



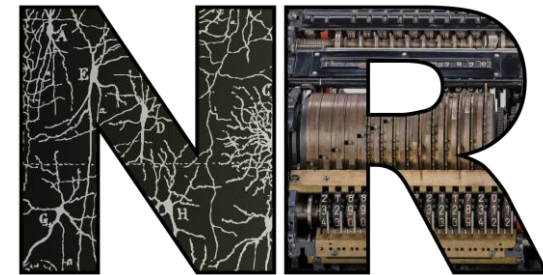
Learning to use neuromodulation for efficient sensory processing

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IMPERIAL



neural-reckoning.org

Philosophical intro: what can we learn from neural models?

Worth asking this question because everyone sees it differently

Plus, we'll be talking about this later in the Discussion

I'm interested in understanding "intelligence", not just the brain (**multiply realisable**)

This opens up many questions that might not obviously interest neuroscientists

But they should!

We can't understand the brain's unique solution to "intelligence" without understanding a bit about the **space of possible alternative solutions - not just about fitting or predicting data**

My limited approach to neural models: *pure theory, comparison across realisations, no fitting/prediction*

Baseline neuron model + Bio-inspired feature = New computational capacity

Experimentally
validated

Biological neuron

Known to exist in brain,
mechanism and function
not fully understood

Hypothesis for
mechanism-function
link in brain

Last minute addition:

ALL parameters solve the task

Many (partially) match data

The neuromodulation model

Following the formula on the previous slide, the approach will be this:

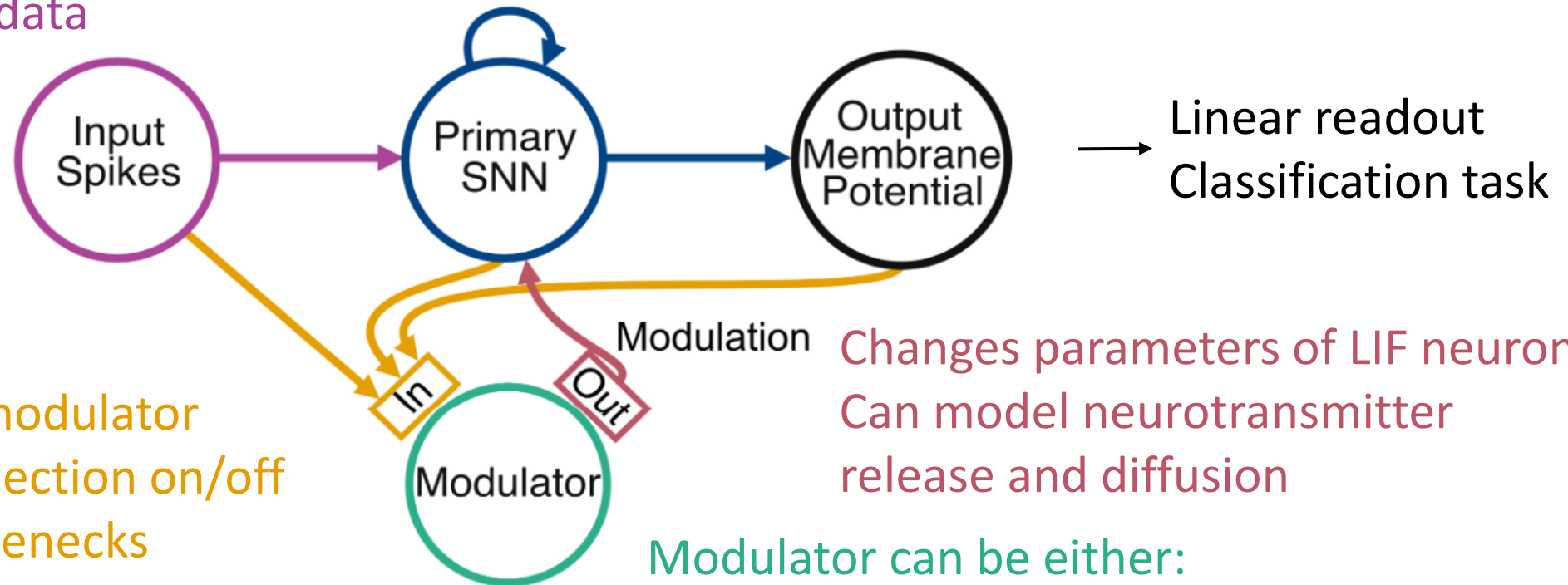
Baseline LIF model + Abstract model of neuromodulation = Lots of nice things (you'll see)

