PROCESSING, FEATURE EXTRACTION AND SHAPE REPRESENTATION OF THE ECG, II

- Basic stages of ECG signal processing
- QRS complex classification
- Normal and abnormal heart beats
- QRS complex classification
- Feature extraction
- Features to distinguish normal and abnormal heart beats
- Feature extraction techniques
- Adjusting QRS complexes by amplitude
- High-pass recursive filter for drift suppression
- Estimating the isoelectric level
- Seeking for the position of the isoelectric level
- Metrics to distinguish QRS complex morphologies
- QRS complex classification, performance evaluation
- QRS complex classification

Basic stages of ECG signal processing

- *ECG filtering*
- *QRS complex detection*

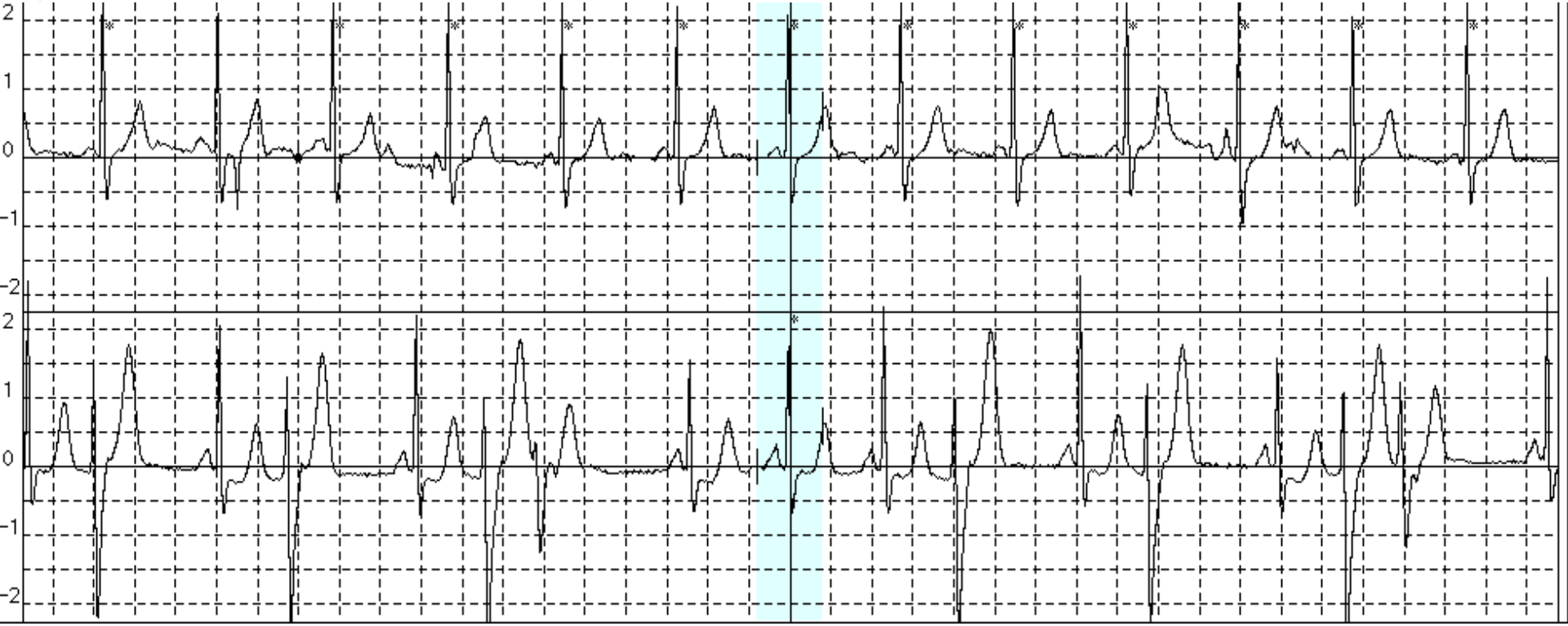
  → (Wave delineation)
- *QRS complex classification*

  → (Rhythm classification)

