Classification of fractionated electrograms in epicardial mappings using a recurrent neural network

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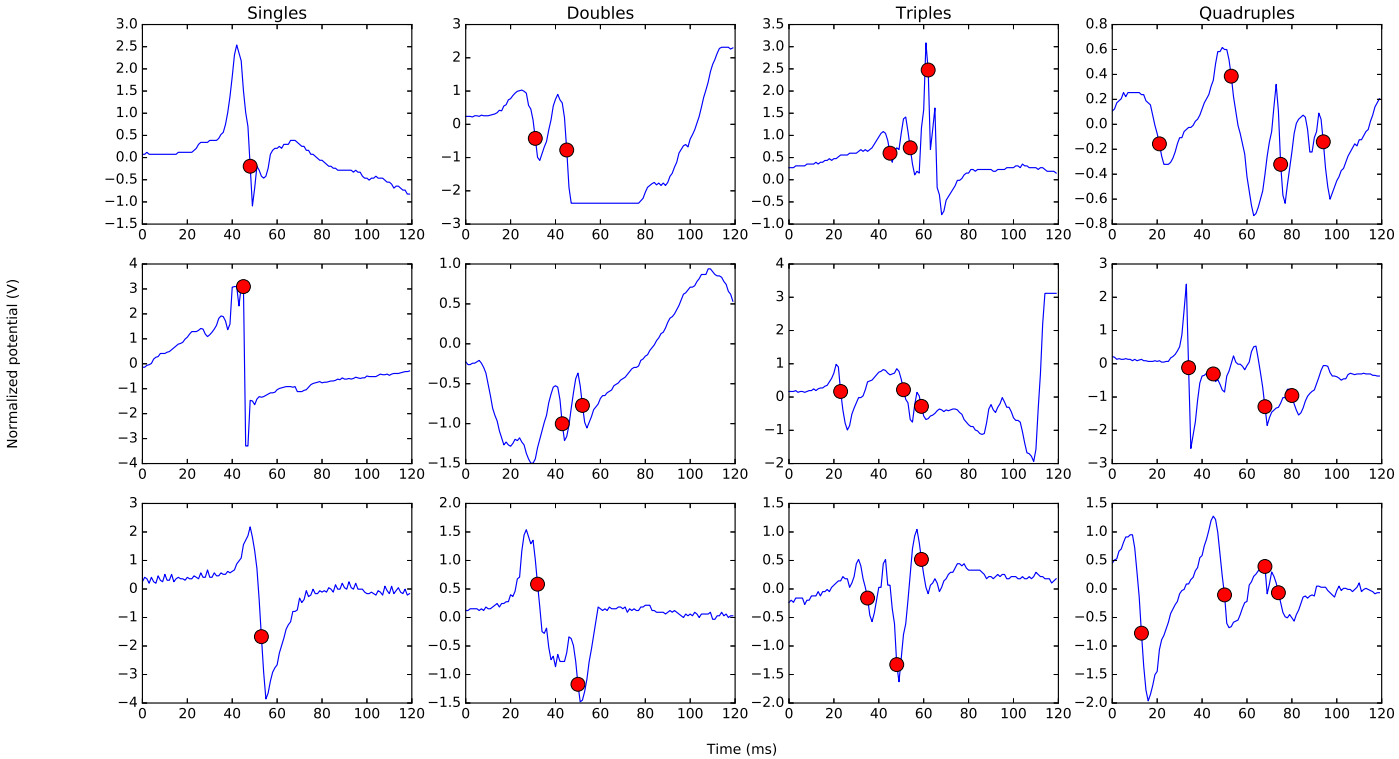
Abstract


Singles
Doubles
Triples
Quadruples
Normalized potential (V)
Time (ms)

