OnLine Handwriting Recognition

(Master Course of HTR)

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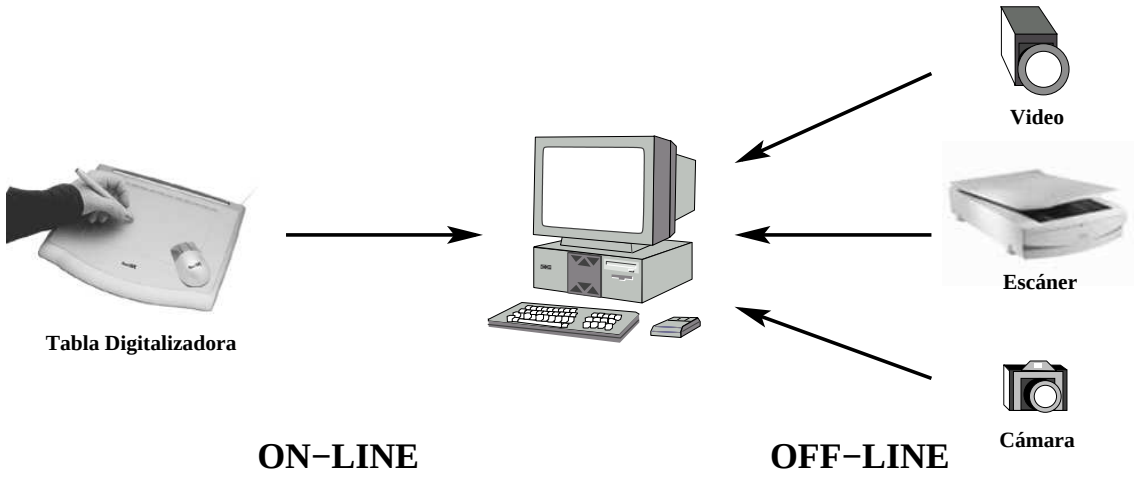
Outline

1. Introduction
2. Feature Extraction for On-Line HTR
3. DFT - Data Global Modelling
4. DFT - Data Local Modelling
5. Experimental Results

On-Line Handwriting Recognition Context

Acquisition types:



Usual applications:

- Sign recognition and verification.
- Recognition of postal codes.
- Recognition of courtesy amount in bank checks.
- Transcription of ancient documents.

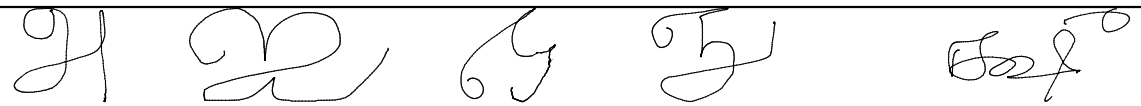
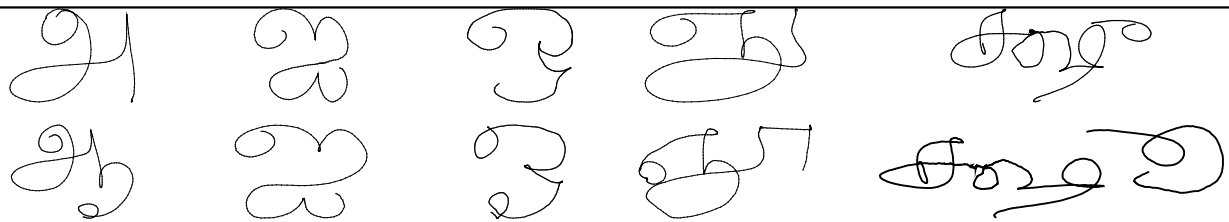
Motivations

- Time-based Feature Extraction adequate for using with HMM.
- Because of the similarity existing between the nature of on-Line HTR and Speech recognition.
- Tamil HCR Competition.

Tamil HCR Competition - Motivation

- Isolated character samples of 156 Tamil characters.
- Written by native Tamil writers.
- Off-Line and On-Line corpus version.

Some examples of Tamil's symbols:

User 54	
User 111	

- Evaluation criterion is the highest top-choice accuracy at zero reject rate.
- 50683 labelled samples available for training purposes.
- 26926 unlabelled samples available for testing purposes.

On-Line Recognition Representation

On-Line handwriting is represented by a points sequence in $\mathbb{R}^2$ space ordered in time. Parametric curve.

A isolated handwritten character/word:

- A series of consecutive pen-downs and pen-up strokes.
- Each stroke is a sequence of coordinates $(x_t, y_t) \quad t = 0..N-1$.
- Some on-line devices included the pressure made on each point.

Our Traditional Feature Extraction

Seven Feature Extractions in function of the time:

- x_t and y_t coordinates normalized between 0 and 100.
- x'_t and y'_t first derivatives normalized between 0 and 1.
- x''_t and y''_t second derivatives.

  All derivatives are calculated using:

$$f_t = \frac{\sum_{c=1}^{C}(r_{t+c} - r_{t-c})}{2\sum_{c=1}^{C} c^2} \quad r_t \in \{x'_t, y'_t, x''_t, y''_t\}$$

- curvature:

$$k_t = \frac{x'_t \cdot y''_t - x''_t \cdot y'_t}{\left(x'^2_t + y'^2_t\right)^{3/2}}$$

DFT representation

On-Line handwriting can be represented

- by a sequence of coordinates $(x_t, y_t) \quad t = 0..N-1$.
- also as a function $f_t : t \rightarrow (x_t + iy_t) \in \mathbb{C}$, or $f_t : t \rightarrow (x_t, y_t) \in \mathbb{R}^2$.

Pair of Discrete Fourier Transforms:

- Direct Transform $F_n = \sum_{t=0}^{N-1} f_t \, e^{-2\pi i \frac{tn}{N}}$
- Inverse Transform $f_t = \frac{1}{N} \sum_{n=0}^{N-1} F_n \, e^{2\pi i \frac{tn}{N}}$

Global/Local Data Modelling

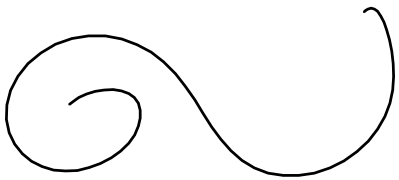
DFT Feature Extraction can be applied to:

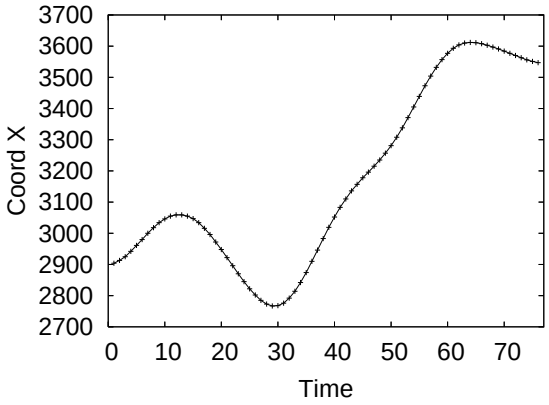
- the whole character stroke - Global Data Modelling
- local stroke segments - Local Data Modelling

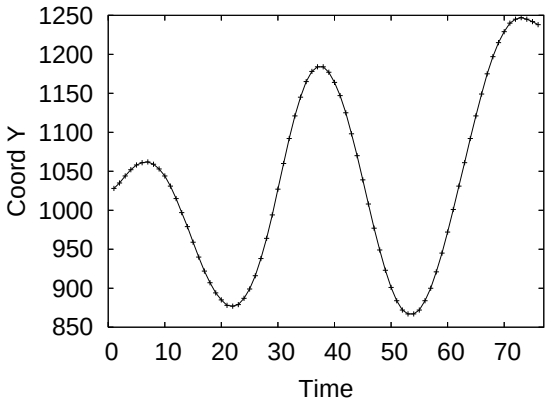
We use two different classifiers:

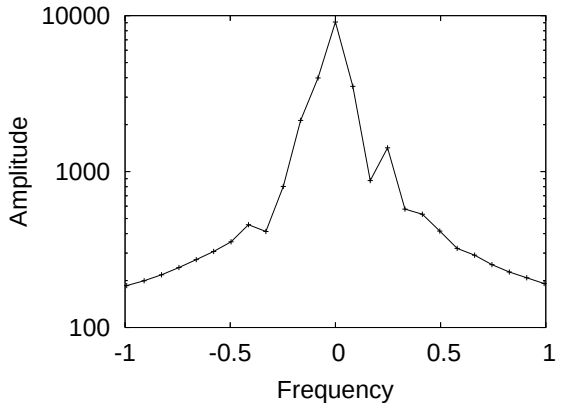
- K-NN classifier for global data modelling.
- Continuous density HMMs for local data modelling.