Spike-coded sensory data

Auditory: SHD, SSC

Visual: DVS

Recurrent SNN trained with surrogate GD



Spikes as input to modulator
Can turn each connection on/off
Can introduce bottlenecks
Can compress

Changes parameters of LIF neurons
Can model neurotransmitter release and diffusion

Modulator can be either:

- MLP (an ANN)
- SNN

The equations slide (feel free to doze if it's not your thing)

Simplest version

Output of the ANN modulator network is x targeting parameter p

Substitution rule: replace $p \leftarrow x$

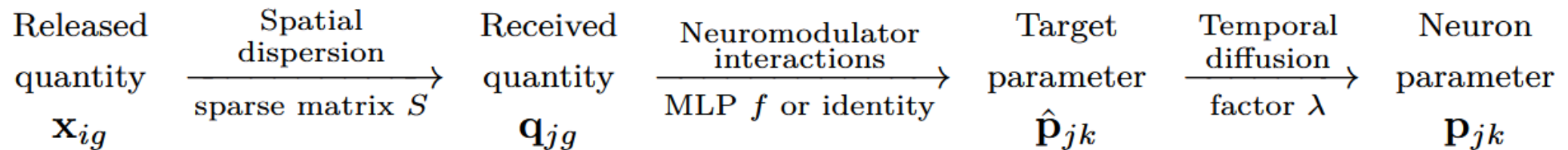
Addition rule: replace $p \leftarrow p + x$

Output of the SNN modulator network is a spike with weight δp targeting parameter p

SNN addition rule: replace $p \leftarrow p + \delta p$

In every case, one output for each target neuron and parameter, or group these effects

Most general version (won't go into detail)



i = release site, j = neuron index, g = neuromodulator type, k = parameter index

Same sound. Different response.

Neuron parameter modulation

$\lambda = 1.0$

REAL-TIME / 1.4 SECONDS

SPOKEN DIGIT · ENGLISH 01 / 05

“six”



0.00 s

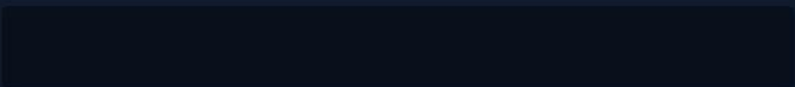
LISTENING

UNMODULATED

Original baseline · fixed neuron parameters



HIDDEN SPIKES



CURRENT PREDICTION

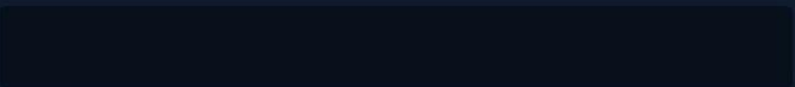
Listening...

