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Master Thesis Final Presentation

Benchmarking of Models for Unsupervised Segmentation of Multivariate Time Series With a Novel Homogeneity Metric

Clausthal University of Technology
Institute for Software and Systems Engineering

2022-04-07

[1]*Automotive Electronic Systems. Clemson Vehicular Electronics Laboratory: Automotive Electronic Systems. (n.d.). Retrieved March 27, 2022, from https://cecas.clemson.edu/cvel/auto/systems/auto-systems.html*

(Automotive) Software Systems

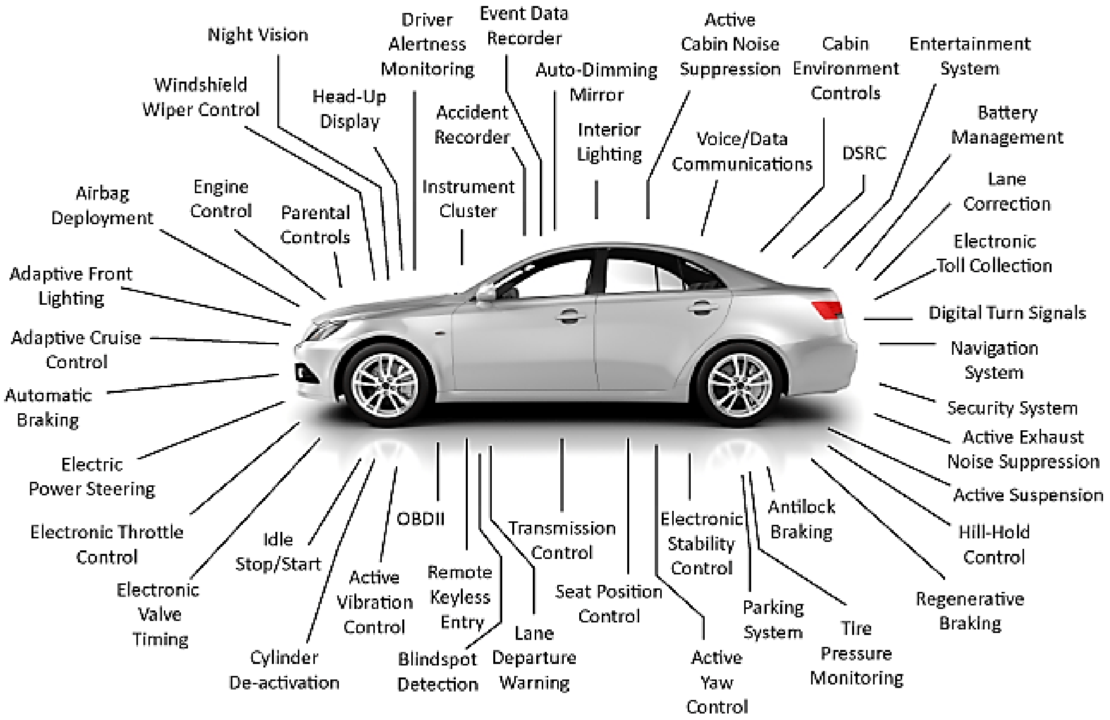
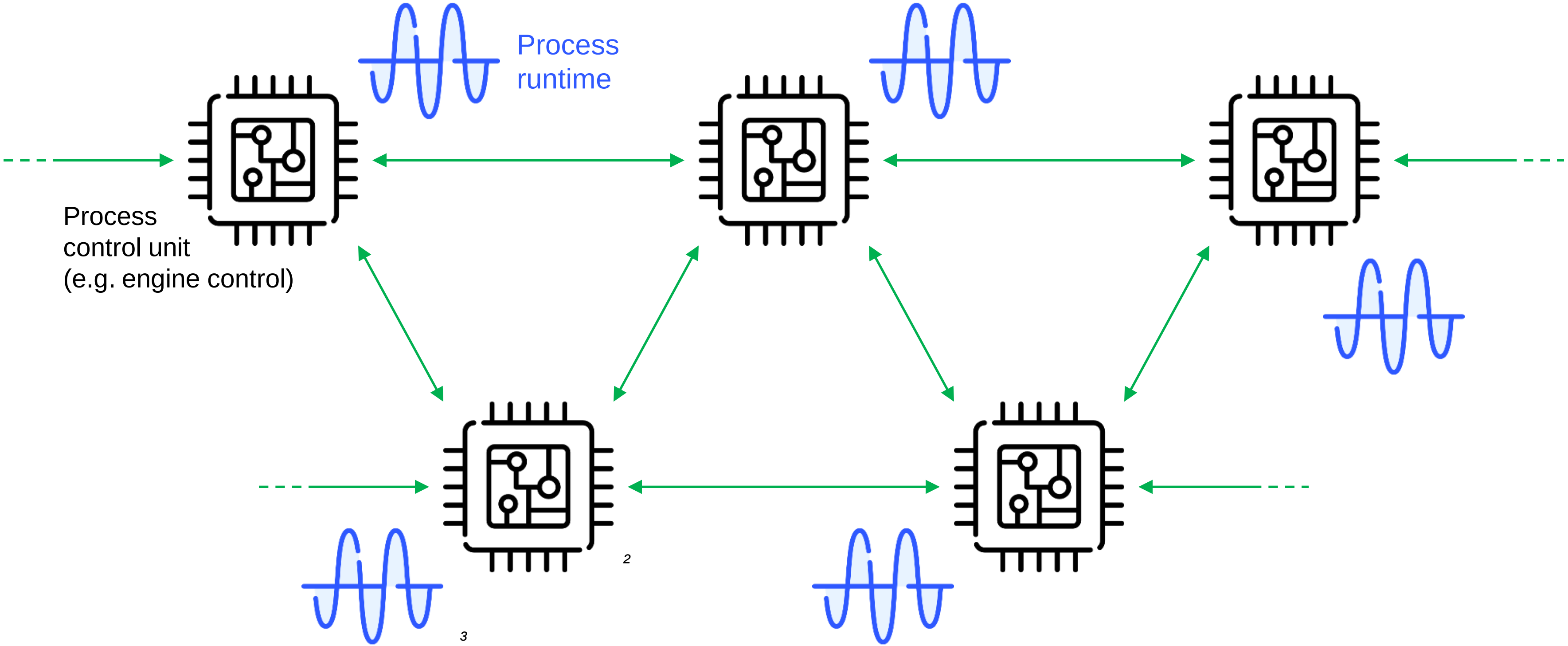


