Dynamic Image Quantization Using Leaky Integrate-and-Fire Neurons

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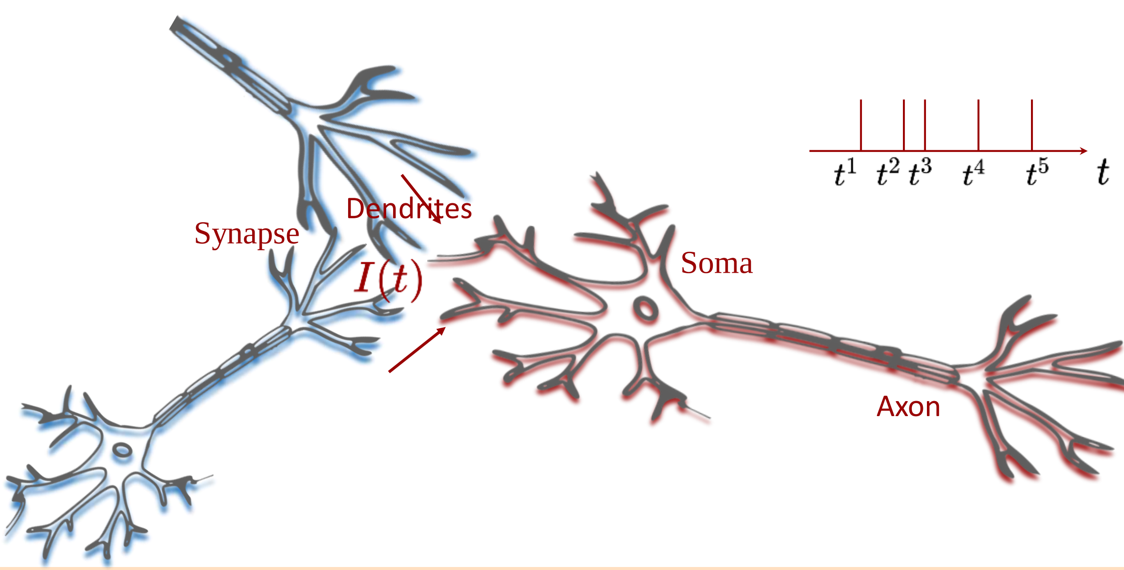
Outline

- ✓ Compression Challenges
- ✓ Motivation
- ✓ Leaky Integrate-and-Fire Quantizer
- ✓ Experimental Results
- ✓ Conclusion

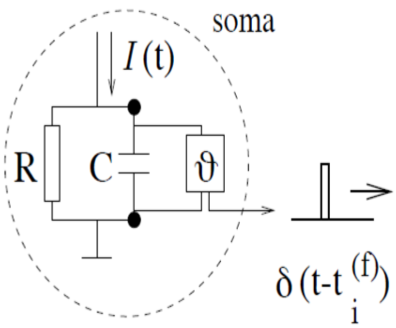
Compression Challenges

- The amount of images and videos is exponentially increasing over time.
- The progress of compression standards is too slow.
- The complexity and power consumption of the state-of-the-art compression algorithms are too high.
- Most of the latest multimedia devices have short battery-life.
- There is a need of new energy-efficient technologies that take under consideration the human visual perception.

Spiking Neurons



Leaky Integrate-and-Fire (LIF) Model*



- Neurons are approximated by an electrical circuit that consists of a capacitor C in parallel with a resistor R driven by an input current $\mathrm{I}(t)$.
- A neuron spikes when its membrane potential $V(t)$ crosses some threshold θ.
- The moment of threshold crossing defines the firing time

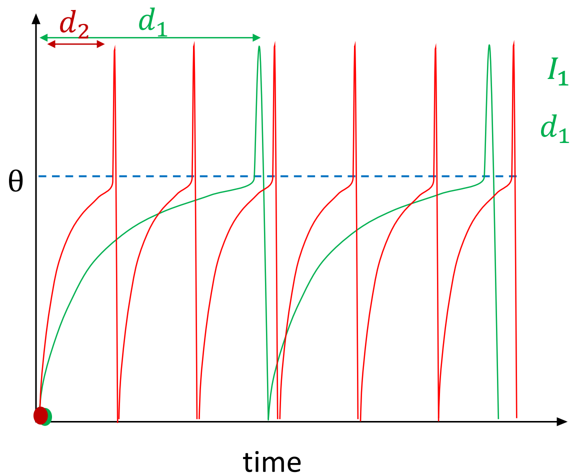
$$t^f : V(t^f) = \theta.$$

*W. Gerstner and W. Kistler, "*Spiking neuron models: Single Neurons, Populations, Plasticity,*" Cambridge University Press, 2002.

