A survey of methods for time series change point detection

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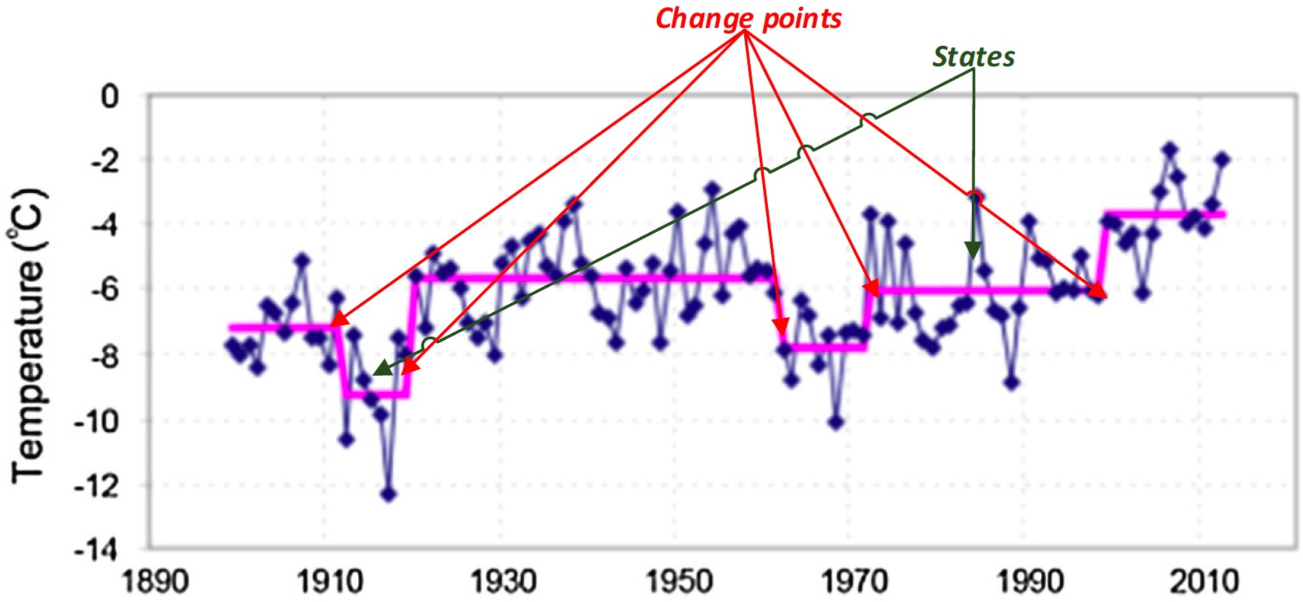


Sample time series and change points (*horizontal lines* indicate separate states)