Overview

Pipeline

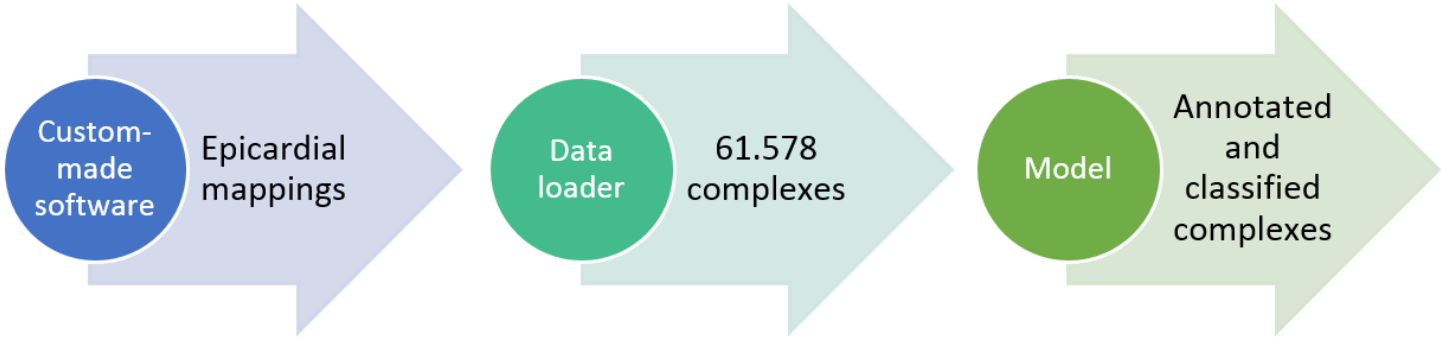


Figure: Data pipeline

Data

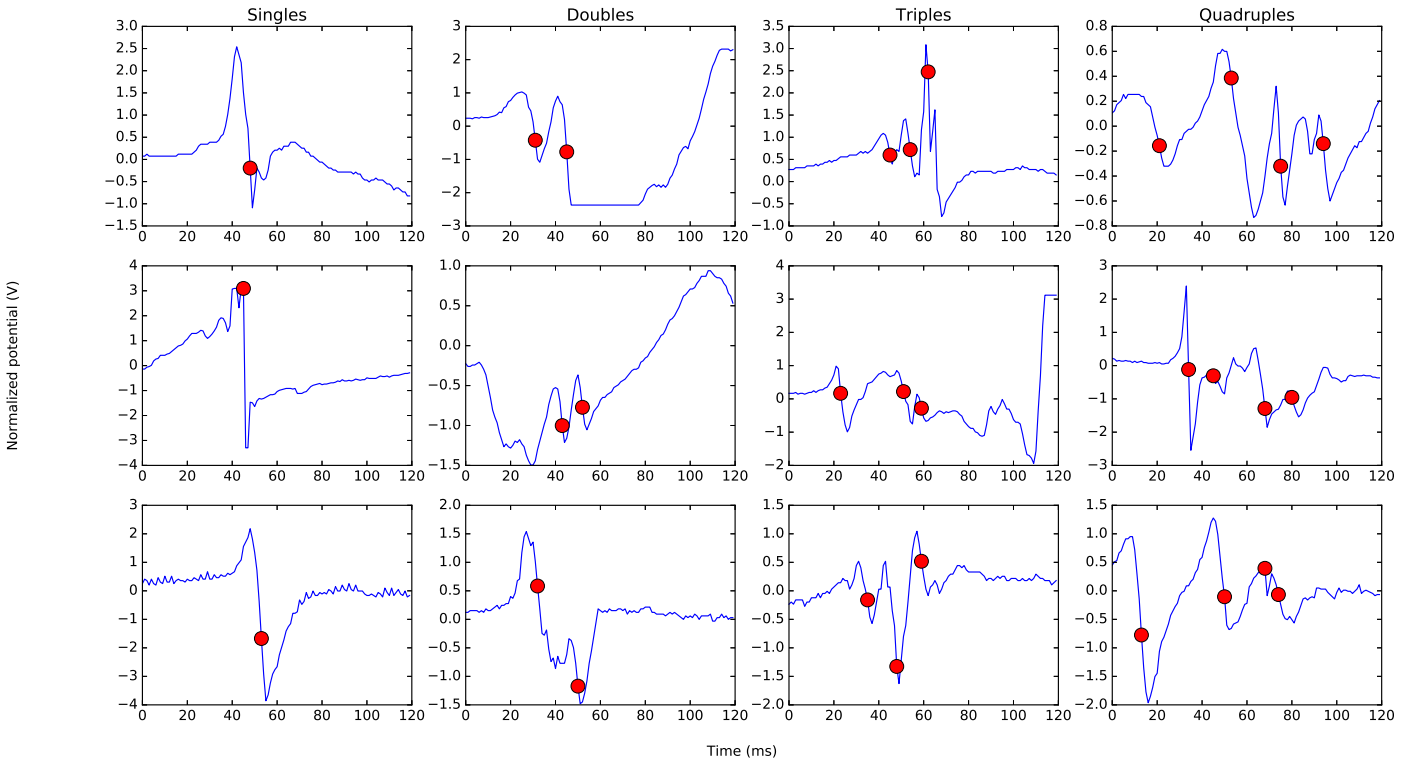


Figure: Examples of simple electrograms

Notation

$$\{(x^{(i)}, y^{(i)})\}_{i=0}^{N-1} \tag{1}$$

- $x^{(i)} \in R^{120}$
  - t indexes time with $t = 0, 1, ..., T-1$
- $y^{(i)} \in \{l_1, l_2, ..., l_{K^i}\}$.
  - l_k denotes the location of the k-th annotation
  - K^i denotes the total number of annotations at sample i
  - For example, $y^i = \{35, 75, 95\}$ is a triple with deflections at 35 ms, 75 ms and 95 ms.

CI and FI

- Complexity Index

$$CI(x^{(i)}) = \frac{1}{T}\sum_{t=1}^{T-1} \mathbb{1}(\mathbb{1}(x_{t-1}^{(i)} \geq 0) = \mathbb{1}(x_t^{(i)} < 0)) \quad (2)$$

- Fractionation Index

$$FI(x^{(i)}) = \frac{1}{T}\sum_{t=2}^{T-1} \mathbb{1}(\mathbb{1}(x_{t-1}^{(i)} \geq x_{t-2}^{(i)}) = \mathbb{1}(x_t^{(i)} < x_{t-1}^{(i)}))) \quad (3)$$