MODULATED

Adaptive neuron parameters · $\lambda = 1.0$



HIDDEN SPIKES



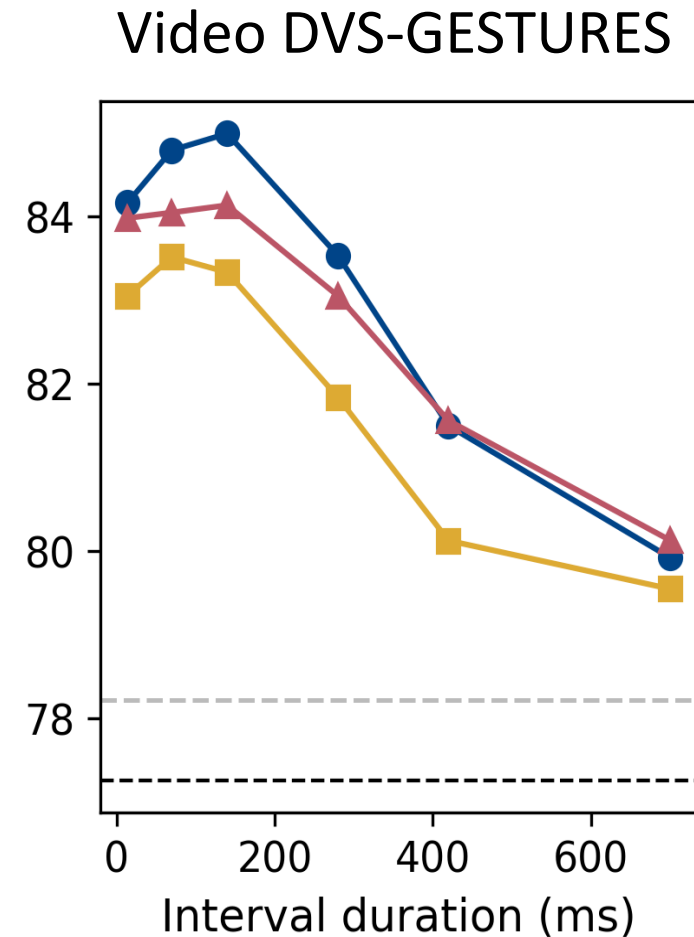