Presenter: Abdullah Mamun

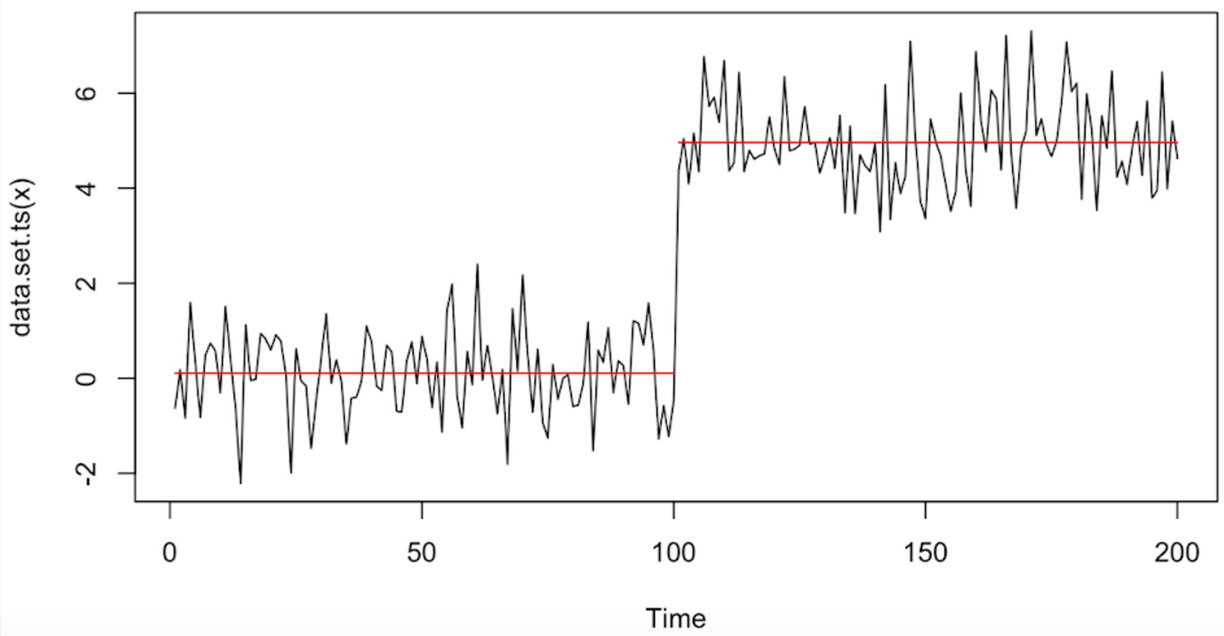
Date: November 8, 2023

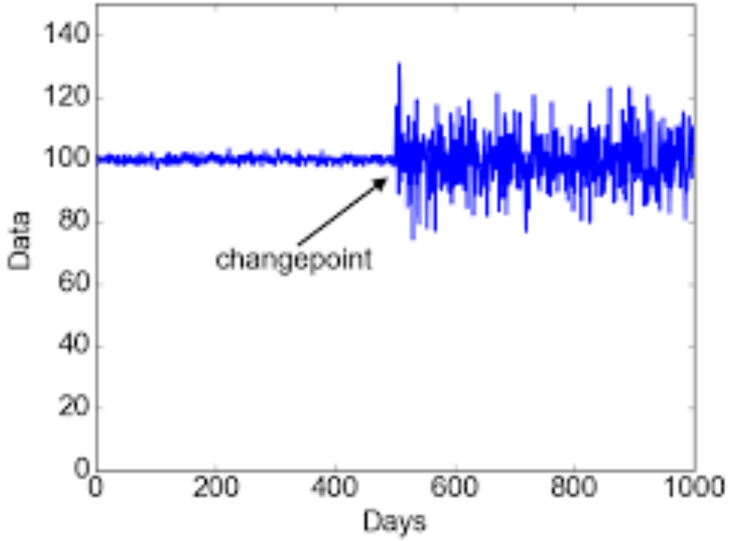
Motivation

- Medical condition monitoring
- Human activity analysis
- Climate change detection

Changepoint detection variations

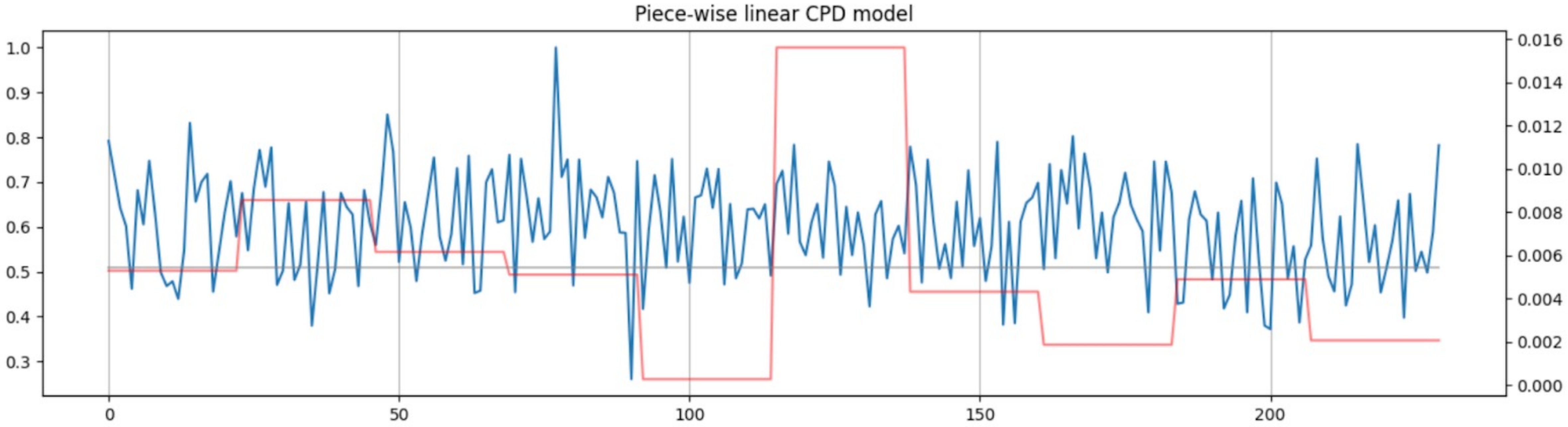
- Mean-changepoint
- Variance-changepoint
- Mean-variance changepoint



