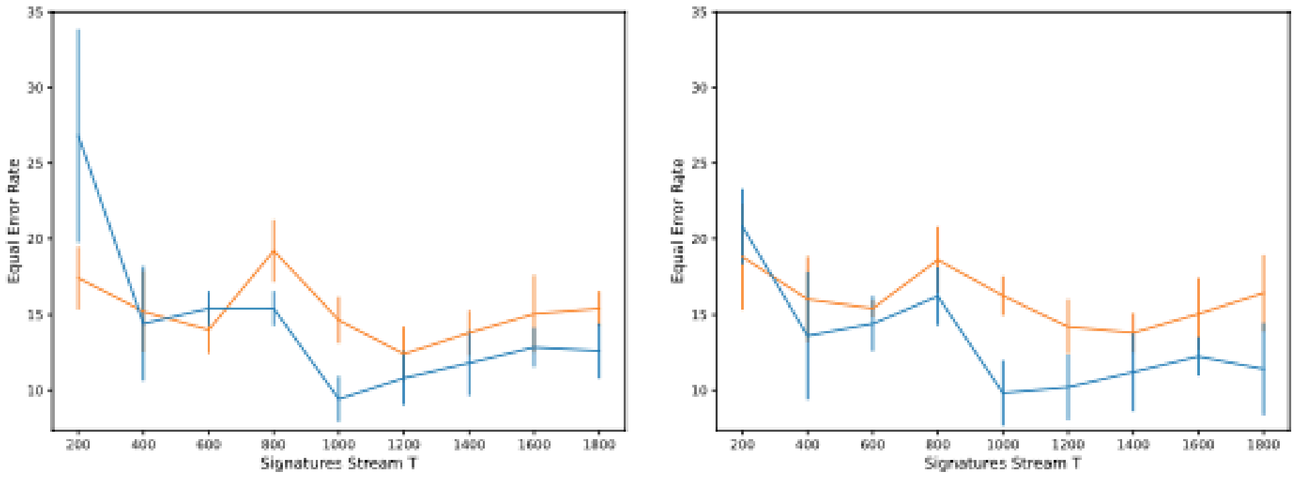
Performance on stream-based settings

Table 5: EER on the last chunk of signatures stream. Results show skilled forgery detection on GPDS Synthetic using SVM and Stream HSV (SHSV). $n\mathcal{D}$ and $n\mathcal{D}_G$ refer to the initial training setup (Table 3a). $n\mathcal{E}_R$ denotes the number of reference signatures (Table 3b). Stream evaluation performed according to Table 4.

$n\mathcal{D}$	$n\mathcal{E}_R$	#G sig. $(n\mathcal{D}_G) = 2$			#G sig. $(n\mathcal{D}_G) = 12$		
		SVM_{last}	$SHSV_{last}$	Δ	SVM_{last}	$SHSV_{last}$	Δ
2	1	19.20 (2.73)	14.00 (2.09)	5.20	19.00 (2.26)	15.00 (1.41)	4.00
	2	17.40 (2.22)	12.00 (2.40)	5.40	17.00 (1.12)	12.90 (1.98)	4.10
	5	14.20 (1.48)	9.20 (1.20)	5.00	14.10 (1.08)	9.00 (1.27)	5.10
	12	12.10 (0.55)	7.70 (1.15)	4.40	11.30 (0.57)	7.80 (1.10)	3.50
10	1	18.50 (2.12)	13.70 (2.05)	4.80	17.70 (2.17)	13.80 (2.08)	3.90
	2	16.00 (1.41)	12.20 (2.61)	3.80	15.20 (2.05)	12.10 (2.88)	3.10
	5	13.00 (1.37)	9.20 (1.35)	3.80	11.90 (1.08)	9.10 (1.19)	2.80
	12	11.10 (1.29)	7.70 (1.15)	3.40	10.80 (1.04)	7.80 (1.30)	3.00
50	1	17.90 (1.67)	14.00 (2.26)	3.90	16.60 (1.78)	14.20 (2.05)	2.40
	2	14.60 (1.14)	12.20 (1.89)	2.40	14.90 (1.39)	12.10 (1.78)	2.80
	5	12.30 (1.15)	9.20 (1.15)	3.10	11.30 (1.04)	9.30 (1.30)	2.00
	12	10.00 (0.71)	7.60 (0.96)	2.40	9.70 (0.76)	7.70 (0.84)	2.00
All	1	16.00 (1.77)	14.50 (2.21)	1.50	14.40 (2.19)	13.90 (2.43)	0.50
	2	13.30 (1.57)	11.90 (1.98)	1.40	12.70 (1.25)	11.80 (1.92)	0.90
	5	10.70 (1.52)	9.30 (1.30)	1.40	9.00 (1.62)	9.10 (1.52)	0.10
	12	8.60 (0.96)	7.80 (0.84)	0.80	7.30 (0.57)	7.90 (1.19)	0.60

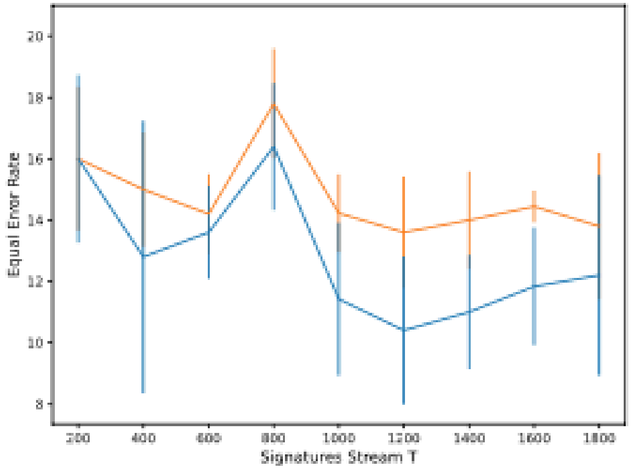
Results

Performance on stream-based settings

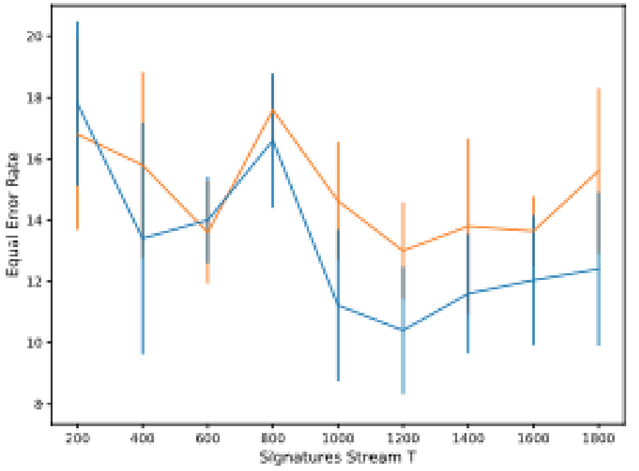


(a) #Users $(n\mathcal{D}) = 5$, #G sig $= 12$

(b) #Users $(n\mathcal{D}) = 10$, #G sig $= 12$



(c) #Users $(n\mathcal{D}) = 50$, #G sig $= 12$



(d) #Users $(n\mathcal{D}) =$ All, #G sig $= 12$

Conclusion & Future Work

- SHSV consistently outperforms traditional approaches.
- More robust to limited initial data.
- Application in scenarios with evolving data.
- Handles variability in handwriting over time.
- Future work:
  - Use of partially labeled data.
  - Adaptive feature representation.

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Pages:

- https://github.com/kdmoura/stream_hsv
- https://www.etsmtl.ca/en/labs/livia
- https://www.etsmtl.ca/

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