Figure 1 – Automotive control units[1]

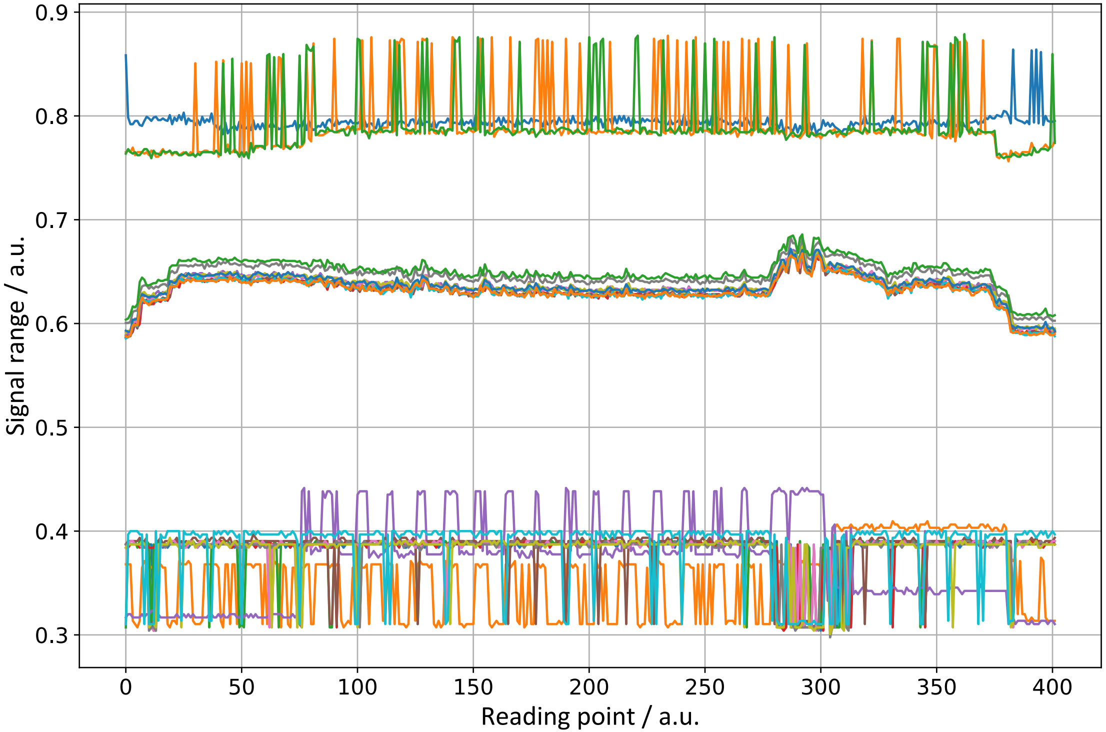
[2]Icon made by Vitaly Gorbachev from Flaticon