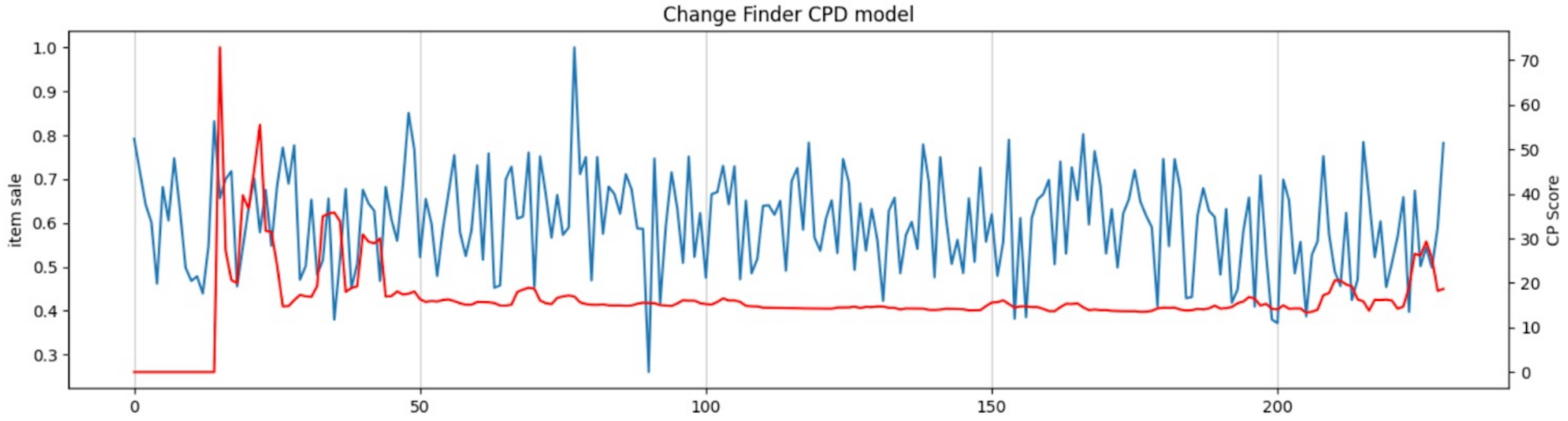


Piece-wise linear CPD

```
ts_df['coeff_1'] = piece_wise_lr_cpd(ts_df, 'sed_ratio', peice_diff=23)
```



ChangeFinder



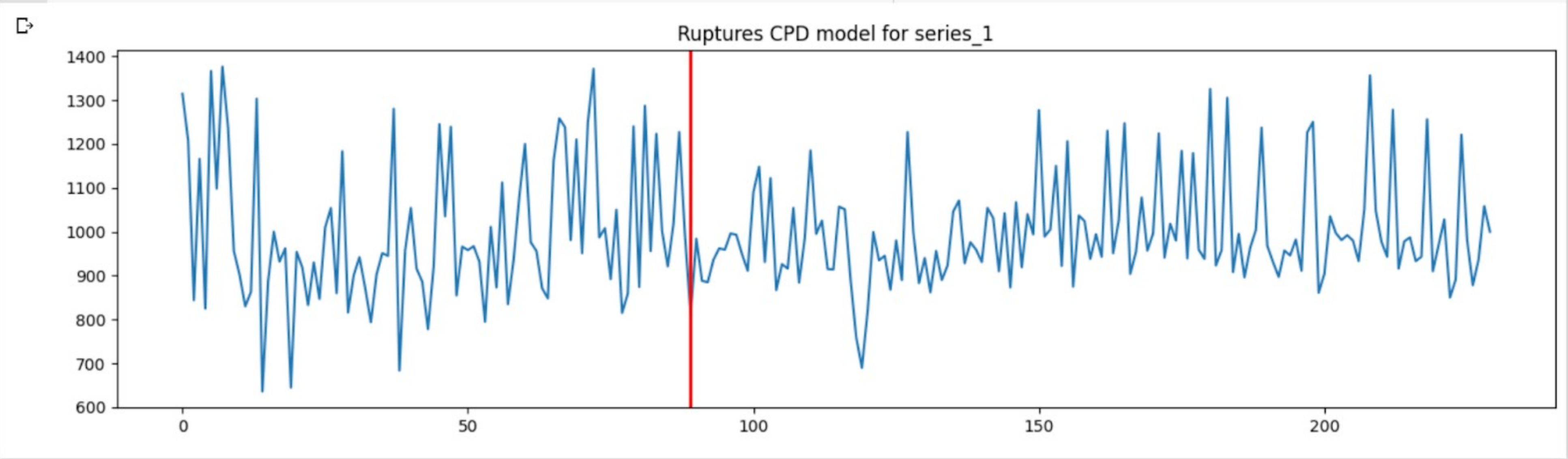
ChangeFinder

Change Finder [34,42,63] is another commonly used method which reduces the problem of change point detection into time series-based outlier detection. This method fits an auto regression (AR) model onto the data to represent the statistical behavior of the time series and updates its parameter estimates incrementally so that the effect of past examples is gradually discounted. Considering time series x_t, we can model the time series using an AR mode of the kth order by:

