УНИВЕРСИТЕТ ЛОБАЧЕВСКОГО
НИЖЕГОРОДСКИЙ ГОСУДАРСТВЕННЫЙ УНИВЕРСИТЕТ

Neuromorphic reservoir computing for ECG heartbeats classification

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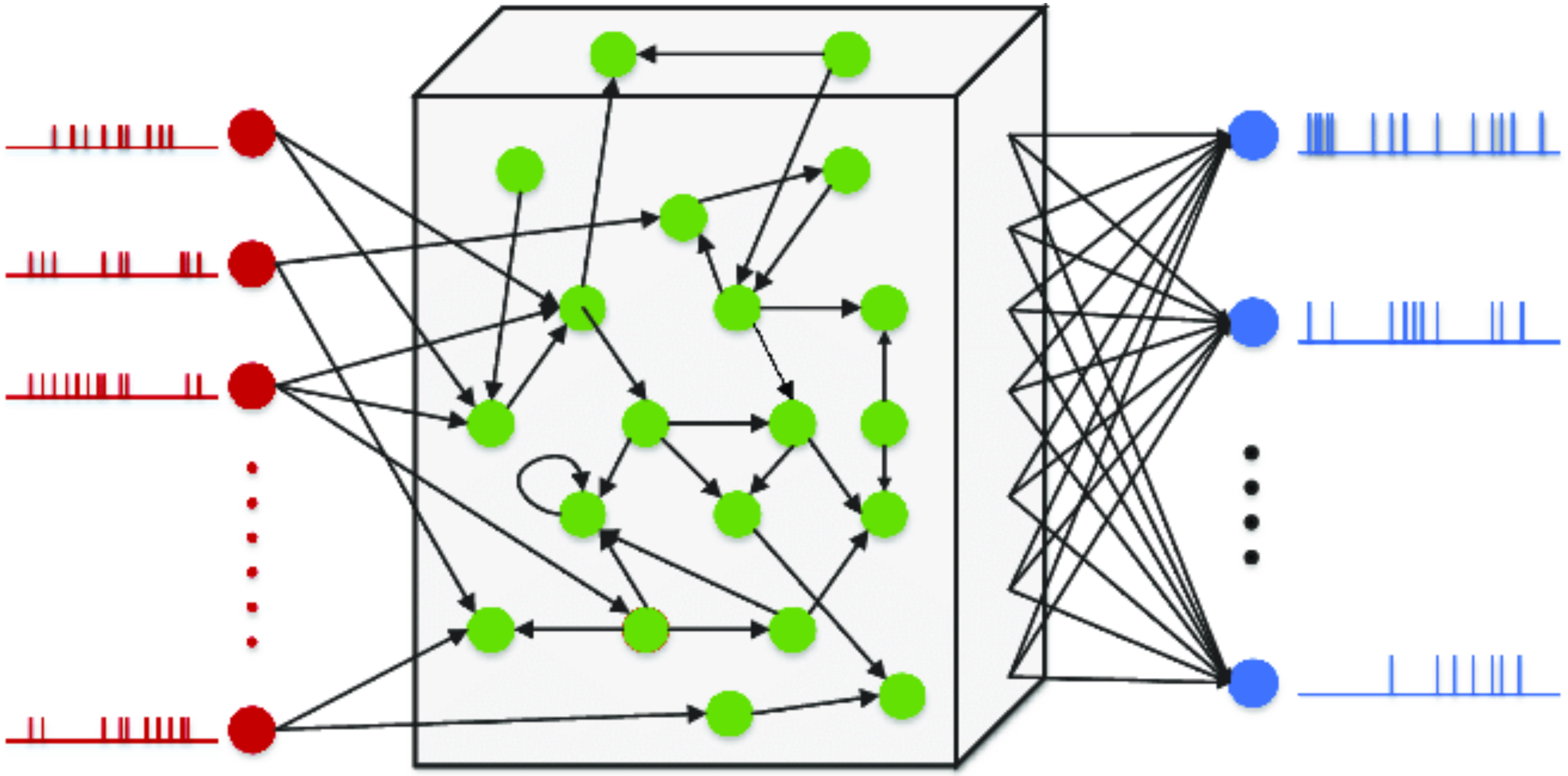
Liquid state machine



Maass, W., Natschläger, T., Markram, H.: Real-Time Computing Without Stable States: A New Framework for Neural Computation Based on Perturbations. Neural Computation 14(11), 2531–2560 (11 2002). https://doi.org/10.1162/089976602760407955

