Fast Channel Selection for Scalable Multivariate Time Series Classification

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Outline

1. Introduction
2. Motivation
3. Channel Selection Techniques
4. Results

Introduction

Multivariate Time Series Classification: The task of classifying an ordered temporal signal (time series) where multiple channels can affect the class outcome.

Figure: if sensors are placed on different body parts, e.g., wrists, shoulders, hips, lower back, etc, they will act as channels for MTS. The class label is attached to a multi-channel time series, eg classify movement as correct/incorrect.

Applications:
- Medical
- Sports Science
- Agriculture
- Manufacturing

Source

Motivation

- Research in UTSC has made significant progress, but there is much less work done on MTSC.
- Most literature in UTSC considers the MTSC problem as an extended version of UTSC and tends to adapt UTSC methods for MTSC.
- Problems with such methods is **computational components such as space and time complexity are ignored** which are crucial elements for MTSC.
- **Three Computation Challenges of MTSC**
    - Scale
    - Channels
    - Length

Contributions

Objective

To enable existing SOTA classifiers to scale better with an increase in the number of MTSC channels, by reducing the time and memory required for computation, while maintaining accuracy.

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Contributions

- Proposed three greedy channel selection strategies.
- Report a 70% reduction in computation time and about 70% reduction in data storage.
- We test our methods on a real-world, 25-channel MTSC dataset, recorded for the Military Press strength and conditioning exercise.

Dataset: UEA MTSC Benchmark - 26 MTSC datasets

Human Activity Recognition
- BasicMotions
- Cricket
- Epilepsy
- ERing
- Handwriting
- Libras
- NATOPS
- UWaveGestureLibrary

Motion Classification
- ArticularyWordRecognition
- CharacterTrajectories
- EigenWorms
- PenDigits

ECG classification
- AtrialFibrillation
- StandWalkJump

EEG/MEG
- FingerMovements
- MotorImagery
- SelfRegulationSCP1
- SelfRegulationSCP2
- FaceDetection
- HandMovementDirection

Audio Spectra Classification
- DuckDuckGeese
- Heartbeat
- InsectWingbeat
- Phoneme
- SpokenArabicDigits
- JapaneseVowels

Others
- EthanolConcentration
- PEMS-SF
- LSST

Source

Channel Selection

- The study analyses if channel selection can be performed using the distance between class centroids.

  Key idea: Useful channels can separate the classes;

  good channel => higher distance between centroids.

Channel Selection

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  <u>Key idea</u>: Useful channels can separate the classes;

  good channel => higher distance between centroids.

- Why centroids?
  - Centroids are typically class prototypes.
  - No need to iterate over full dataset, thus making following process fast.

Channel Selection

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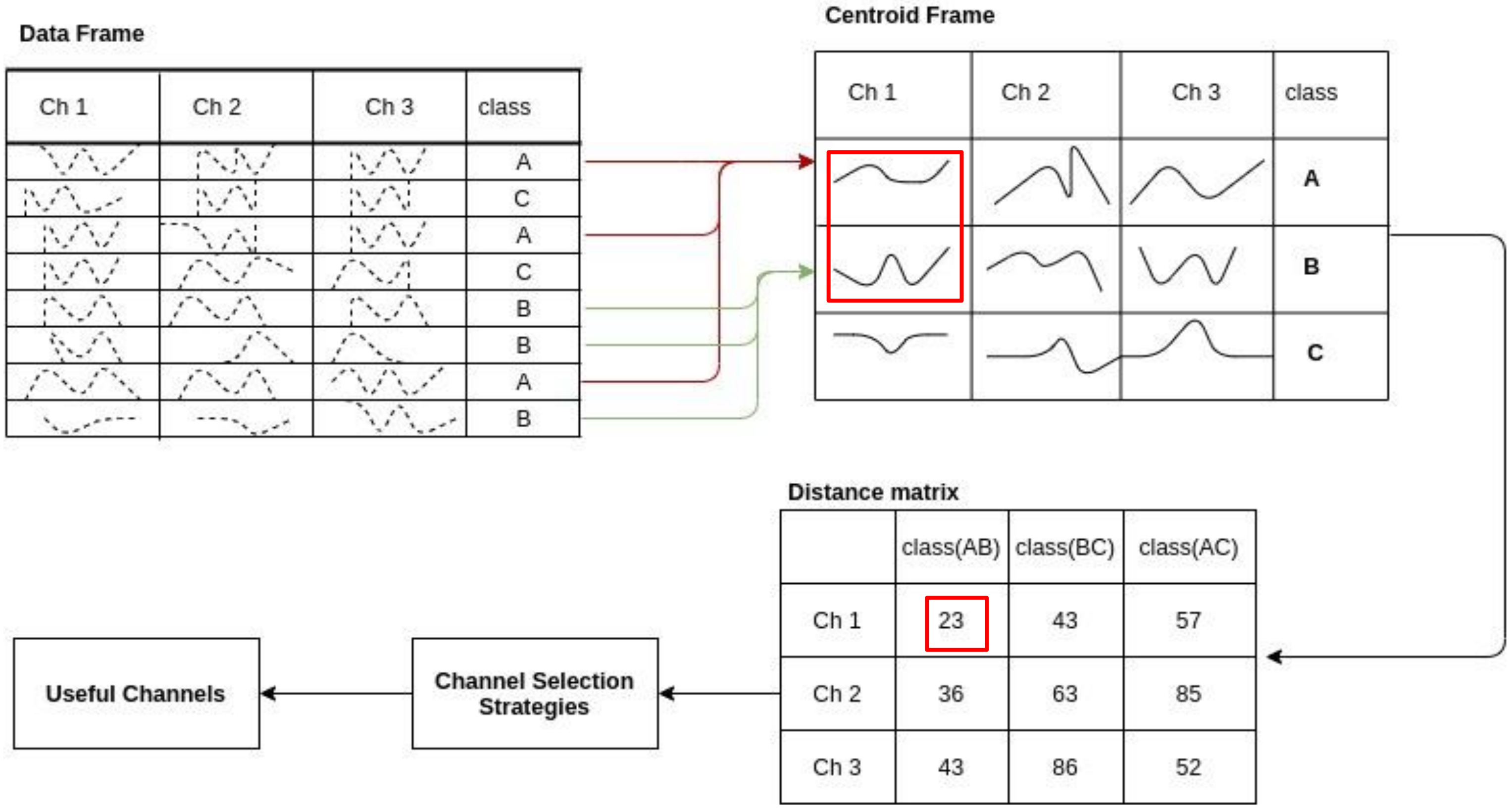
  Key idea: Useful channels can separate the classes;

  good channel => higher distance between centroids.