Introduction - DFT Modelling Example



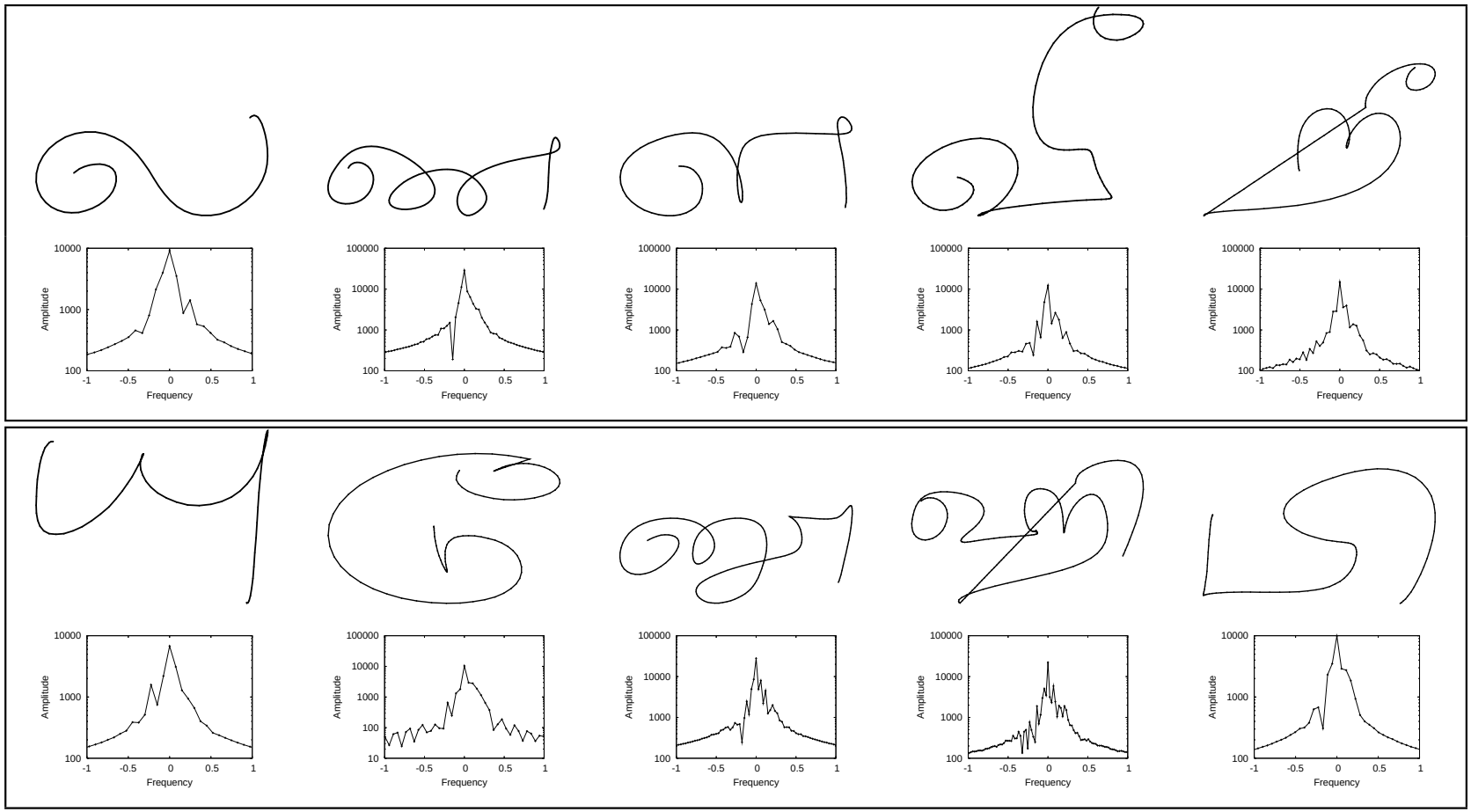






Data Global Modelling - Direct DFT

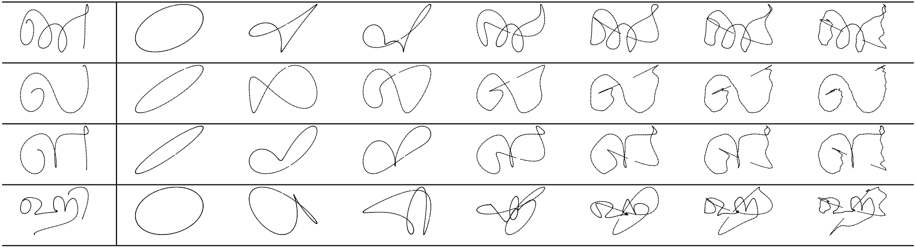
DFT feature extraction examples using the first 40 coefficients:



Data Global Modelling - Inverse DFT

Examples of reconstructed samples considering different number of Fourier-Coefficients.

