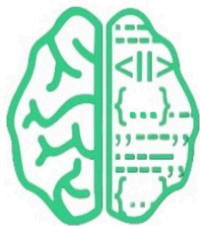


Beyond Pixels: Novel Evaluation Frameworks for Spike-Based Compression Mechanisms

Effrosyni Doutsis, Ph.D.

VQEG 2025



BRAINCODE

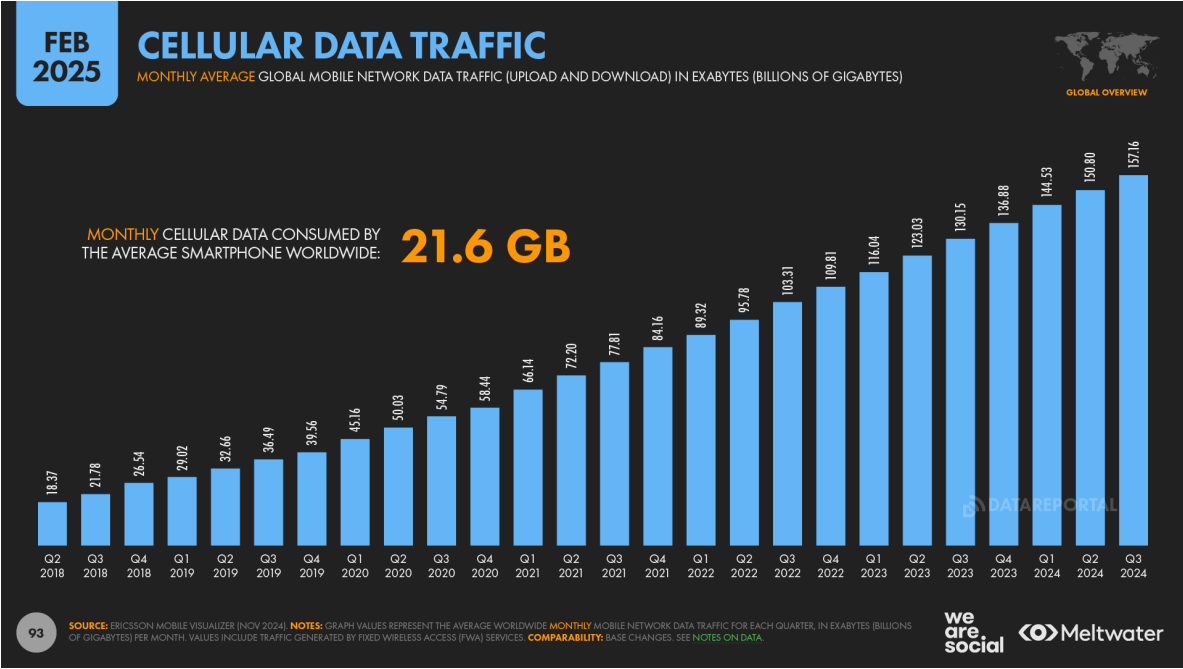
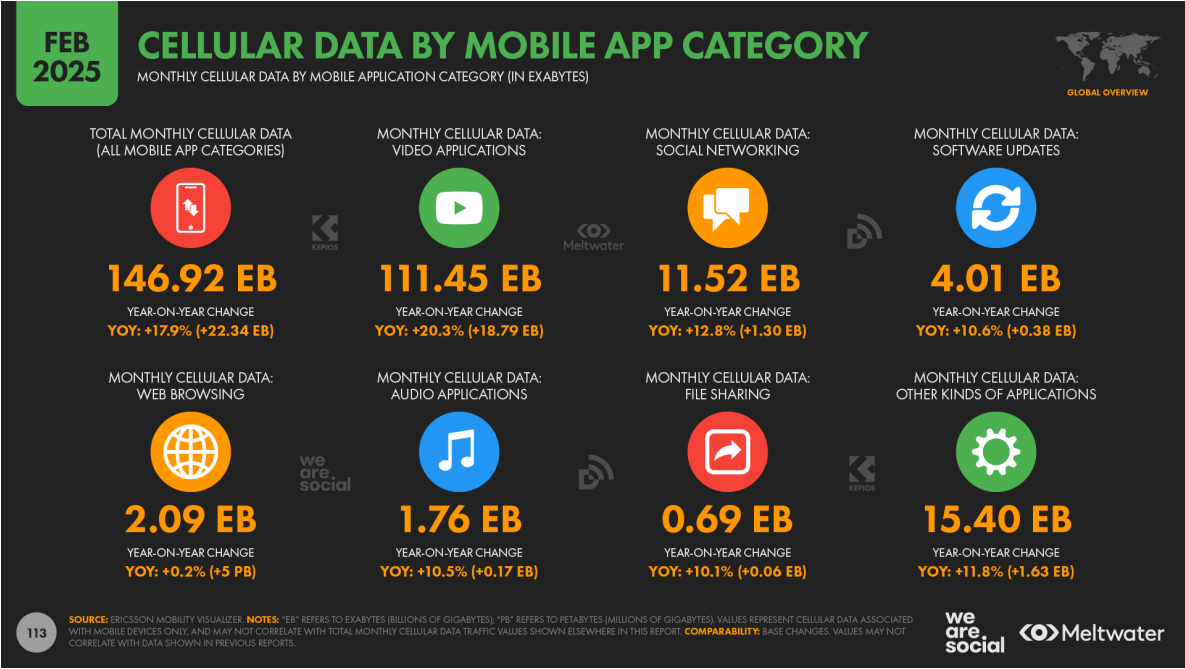
Brain-inspired Intelligence for
Semantic Video Compression