- Why centroids?
  - Centroids are typically class prototype.
  - No need to iterate over full dataset, thus making following process fast.
- How?
  - Calculate distance between class centroid-pairs for each channel and store them into a distance matrix.
  - Using this distance matrix, find the best set of channels.
    - We evaluate three strategies to find best set of channels.

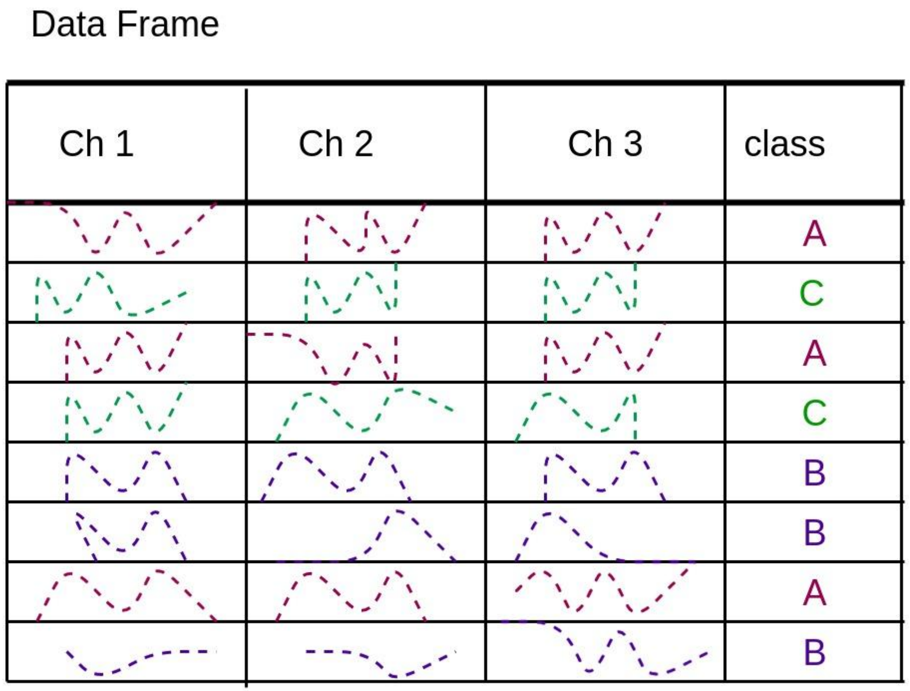
Channel Selection: Methodology



Methodology to select channels

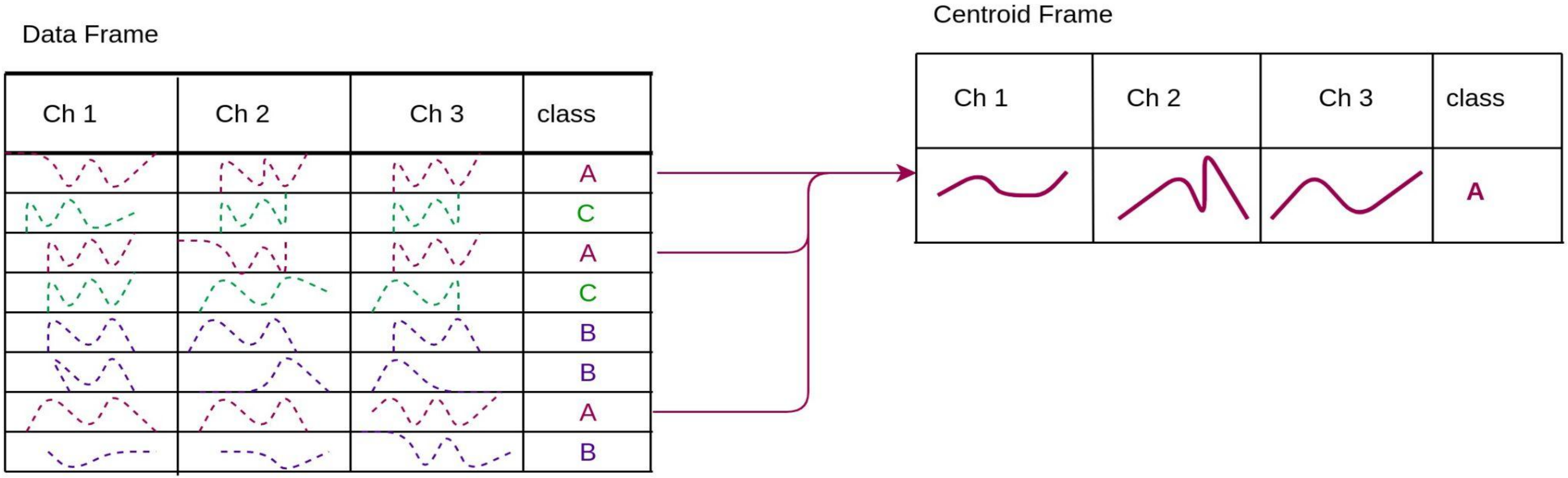
1. Create a centroid frame from the time-series dataframe.
2. To create distance matrix, calculate distance between channels for each centroid pairs.
3. Use proposed channel selection strategies (KMeans, ECP, and ECS) to select relevant channel.