Original	2 FC	4 FC	6 FC	12 FC	20 FC	30 FC	60 FC

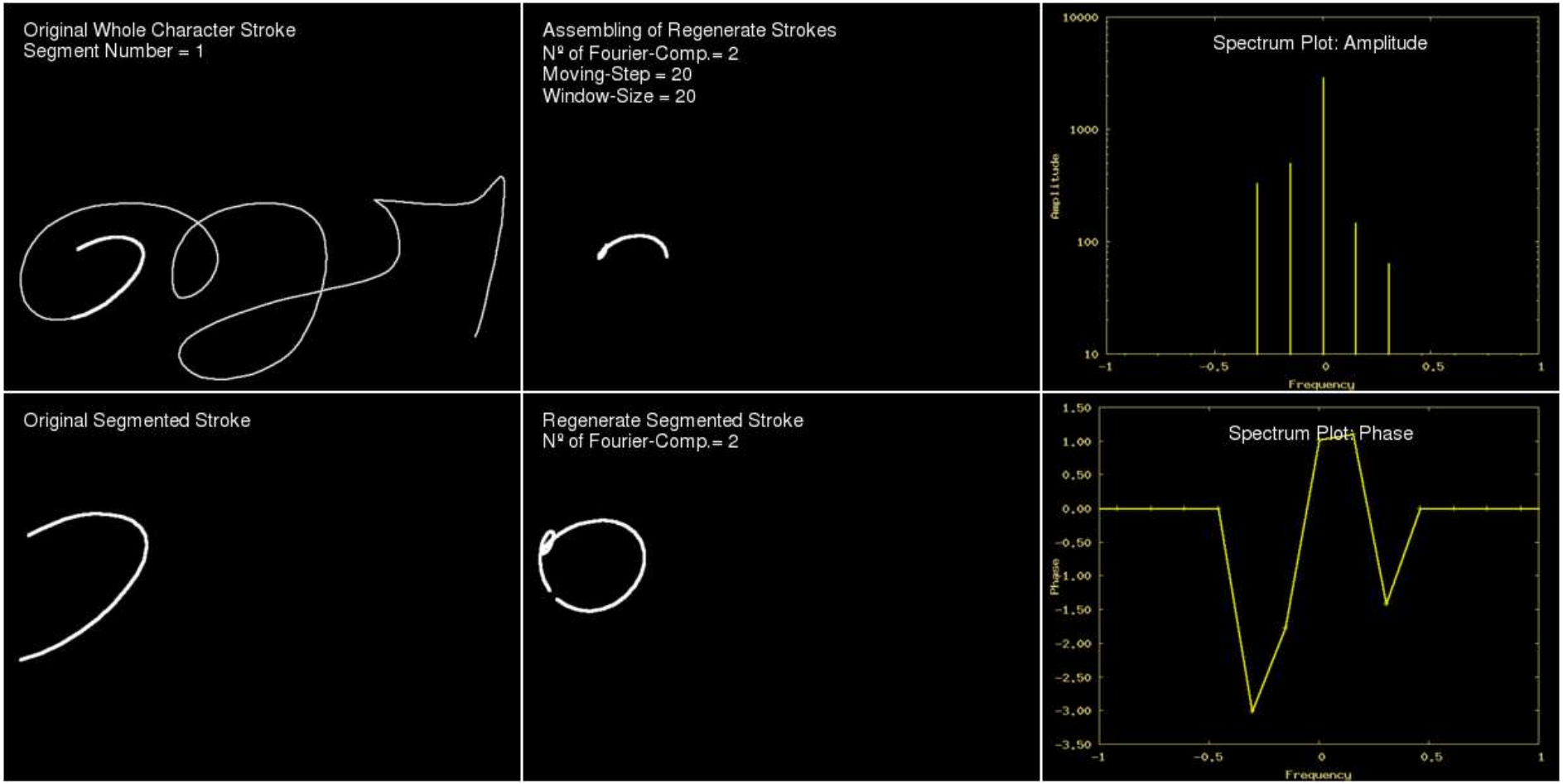


Local Data Modelling

Local DFT Features Extraction:

- Sliding-Window running through the whole stroke.
- Window size: 40 points.
- Moving step: 1 points.
- Hamming windows.

Demo 1



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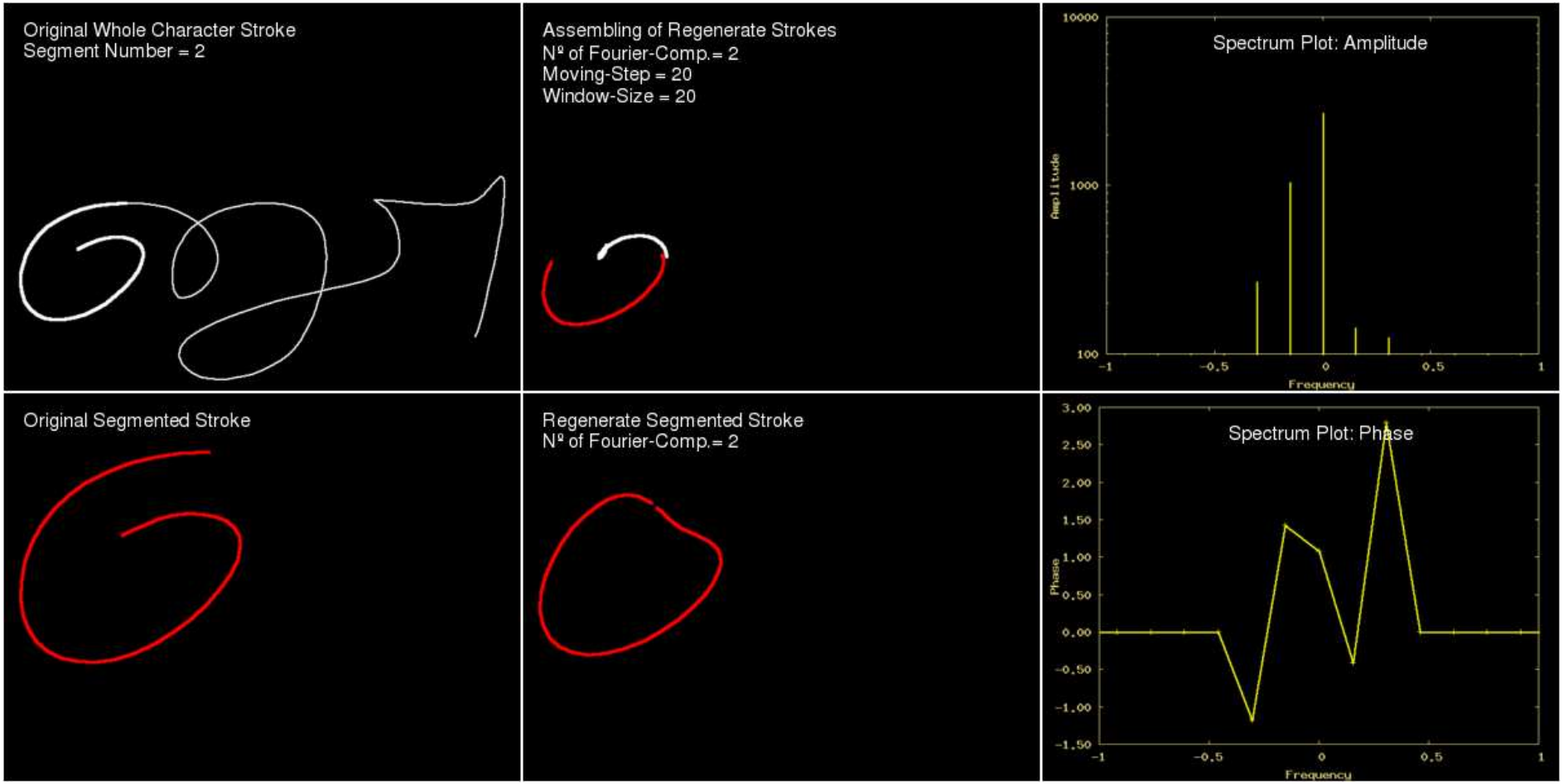
Demo 1



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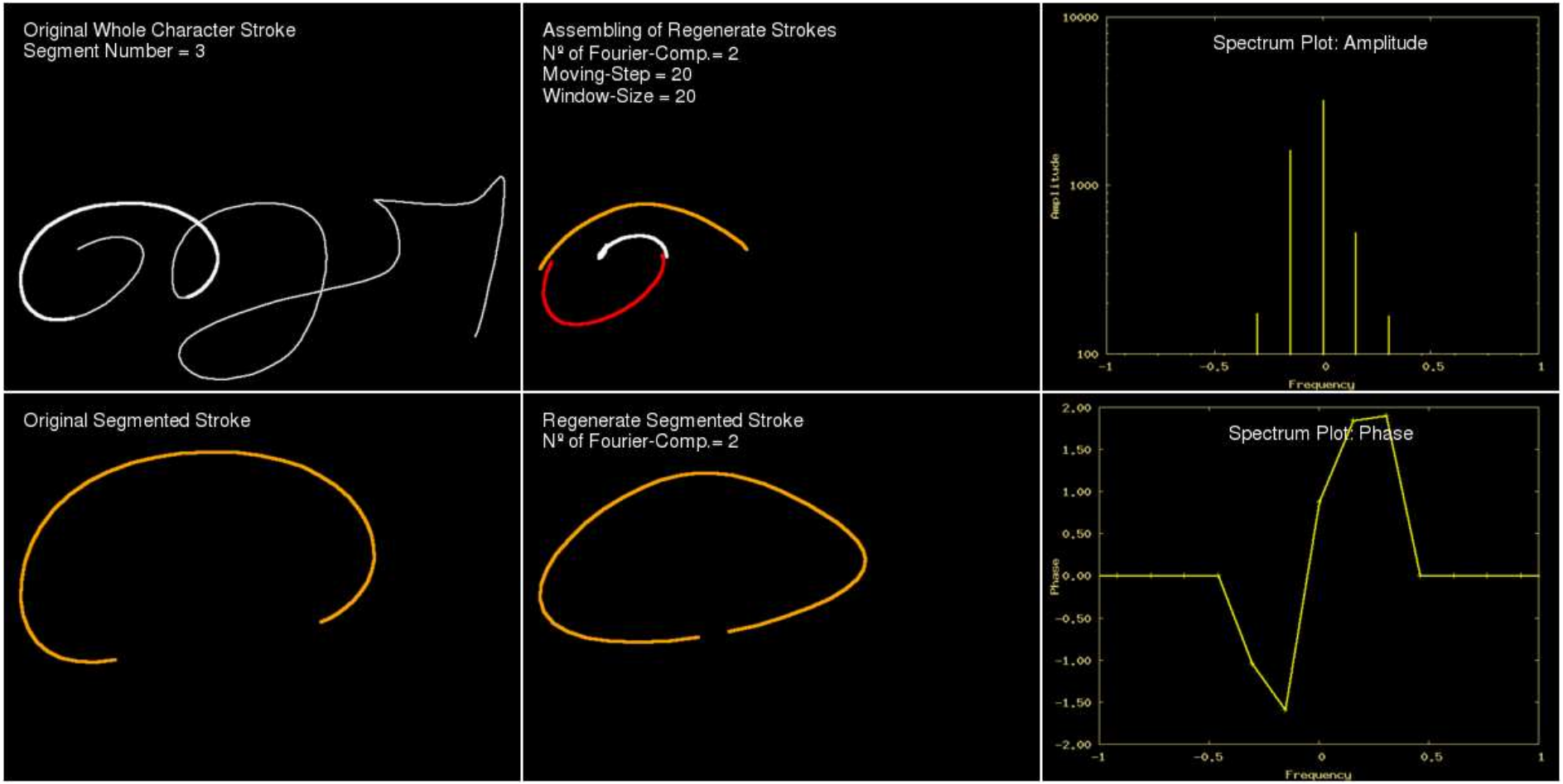