[3]Icon made by Freepik from Flaticon

Control Units in (Automotive) Software Systems



Recorded Process Runtimes from Automotive Software System



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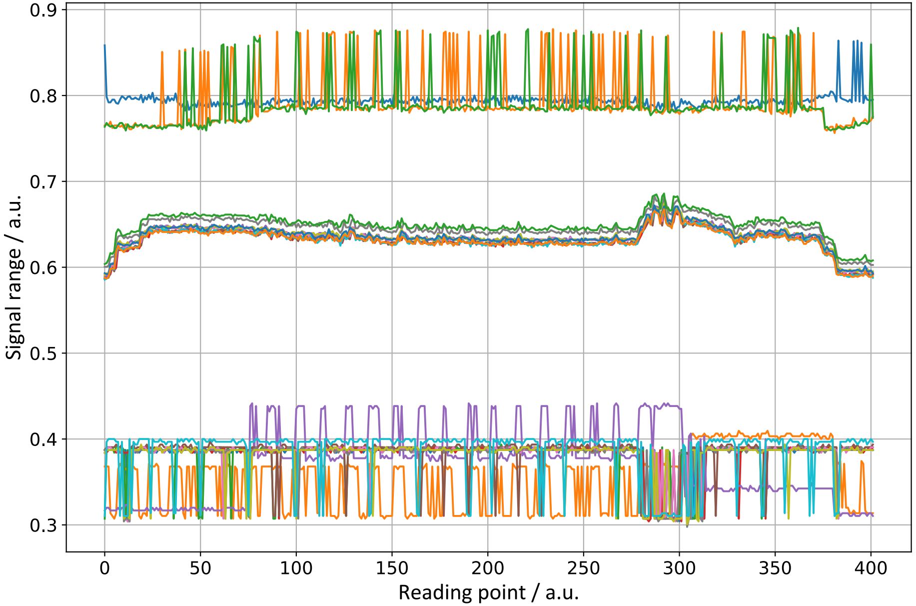
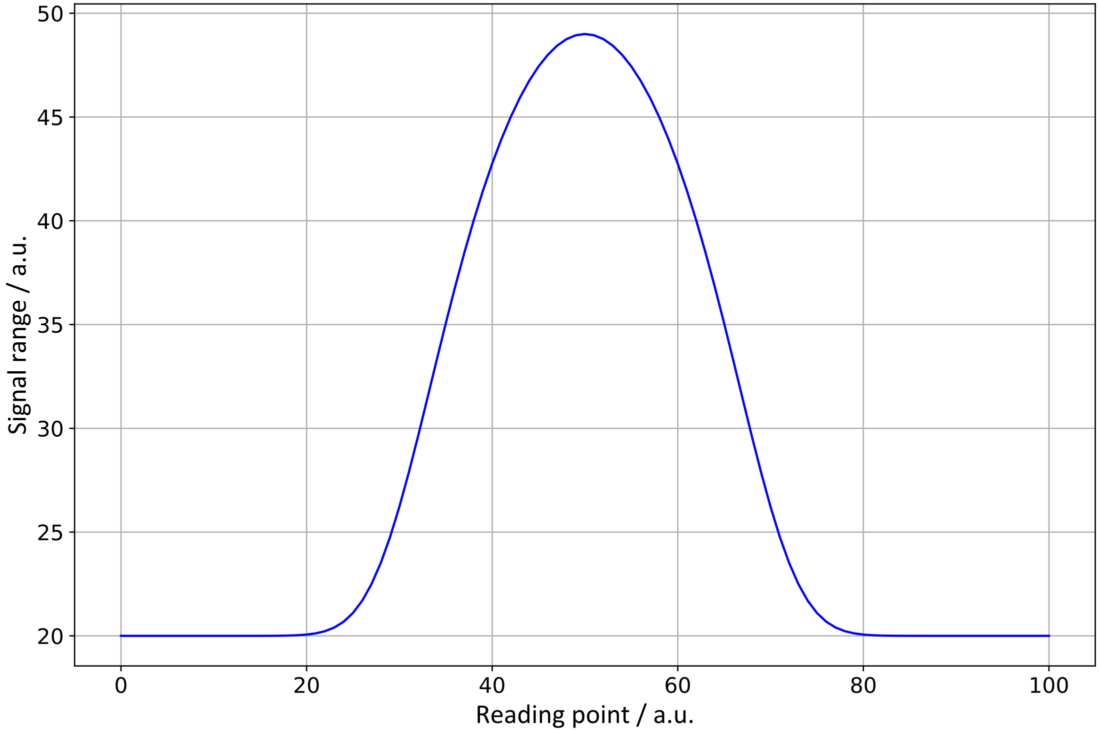


1. How can homogeneity in segments of a multivariate time series be defined and measured?
2. How can the ideal number of segments in a multivariate time series be determined without supervision?
3. How can precise segmentation indices for maximizing homogeneity in segments be determined?

Analysis of Signals



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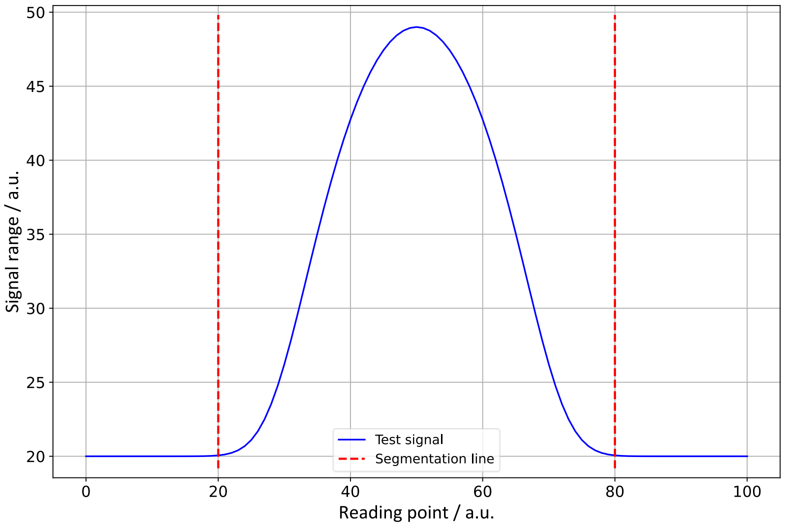