with $\mathbb{1}()$ *denoting the indicator function*

- Sample entropy *(Cirugeda-Roldan, 2015)*

Design choices

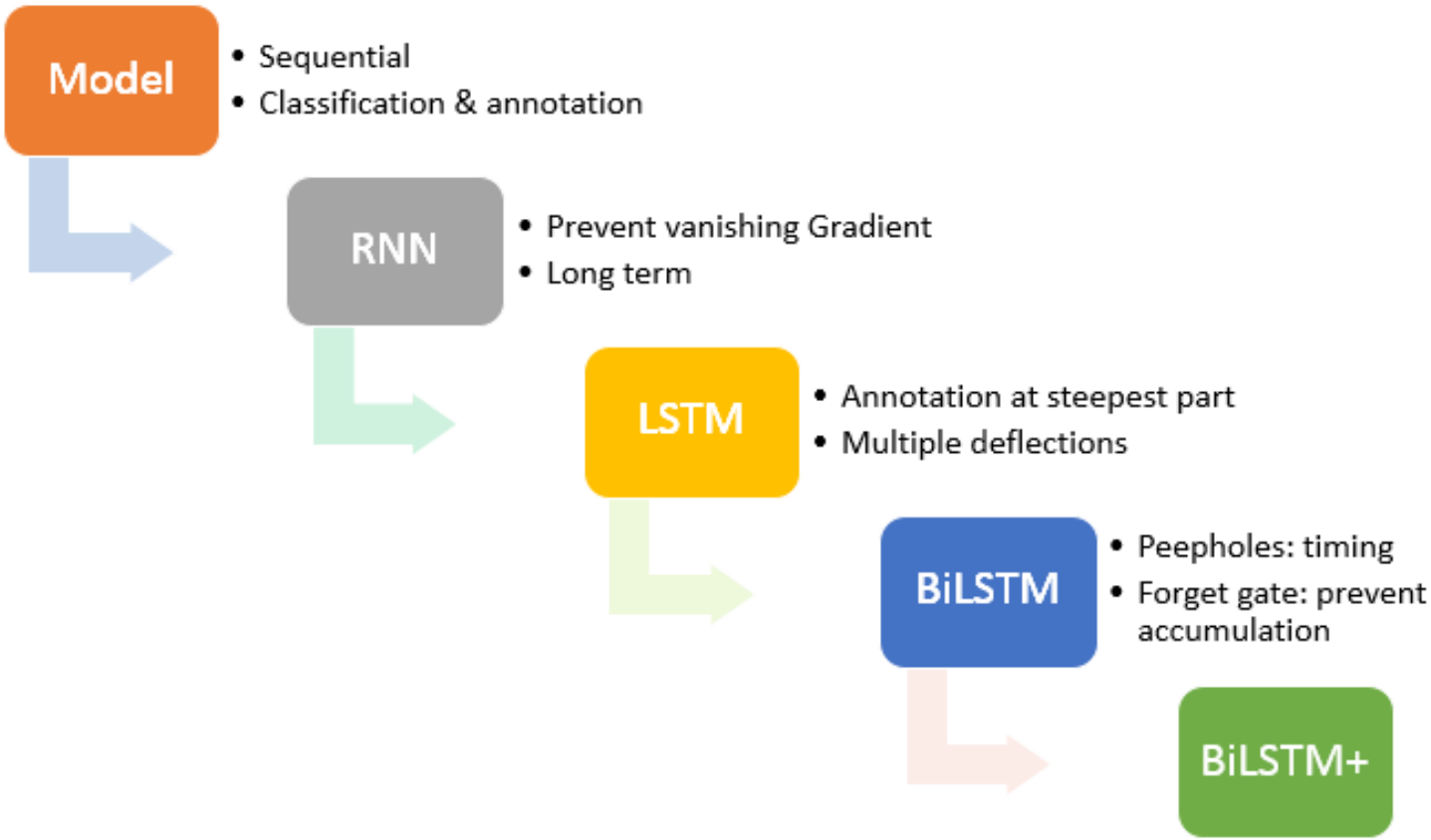


Figure: Flow graph for design choices

Model

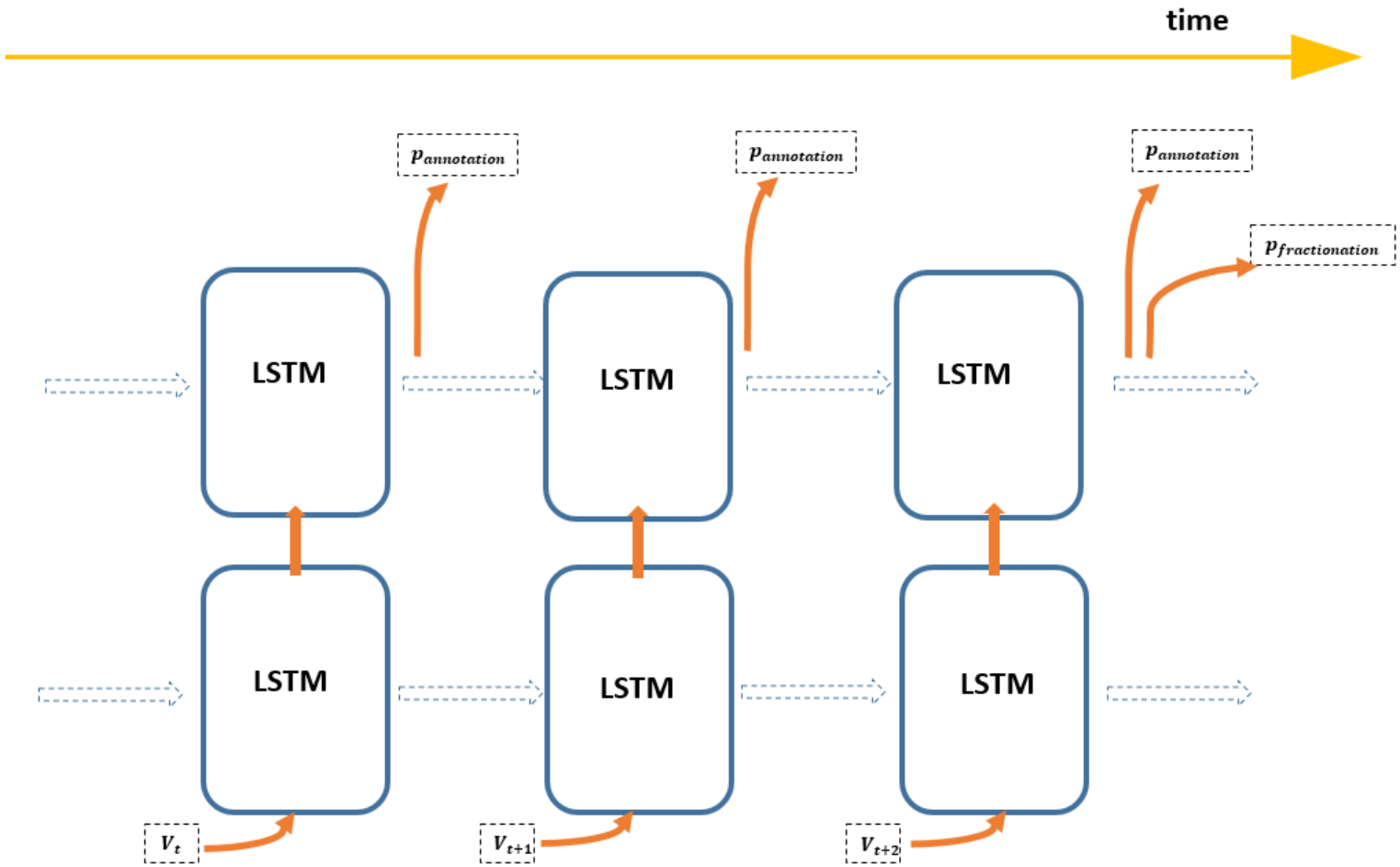


Figure: Network architecture

Long Short-term memory

$$i_t = \sigma(W_{xi}x_t + W_{hi}h_{t-1} + W_{ci}c_{t-1} + b_i) \quad (4)$$

$$f_t = \sigma(W_{xf}x_t + W_{hf}h_{t-1} + W_{cf}c_{t-1} + b_f) \quad (5)$$

$$o_t = \sigma(W_{xo}x_t + W_{ho}h_{t-1} + W_{co}c_{t-1} + b_o) \quad (6)$$

$$c_t = f_t c_{t-1} + tanh(W_{xc}x_t + W_{hc}h_{t-1} + b_c) \quad (7)$$

$$h_t = o_t \ tanh(c_t) \quad (8)$$

Classification and annotation

- $$m_t = W_{hm} h_t + b_m$$
$$p(C_k|h_t) = \frac{e^{m_{t,k}}}{\sum_{\kappa=1}^{4} e^{m_{t,\kappa}}} \quad (9)$$
$$K = \underset{k}{\text{argmax}}\, C_k \quad (10)$$