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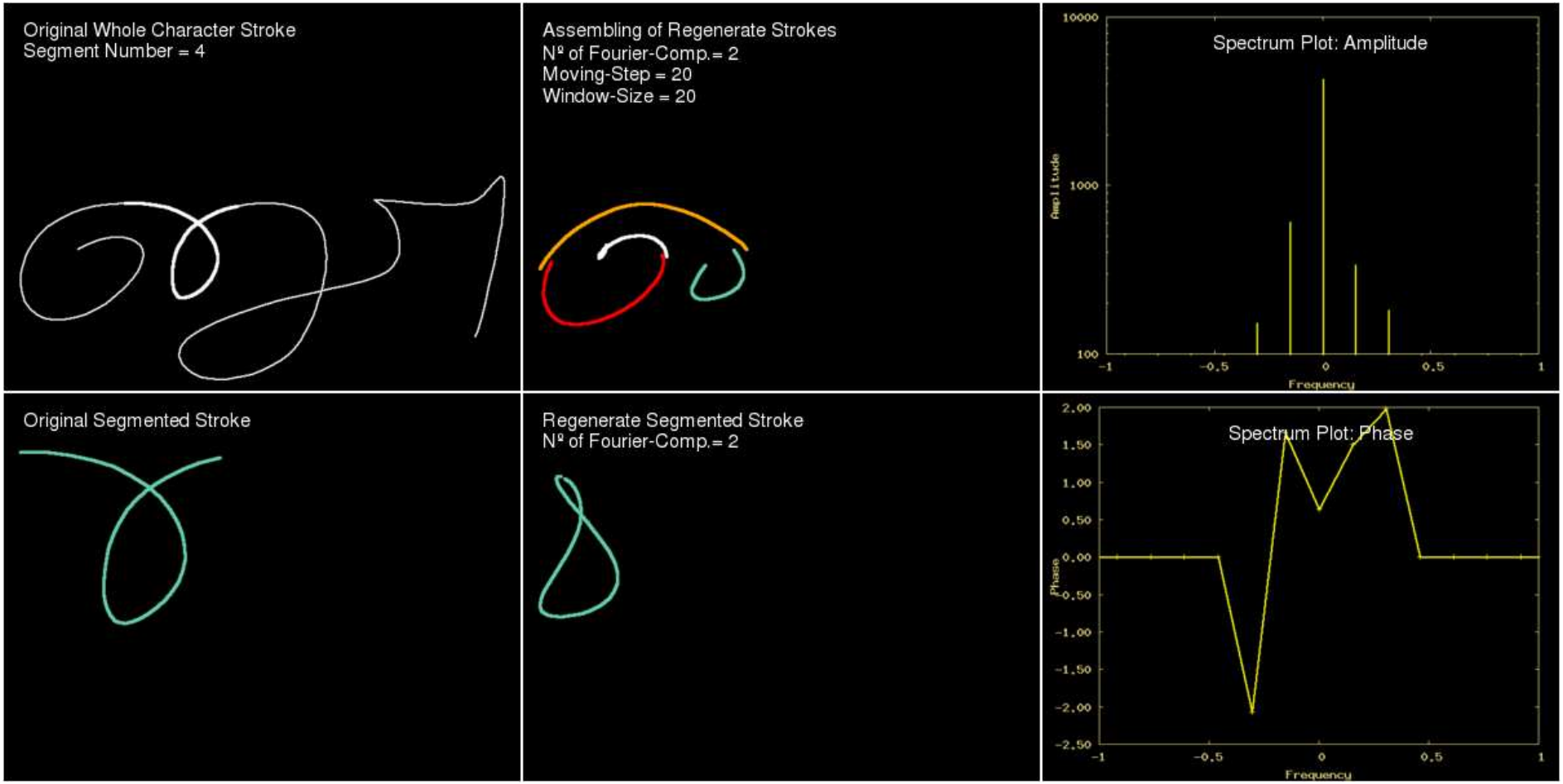

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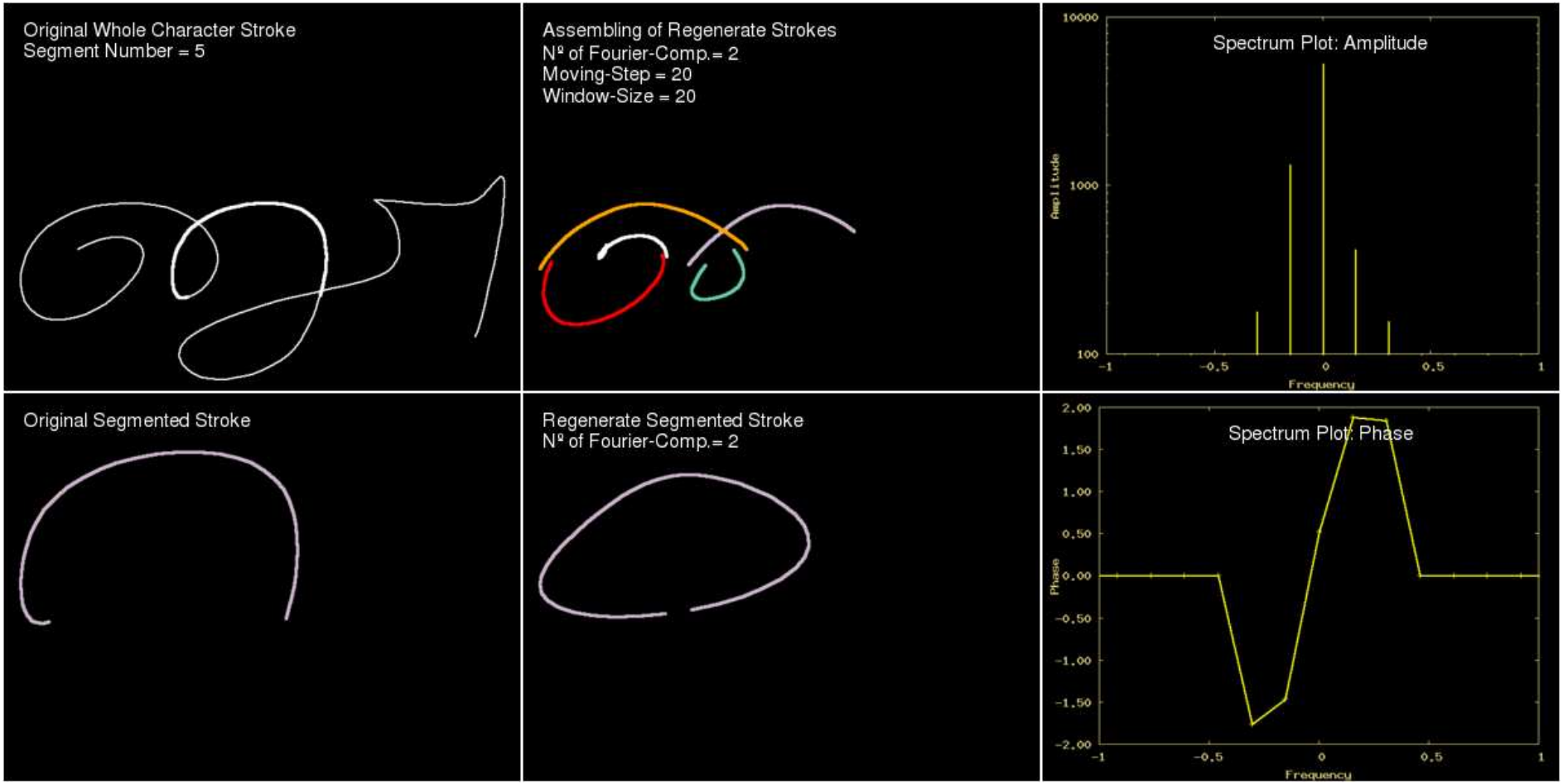