Channel Selection: Methodology



Channel Selection: Methodology

STEP 1: Compute and store centroid for each class



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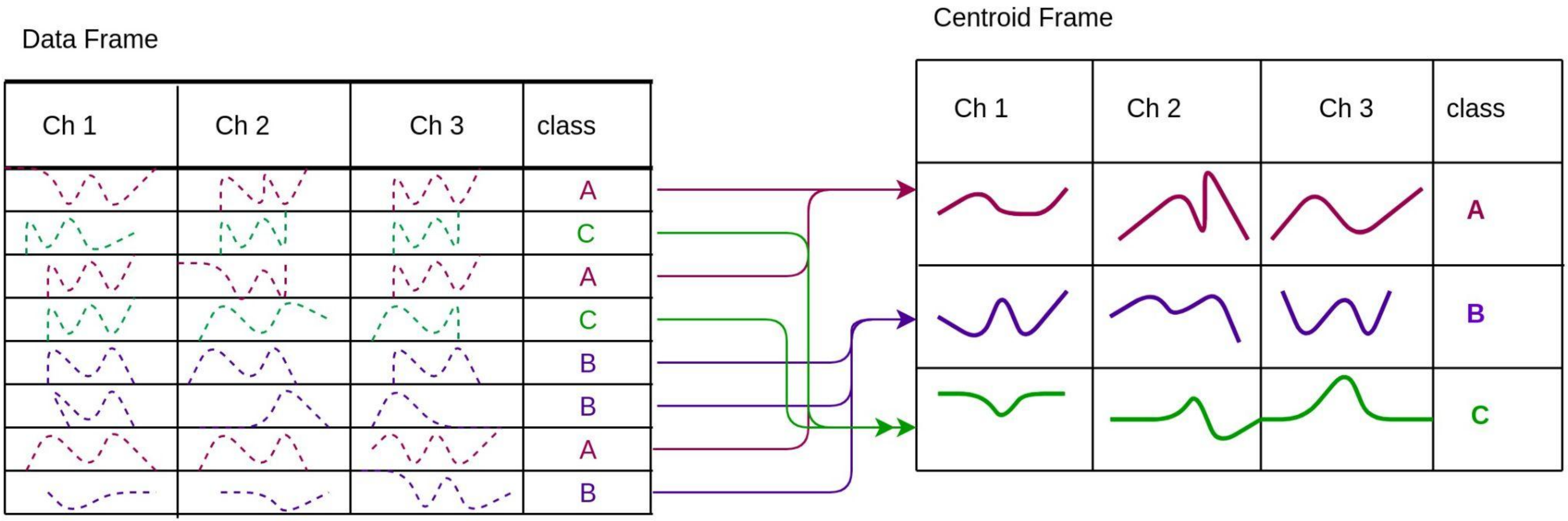
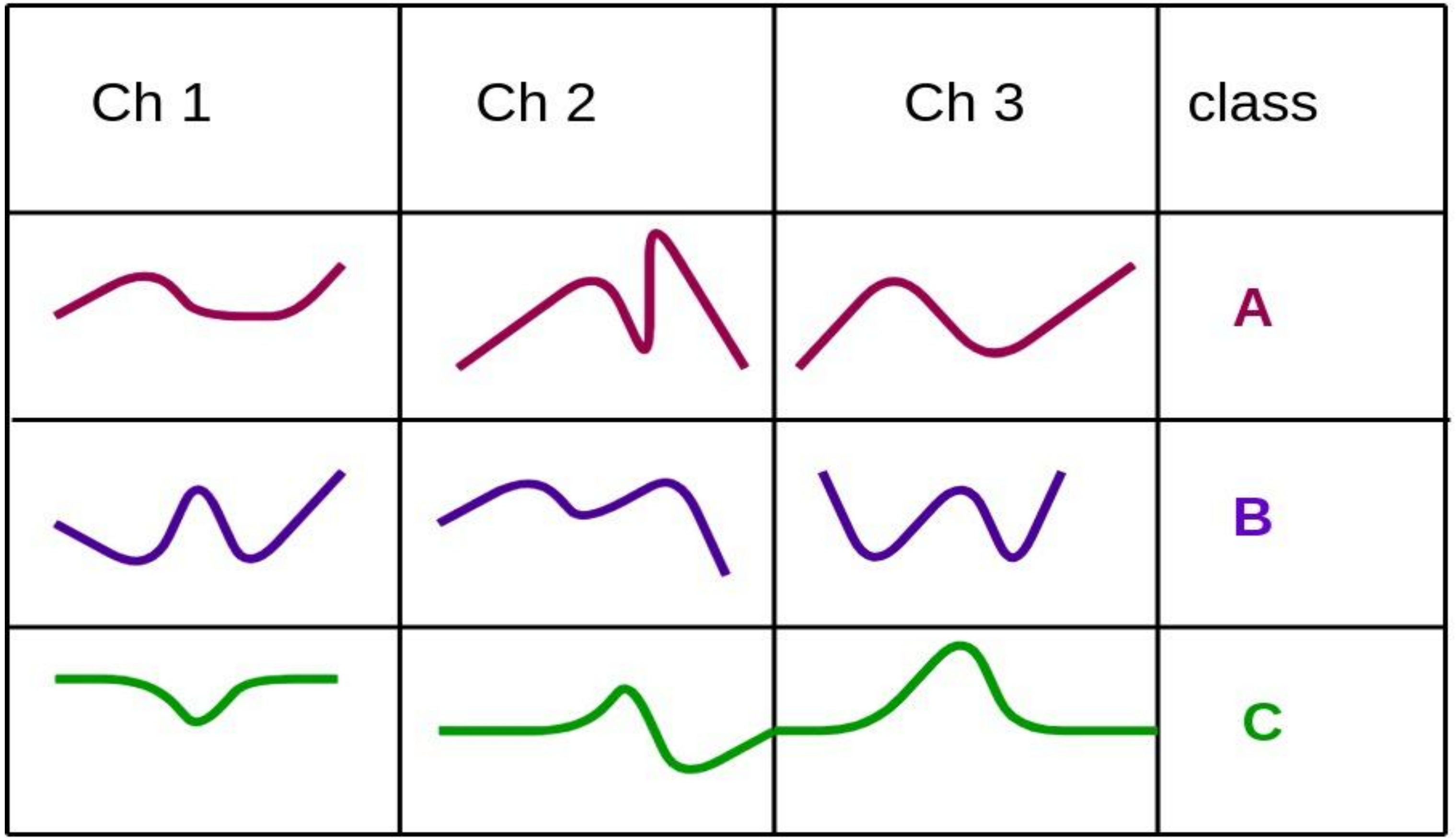