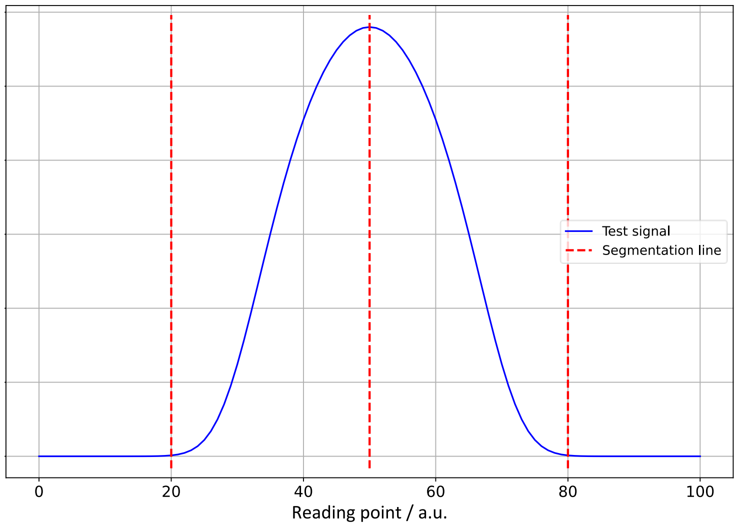

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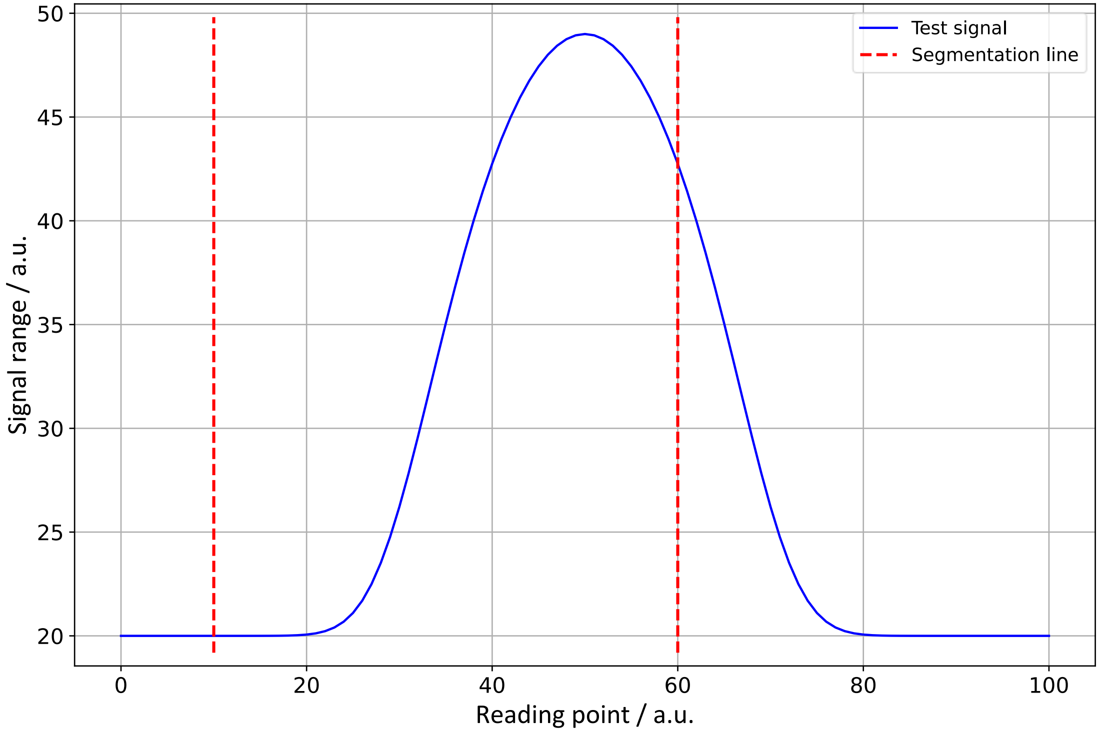

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Analysis of Multivariate Signal

$$\textit{Homogeneity} \coloneqq \frac{\left(\frac{\sum_{p=1}^{l}\sum_{s=1}^{S}\left(\max\left(s_p\right) - \min\left(s_p\right)\right) * n_s}{\sum_{p=1}^{l}\left(\max(p) - \min(p)\right) * n} + \frac{\sqrt{n} * S}{1.7n}\right)}{1 + \frac{\sqrt{n}}{1.7}}$$