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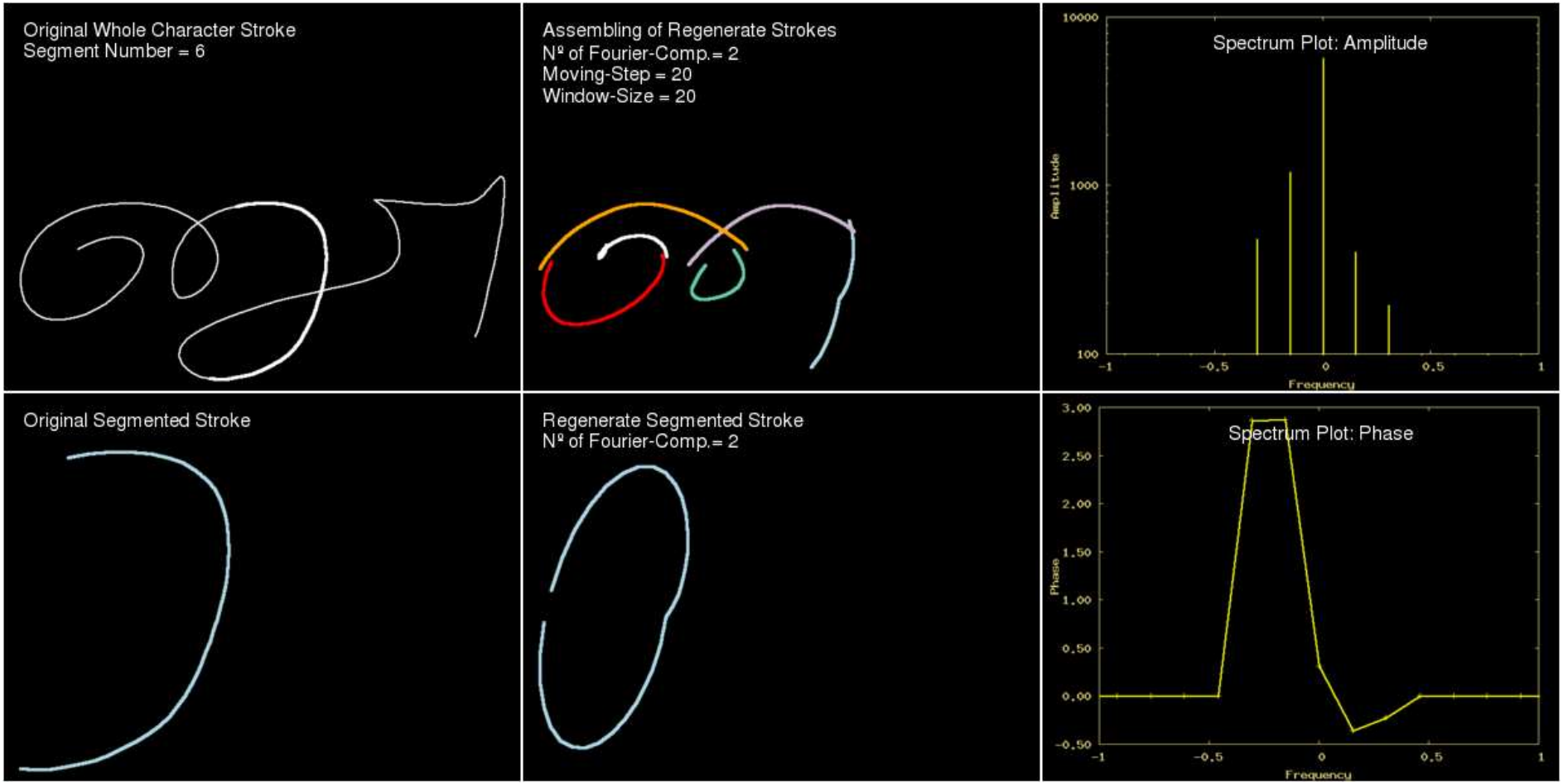

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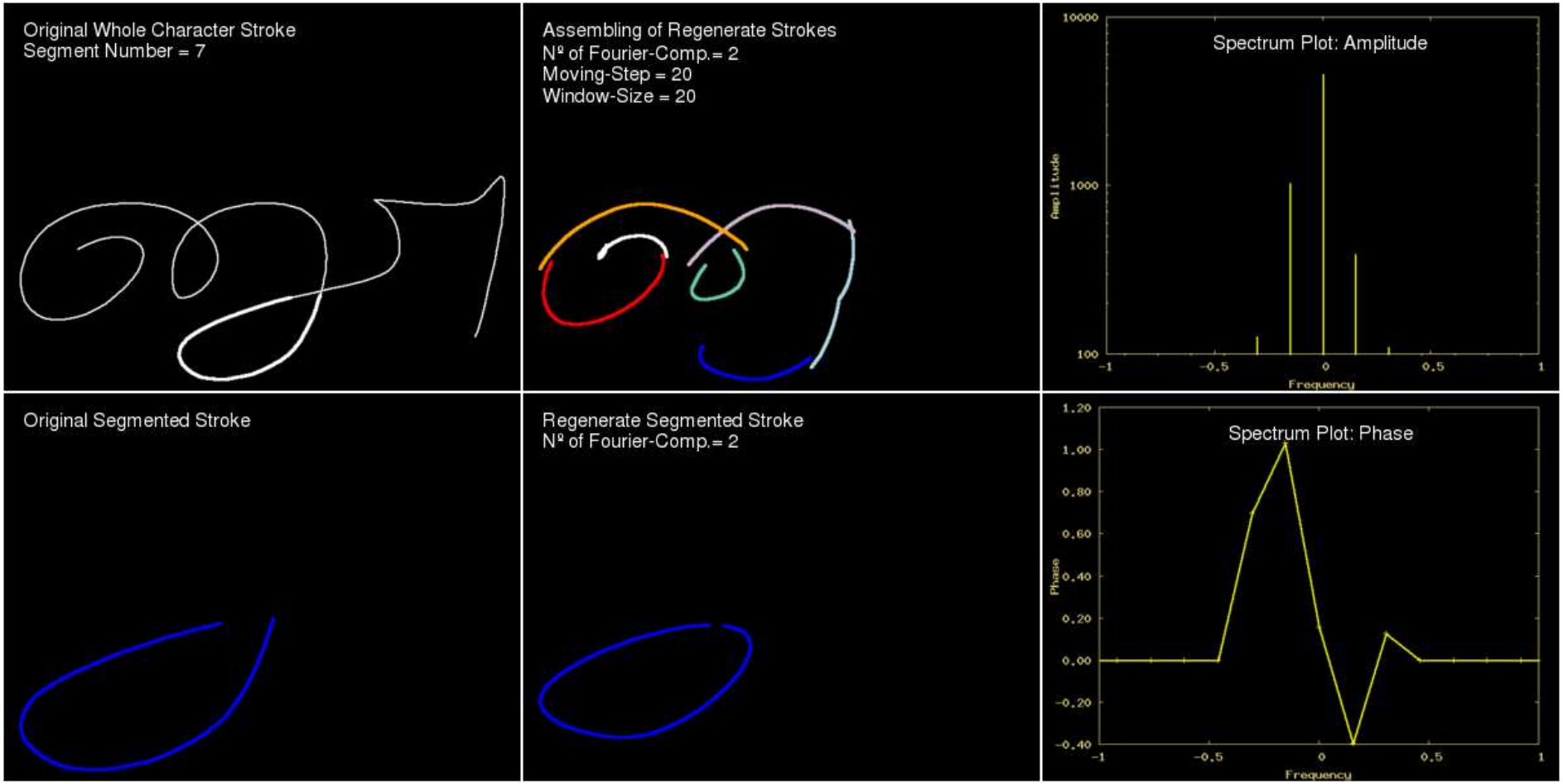