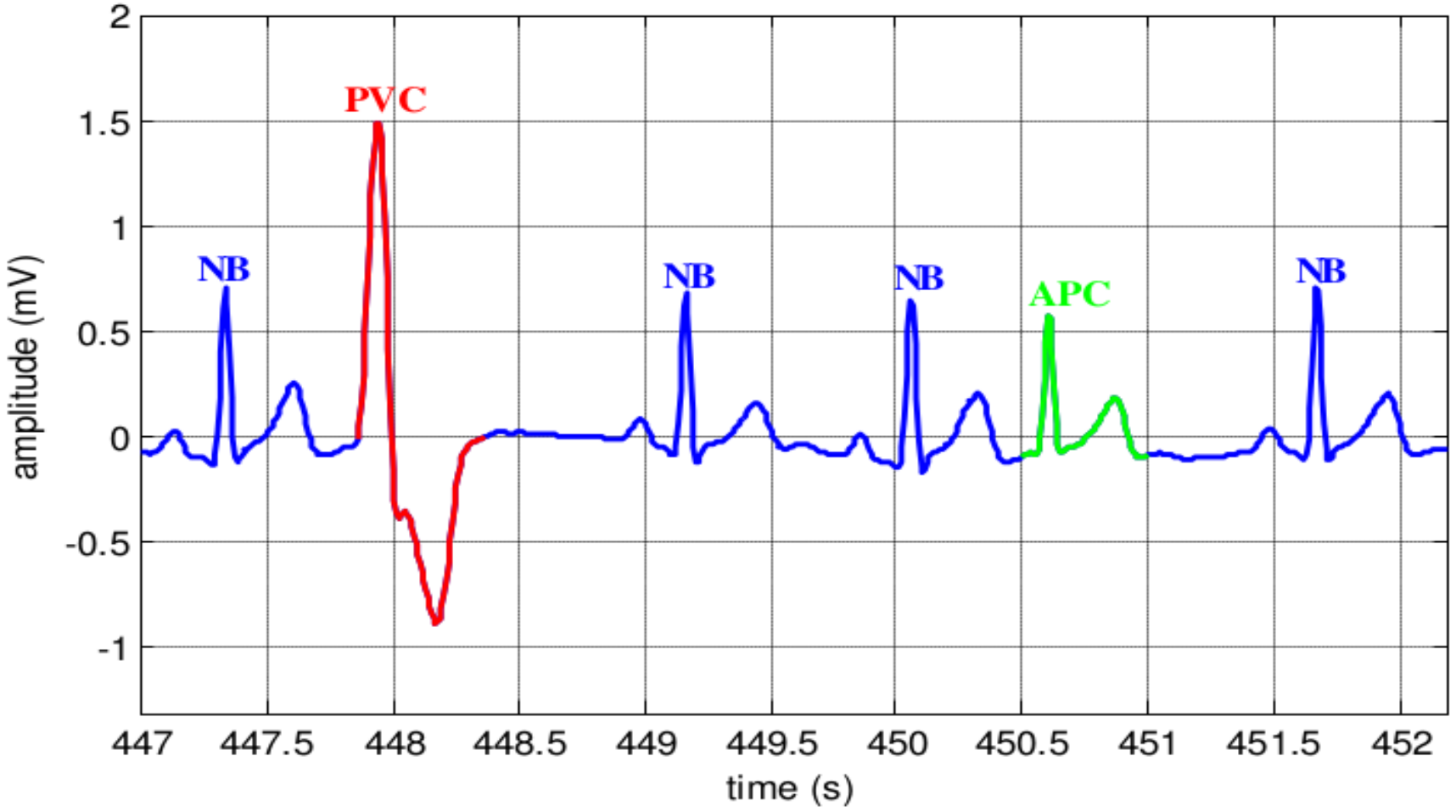
  → *Ischaemia detection* (*classifying ischaemic events*, detecting transient ischaemic episodes, and their precise beginnings, extrema and ends)