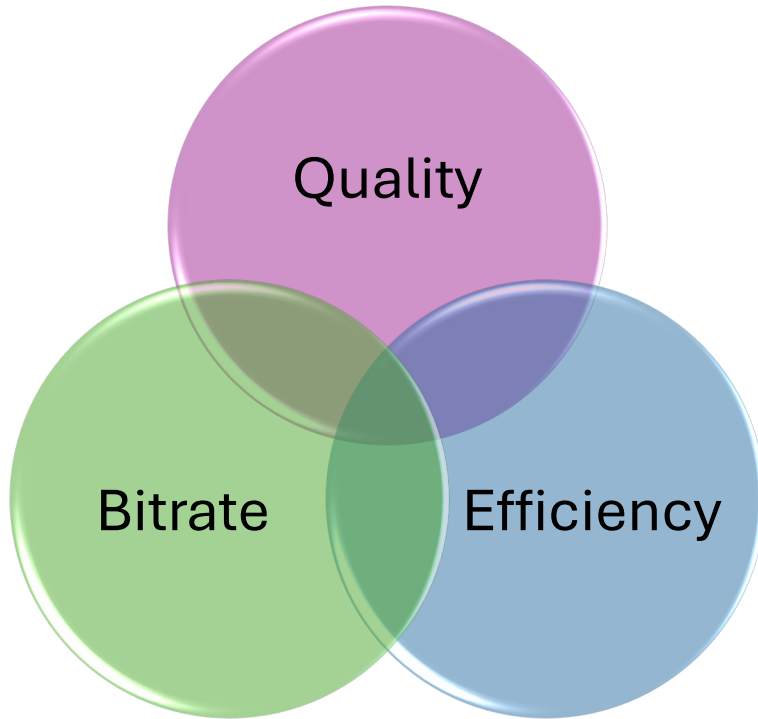
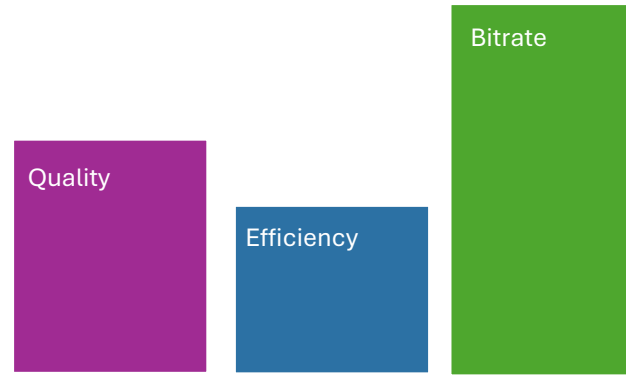
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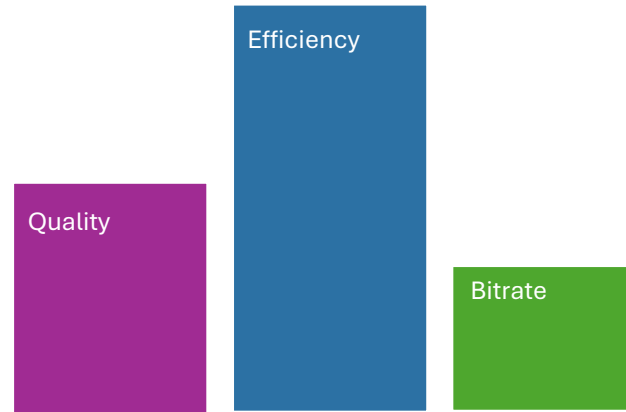
Challenges - Mobile Data Traffic