Leaky Integrate & Fire neuron

$$v(0) = 0$$

$$v(t+1) = v(t) + W_{in} \cdot u(t) + W \cdot s(t) - v_{leak}$$

$$\text{if } v_i(t) > v_{th}: \; v_i(t) = v_{res}; s_i(t) = 1,$$

$v(t)$ – the neuron membrane potential

v_{th} – the spiking threshold

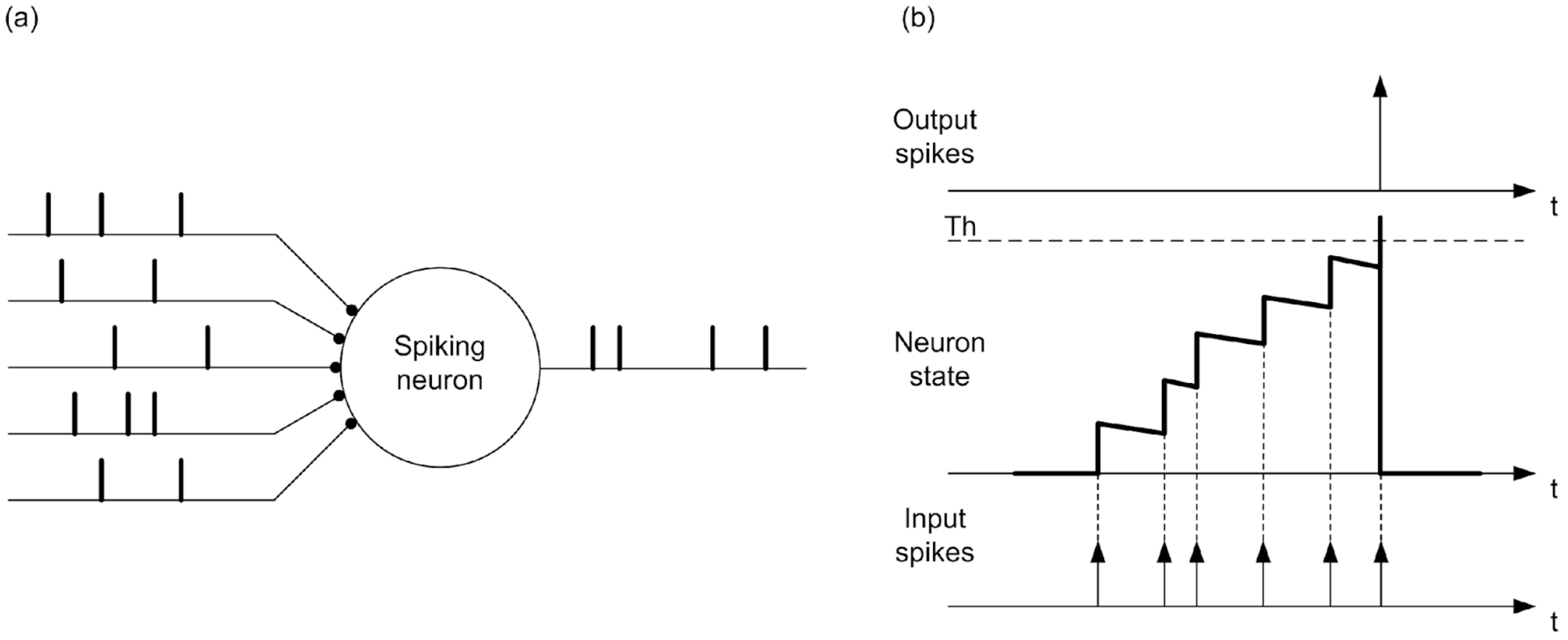
v_{leak} – the leak value

$u(t)$ – the external input spikes

$s(t)$ – the internal spikes

W_{in} – the input weights matrix