Channel Selection: Methodology

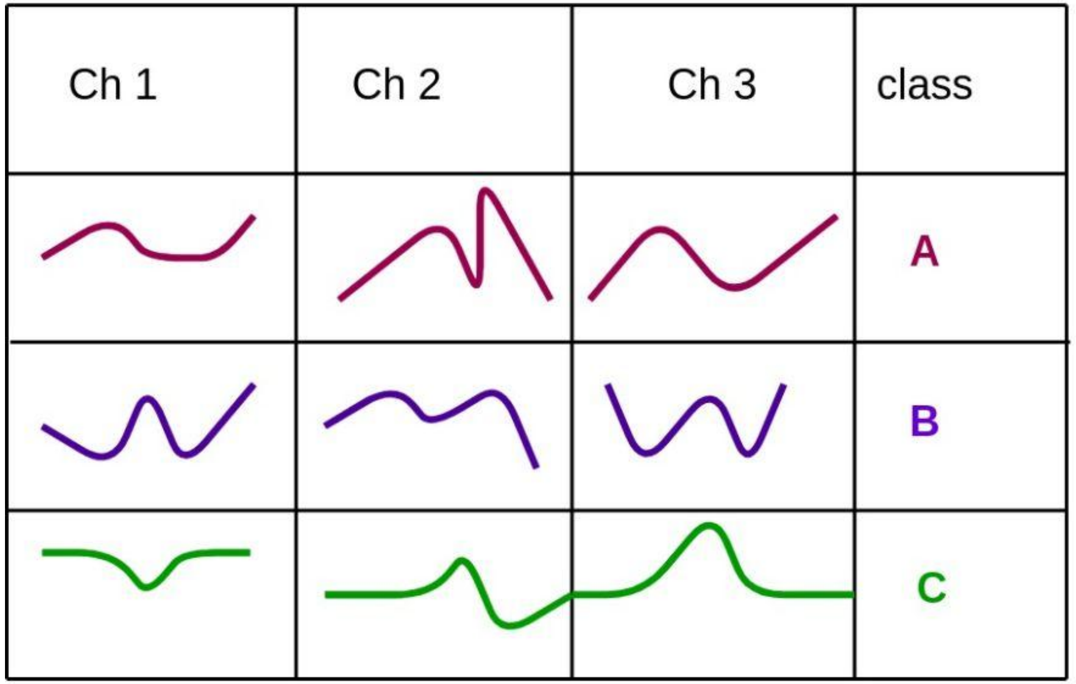
Centroid Frame



Channel Selection: Methodology

STEP 2: Calculate distance matrix

Centroid Frame



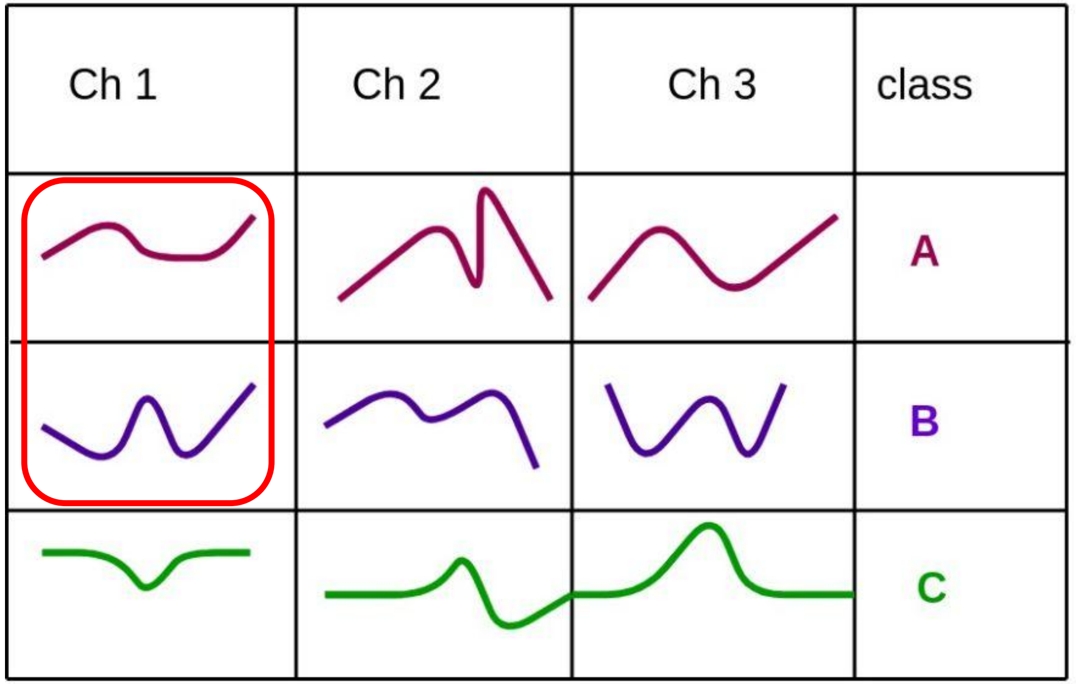
Distance matrix

	class(AB)	class(BC)	class(AC)
Ch 1	23	43	57
Ch 2	36	63	85
Ch 3	43	86	52

Channel Selection: Methodology

STEP 2: Calculate distance matrix

Centroid Frame



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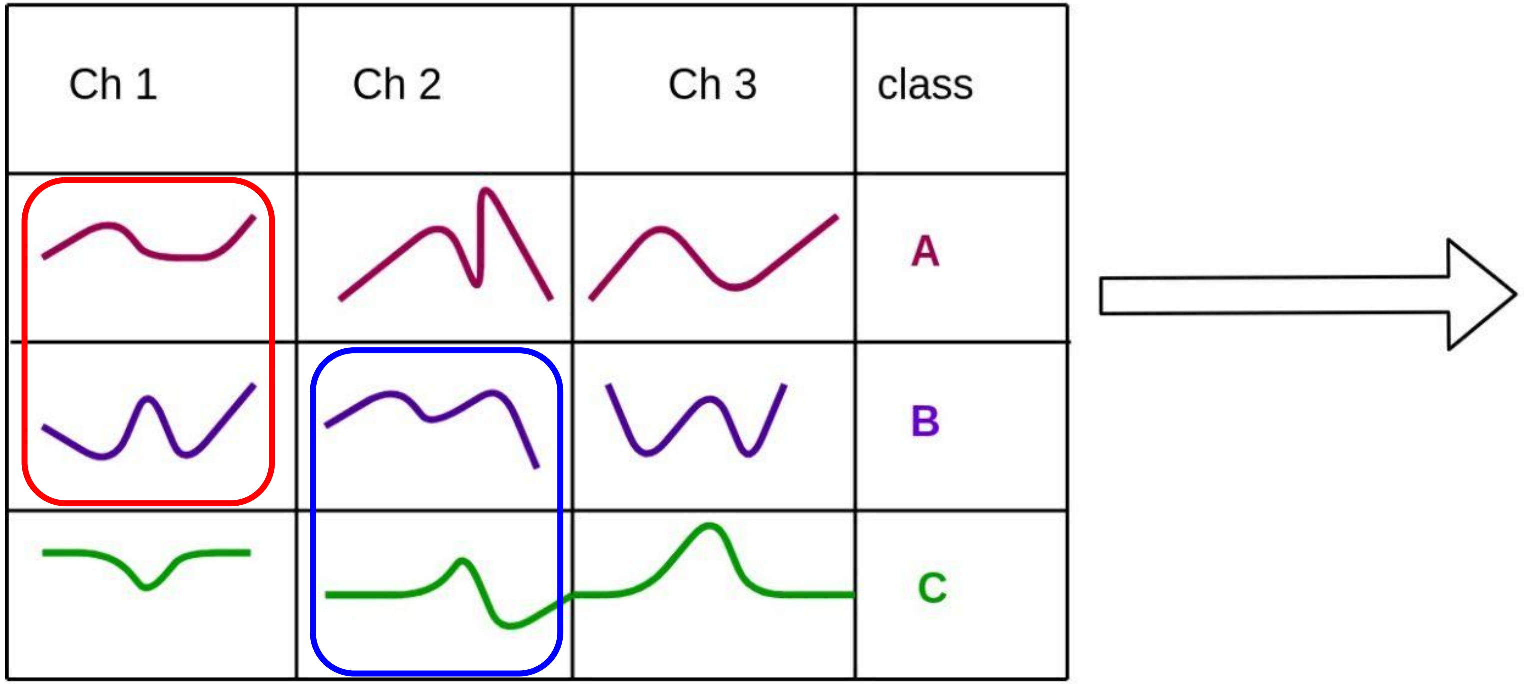