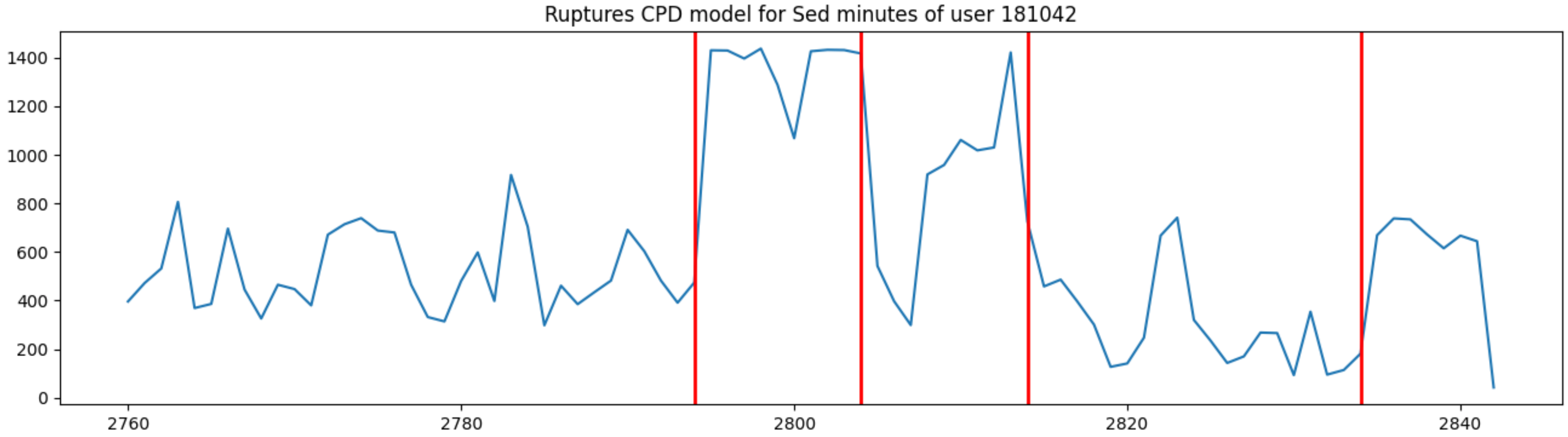
$$x_t = \omega x_{t-k}^{t-1} + \varepsilon$$

where $x_{t-k}^{t-1} = (x_{t-1}, x_{t-2}, \ldots, x_{t-k})$ are previous observations, $\omega = (\omega_1, \ldots, \omega_k) \in \mathbb{R}^k$ are constants, and ε is a normal random variable generated according to a Gaussian distribution like white noise. By updating model parameters the probability density function at time t is calculated and we have a sequence of probability densities $\{p_t : t = 1, 2, \ldots\}$. Next, an

Ruptures



Ruptures CPD model for series_1
1400
1300
1200
1100
1000
900
800
700
600
0
50
100
150
200



Ruptures CPD model for Sed minutes of user 181042
1400
1200
1000
800
600
400
200
0
2760
2780
2800
2820
2840

Ruptures

The intuition behind PELT is that for a time step to be detected as a change point, it must reduce the segmentation cost by more than the penalty value that is added. If the cost reduction is less than the added penalty, the penalized cost will increase, and the time step will not be detected as a change point.