s – segment
p – process
n – total number of data points (i.e. columns) per process
l – total number of processes (i.e. signals) in multivariate data set
S – total number of segments in data set
s_p – segment *s* in process *p*
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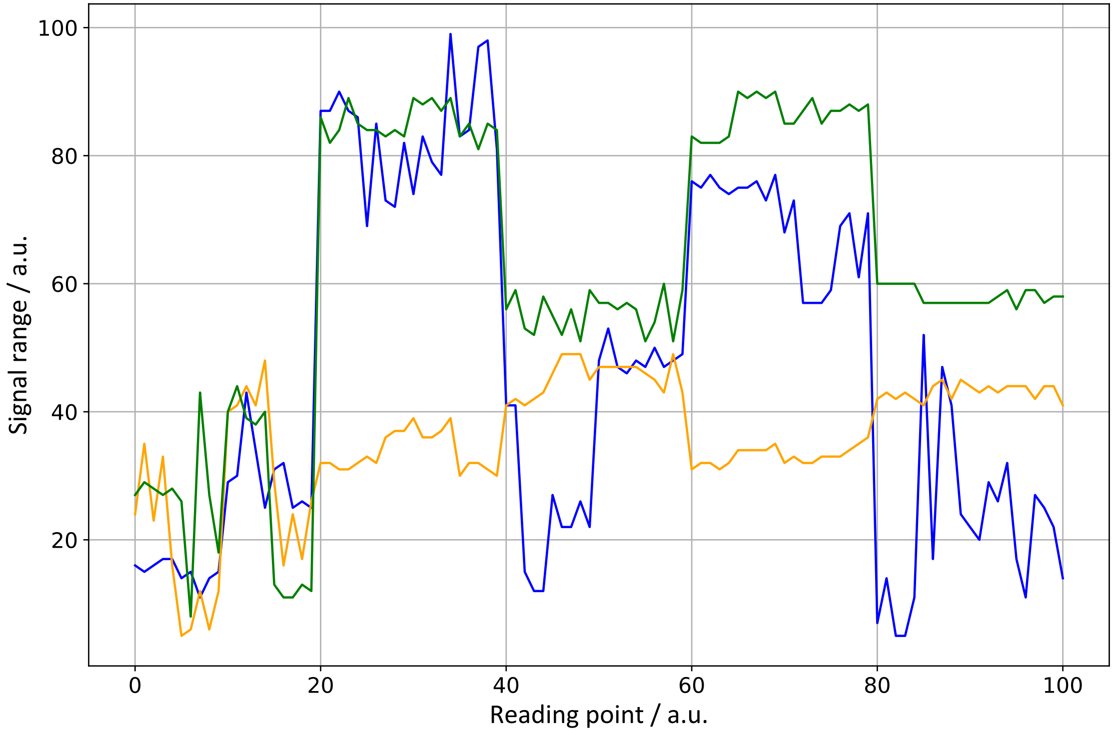

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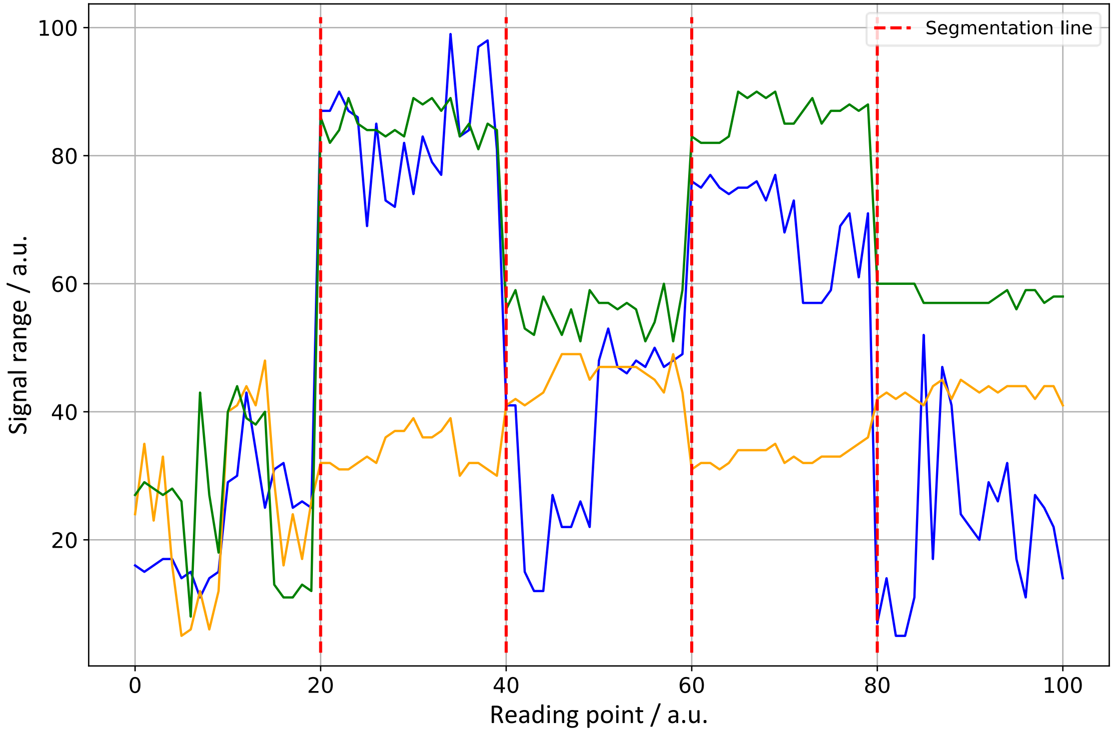
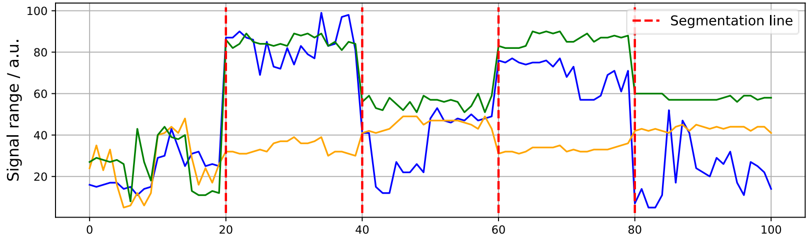
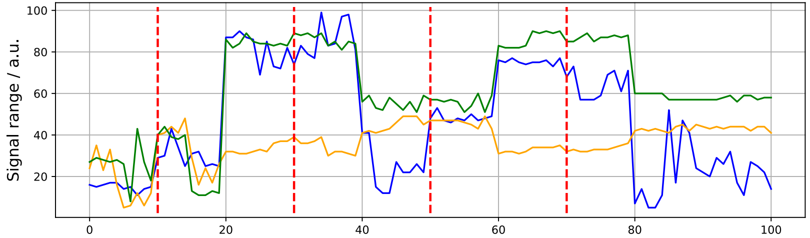