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Channel Selection: Methodology

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Channel Selection: Methodology

STEP 3: Select useful channels

Distance matrix

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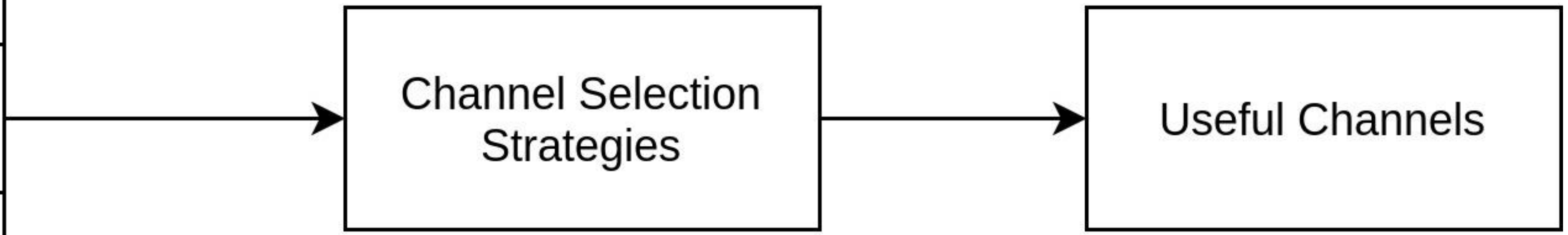
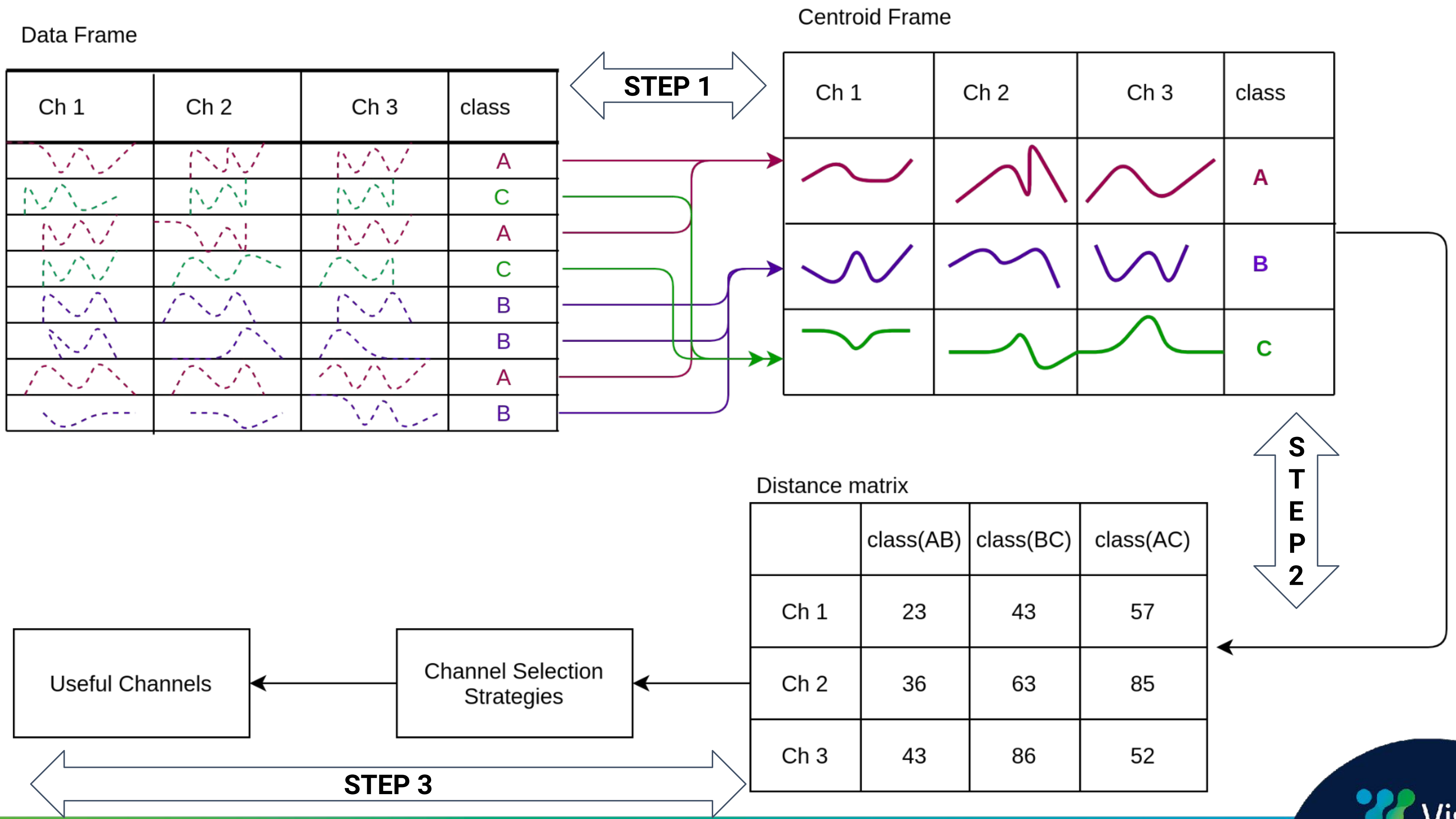
Ch 3	43	86	52



Channel Selection: Methodology



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Channel Selection: Methodology

Distance Matrix

- Distance Matrix stores distance for every pair of centroids for each channel.
- The mentioned distance matrix is for a Military Press dataset collected at Insight Centre for Data Analytics at UCD with following features.
  - Channels: 25
  - Classes: 4
  - Centroid pairs: 6
- Each channel represents a body part.

CHANNELS	Centroid_a_arch	Centroid_a_n	Centroid_a_r	Centroid_arch_n	Centroid_arch_r	Centroid_n_r
Nose	15.93	11.13	14.89	14.20	14.61	16.94
Neck	43.67	31.00	13.27	32.05	43.11	39.04
RShoulder	44.57	32.36	15.52	31.13	44.47	41.72
RElbow	34.62	48.95	157.14	33.04	153.80	166.99
RWrist	45.09	50.54	157.34	55.39	161.09	172.09
LShoulder	43.90	30.24	14.02	32.93	43.52	39.26
LElbow	29.78	51.38	149.37	37.56	147.62	165.01
LWrist	38.55	42.95	148.48	47.40	155.56	157.55
MidHip	25.91	6.32	2.97	24.26	23.82	7.15

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Channel Selection: Strategies

- KMeans
- Elbow cut sum (ECS)
- Elbow class pair (ECP)

Channel Selection: Strategies

KMeans

CHANNELS	Centroid_a_arch	Centroid_a_n	Centroid_a_r	Centroid_arch_n	Centroid_arch_r	Centroid_n_r
Nose	15.93	11.13	14.89	14.20	14.61	16.94
Neck	43.67	31.00	13.27	32.05	43.11	39.04
RShoulder	44.57	32.36	15.52	31.13	44.47	41.72
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KMeans

- Create two clusters using KMeans.
- The value for K=2.
- Clusters with mean distance higher than the other consist of useful channels.