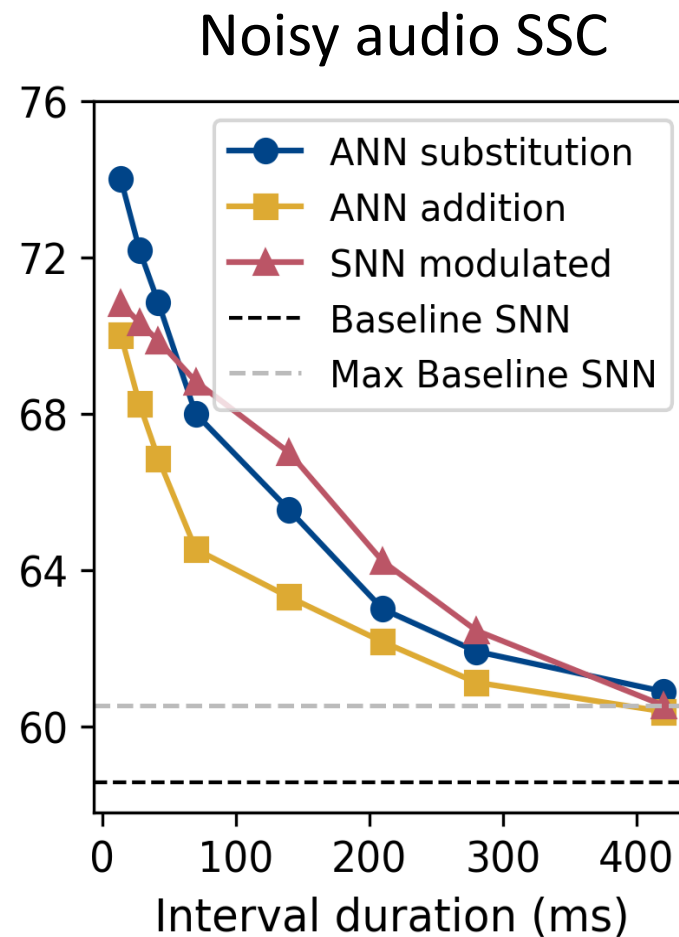
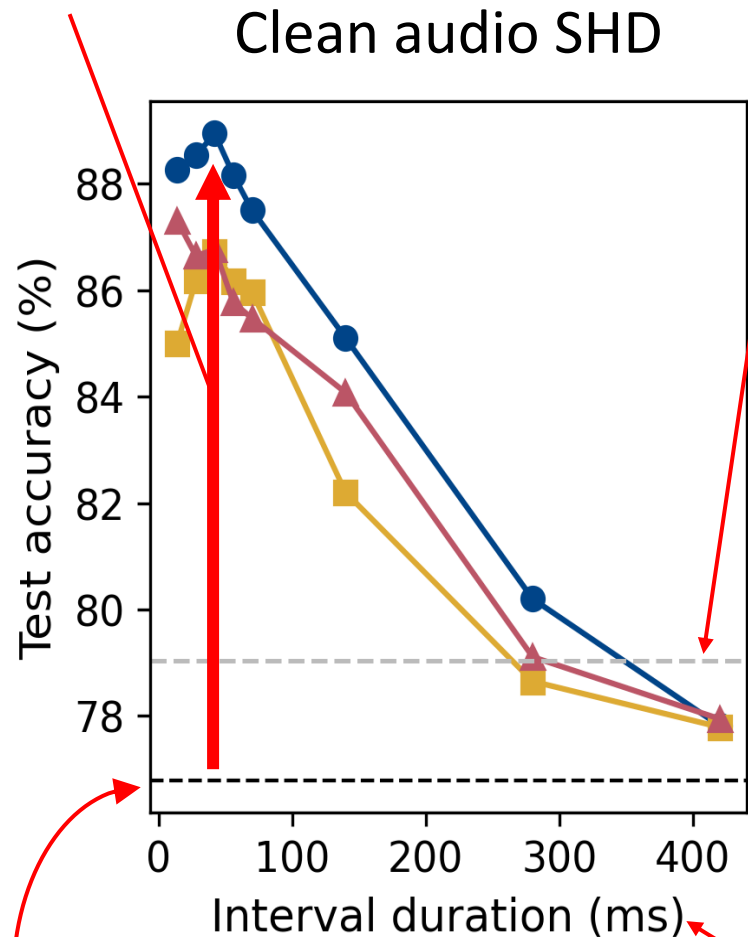
CURRENT PREDICTION