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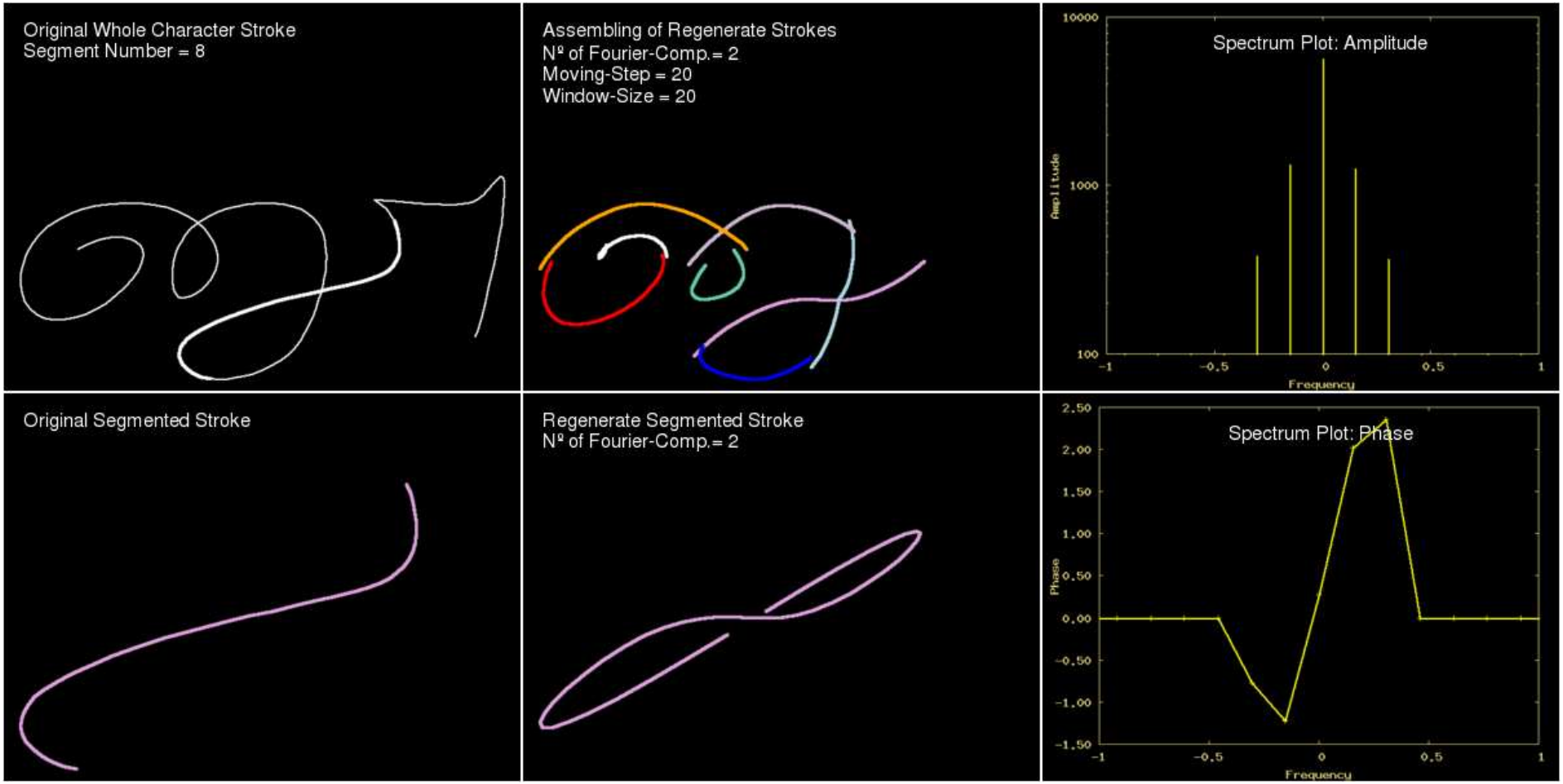

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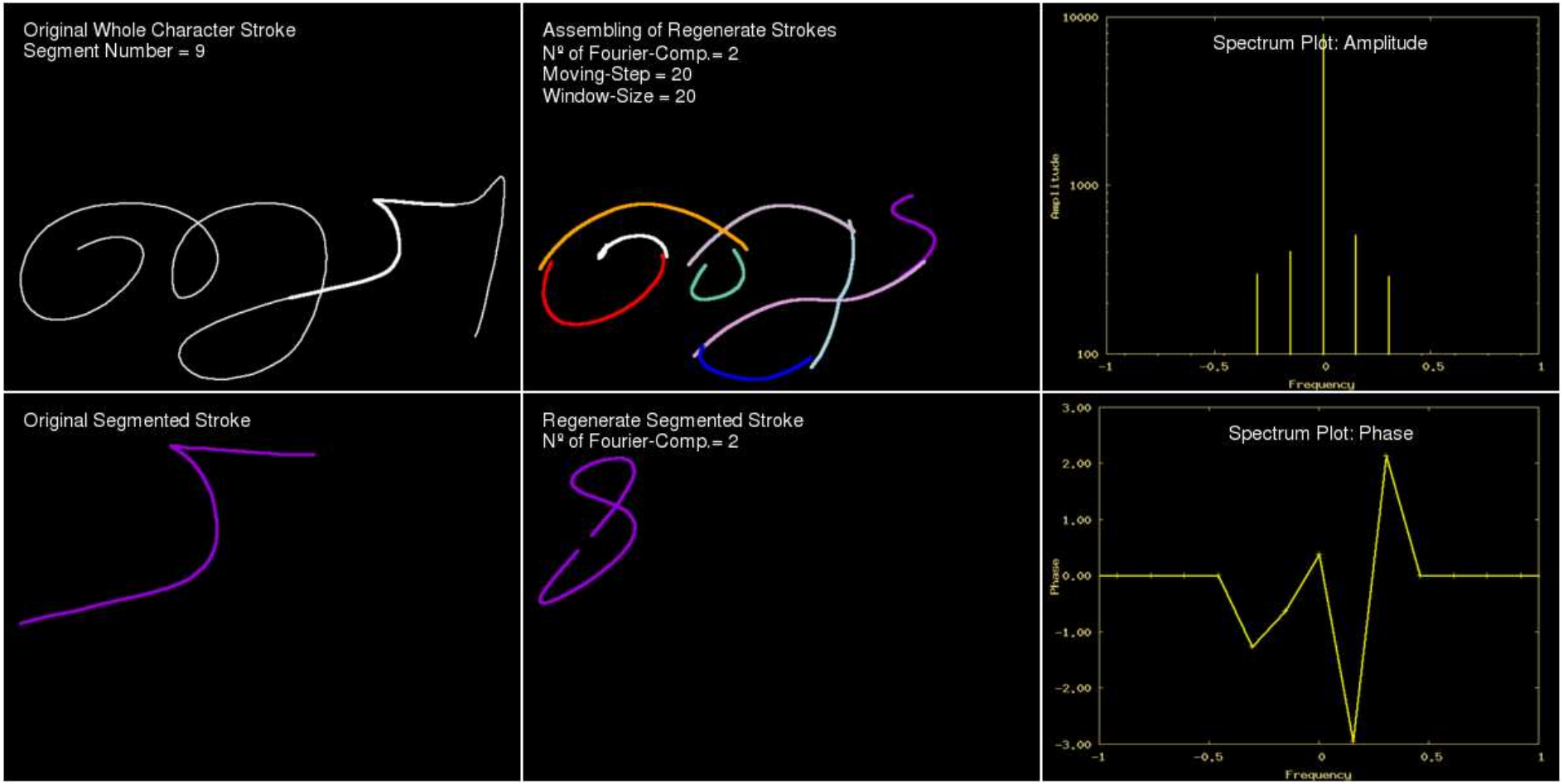