- $$p_t(annotation) = \sigma(W_{ha} h_t + b_a) \quad (11)$$

Next, $l_k = t$ joins y if

$$p_t(annotation) > threshold \quad (12)$$

Binary classification

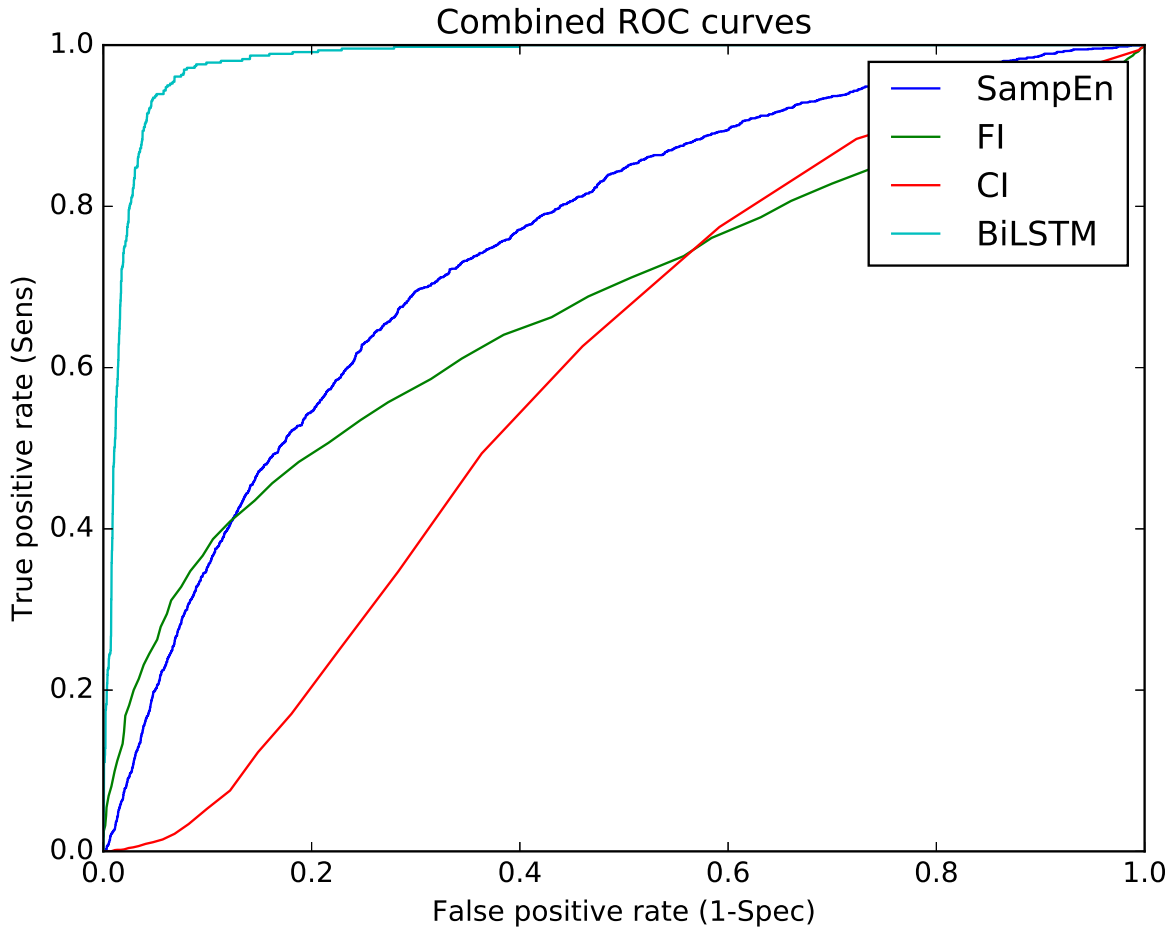
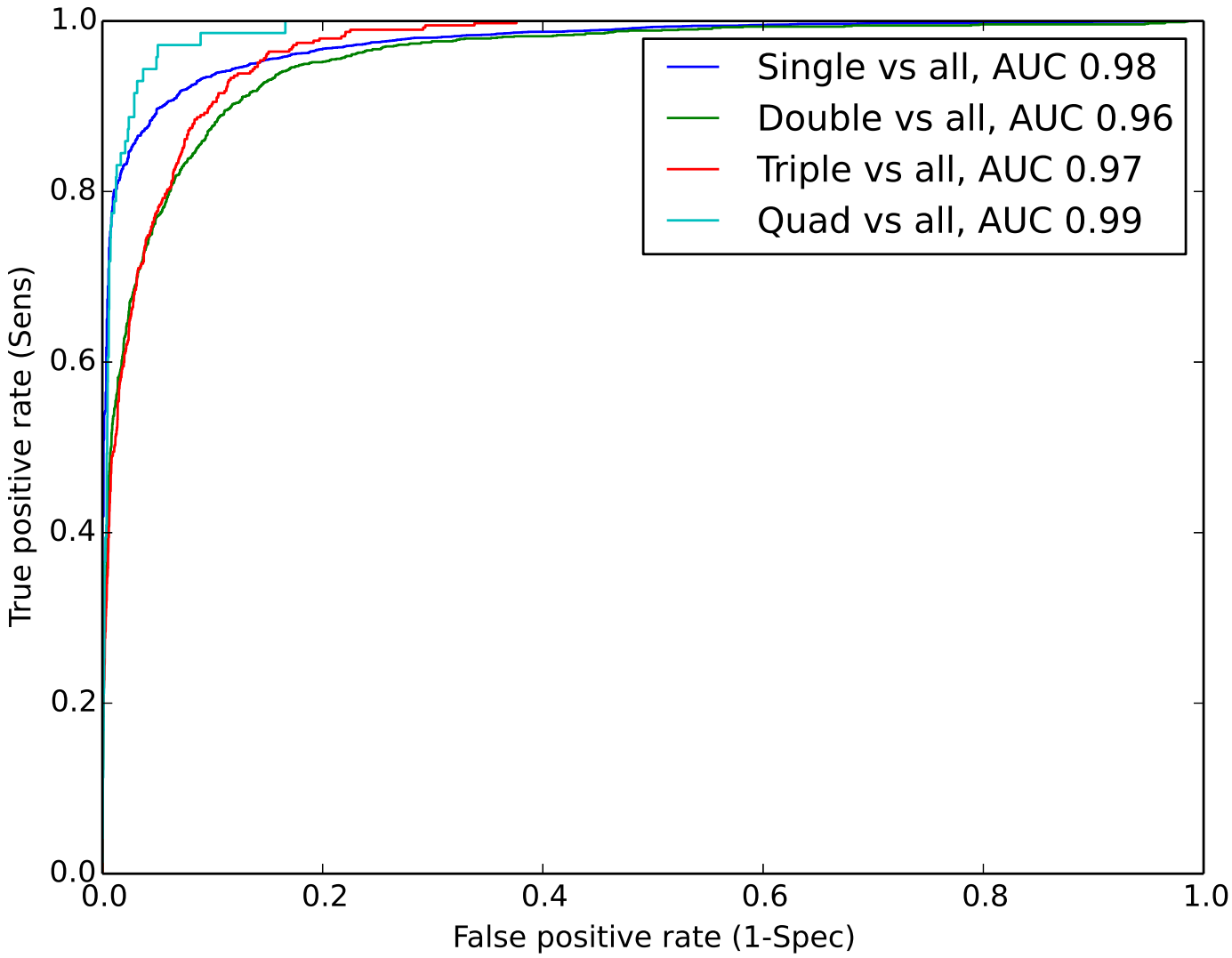


Figure: CI: 0.58 – FI: 0.68 – SampEn: 0.75 – BiLSTM: 0.98 (in AUC)

Refined classification



Misclassifications

		Model			
		Single	Double	Triple	Quad
Expert	Single	3565	821	134	36
	Double	76	1292	123	20
	Triple	2	58	262	68
	Quad	1	4	9	57

Table: **Confusion matrix** row, i, column, j, indicates how many complexes the expert classifies i and the model classifies j