Listening...

It works!

Modulation
Improvement ~12%

Optimal non-modulated SNN performance (large network)

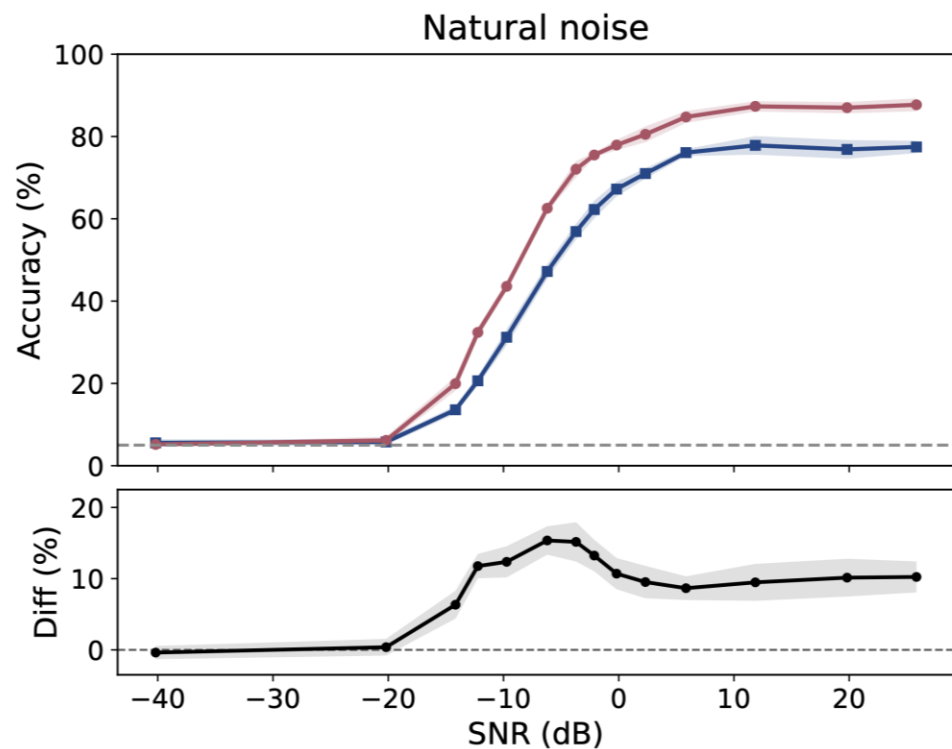
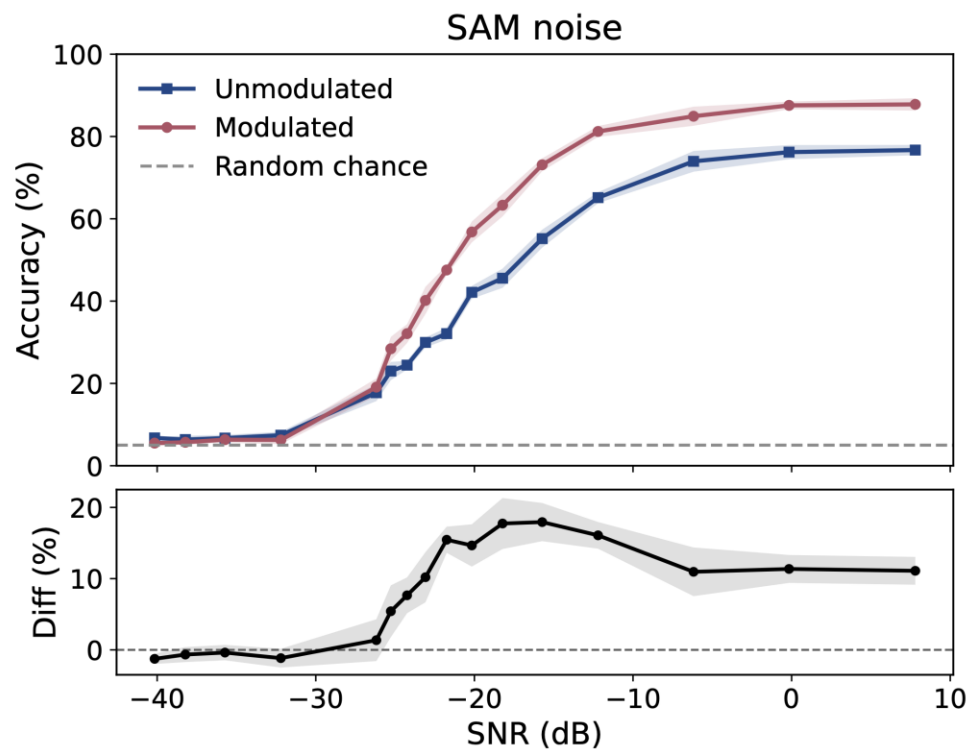


Baseline (unmodulated SNN)