Supervised methods

- Binary classification: changepoint / no changepoint
- Virtual classifier

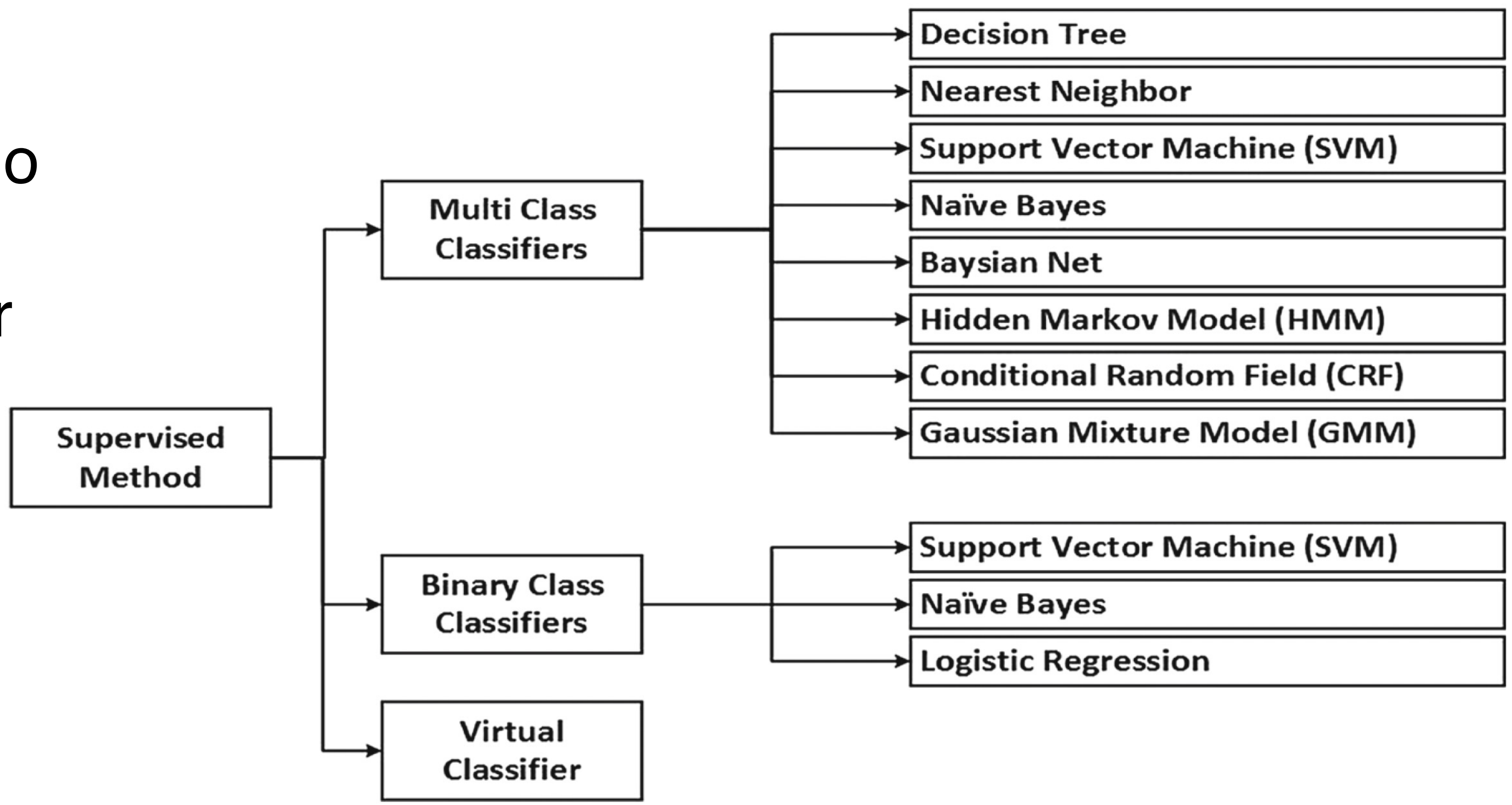


Fig. 3 Supervised methods for change point detection

Metrics beyond accuracy, and f1-scores

G-mean is commonly used as an indicator of CPD performance. This utilizes both sensitivity and specificity measures to assess the performance of the algorithm both in terms of the ratio of positive accuracy (sensitivity) and the ratio of negative accuracy (specificity).

$$G\text{-mean} = \sqrt{\text{Sensitivity} \times \text{Specificity}} = \sqrt{\frac{\text{TP}}{\text{TP} + \text{FN}} \times \frac{\text{TN}}{\text{FP} + \text{TN}}}$$