Quality, Bitrate and Efficiency Trade-off



Holding Quality **constant**, while **minimizing** Efficiency, **increases** the Bitrate



Holding Quality **constant**, while **minimizing** the Bitrate, **increases** the computational cost

BrainCode: Brain-inspired intelligence for Semantic Video Compression



BRAINCODE
Brain-inspired Intelligence for
Semantic Video Compression

Objectives

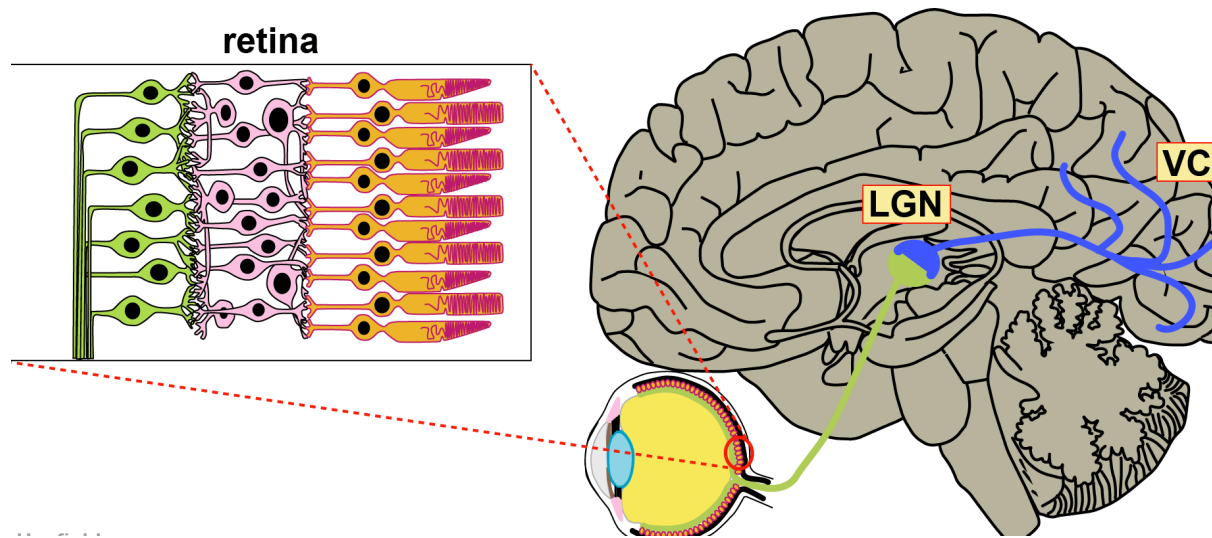
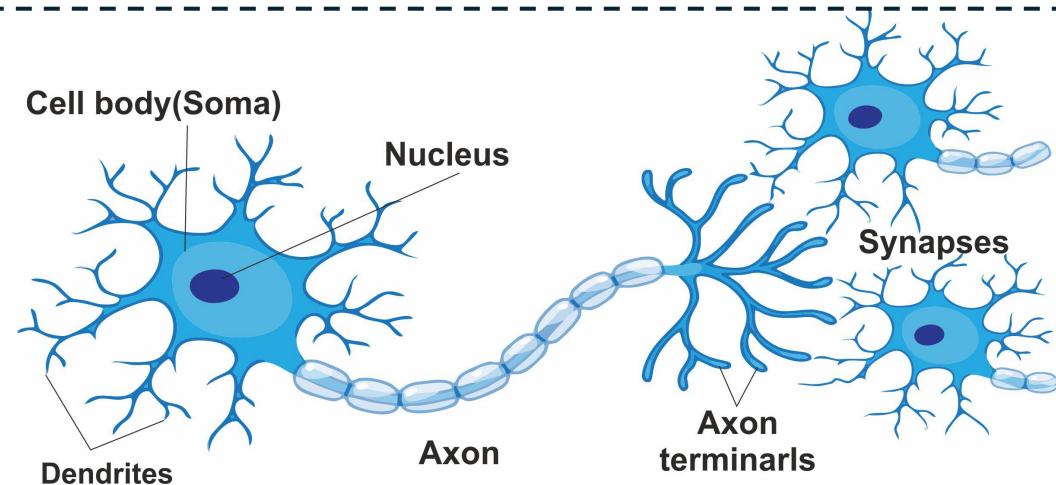
- Design a compression architecture inspired by the **structure and computation** of the biological visual system.
- Develop a **content-aware** video compression system that dynamically drives bit allocation using AI.
- Achieve **high accuracy with minimal operations** by mimicking the brain's energy-efficient processing.
- **Reduce energy consumption** compared to current compression standards by leveraging neuromorphic architectures.
- Capture **temporal dynamics** of visual scenes in a **biologically plausible** and adaptive way.