W – the liquid connections weights matrix



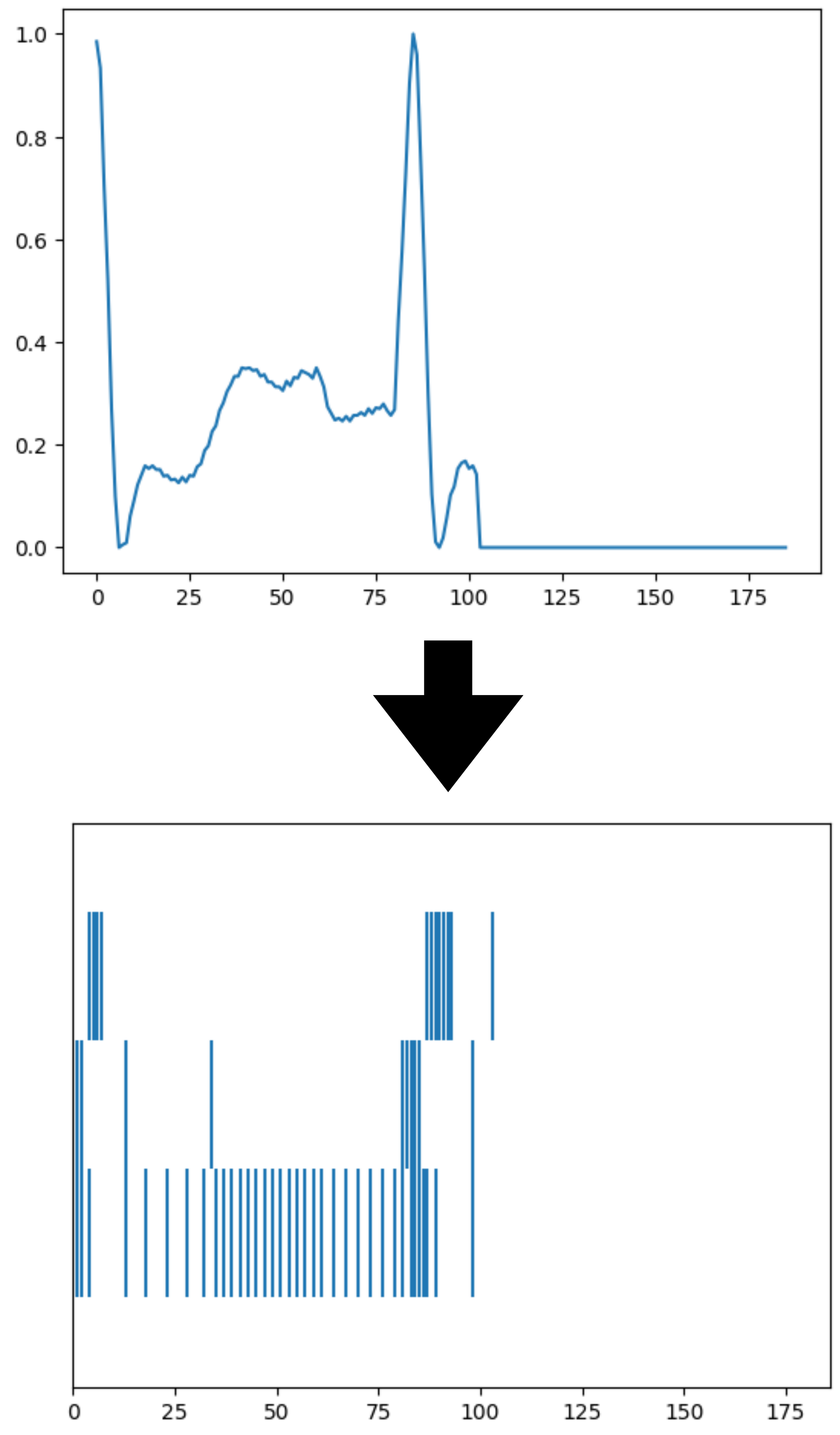
Spike encoding

Step-Forward algorithm:

```
input: signal
threshold = 0.1
out = zeros(len(signal), 2)
base = signal(1)
for t = 2:len(signal)
    if signal(t) > base + threshold
        out(t, 1) = 1
        base = base + threshold
    elseif signal(t) < base - threshold
        out(t, 2) = 1
        base = base - threshold
    end if
end for
output: out
```