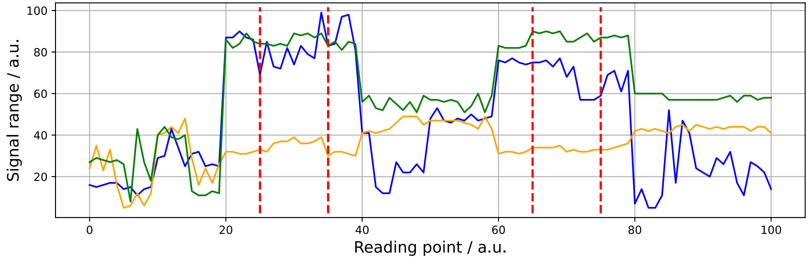
Analysis of Multivariate Signal



Homogeneity: 0.08



Homogeneity: 0.12

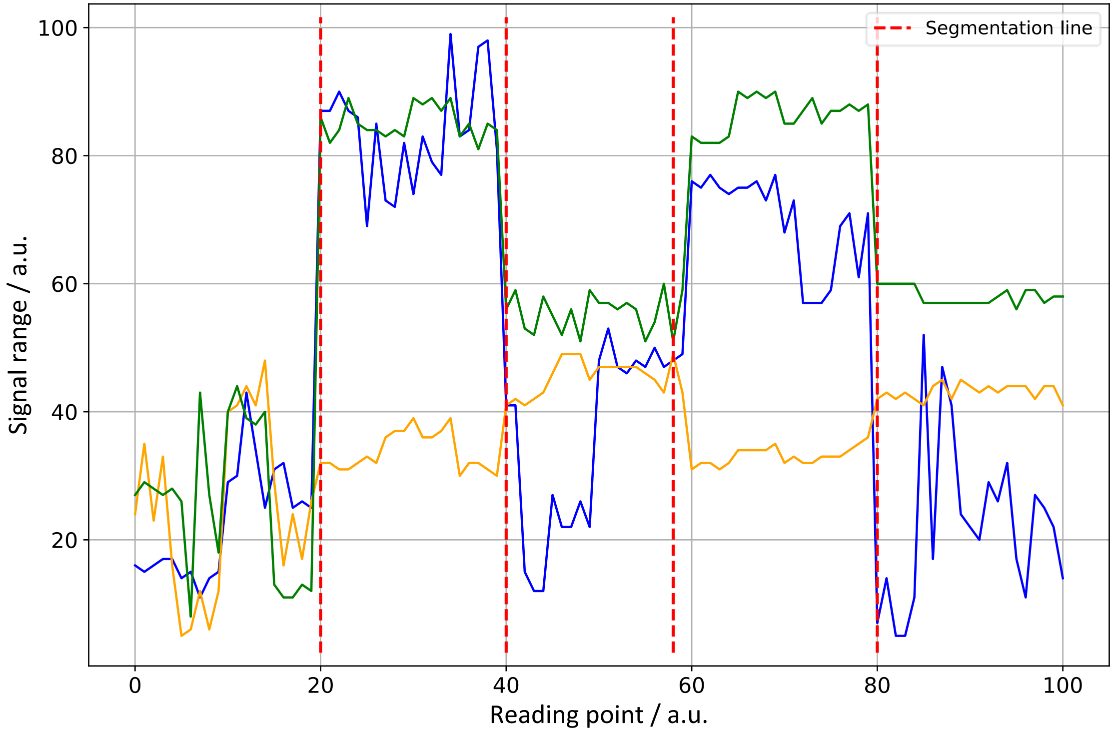


Homogeneity: 0.13

Time Series Segmentation Models

- The time series segmentation models used in this work are state-of-the-art statistical models for analyzing and clustering (i.e. segmenting) multivariate time series
- Two models are used to segment multivariate time series:
  - Principal component analysis based fuzzy clustering (PCAFC)
  - Multiple hidden Markov model for regression (MHMMR)
- Both models are first validated for their capability of segmenting multivariate time series before applying them to multivariate time series