QRS complex classification

- Exercises 2: QRS complex classification



Normal and abnormal heart beats



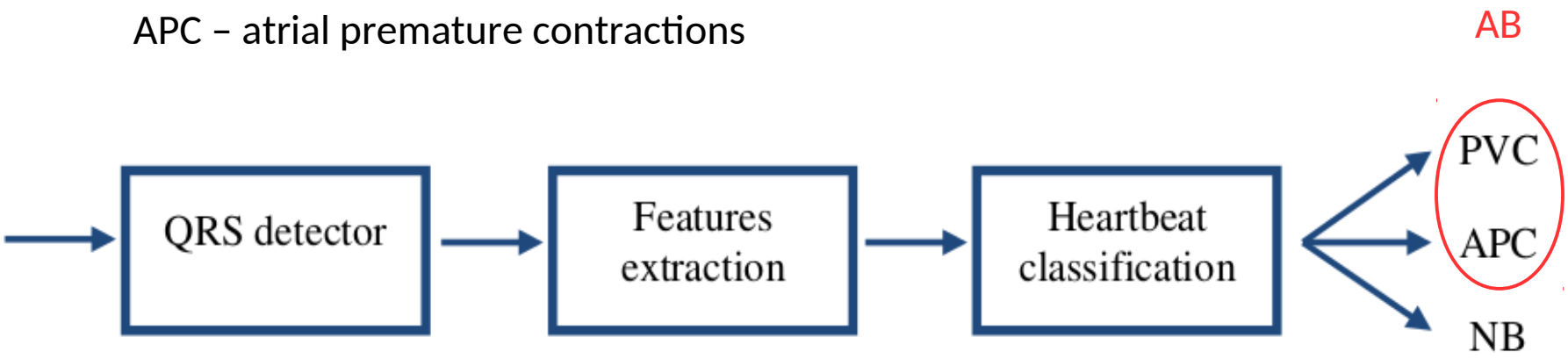
(Garcia, Romano, Laciar, Correa)