Annotation

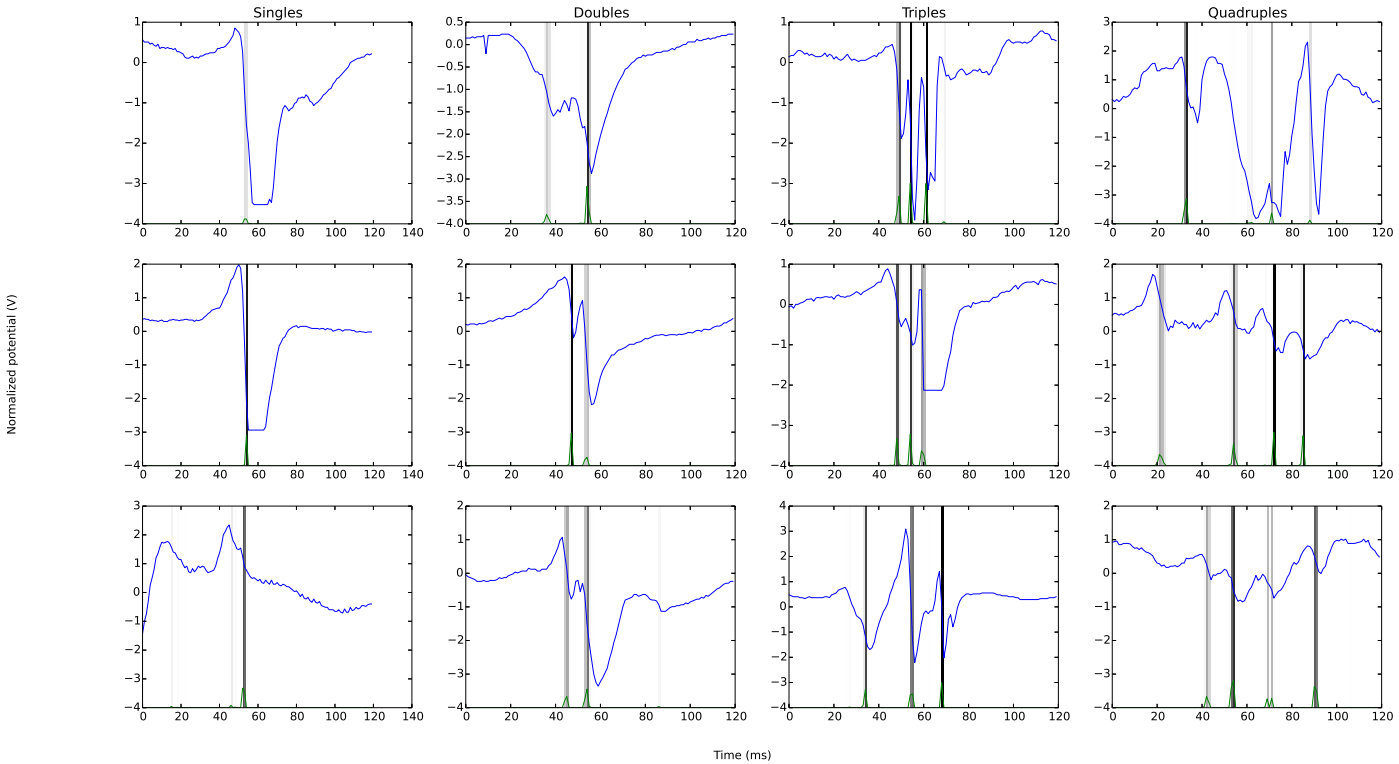


Figure: Probability for annotation per time

Annotation accuracy

- The model annotates 91% of the annotations within 3 ms of the expert annotation

Discussion

- Misclassifications
  - Unbalanced confusion matrix
- Limitations
  - Pipeline
  - Modelling of annotations
  - Early stopping
- Future perspectives
  - Output capability metric

Questions

Anomaly detection

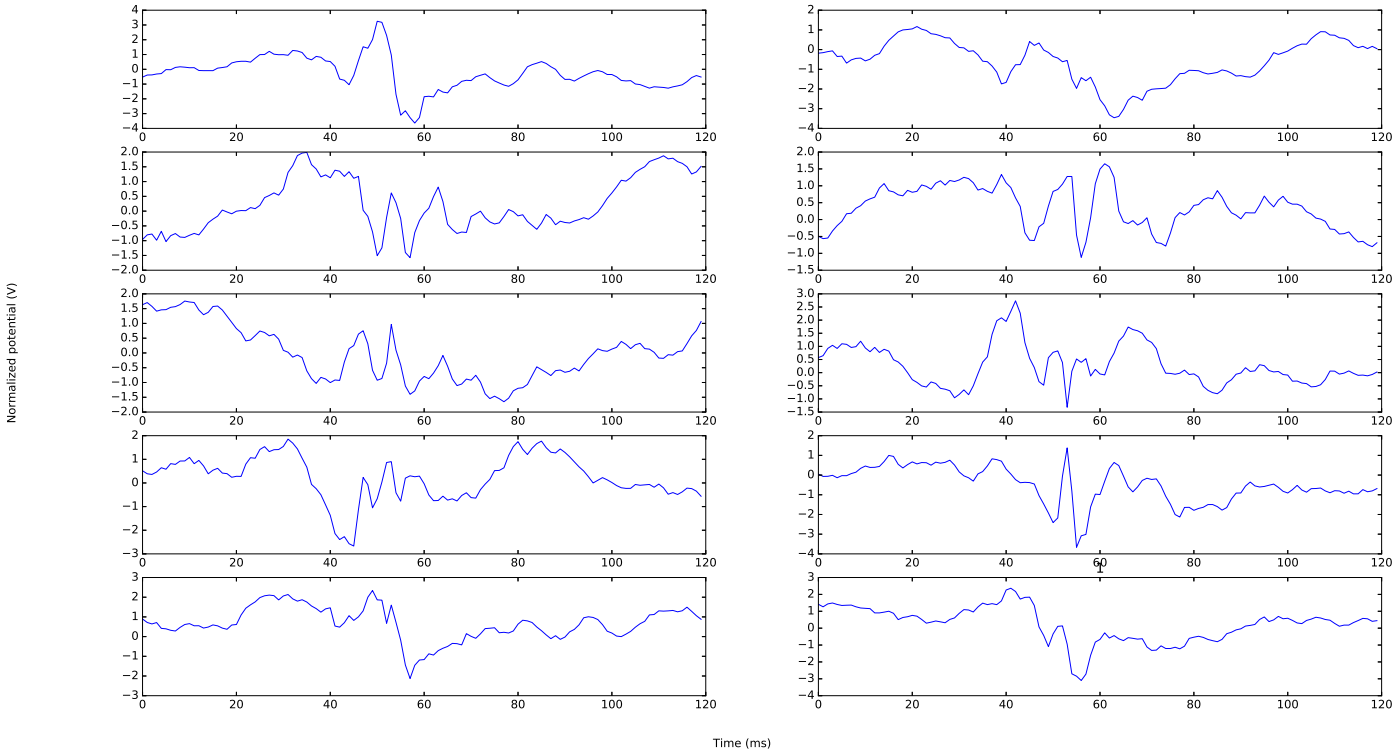


Figure: Noise sampled from 120D Gaussian fit to the data

Accuracy of annotations

		Range		
		3	4	5
Th	0.3	0.912 (0.892)	0.917 (0.901)	0.919 (0.906)
	0.5	0.767 (0.796)	0.772 (0.801)	0.778 (0.805)