Spike Interpretation Mechanisms (SIM)

- Rate-SIM
  - Mean firing rate
  - Spike count
  - Spike Density
- Time-SIM
  - Time-to-first-spike
  - Rank-order-coder

Spike Arrival Delay



- Assumption $f(x,t) = f(x)1_{[0,T]}(t)$
- The exact spike arrival time is given by:

$$d = \begin{cases} +\infty, & RI < \theta \\ h(RI;\theta) = -\tau_m \ln\left[1 - \frac{\theta}{RI}\right], & RI > \theta \end{cases}$$

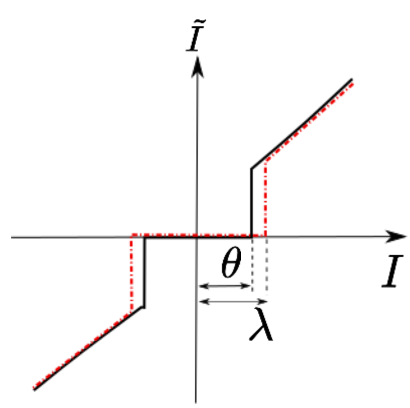
Perfect-LIF Quantizer*

If one knows the delays d it is possible to perfectly reconstruct all the input intensities above the threshold θ :

$$\tilde{I} = \begin{cases} 0, & d > T \\ I = h^{-1}(d;\theta), & d \le T \end{cases}$$

where

$$h^{-1}(d;\theta) = \frac{\theta}{R\left(1-\exp\left(-\frac{d}{\tau_m}\right)\right)}.$$

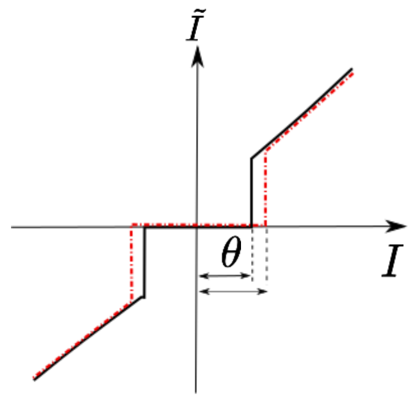


* E. Doutsi, L. Fillatre, M. Antonini, and J. Gaulmin, "Neuro-inspired Quantization," in *IEEE ICIP*, Athens, 2018.

Perfect-LIF Quantizer*

PROS AND CONS

- ❖ Thresholding function
- ❖ High reconstruction quality
- ❖ High memory cost
- ❖ Inefficient in terms of compression



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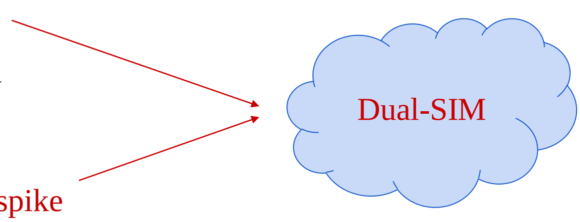
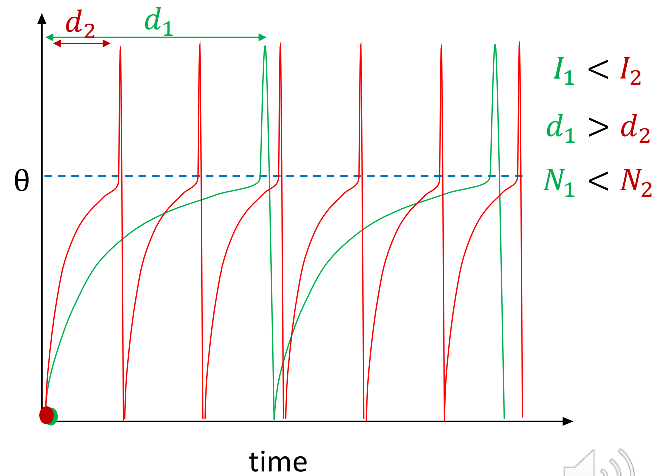