QRS complex classification

NB - normal beats, AB – Abnormal Beats

PVC – premature ventricular contractions

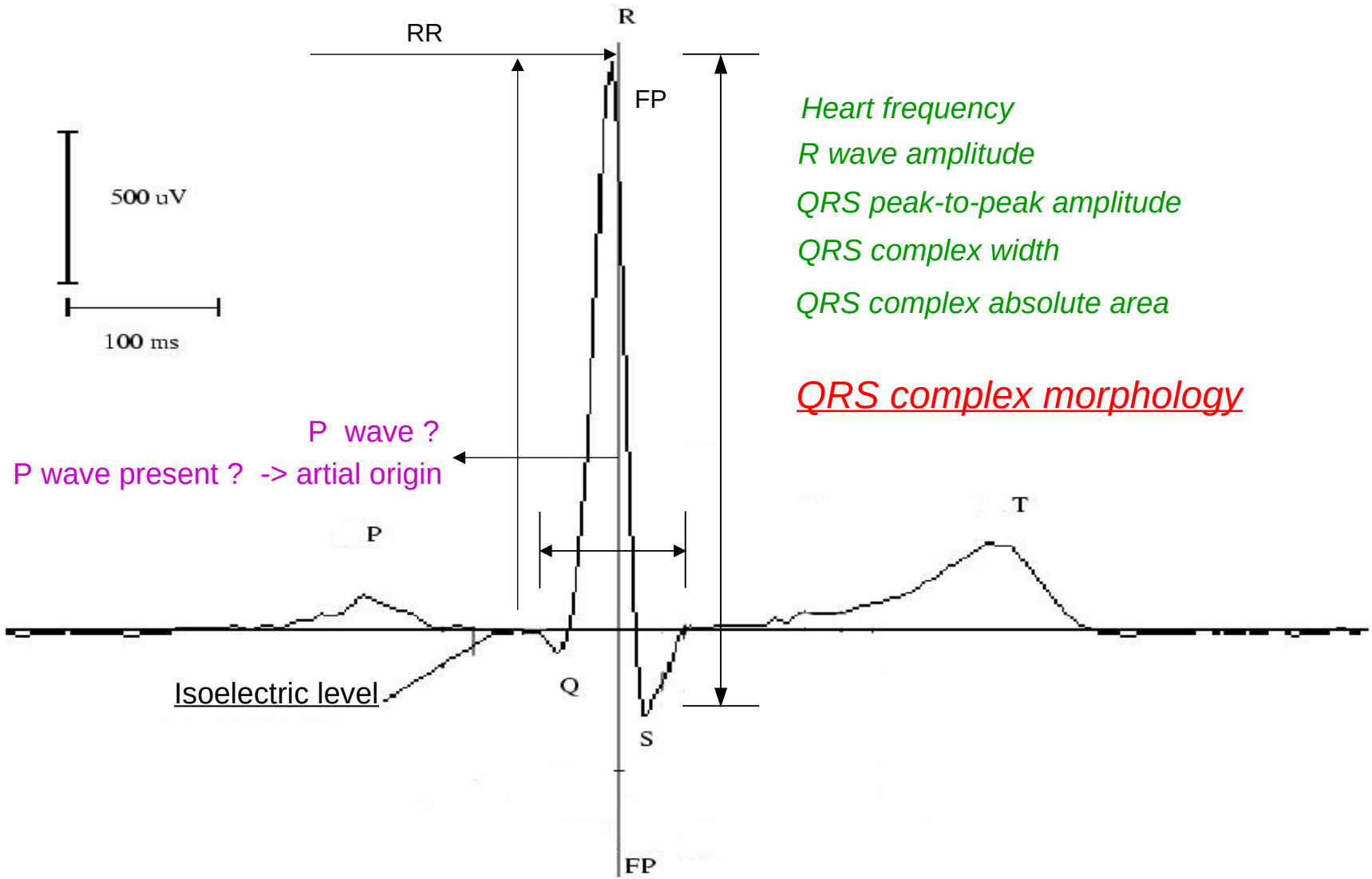
APC – atrial premature contractions



Feature extraction

- Derivation of morphologic feature vectors:
  - The representation of *M-dimensional ECG pattern vector*, ***x*** (e.g., QRS complexes, or any other set of consecutive original ECG signal samples), in terms of a set of a few features or numerical parameters, is a critical step in automated ECG analysis
  - The information content of a set of signal samples that constitutes a pattern vector usually far exceeds what is necessary for the analysis
  - The feature extraction techniques reduce the data dimensionality yielding an *N-dimensional, N< M, feature vector*, ***y***, whose components are termed features

Features to distinguish normal and abnormal heart beats



Heart frequency

R wave amplitude

QRS peak-to-peak amplitude

QRS complex width