Table: **Accuracy of annotations** Range is the maximum allowed distance between annotations by model and expert. Threshold (th) binarizes the probability of an annotation

Pipeline

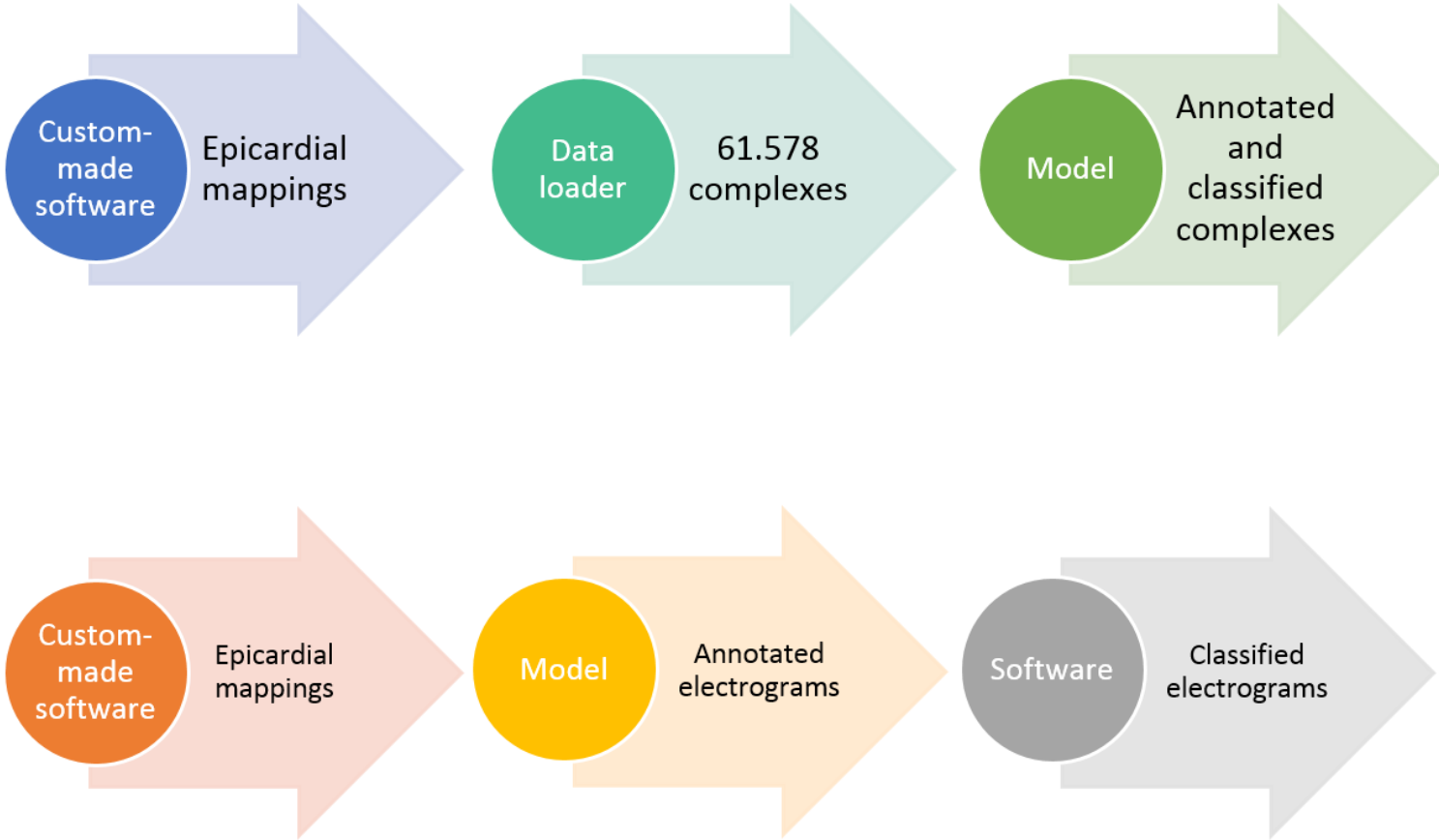


Figure: Data pipeline with improved pipeline

Resampling

Set	Non-fractionated		Fractionated	
	Singles	Doubles	Triples	Quad.
Train.	36414 (12263)	12263 (12263)	3235 (12263)	516 (12263)
Val.	4589 (1493)	1493 (1493)	411 (1493)	61 (1493)
Test	4618 (1485)	1485 (1485)	376 (1485)	75 (1485)

Table: **Sizes of training, validation and test set** The first line denotes size before resampling and the second line (in parentheses) denotes size after resampling