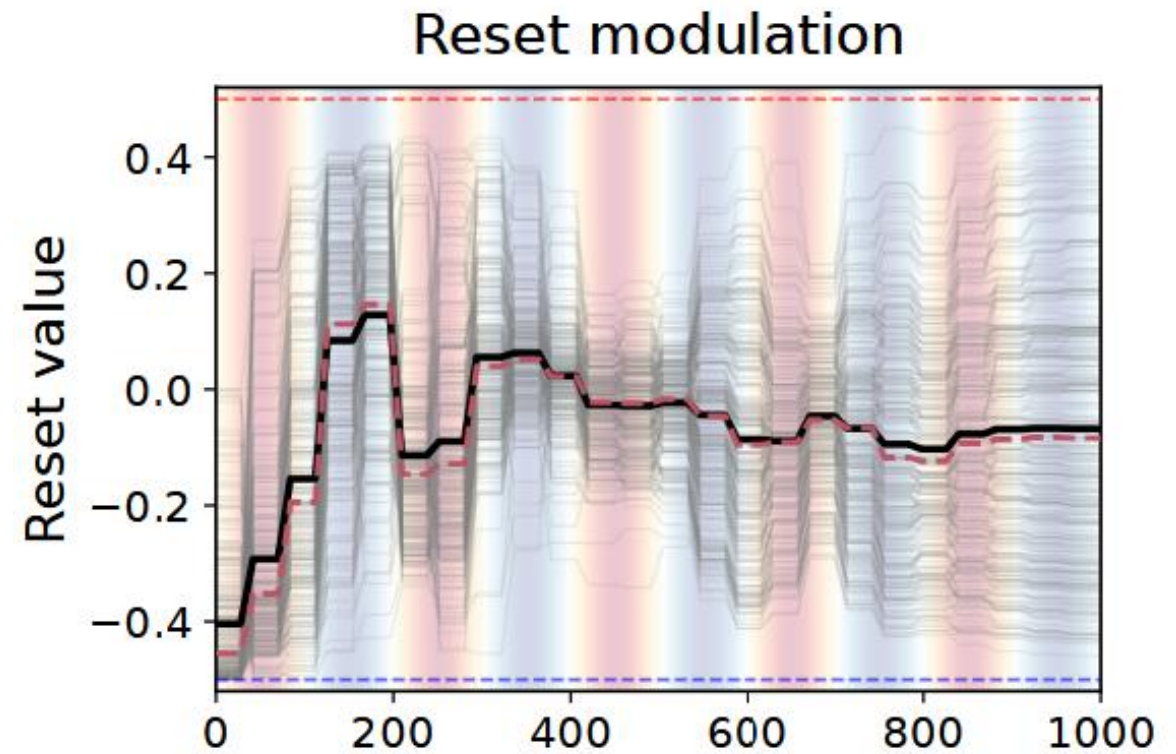
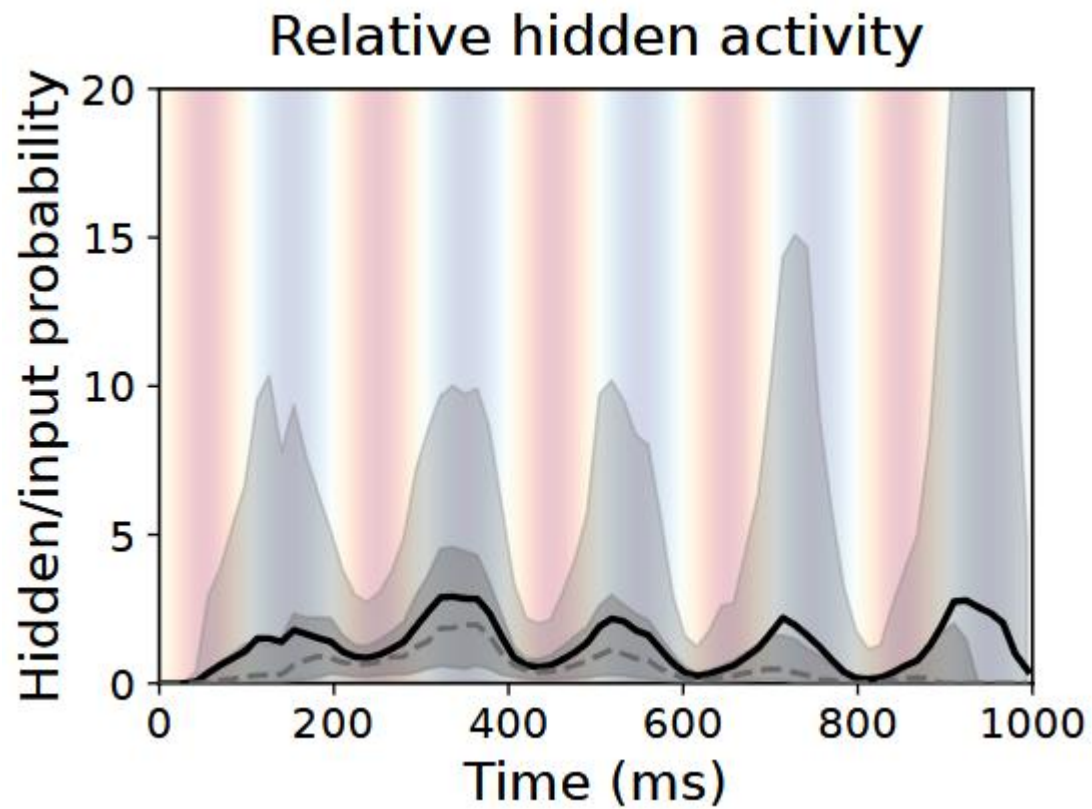
How often the parameters are updated