QRS complex absolute area

QRS complex morphology

Feature extraction techniques

- Feature extraction techniques to estimate QRS complex morphology
  - Use different morphology metrics (norms of linear algebra or correlation) to distinguish QRS complex morphologies
  - Use moving average filters (non-linear trimmed moving average filters)
  - Use orthonormal function model transform-based feature extraction technique (Karhunen-Loeve coefficients)
  - (-) Extract time-domain features from each individual QRS complex
  - (-) Use wavelet-based feature extraction

Adjusting QRS complexes by amplitude

- Use high-pass recursive filter for drift suppression
- Estimate the isoelectric level
- Automatically seek for the position of the isoelectric level

High-pass recursive filter for drift suppression

$$H(z) = \frac{c_1\left(1 - z^{-1}\right)}{\left(1 - c_2 z^{-1}\right)}$$

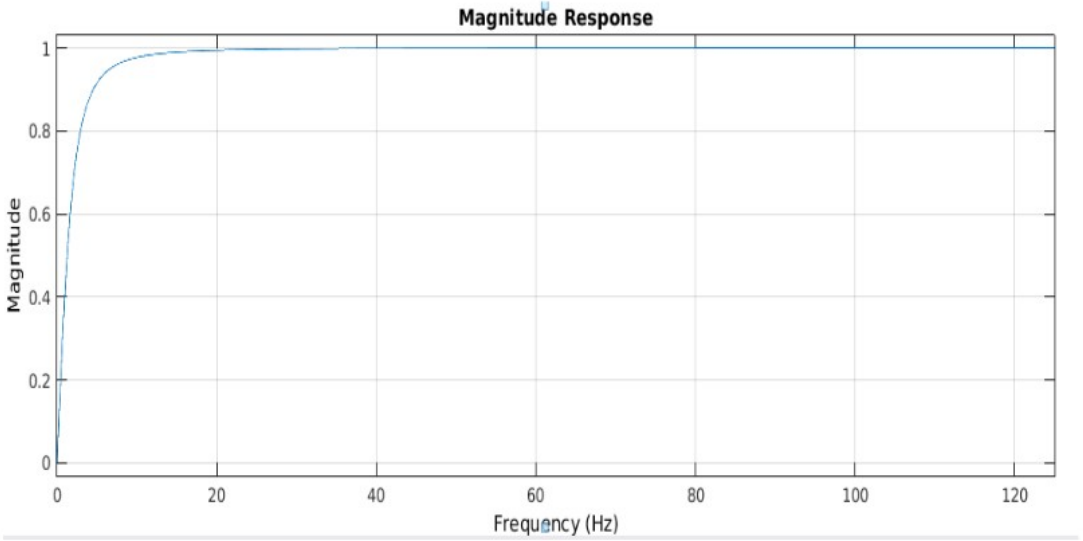
$$y[n] = c_2\, y[n-1] + c_1\left(x[n] - x[n-1]\right)$$