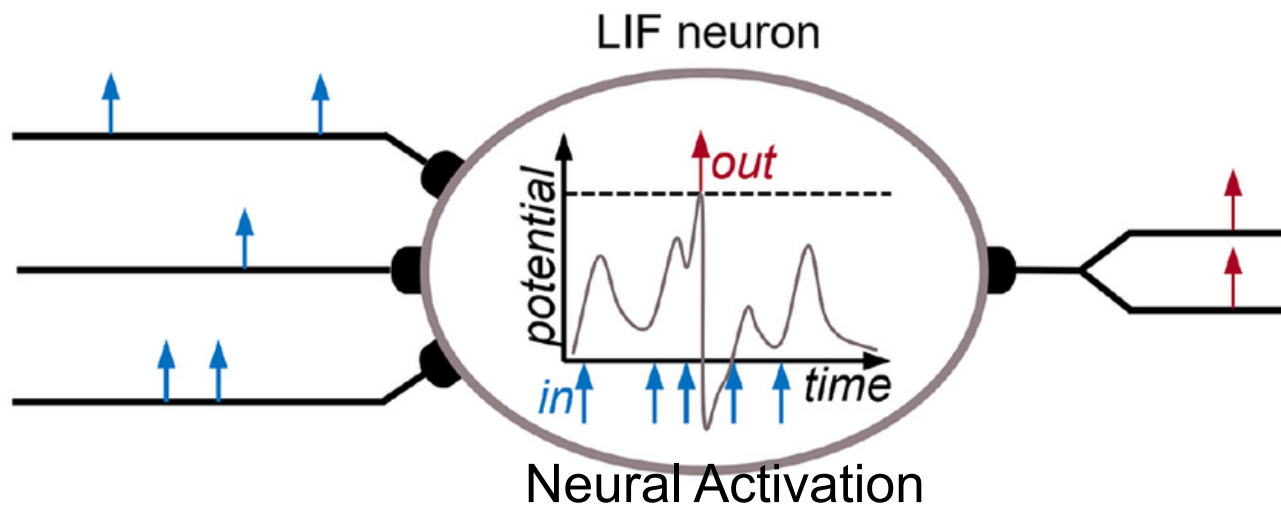
Frames vs Events



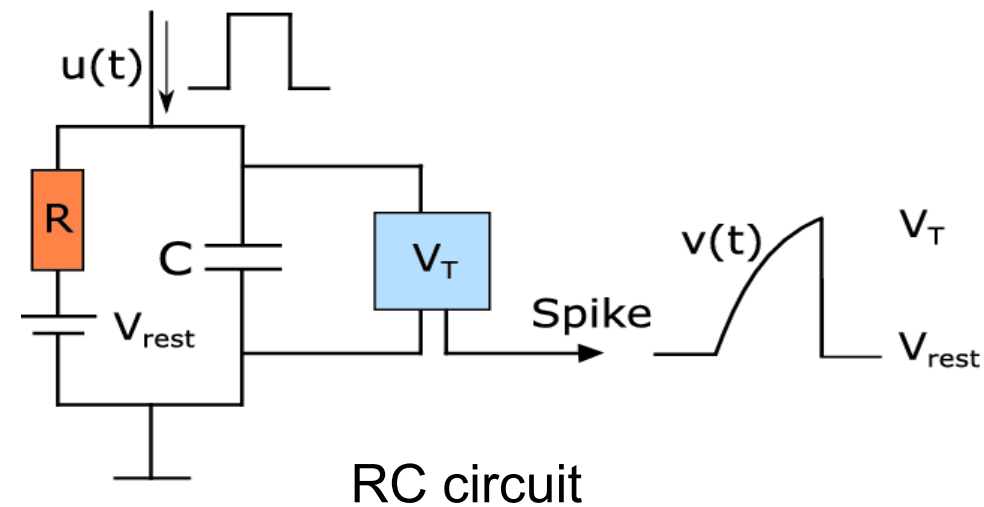
A Glimpse in Neural Processing