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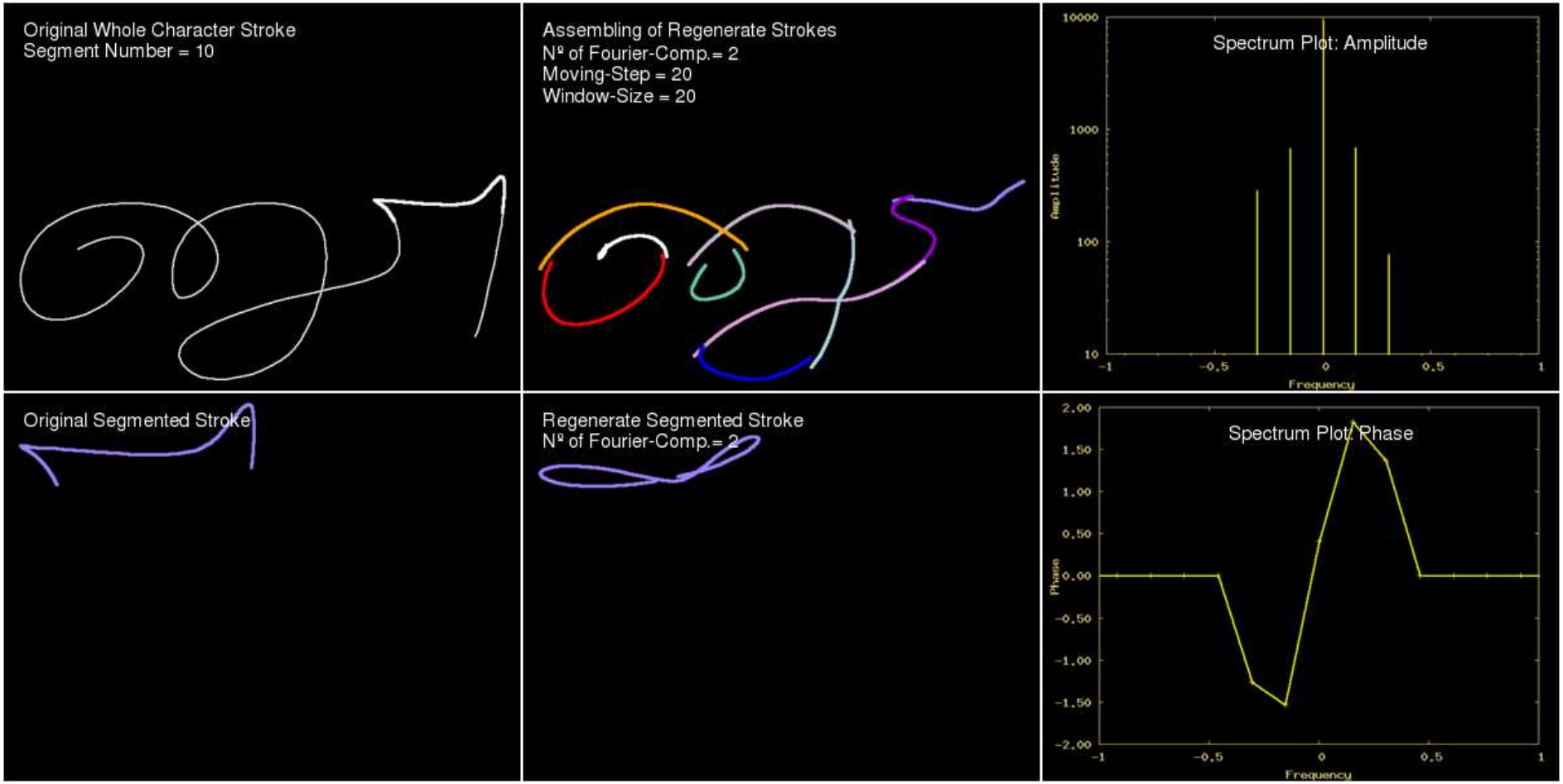

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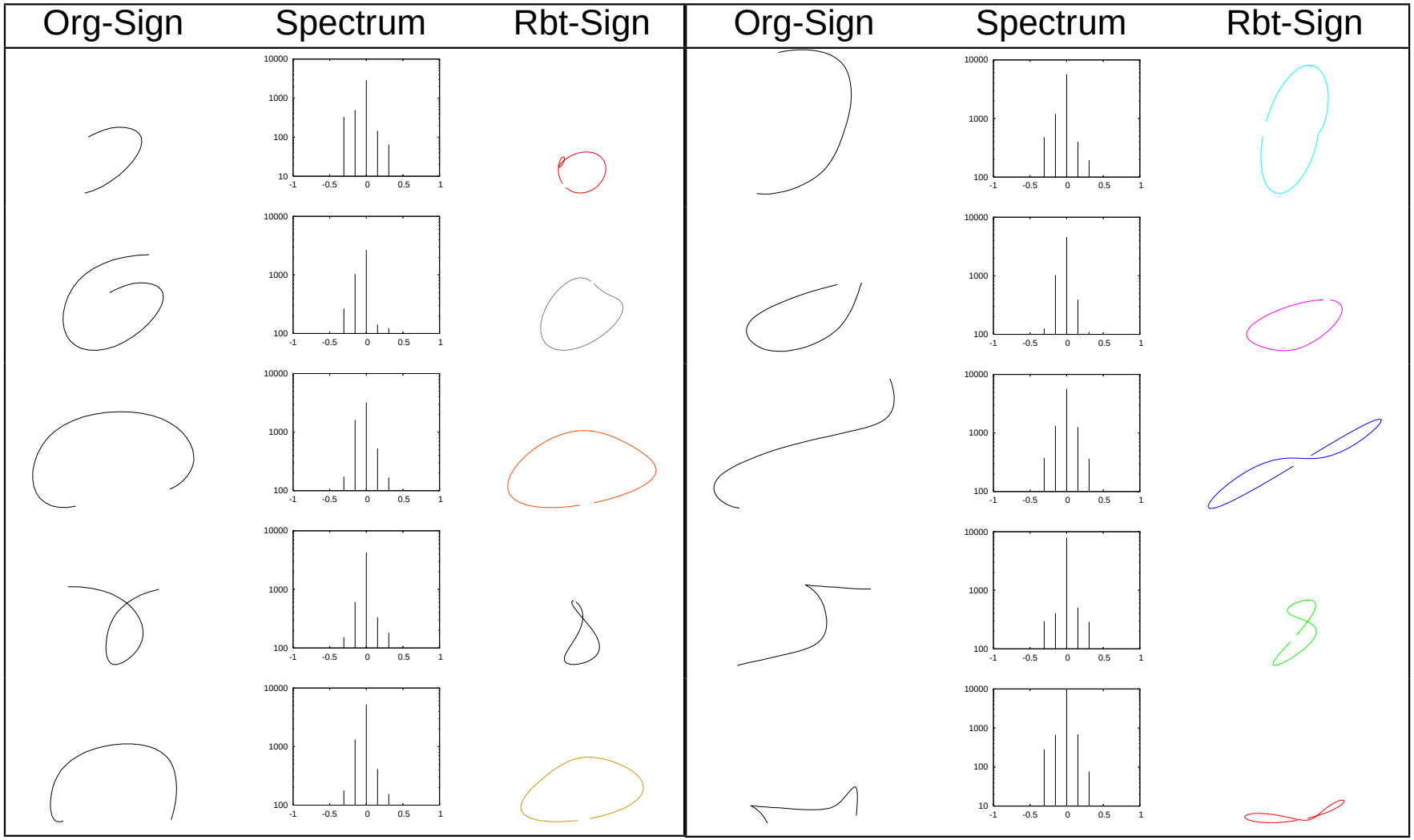
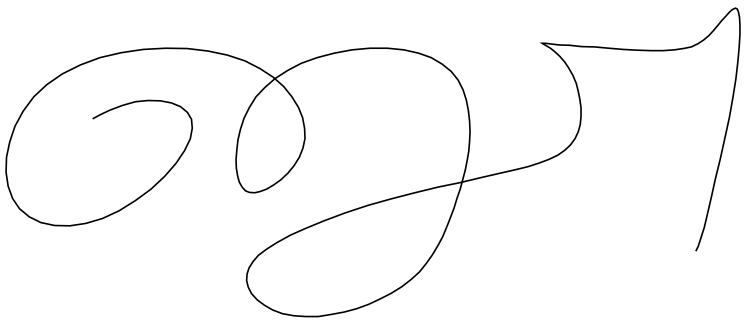
Sliding-Window Segments