$$c_1 = \frac{1}{\left(1 + \tan\left(F_C\ \pi\ T\right)\right)}$$

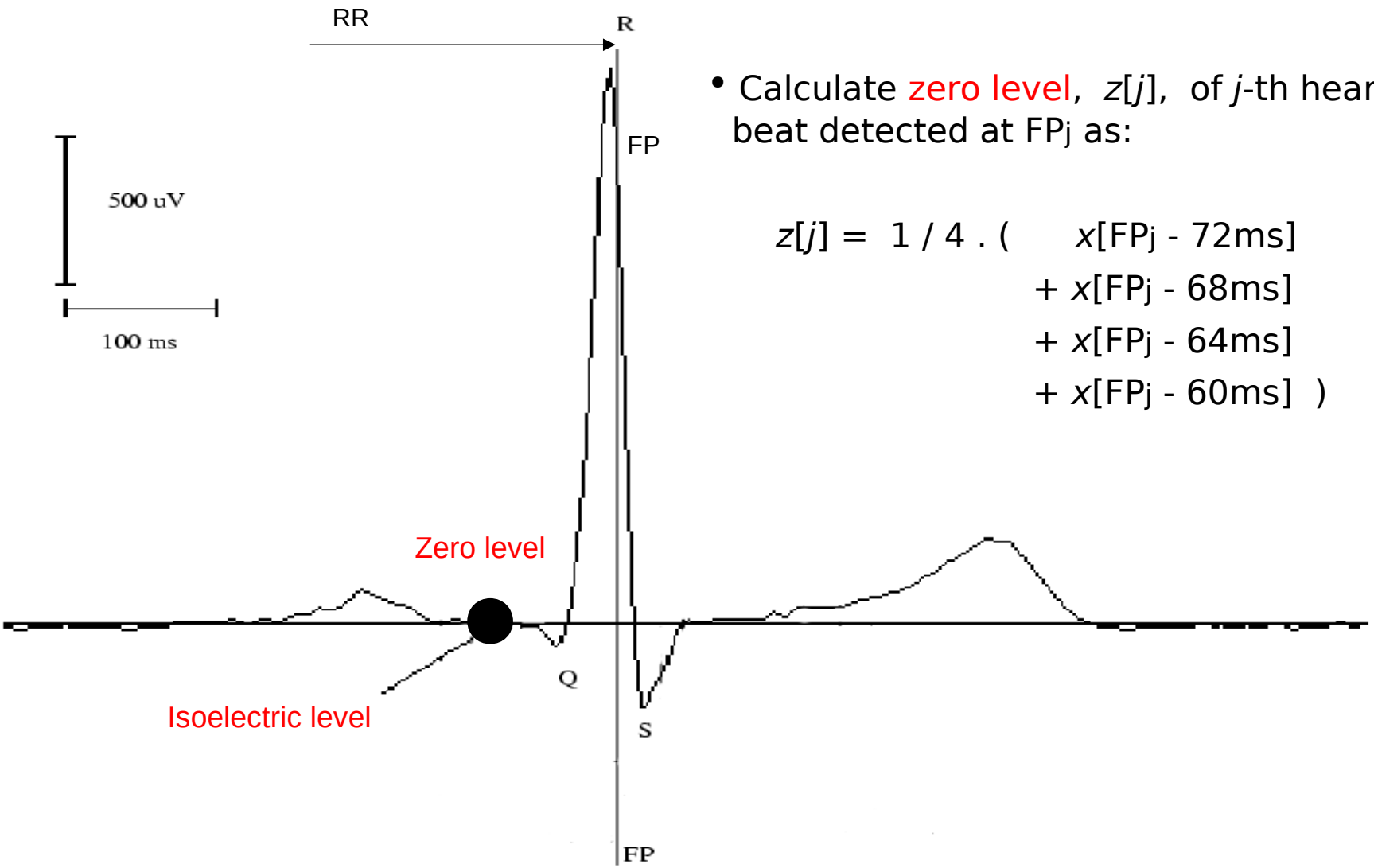
$$c_2 = \frac{\left(1 - \tan\left(F_C\ \pi\ T\right)\right)}{\left(1 + \tan\left(F_C\ \pi\ T\right)\right)}$$