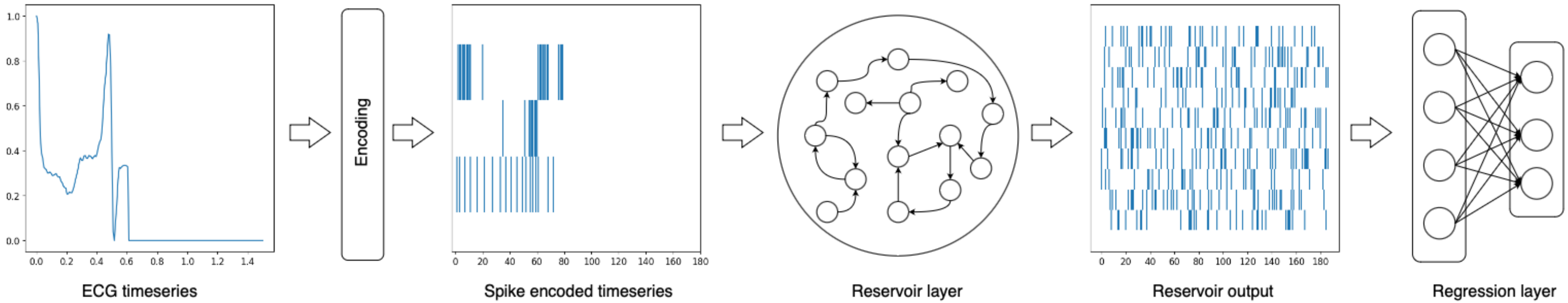
Rate encoding algorithm:

```
input: signal
threshold = 1.0
out = zeros(len(signal), 1)
potential = 0
for t = 1:len(signal)
    potential += signal(t)
    if potential > threshold
        out(t, 1) = 1
        potential = 0
    end if
end for
output: out
```



Petro, B., Kasabov, N., Kiss, R.M.: Selection and Optimization of Temporal Spike Encoding Methods for Spiking Neural Networks. IEEE Transactions on Neural Networks and Learning Systems 31(2), 358–370 (Feb 2020). https://doi.org/10.1109/TNNLS.2019.2906158

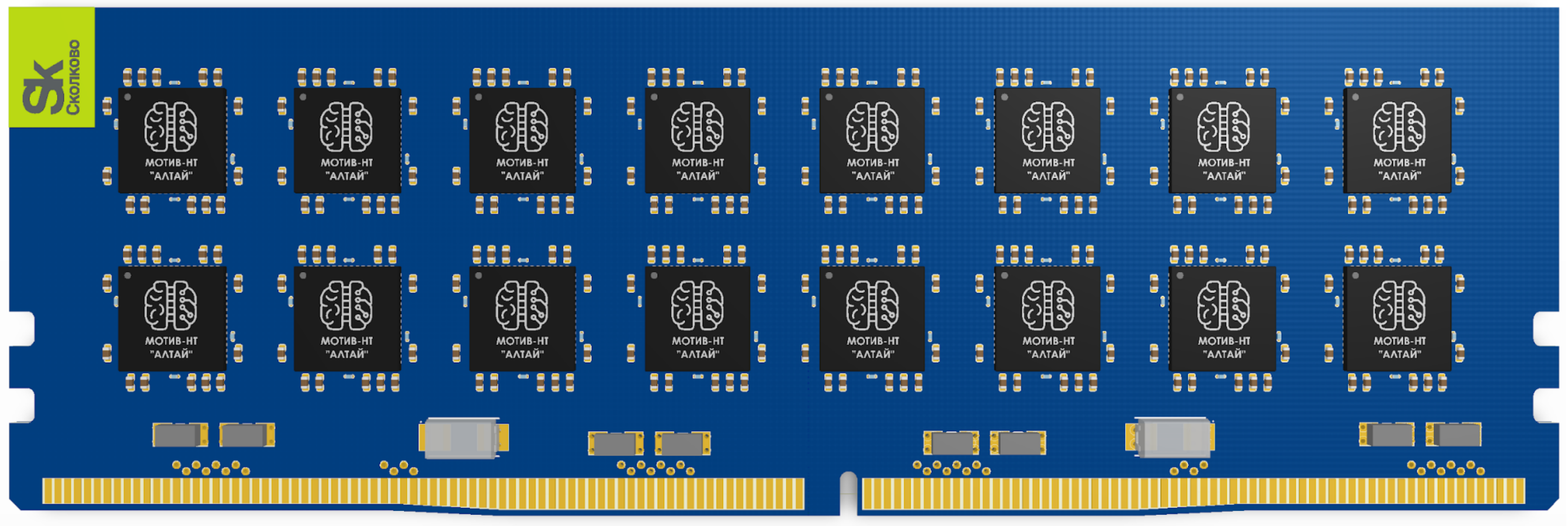
Model



Encoding
ECG timeseries
Spike encoded timeseries
Reservoir layer
Reservoir output
Regression layer