Time Series Segmentation Models - PCAFC



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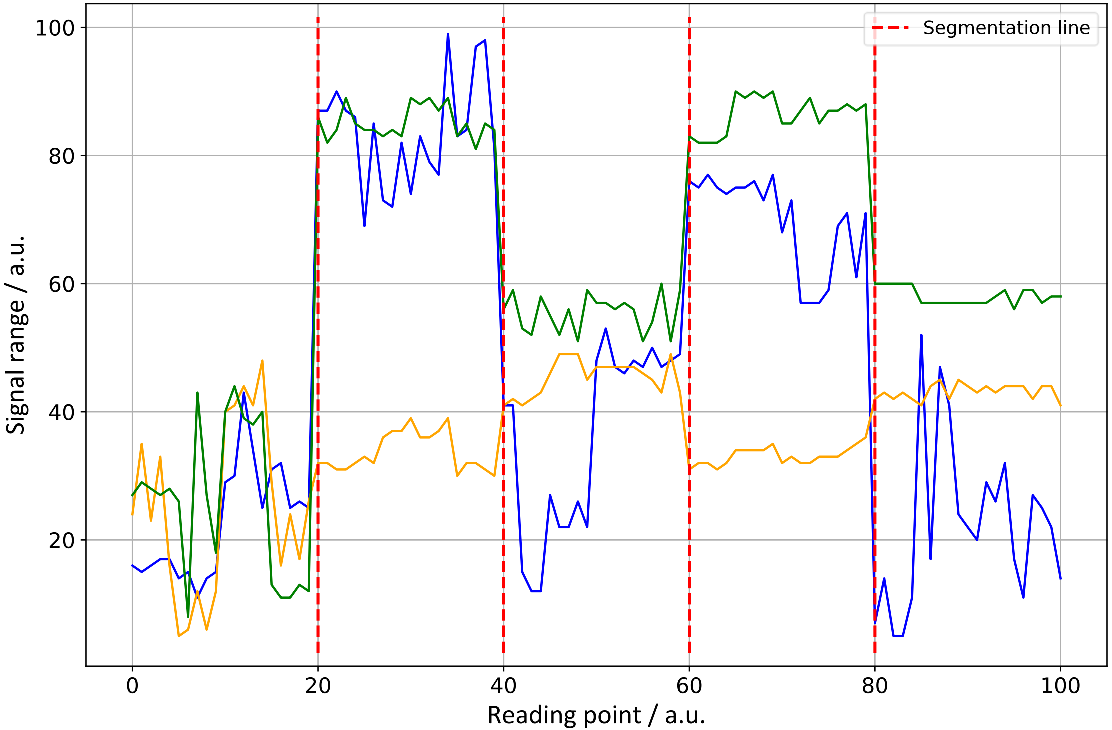
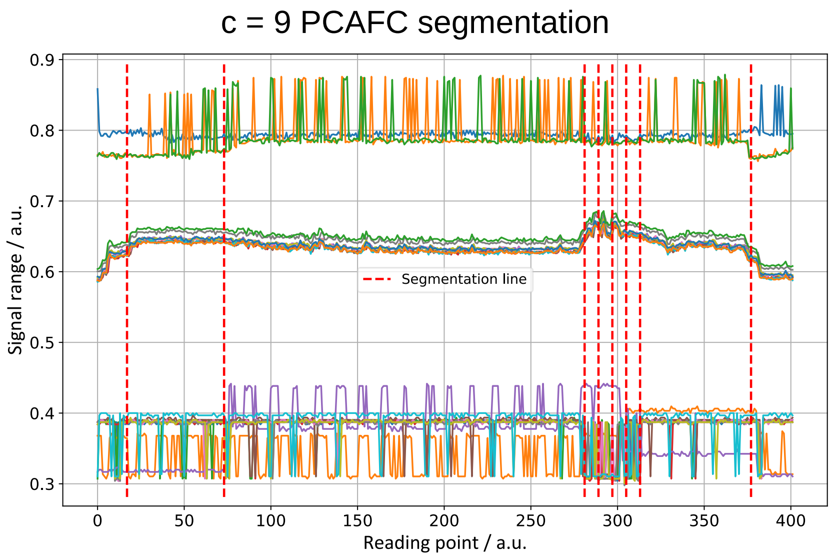
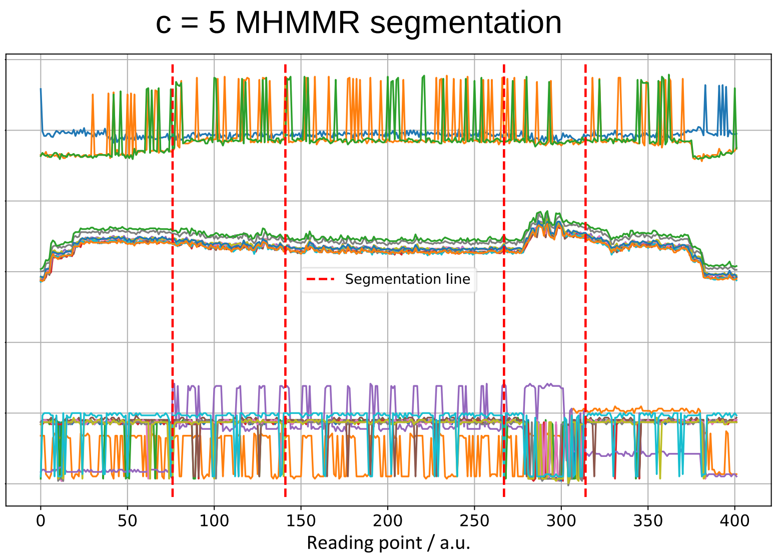
Time Series Segmentation Models - MHMMR