Clusters here are representational.

Channel Selection: Strategies

ECS: Elbow Class Sum

CHANNELS	Centroid_a_arch	Centroid_a_n	Centroid_a_r	Centroid_arch_n	Centroid_arch_r	Centroid_n_r
Nose	15.93	11.13	14.89	14.20	14.61	16.94
Neck	43.67	31.00	13.27	32.05	43.11	39.04
RShoulder	44.57	32.36	15.52	31.13	44.47	41.72
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LElbow	29.78	51.38	149.37	37.56	147.62	165.01
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Channel Selection: Strategies

ECS: Elbow Class Sum

CHANNELS	Centroid_a_arch	Centroid_a_n	Centroid_a_r	Centroid_arch_n	Centroid_arch_r	Centroid_n_r
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CHANNELS	Centroid_a_arch	Centroid_a_n	Centroid_a_r	Centroid_arch_n	Centroid_arch_r	Centroid_n_r	SUM
Nose	15.93	11.13	14.89	14.20	14.61	16.94	87.70
Neck	43.67	31.00	13.27	32.05	43.11	39.04	202.14
RShoulder	44.57	32.36	15.52	31.13	44.47	41.72	209.77
RElbow	34.62	48.95	157.14	33.04	153.80	166.99	594.54
RWrist	45.09	50.54	157.34	55.39	161.09	172.09	641.53
LShoulder	43.90	30.24	14.02	32.93	43.52	39.26	203.86
LElbow	29.78	51.38	149.37	37.56	147.62	165.01	580.71
LWrist	38.55	42.95	148.48	47.40	155.56	157.55	590.50
MidHip	25.91	6.32	2.97	24.26	23.82	7.15	90.43

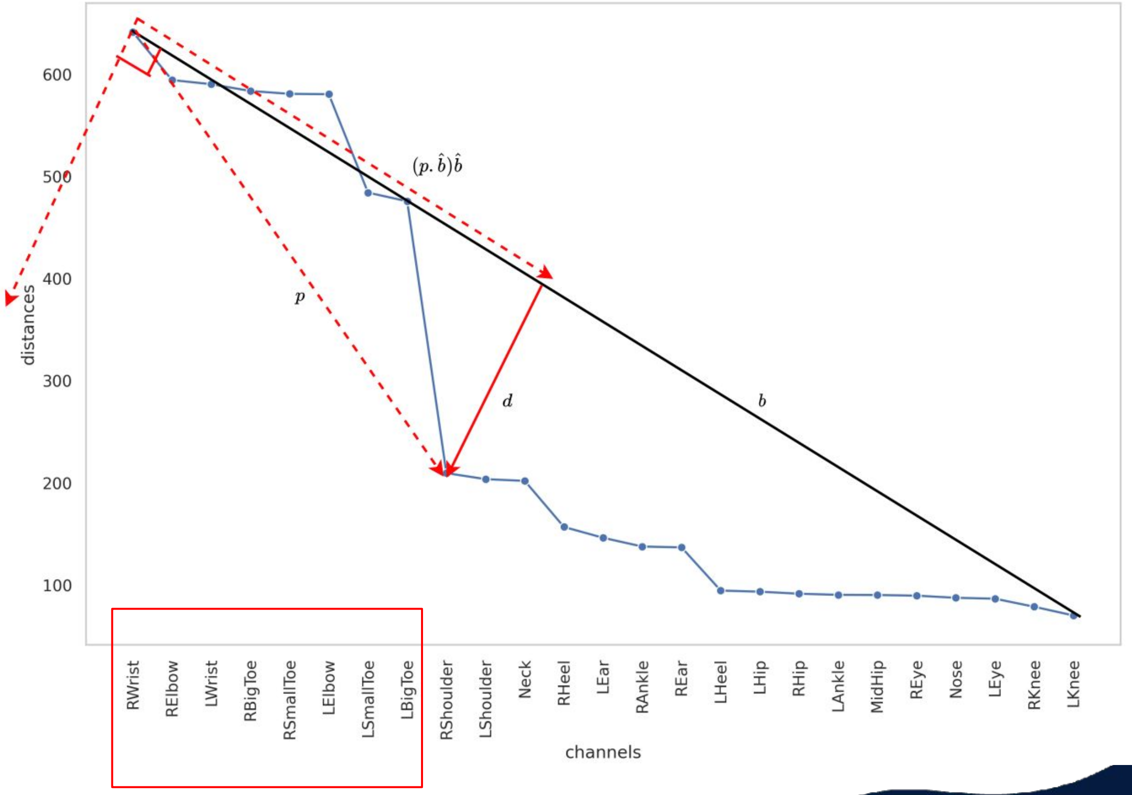
Channel Selection: Strategies

ECS: Elbow Class Sum

CHANNELS	Centroid_a_arch	Centroid_a_n	Centroid_a_r	Centroid_arch_n	Centroid_arch_r	Centroid_n_r	SUM
Nose	15.93	11.13	14.89	14.20	14.61	16.94	87.70
Neck	43.67	31.00	13.27	32.05	43.11	39.04	202.14
RShoulder	44.57	32.36	15.52	31.13	44.47	41.72	209.77
RElbow	34.62	48.95	157.14	33.04	153.80	166.99	594.54
RWrist	45.09	50.54	157.34	55.39	161.09	172.09	641.53
LShoulder	43.90	30.24	14.02	32.93	43.52	39.26	203.86
LElbow	29.78	51.38	149.37	37.56	147.62	165.01	580.71
LWrist	38.55	42.95	148.48	47.40	155.56	157.55	590.50
MidHip	25.91	6.32	2.97	24.26	23.82	7.15	90.43

Elbow Cut Sum (ECS)

Elbow cut Heuristic



Useful Channels

Channel Selection: Strategies

ECP: Elbow Class Pairwise

Elbow Class Pairwise (ECP)

CHANNELS	Centroid_a_arch	Centroid_a_n	Centroid_a_r	Centroid_arch_n	Centroid_arch_r	Centroid_n_r
Nose	15.93	11.13	14.89	14.20	14.61	16.94
Neck	43.67	31.00	13.27	32.05	43.11	39.04
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Elbow Cut 1 -- Useful Channels set 1