F_C - cut-off frequency (= 2.2 Hz), T – sampling period, F_s = 250 smp/sec

$c_1 = 0.97309$ $c_2 = 0.94618$



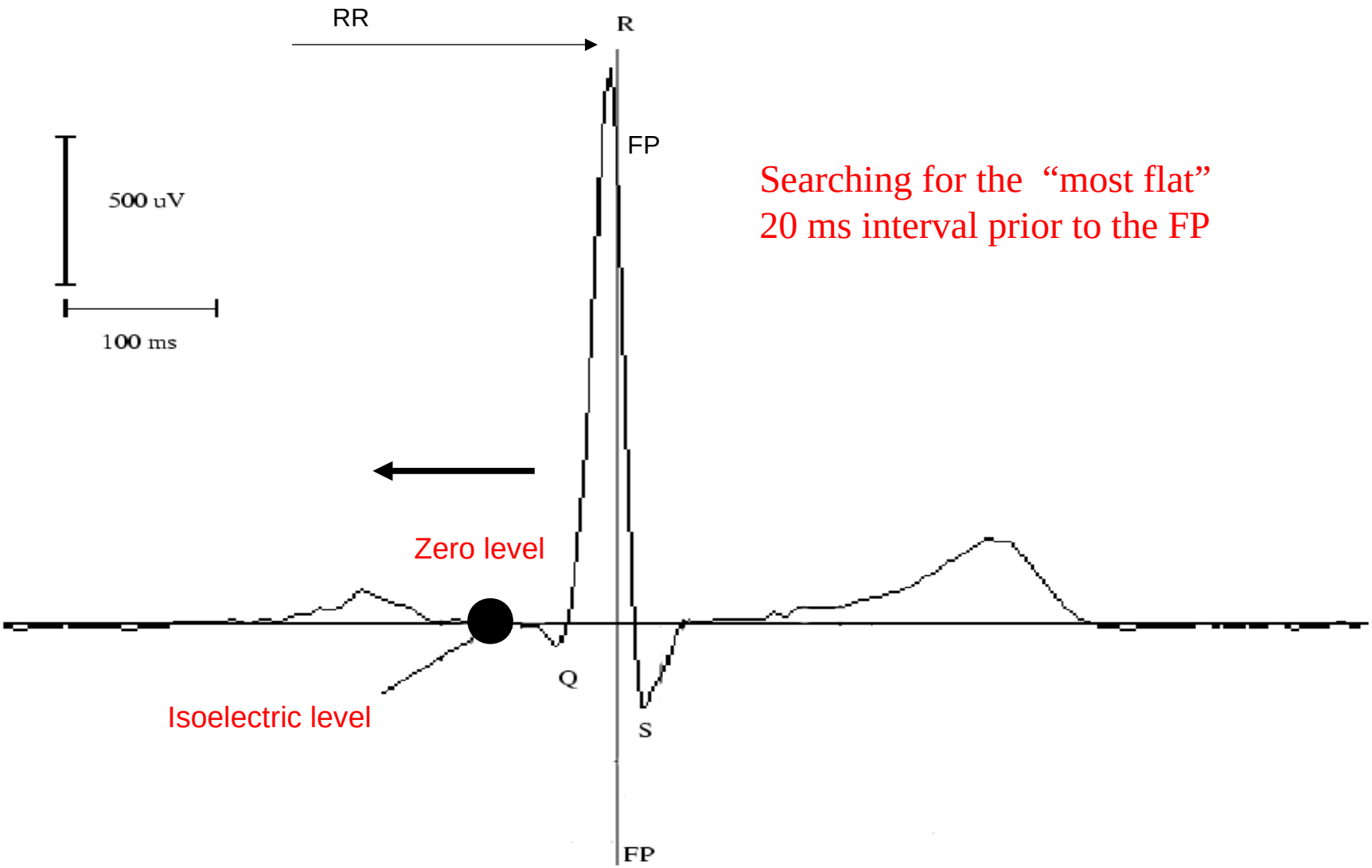
Estimating the isoelectric level



- Calculate zero level, $z[j]$, of j-th heart beat detected at FP_j as:

$$z[j] = 1/4 \cdot (x[FP_j - 72ms] + x[FP_j - 68ms] + x[FP_j - 64ms] + x[FP_j - 60ms])$$

Seeking for the position of the isoelectric level



Searching for the "most flat"
20 ms interval prior to the FP

Seeking for the position of the isoelectric level

- Use heuristic algorithm that seeks for the position of the isoelectric level, *I(i,j)*, and its amplitude, *z(i,j)*, prior to the *j*-th QRS complex

Constants:

f_{samp}: Sampling frequency
$\Delta T = 1/f_{samp}$; Time step
T_Q: Interval to search for Q peak (60 ms)
$QS = T_Q / \Delta T$; Samples to search for Q peak
T_{PQ}: Interval to search for PQ segment (80 ms)
$PQS = T_{PQ} / \Delta T$; Samples to search for PQ
T_f: Flatness interval (20 ms)
$L = T_f / \Delta T$; Samples for flatness interval

Input:

i: Lead number
j: Heart-beat number
$FP(j)$: Fiducial point [ms]
$x(i,.)$: ECG signal samples [μV]

Output:

$I(i,j)$: Position of the isoelectric point [ms]
$z(i,j)$: Estimated isoelectric level [μV]

procedure pq_segment$(I(i,j),\ z(i,j))$;
$k = FP(j) / \Delta T$;
$sp = \text{sign}\,(x(i,k-2) - x(i,k))$;
$k = k - 2$;
$s = \text{sign}\,(x(i,k-1) - x(i,k))$;
while $(s \neq 0) \wedge (s = sp) \wedge (FP(j)/\Delta T - k < QS)$ **do**
  $sp = s$;
  $k = k - 1$;
  $s = \text{sign}\,(x(i,k-1) - x(i,k))$;
enddo
$k = k - 2$;
$z(i,j) = \frac{1}{L} \sum_{l=-L/2}^{L/2} x(i,k+l)$;
$I(i,j) = k\,.\,\Delta T$;
$minabsdev = \sum_{l=-L/2}^{L/2} | x(i,k+l) - z(i,j) |$;
for $m = k-1$ **downto** $k - PQS + 2$ **do**
  $mean = \frac{1}{L} \sum_{l=-L/2}^{L/2} x(i,m+l)$
  $absdev = \sum_{l=-L/2}^{L/2} | x(i,m+l) - mean |$;
  if $absdev < minabsdev$ **then**
    $z(i,j) = mean$;
    $I(i,j) = m\ \Delta T$;
    $minabsdev = absdev$;
  endif
enddo
end_procedure

Searching for the "most flat" 20 ms interval

For each signal sample, the Mean Absolute Deviation (MAD) of 20 ms interval from its own mean value is computed