Assembling of Regenerated Stroke Segments

Original Signal



Reconstructed from 4 Fourier-Coefficients Sliding-Window, 40 points windows-size and 20 points moving-step.

Tamil Corpus Partition

- Isolated character samples of 156 Tamil characters.
- Written by native Tamil writers.
- Experiments carried out with 2 different versions of the corpus.

Full version:

	Training	Test	Total
#Writers	90	27	117
#Samples	39618	11065	50683

Reduced version:

	Training	Test	Total
#Writers	89	26	115
#Samples	6240	1560	7800

Classification Results with K-NN - Global Modelling

Used feature extraction:

- First 20 Fourier coefficients.
- Coefficient are represented by real and imaginary parts.
- Experiments carried our with the full version of the corpus.

K-NN	WER(%)
1	22.7
3	21.4
5	21.0
8	**20.9**
10	21.0

HMM Classifier - Local Modelling

HMM classifier specification:

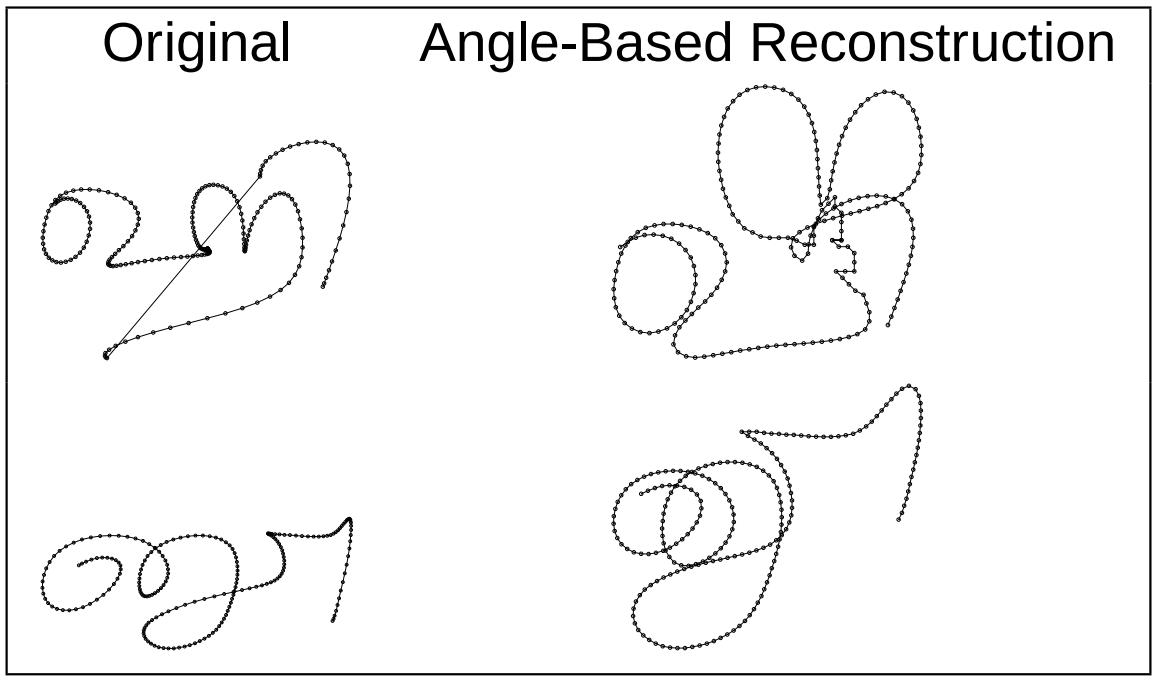
- Left-to-Right topology.
- Number of states as a function of average class length.
- Mixture of Gaussian densities as probability emission per HMM state.
- Baum-Welch re-estimation algorithm for training process.
- Viterbi algorithm for test recognition for process.

DFT Application Problems

Inconvenient: DFT applied to a complex function modulated by a Hamming filter.

As alternatives, DFT was applied:

- on the angle function, defined as: $a_t = \arctan \frac{y'_t}{x'_t}$.
- on x_t and on y_t in an independent way.



Results with Different DFT Application Schemes

Experiments carried out with the reduced version of the corpus and using only DFT coefficients as features.

#Gauss	DFT-Complex	DFT-Ang	DFT-XYind
1	23.91	30.77	19.68
2	20.19	25.77	16.41
4	19.29	23.46	16.60
8	20.71	25.00	18.01
16	22.24	29.17	19.42
32	25.64	37.69	21.92
64	28.78	47.12	23.21
128	30.45	46.41	25.77

Experimental Validation of the Hamming Filter

Experiments carried out with the reduced version of the corpus and using only DFT coefficients as features.

#Gauss	Hamming	Rectangular
1	23.91	24.55
2	20.19	21.73
4	19.29	21.15
8	20.71	22.88
16	22.24	25.64
32	25.64	30.64
64	28.78	33.53
128	30.45	36.86

Classification Results with HMMs - Full Version

Feature extraction:

- TFE: x and y normalized coordinates, their first and second derivatives, and curvature.
- FFC: First 4 Fourier transform coefficients (real and imaginary parts).

#Gauss	TFE	FFC	TFE+FFC
1	12.7	19.6	12.4
2	12.2	15.4	11.1
4	12.1	14.2	10.5
8	12.0	13.6	10.3
16	11.6	13.1	**10.0**
32	11.6	13.5	10.2
64	11.7	13.9	10.4

Tamil HCR Competition - Ranked List of Results

Rank	Recognition Accuracy	Data-Entry
1	93.53	on
2	91.2	on
3	**90.72**	**on**
4	90.63	on
5	90.15	on
6	90.07	on
7	89.9	on
8	88.91	on
9	87.66	off
10	87.22	off
11	85.81	off
12	77.61	on
13	76.51	off
14	74.99	off
15	73.4	off
16	67.6	on
17	66.33	on

Conclusions and Future Work

- DFT feature extraction complements time-based feature extraction.
- Experiments applying DFT on x_t and on y_t in an independent way.
- Test the feature extraction with the On-Line UNIPEN corpus.