Channel Selection: Strategies

ECP: Elbow Class Pairwise

CHANNELS	Centroid_a_arch	Centroid_a_n	Centroid_a_r	Centroid_arch_n	Centroid_arch_r	Centroid_n_r
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Elbow Class Pairwise (ECP)

Elbow Cut 1 -- Useful Channels set 1

Elbow Cut 2 -- Useful Channel Set 2

Channel Selection: Strategies

ECP: Elbow Class Pairwise

Elbow Class Pairwise (ECP)

CHANNELS	Centroid_a_arch	Centroid_a_n	Centroid_a_r	Centroid_arch_n	Centroid_arch_r	Centroid_n_r
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Elbow Cut 1 -- Useful Channels set 1
Elbow Cut 2 -- Useful Channel Set 2
Elbow Cut 3 -- Useful Channels Set 3

Channel Selection: Strategies

ECP: Elbow Class Pairwise

Elbow Class Pairwise (ECP)

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Elbow Cut 1 -- Useful Channels set 1
Elbow Cut 2 -- Useful Channel Set 2
Elbow Cut 3 -- Useful Channels Set 3
Elbow Cut 4 -- Useful Channel Set 4

Channel Selection: Strategies

ECP: Elbow Class Pairwise

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Elbow Cut 5 -- Useful Channel Set 5

Channel Selection: Strategies

ECP: Elbow Class Pairwise

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Elbow Class Pairwise (ECP)

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Elbow Cut 4 -- Useful Channel Set 4
Elbow Cut 5 -- Useful Channel Set 5
Elbow Cut 6 -- Useful Channel Set 6

Channel Selection: Strategies

ECP: Elbow Class Pairwise

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Elbow Class Pairwise (ECP)

Union

Elbow Cut 1 -- Useful Channels set 1
Elbow Cut 2 -- Useful Channel Set 2
Elbow Cut 3 -- Useful Channels Set 3
Elbow Cut 4 -- Useful Channel Set 4
Elbow Cut 5 -- Useful Channel Set 5
Elbow Cut 6 -- Useful Channel Set 6

⇒ Recommended Channels

Channel Selection: Experiments & Results

Dataset

- UEA/UCR MTSC data archive
- In this work we work with 26 equal length datasets.
- Number of channel ranges from 2 to 1345.
- Number of sample varies from 12 to 30000.
- Length of time series varies from 8 to 17894.

Implementation

- **sktime**

Channel Selection: Experiments & Results

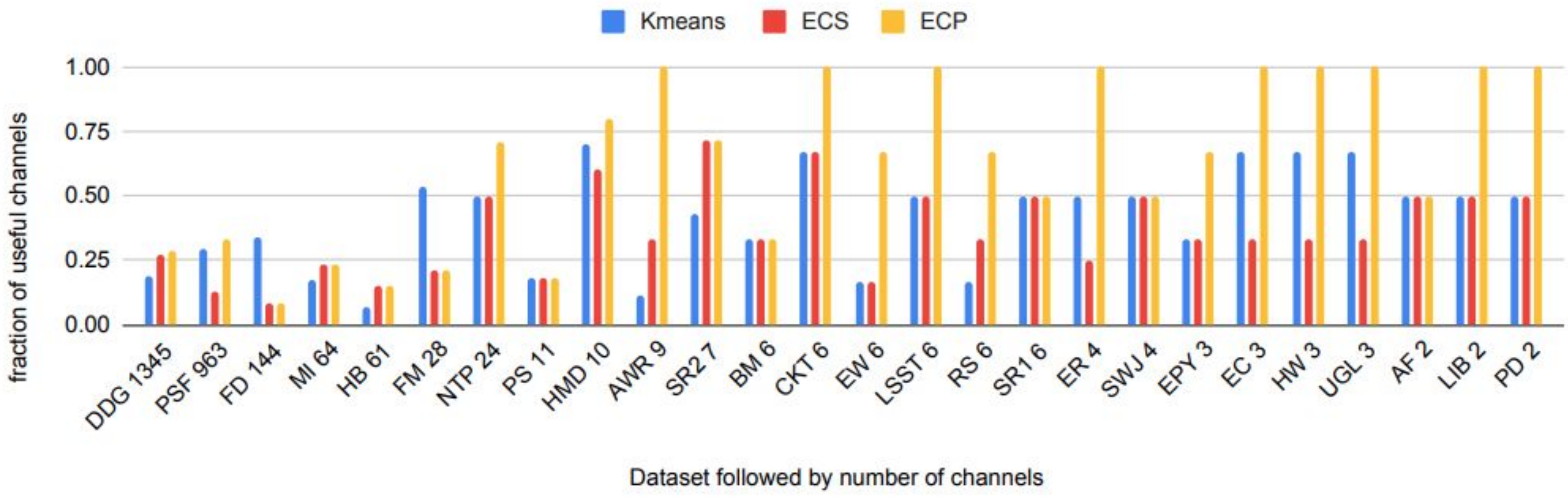
Evaluation

- Run the SOTA algorithms with all channels.
- ROCKET and WEASEL-MUSE have almost similar mean accuracy, but ROCKET is much faster.
- ROCKET uses a multi-threaded implementation, while all the other algorithms are single-thread implementations, hence the significant difference in runtime.
- The baseline 1NN-DTW is the least accurate and the slowest method among the four.
- WEASEL-MUSE and MrSEQL are impacted by the runtime taken by the symbolic transform.

Classifier	Accuracy	Time(in hrs)
ROCKET	71.59	0.1
WEASEL-MUSE	70.28	73.22
MrSEQL-SAX	66.99	141.40
1NN-DTW	65.38	152.07

Channel Selection: Experiments & Results

Results



Fraction of channels selected by each of three channel selection strategies.

Channel Selection: Experiments & Results

Results

Channel Selection Strategy	KMeans	ECS	ECP
Total Time (minutes)	0.34	0.33	0.35

Total time taken by three channel selection strategies on 26 UEA datasets.

Channel Selection: Experiments & Results

Results

Channel Selection Strategy	KMeans	ECS	ECP
Total Time (minutes)	0.34	0.33	0.35

Channel Selection→ Classifiers↓	KMeans ΔAcc | %Time	ECS ΔAcc|%Time	ECP ΔAcc | %Time
ROCKET	-4.01 | 33.62	-4.40 | 29.23	+0.13 | 21.43
WEASEL-MUSE	-4.63 | 70.46	-3.80 | 79.90	-1.53 | 73.21
MrSEQL-SAX	-3.33 | 72.68	-3.80 | 84.00	+0.45 | 77.06
1NN-DTW	-4.28 | 68.30	-6.08 | 68.82	+0.67 | 44.80
Mean ΔAcc| Mean %Time	-4.06 | 61.26	-4.52| 65.48	-0.07 | 54.12
Mean Storage Saved	73.95%	82.59%	74.38%

Loss/Gain in mean accuracy (ΔAcc) vs percentage time saved (%Time) with respect to All channels for our three channel selection techniques on 26 UCR datasets.