Biological Neuron

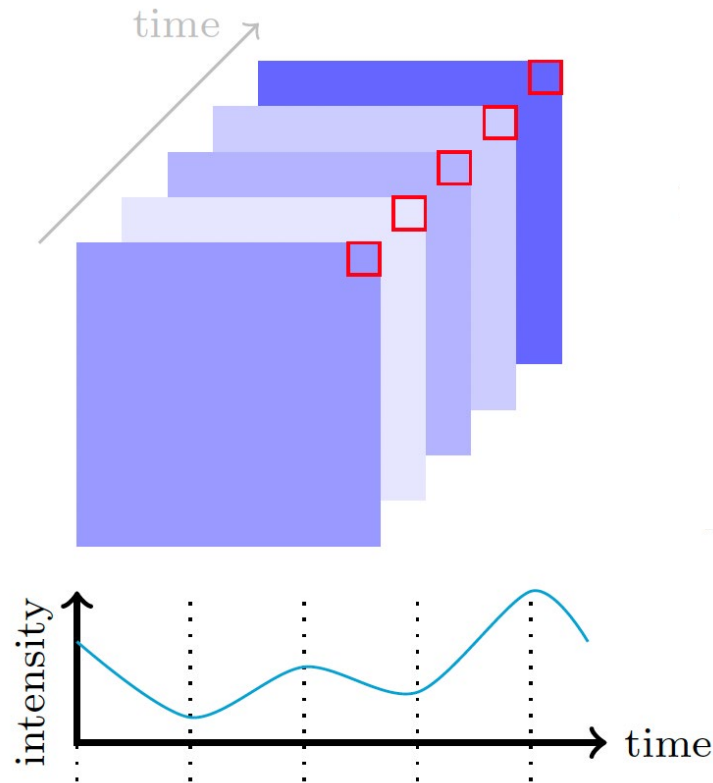
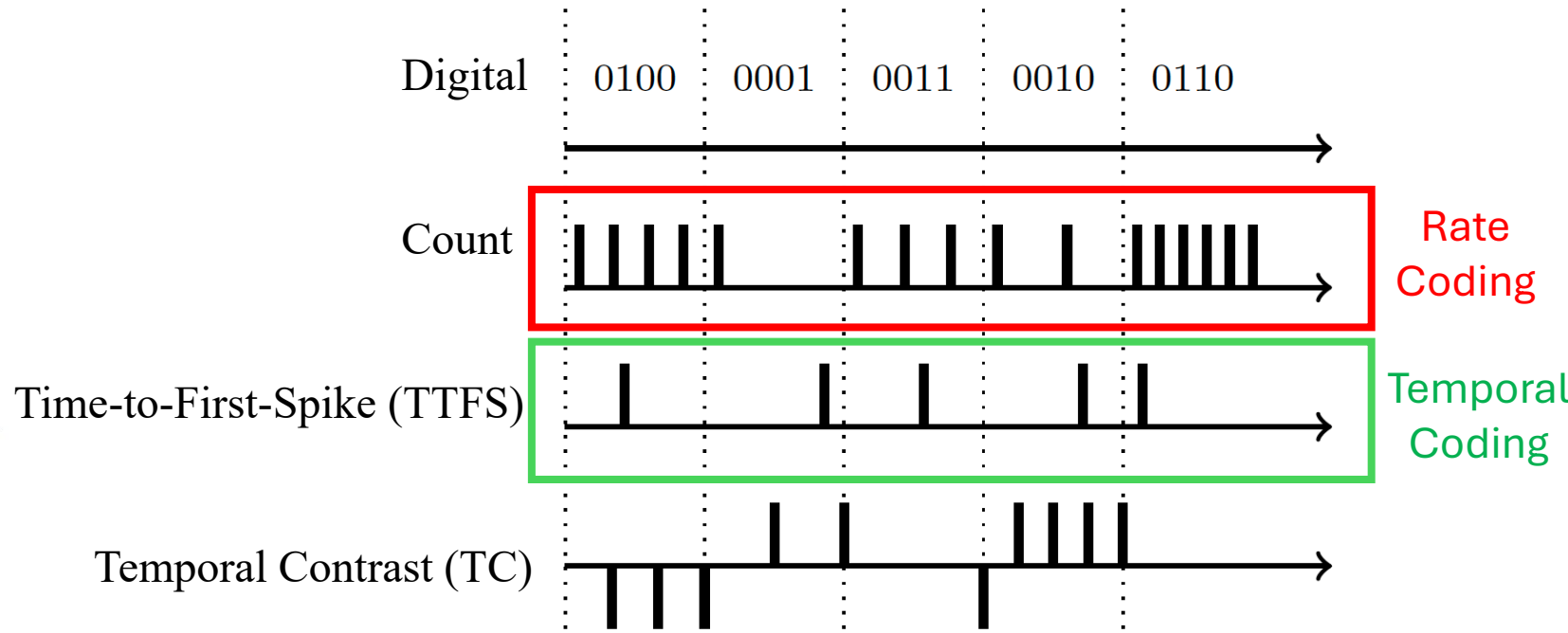