Exemplary PCAFC and MHMMR segmentations

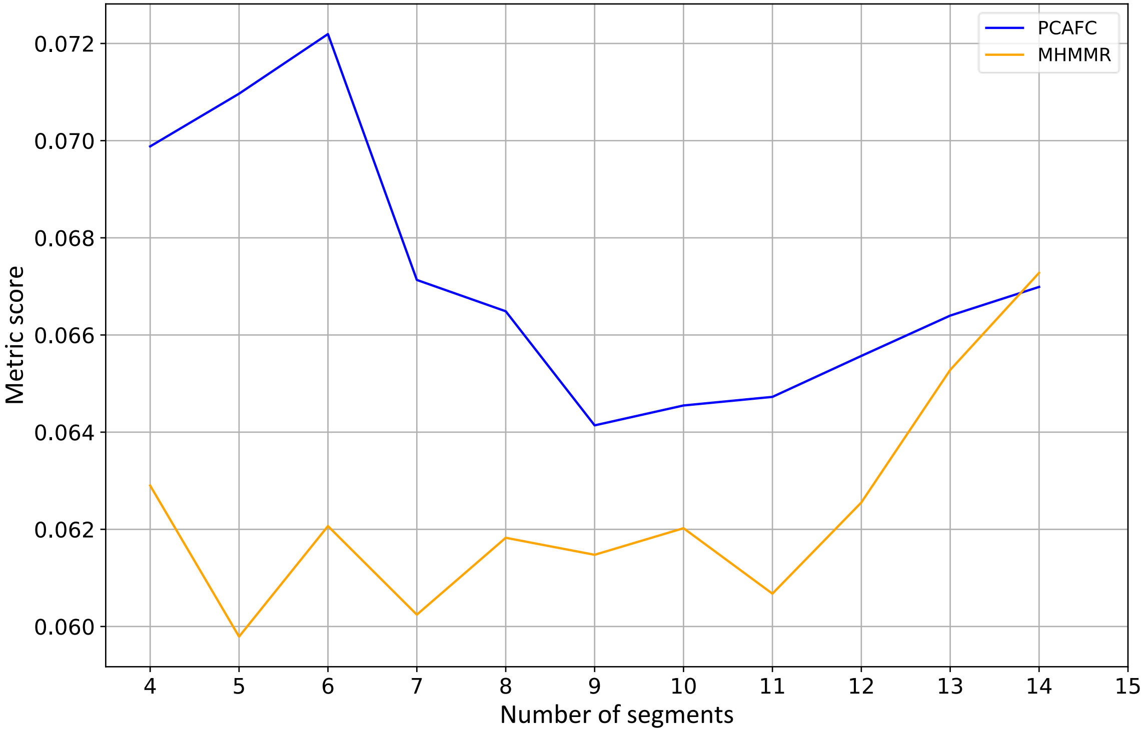




Time Series Segmentation Models - Evaluation

# of segments	Segmentation algorithm	
	PCAFC	MHMMR
Four	0.070	0.063
Five	0.071	**0.060**
Six	0.072	0.062
Seven	0.067	0.060
Eight	0.066	0.062
Nine	**0.064**	0.061
Ten	0.065	0.062
Eleven	0.065	0.061
Twelve	0.066	0.063
Thirteen	0.066	0.065
Fourteen	0.067	0.067

Time Series Segmentation Models - Evaluation



Conclusion and Future Outlook

- This work was motivated by the problem of state extraction from (i.e. segmentation of) multivariate time series.
- A novel metric for defining and measuring homogeneity for segmentations was defined and two segmentation models, namely PCAFC and MHMMR, were presented.
- The segmentation models were first applied to a multivariate test signal and then to a multivariate time series taken out of industry data.
- Findings: Both segmentation models show relevant results, which could be successfully measured with the novel homogeneity metric
- Future Outlook: The presented tools, models, and metric should be incorporated into future works in the field of multivariate time series analysis

Recommendable References

- “Segmentation of Multivariate Time-series”. In: *Cluster Analysis for Data Mining and System Identification*. Basel: Birkhäuser Basel, 2007, pp. 253–273. ISBN: 978-3-7643-7988-9. doi: https://doi.org/10.1007/978-3-7643-7988-9_6.
- Faicel Chamroukhi et al. “Model-based clustering with Hidden Markov Model regression for time series with regime changes”. In: *The 2011 International Joint Conference on Neural Networks (2011)*, pp. 2814–2821.

Thank you for your attention!