- Unsupervised methods
- Clustering,
- Outlier detection

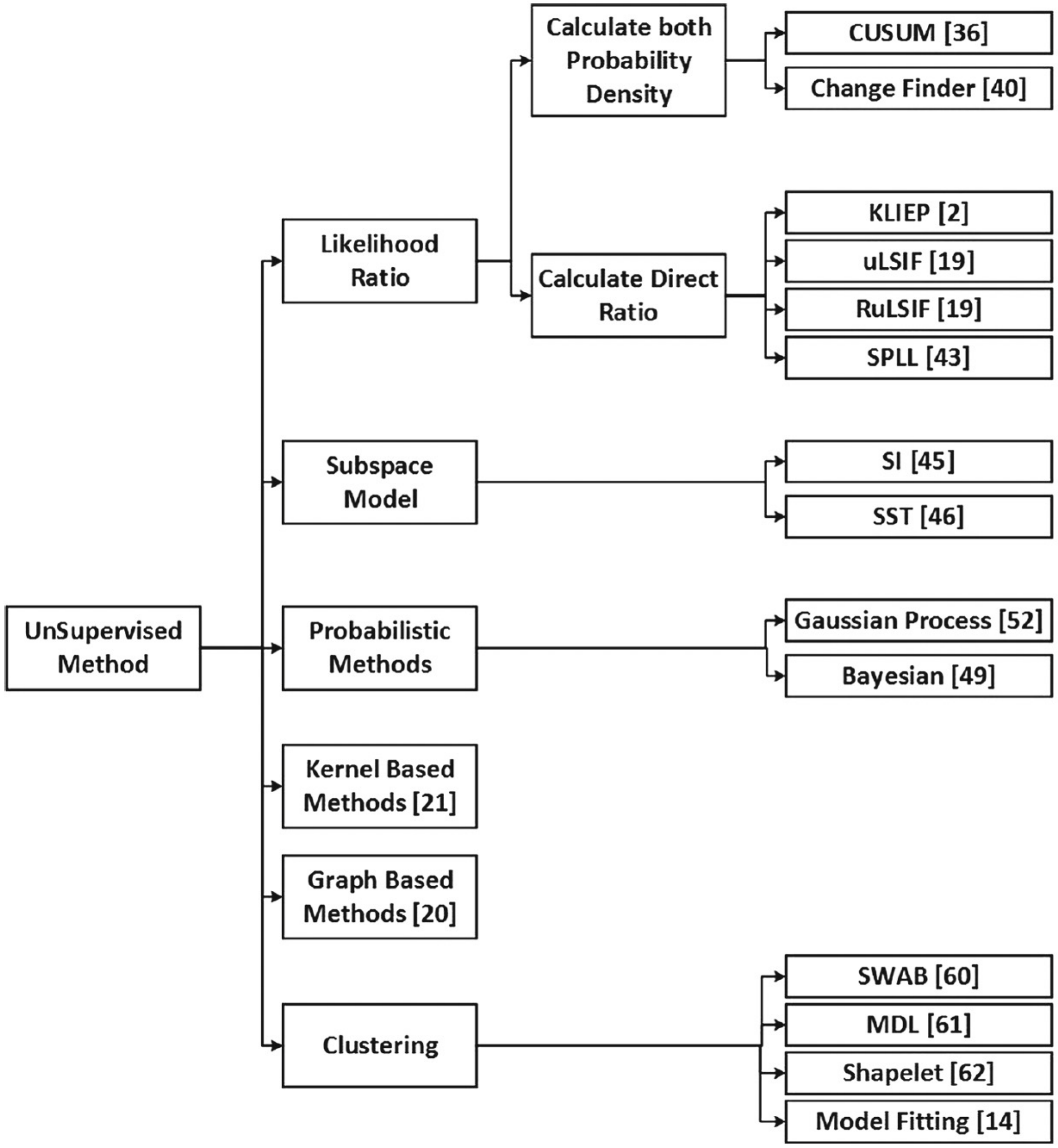


Fig. 4 Unsupervised methods for change point detection

- Unsupervised methods – Model fitting

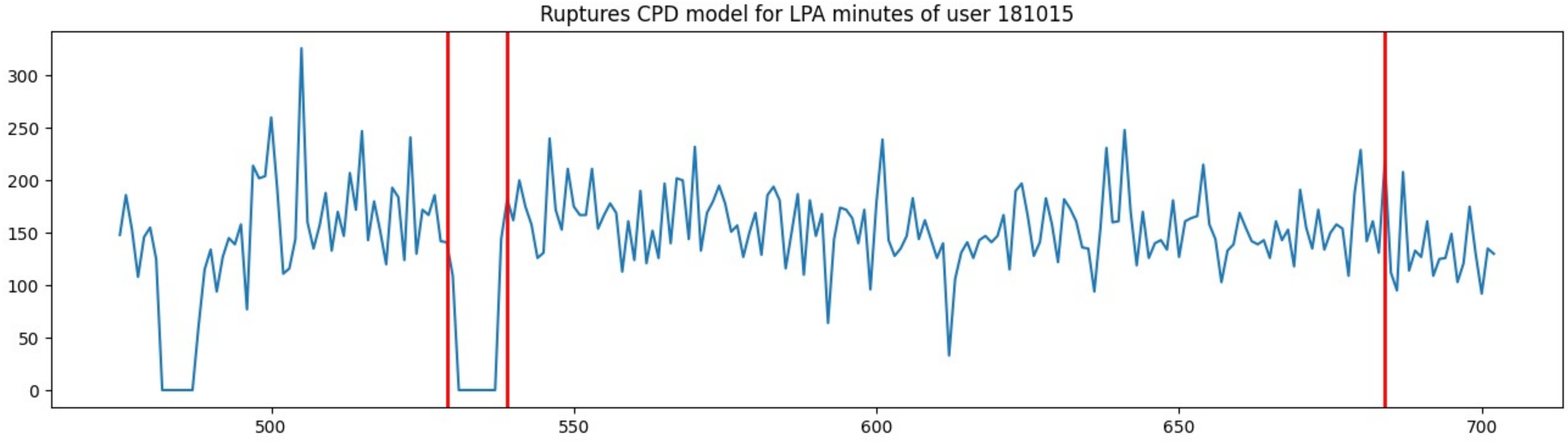
Yet another time series clustering approach is Model fitting, in which a change can be considered to occur when a new data item or block of data items do not fit into any of the existing clusters [60]. Assuming a data stream $\{x_1, \ldots, x_i, \ldots\}$, change point is occurred after data point x_i, if the following logical expression is true.