Spike Count*

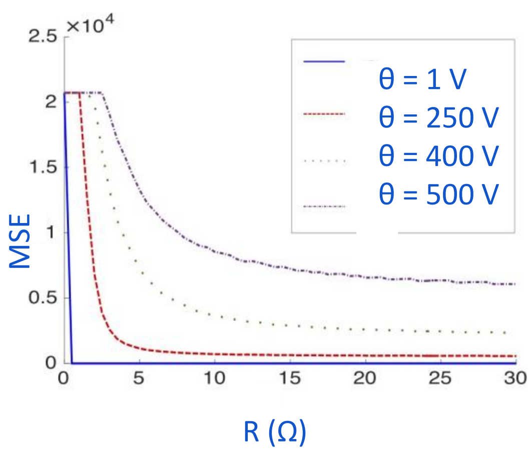
To reduce the range of the delays and produce a more efficient code we have decided to count the number of spikes within the time interval $[0, T]$ when the input signal exists:

$$N = N(I)\begin{cases} 0 & \text{if} \quad RI \leq \lambda \\ \left\lfloor \frac{T}{d} \right\rfloor & \text{if} \quad RI > \lambda \end{cases}$$

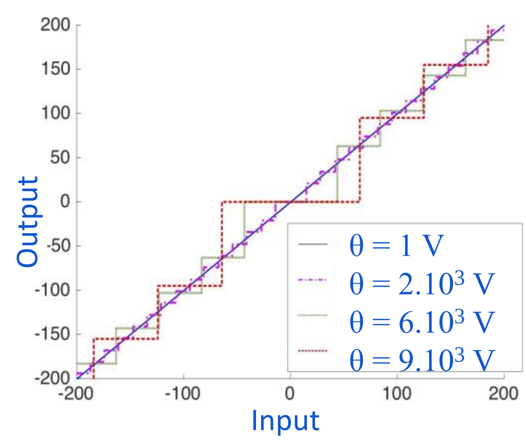


* E. Doutsi, *et. al*. "Efficiency of the bio-inspired Leaky Integrate-and-Fire neuron for signal coding," *IEEE EUSIPCO*, 2019.

Threshold θ

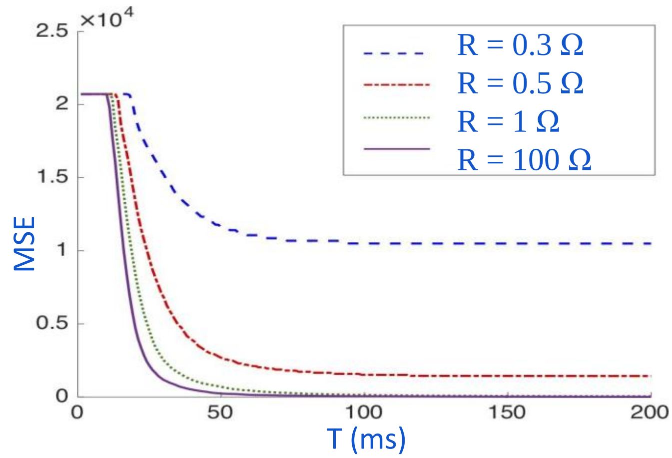


(a) Parameters: C = 50 F, T = 200 ms.



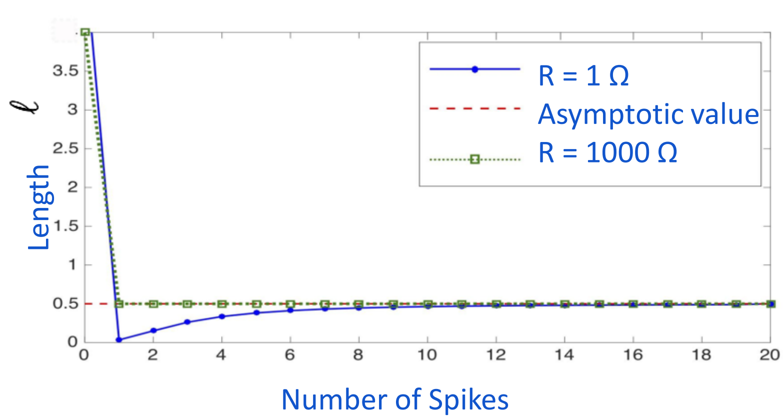
(b) Parameters: T = 150 ms, R = 10^3 Ω, C = 1 F

Observation window T



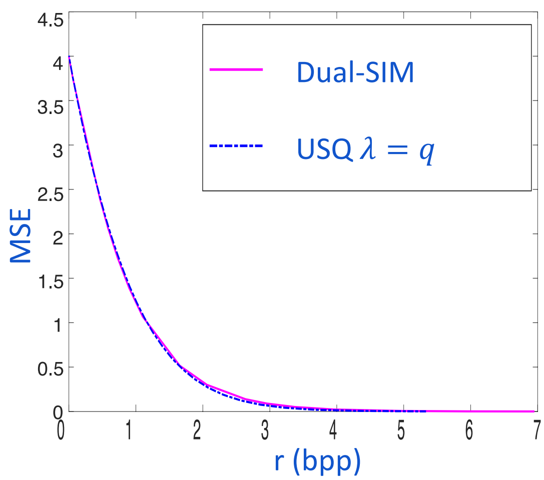
Parameters: C = 50 F, θ = 50 V.