Neural Activation



RC circuit

Example of Coding Schemes for a sequence of Images in time



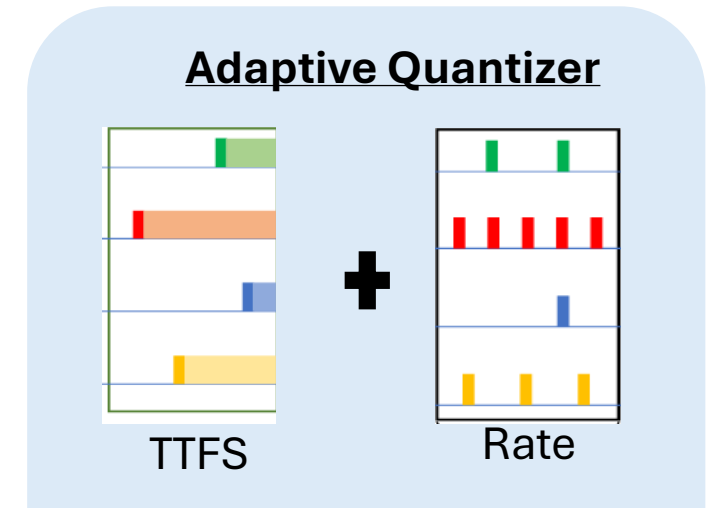
Where to use spikes

- Image/Video Compression
- Transcoding
- Reduce the computational cost of CNNs by converting into SNN
- Learning Tasks
 - Classification ([Tavanaei et. al. 2019](#), [Sboev et. al. 2020](#))
 - Event/Anomaly detection ([Chen et. al. 2017](#))
 - Robotic applications ([Bing et. al. 2018](#), [Milde et. al. 2017](#))
 - Visual Pattern recognition ([Serre et. al. 2007](#), [Wysoski et. al. 2008](#))
 - Object Tracking ([Zhang et. al. 2022](#),)
- Neuromorphic Chips (TrueNorth, Loihi 1/2, Tianji, NorthPole)

Evaluation Process

Bitrate

- Generate the code of **spikes** using a TTFS model
- Use the **adaptive quantizer** (TTFS + Rate Coding)
 - Each pixel is encoded by a different time delay
 - For given time instances we counted the number of spikes
 - Entropy coding



Quality

- Reconstruct the pixel values and use famous full-reference and/or no-reference quality metrics

Limitations

- VMAF/PSNR/SSIM focus on pixel-wise similarity
- Spike-based algorithms are temporal and sparse — not frame-based
- Need evaluation that respects spike timing, information content, and perceptual quality

What does the brain perceive?



- Initially, it captures **low frequencies** - approximated by a Gaussian filter
- As time evolves, higher the eye selects both **low and high frequencies** - approximated by a Difference of Gaussians (DoG)
- Finally, **higher frequencies** are captured – approximated by another DoG filter.

Remark – Overall, a **weighted Difference of Gaussian (wDoG)** has been a good approximation of the human vision filtering according to neuroscience models