$$\text{change} = \bigwedge_{K}^{j=1} \left[d\left(x_{i+1}, \text{center}\left(C_j\right)\right) > \text{radius}\left(C_j\right)\right]$$

where $d\left(x_{i+1}, \text{center}\left(C_j\right)\right)$ is the Euclidian distance between a newly incoming data point x_{i+1} and the center of cluster C_j, radius $\left(C_j\right)$ is the radius of cluster j, K is the number of clusters, and $^\wedge$ is the logical and symbol. The radius of cluster C with n data point and mean value of μ is:

$$\text{radius}\,(C) = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \mu)^2}{n}}$$

Neural network –based detection
Label with ruptures

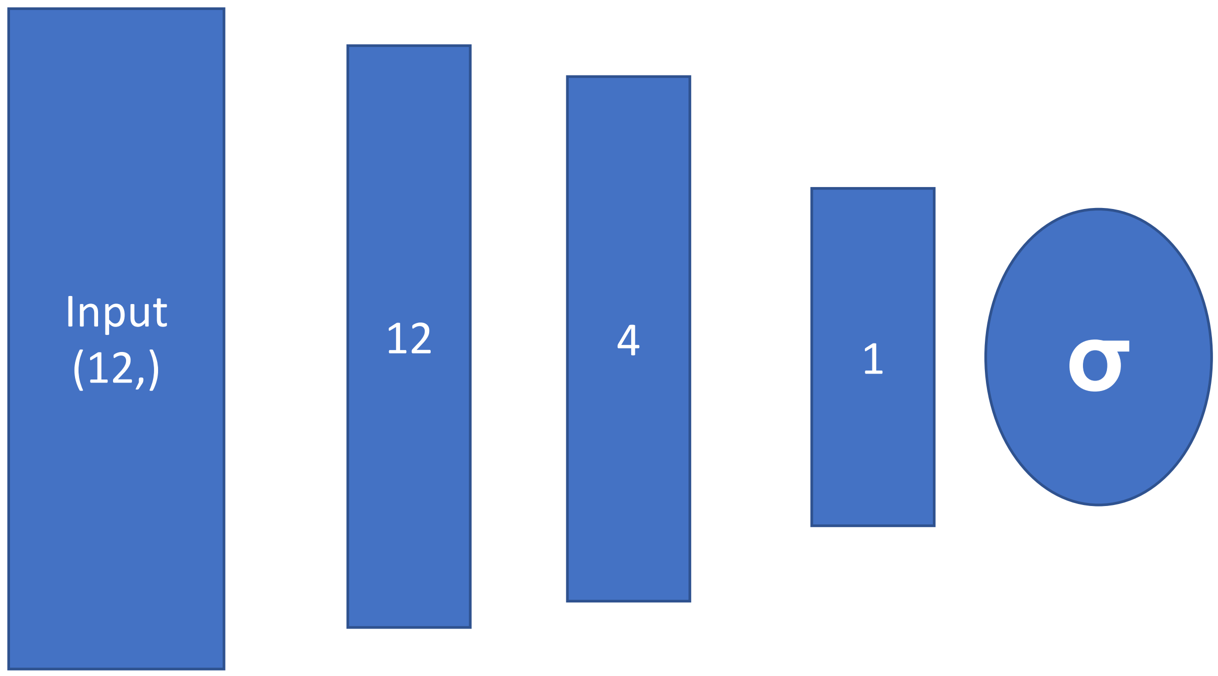


Labeling with ruptures

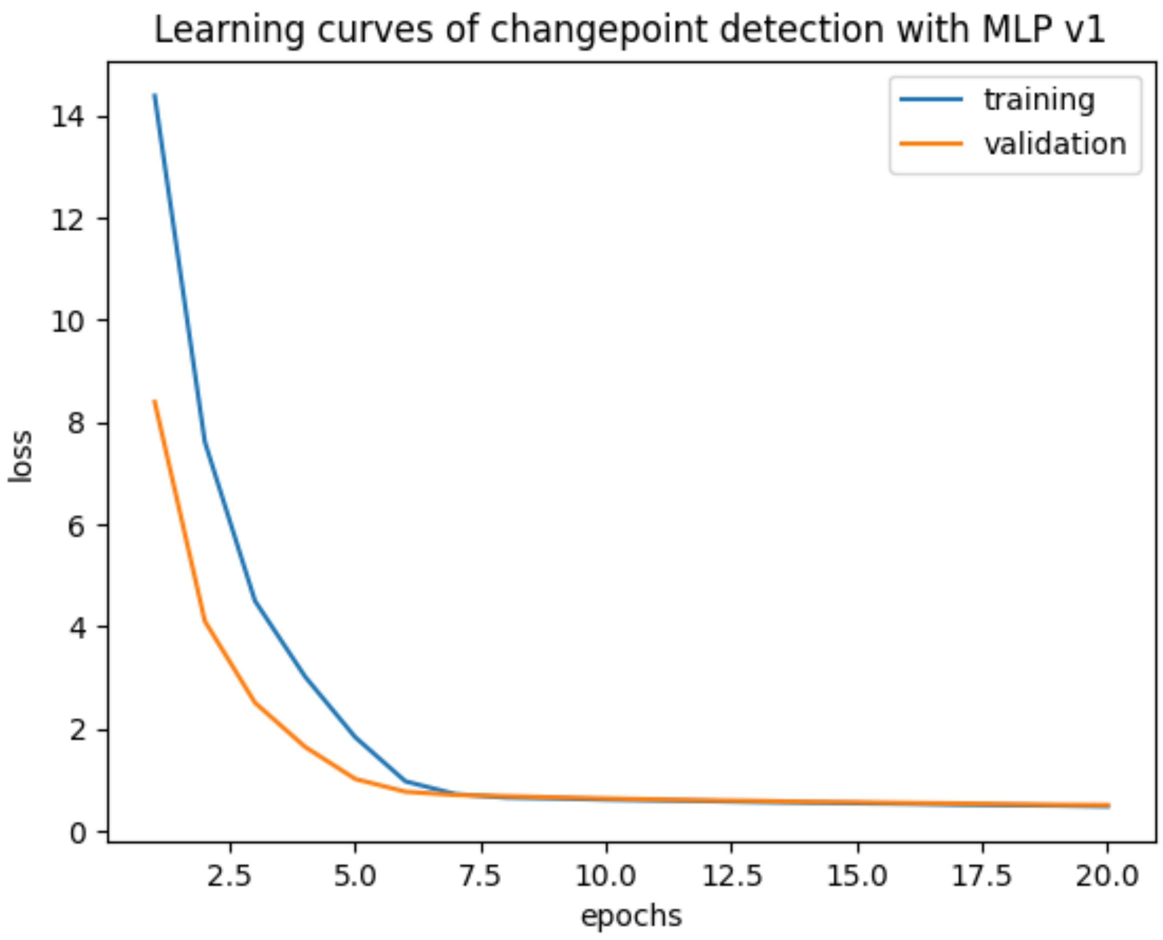
```
[[148 186 153 108 146 155 125   0   0   0   0   0]
 [146 155 125   0   0   0   0   0   0  61 115 134]
 [  0   0   0   0   0  61 115 134  94 127 145 139]
 [  0  61 115 134  94 127 145 139 158  77 214 202]
 [ 94 127 145 139 158  77 214 202 204 260 192 111]
 [158  77 214 202 204 260 192 111 116 144 326 160]
 [204 260 192 111 116 144 326 160 135 157 188 133]
 [116 144 326 160 135 157 188 133 170 147 207 172]
 [135 157 188 133 170 147 207 172 247 143 180 152]
 [170 147 207 172 247 143 180 152 120 193 184 124]
 [247 143 180 152 120 193 184 124 241 130 172 167]
 [120 193 184 124 241 130 172 167 186 142 141 109]
 [241 130 172 167 186 142 141 109   0   0   0   0]
 [186 142 141 109   0   0   0   0   0   0   0 144]
 [  0   0   0   0   0   0   0 144 182 162 200 175]
 [  0   0   0 144 182 162 200 175 158 126 131 240]
 [182 162 200 175 158 126 131 240 172 153 211 175]
```

```
[0 0 0 0 0 0 0 0 0 0 0 1 1 1 1 1 1
```

Changepoint detection with MLP



Changepoint detection



Test accuracy: 0.8696682453155518

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