Quantization

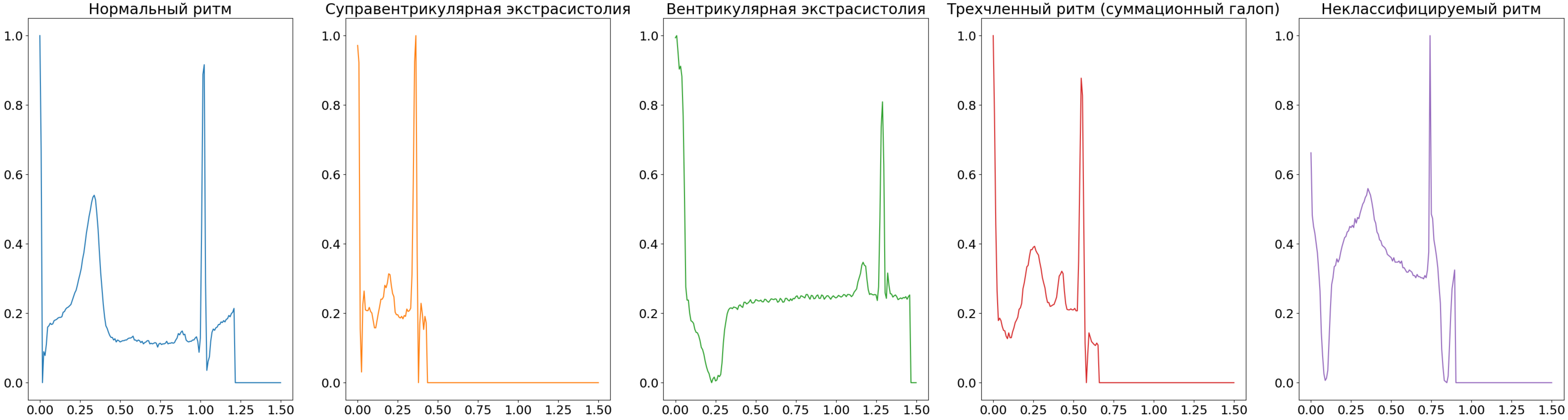
Variable	Bits	Values
Spike	1	{0,1}
Weight	9	[-256, 255]
Potential	16	[-32768, 32767]



https://motivnt.ru/neurochip-altai/

Parameter	Description	Value
E/I	Excitatory/inhibitory neurons ratio	80%/20%
V_{res}	Neuron potential reset value	0
V_{th}	Neuron potential reset value	128
$C_{E->E}$	Excitatory to excitatory connections per neuron	2
$C_{E->I}$	Excitatory to inhibitory connections per neuron	2
$C_{I->E}$	Inhibitory to excitatory connections per neuron	1
$C_{I->I}$	Inhibitory to inhibitory connections per neuron	1

MIT-BIH dataset for hearbeat categorization



Results

Paper	Approach	Average accuracy
This paper	Quantized LSM with LIF neurons	98.56%
Ganguly et al [1]	LSTM	97.3%
S. L. Oh et al. [2]	CNN+LSTM	98.10%
Pham et al. [3]	CNN	98.56%

Hyper-parameter	Description	Value
N	Reservoir size (neurons count)	4000
V_{leak}	Leakage value	8
α_{in}	Neurons percentage per input channel	30 %

1. Ganguly, B., Ghosal, A., Das, A., Das, D., Chatterjee, D., Rakshit, D.: Automated Detection and Classification of Arrhythmia From ECG Signals Using Feature- Induced Long Short-Term Memory Network. IEEE Sensors Letters 4(8), 1–4 (Aug 2020). https://doi.org/10.1109/LSENS.2020.3006756
2. Acharya, U.R., Oh, S.L., Hagiwara, Y., Tan, J.H., Adam, M., Gertych, A., Tan, R.S.: A deep convolutional neural network model to classify heartbeats. Computers in Biology and Medicine 89, 389–396 (Oct 2017). https://doi.org/10.1016/j.compbiomed.2017.08.022
3. Pham, B.T., Le, P.T., Tai, T.C., Hsu, Y.C., Li, Y.H., Wang, J.C.: Electrocardio- gram Heartbeat Classification for Arrhythmias and Myocardial Infarction. Sensors (Basel, Switzerland) 23(6), 2993 (Mar 2023). https://doi.org/10.3390/s23062993

Acknowledgments

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Thank you for your attention!