Step 1 - Visual Features Perceived over Time



Original



WDog
t = 26ms



WDog
t = 31ms

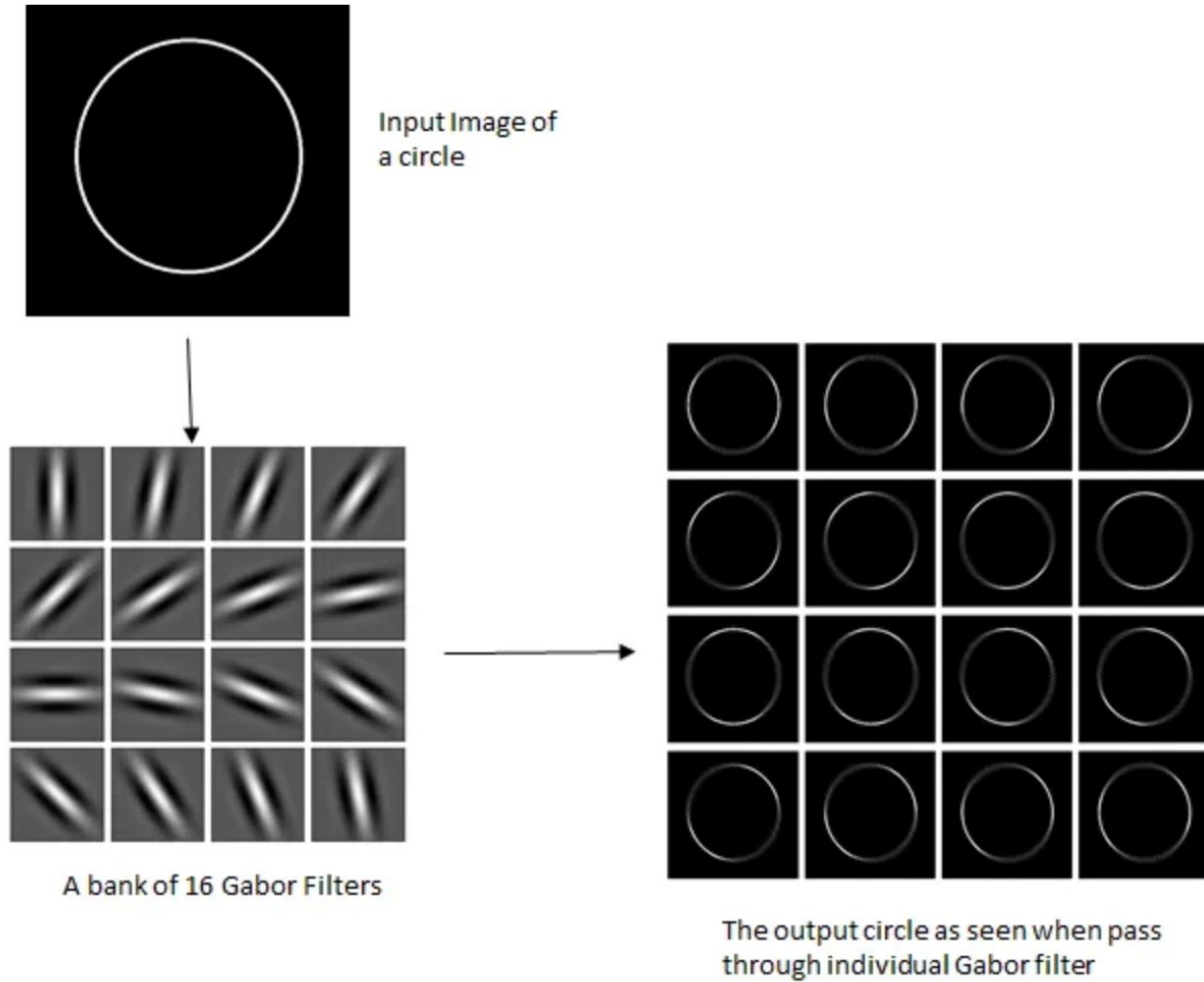


WDog
t = 36ms



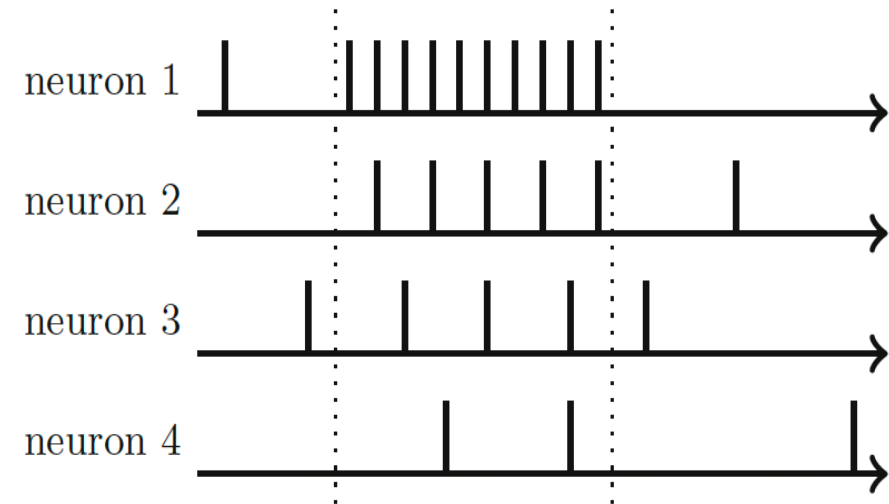
WDog
t = 41ms

Step 2 - Oriented Edge Features



Step 3 – Spike Train Distances

- Assess the spike code by applying **statistical metrics** that quantify differences between spike train distributions.
- While precise timing is critical for generating the code, it is the **collective** change in population response that must be detectable by the brain.



Conclusion

- Understanding how the brain perceives visual input is critical for effective evaluation.
- Integrating neuroscience models can enhance both the **processing** and **assessment** of visual information.
- Quality metrics would leverage:
 - Knowledge of **spike generation mechanisms**
 - **Neuronal selectivity** and population responses
 - **Neuroscience models** explaining the different structures and processing units of visual pathway

Thank you
Q&A