Resistance R

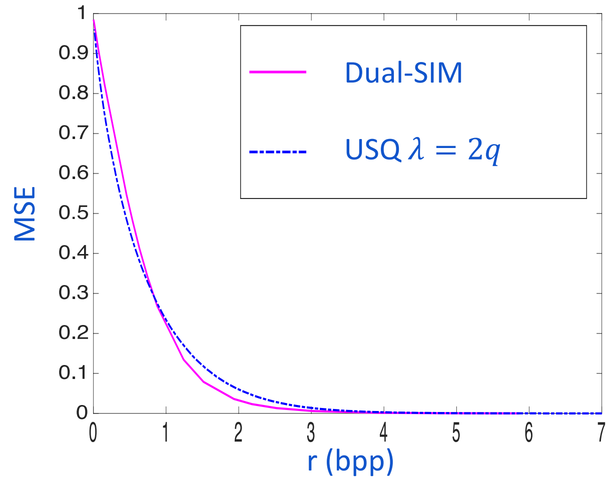


Parameters: θ = 5 V, C = 10 F and T = 100 ms.

Dual-SIM vs Uniform Scalar Quantizer

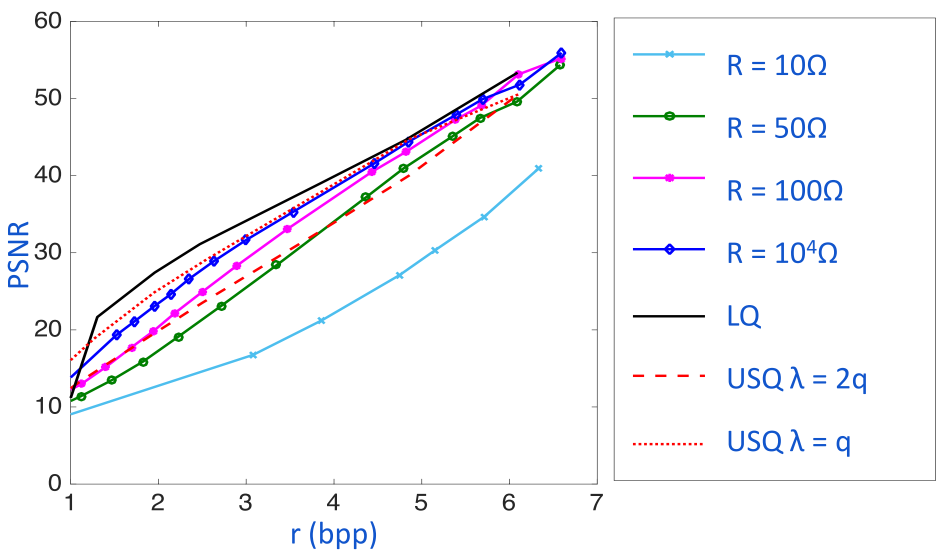


(a) Laplacian



(a) Gaussian

Dual-SIM vs SOTA Quantizer for Synthetic Data



Visual Comparison between Dual-SIM and SOTA

USQ
PSRN = 46.27dB
R = 5.33 bpp

LQ
PSRN = 48.91dB
R = 5.73 bpp

Dual-SIM
PSRN = 46.43dB
R = 5.38 bpp

USQ
PSRN = 26.26dB
R = 2.21 bpp

LQ
PSRN = 27.22dB
R = 2.25 bpp

Dual-SIM
PSRN = 26.86dB
R = 2.2 bpp

Conclusion

In this work…

- ✓ We propose a novel, bio-inspired encoder/decoder of natural images called Dual-SIM quantizer
- ✓ The encoder is based on the Leaky Integrate-and-Fire model
- ✓ The decoder is a combination of two spike generation mechanisms
- ✓ The Dual-SIM quantizer allows to encode the input values in a simple and dynamic manner, mimicking the neural behavior.

Contact

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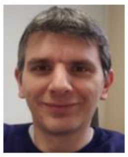

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