The sample with minimum MAD, defines *I(i,j)*

Metrics to distinguish QRS complex morphologies

- Metrics to distinguish QRS complex morphologies of normal and abnormal heart beats. Standard 1st (mean-absolute, $d1$), 2nd (root-mean-square, $d2$) or ∞ (max-absolute, $d\infty$) norms of linear algebra, or correlation, r (dr)

$$d_1 = \frac{1}{N}\left(|x_1 - y_1| + |x_2 - y_2| + \ \ldots\ + |x_N - y_N|\right)$$

$$d_2 = \sqrt{1/N\left(|x_1 - y_1|^2 + |x_2 - y_2|^2 + \ \ldots\ + |x_N - y_N|^2\right)}$$

$$d_\infty = \max\left(|x_1 - y_1|, |x_2 - y_2|, \ \ldots\ , |x_N - y_N|\right)$$

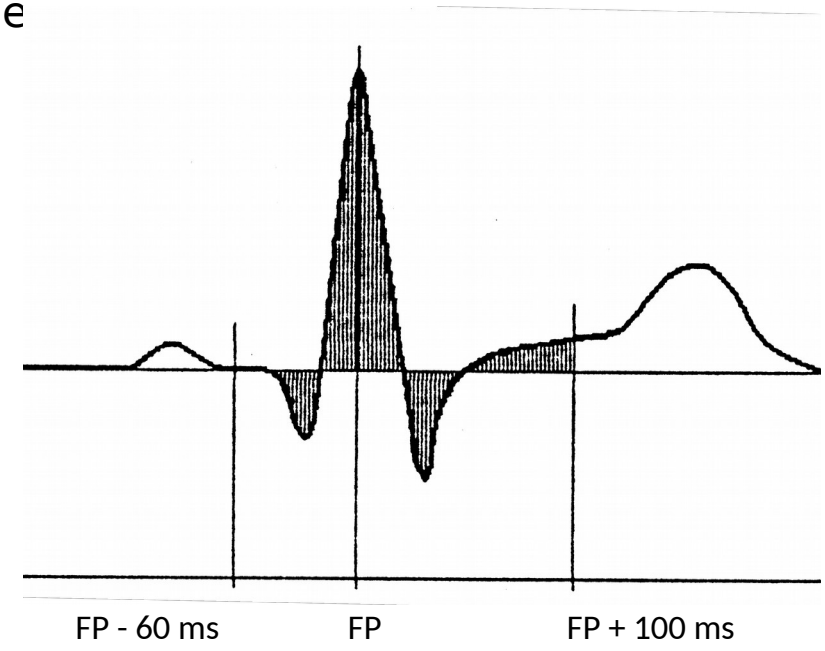
$$d_r = \begin{cases} 1 - r, & \text{if} \quad r > 0 \\ 1, & \text{otherwise} \end{cases}$$

$$r = \left(S_x\, S_y\right)^{-\frac{1}{2}} \cdot \sum_{i=1}^{N}\left(\left(x_i - x_{\text{ave}}\right)\left(y_i - y_{\text{ave}}\right)\right)$$

$$S_x = \sum_{i=1}^{N}\left(x_i - x_{\text{ave}}\right)^2, \qquad S_y = \sum_{i=1}^{N}\left(y_i - y_{\text{ave}}\right)^2$$

Metrics to distinguish QRS complex morphologies

- The value of a norm, or correlation coefficient, is then compared to a certain threshold
  - In the case of norms of linear algebra → e.g., area under the reference heart beat obtained during learning phase
  - In the case of correlation coefficient → predefined value obtained during learning phase



QRS complex classification, performance evaluation

- Performance evaluation

		Analyzer	Analyzer
		EVENT	NON-EVENT
Reference	event	*TP*	*FN*
Reference	non-event	*FP*	*TN*

Sensitivity:

$$Se = \frac{TP}{TP + FN}$$

The proportion of events which were correctly classified as EVENTS

(Positive predictivity:)

$$+P = \frac{TP}{TP + FP}$$

(The proportion of classified EVENTS which actually were events)

Specificity:

$$Sp = \frac{TN}{TN + FP}$$

The proportion of non-events which were correctly classified as NON-EVENTS

QRS complex classification

- Evaluation using MIT BIH arrhythmia DB (time domain features)

Classifying between NB and AB (PVC and APC), typical performances:
Se = 97.17%, Sp = 98.16%

Garcia, Romano, Laciar, Correa, Development of an algorithm for heartbeats detection and classification in Holter records based on temporal and morphological features, Journal of Physics: Conference Series 332, pp. 1-10, 2011