Channel Selection: Experiments & Results

Results

Channel Selection Strategy	KMeans	ECS	ECP
Total Time (minutes)	0.34	0.33	0.35

Channel Selection→	KMeans	ECS	ECP
Classifiers↓	ΔAcc | %Time	ΔAcc|%Time	ΔAcc | %Time
ROCKET	-4.01 | 33.62	-4.40 | 29.23	+0.13 | 21.43
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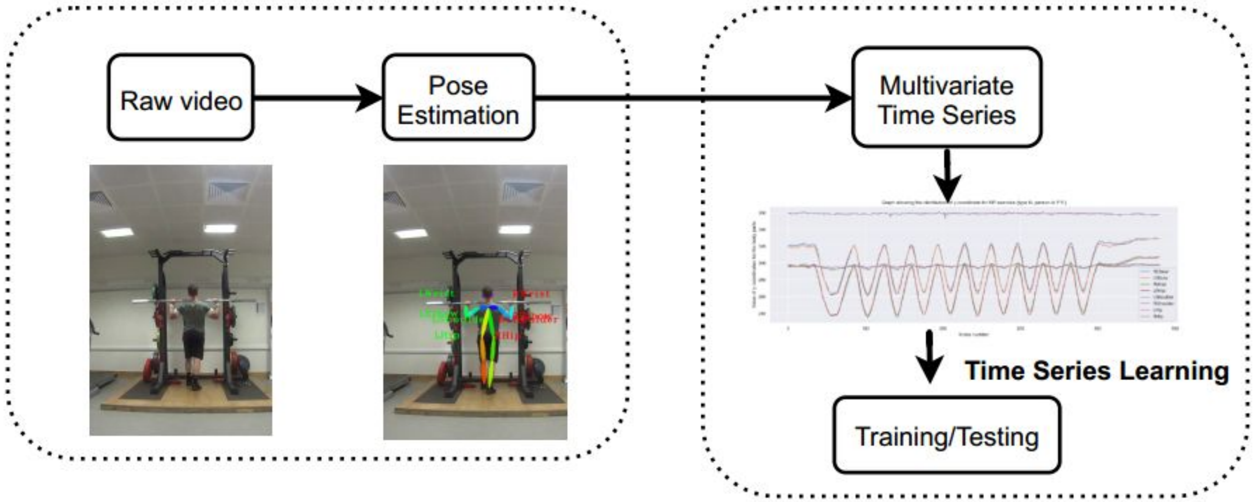
1NN-DTW	-4.28 | 68.30	-6.08 | 68.82	+0.67 | 44.80
Mean ΔAcc| Mean %Time	-4.06 | 61.26	-4.52| 65.48	-0.07 | 54.12
Mean Storage Saved	73.95%	82.59%	74.38%

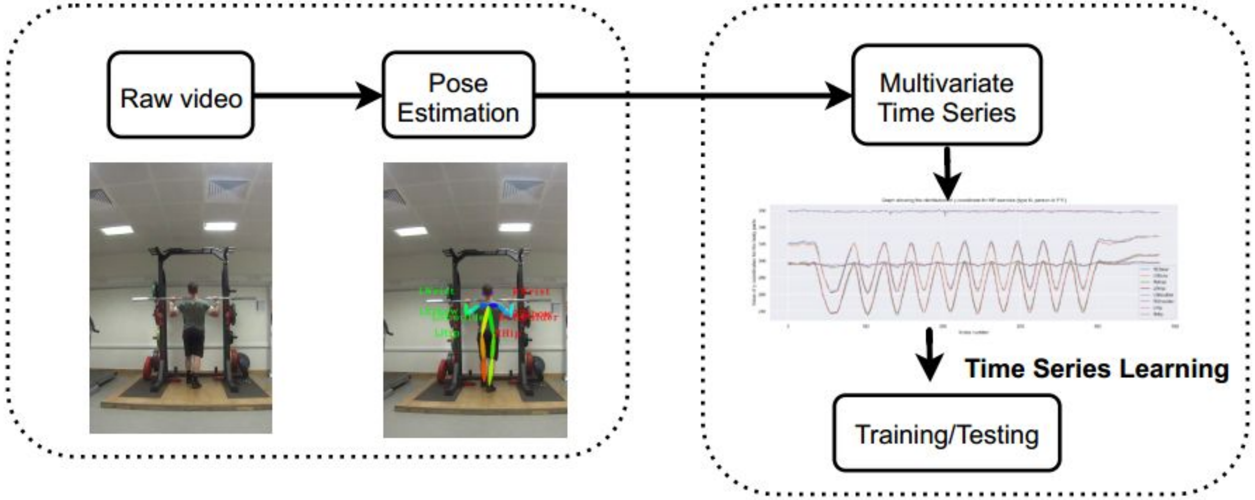
Loss/Gain in mean accuracy (ΔAcc) vs percentage time saved (%Time) with respect to All channels (Table 3) for our three channel selection techniques on 26 UCR datasets.

Channel Selection: Case Study



Channel Selection	Body Parts
KMeans	Elbows, Wrists, BigToes, SmallToes
ECS	Wrists, Elbows, BigToes, SmallToes
ECP	Elbows, Wrists, BigToes, SmallToes

Channel Selection: Case Study



Channel Selection	Body Parts
KMeans	Elbows, Wrists, BigToes, SmallToes
ECS	Wrists, Elbows, BigToes, SmallToes
ECP	Elbows, Wrists, BigToes, SmallToes

Classifiers	Accuracy ECP | All	Time (minutes) ECP| All
ROCKET	76.26 | 77.53	2.14 | 2.25
WEASEL-MUSE	57.57 | 57.57	30.29 | 107.02
MrSEQL-SAX	58.23 | 61.56	139.53 | 516.79
1NN-DTW	48.58 | 47.25	10.39 | 24.36
Data Size (MB) Reduced|Original	15.77 | 49.29	

Conclusion

- Not all the channels for MTSC are helpful.
- Uninformative channels can prevent the classifier from achieving its maximum potential
- Channel selection can remove some of the noise and drastically reduce the required computation time for existing MTSC methods
- Distance between the class centroids of various channels plays a crucial role in identifying the noisy channels.
- Three techniques significantly reduced the runtime and memory required to run SOTA classifiers.

Thank you!
Questions?

Code in Github:
https://github.com/mlgig/Channel-Selection-MTSC

Further Information

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