LSTM block

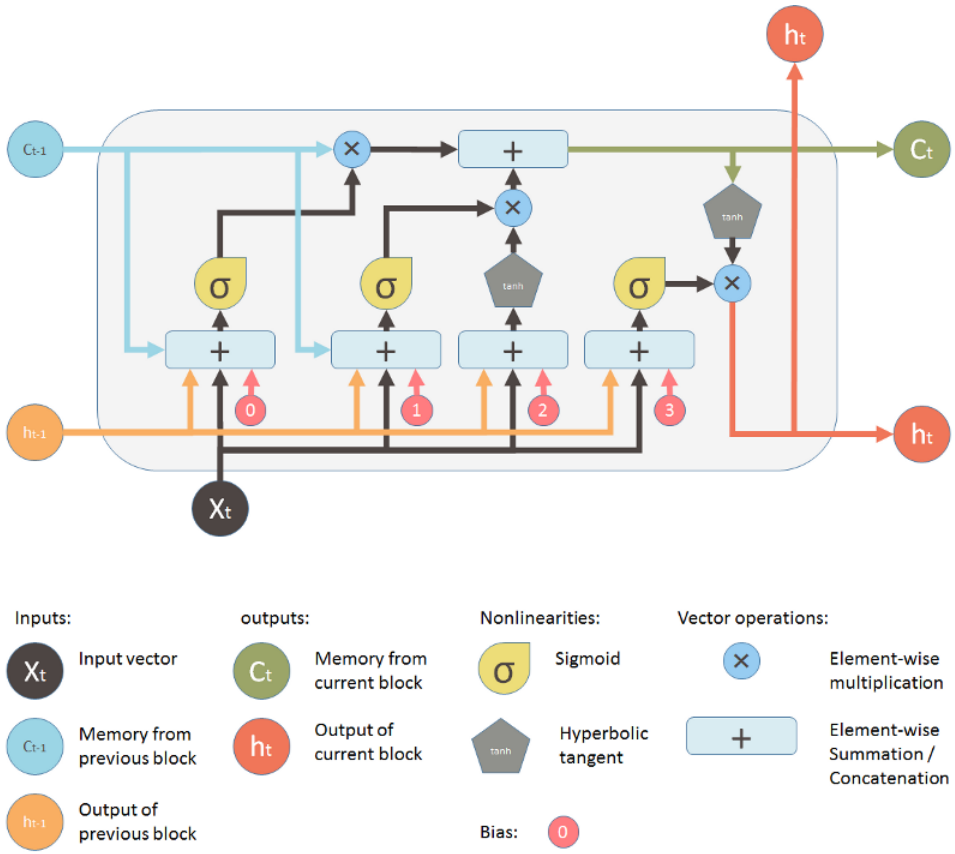


Figure: Diagram depicting LSTM block
Author: Shi Yan. Source: medium.com/@shiyan/

Low confidence samples

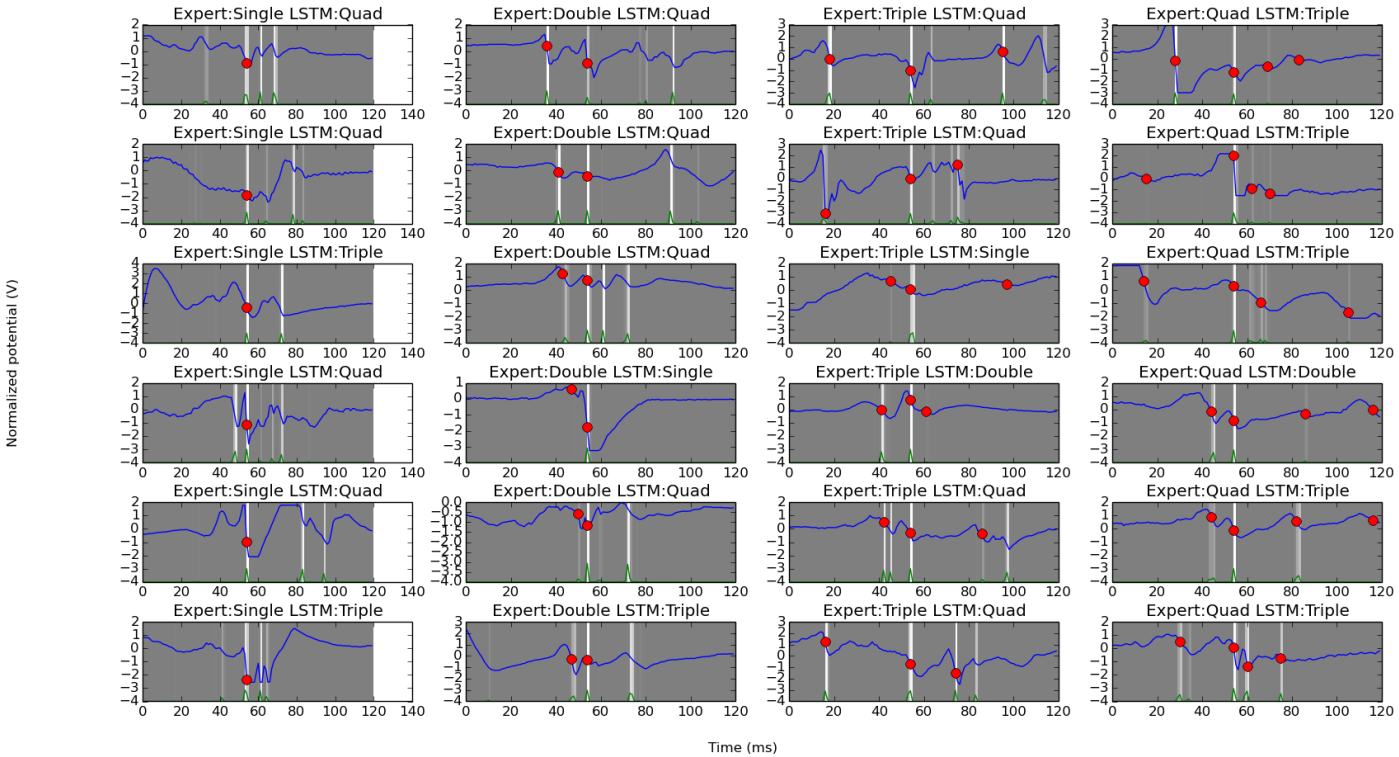


Figure: Samples of low confidence. Ordered per column