More challenging version: speech in noise

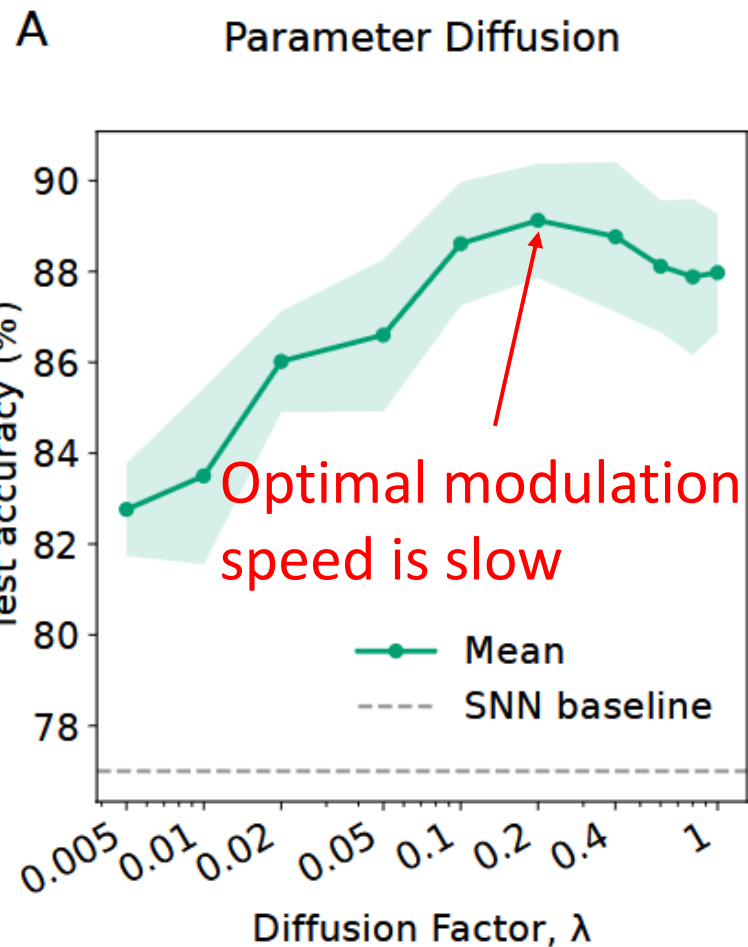
Sinusoidally amplitude modulated (SAM) noise



Learns dynamic gain control strategy (“listening in the dips”)



Temporal diffusion can help performance

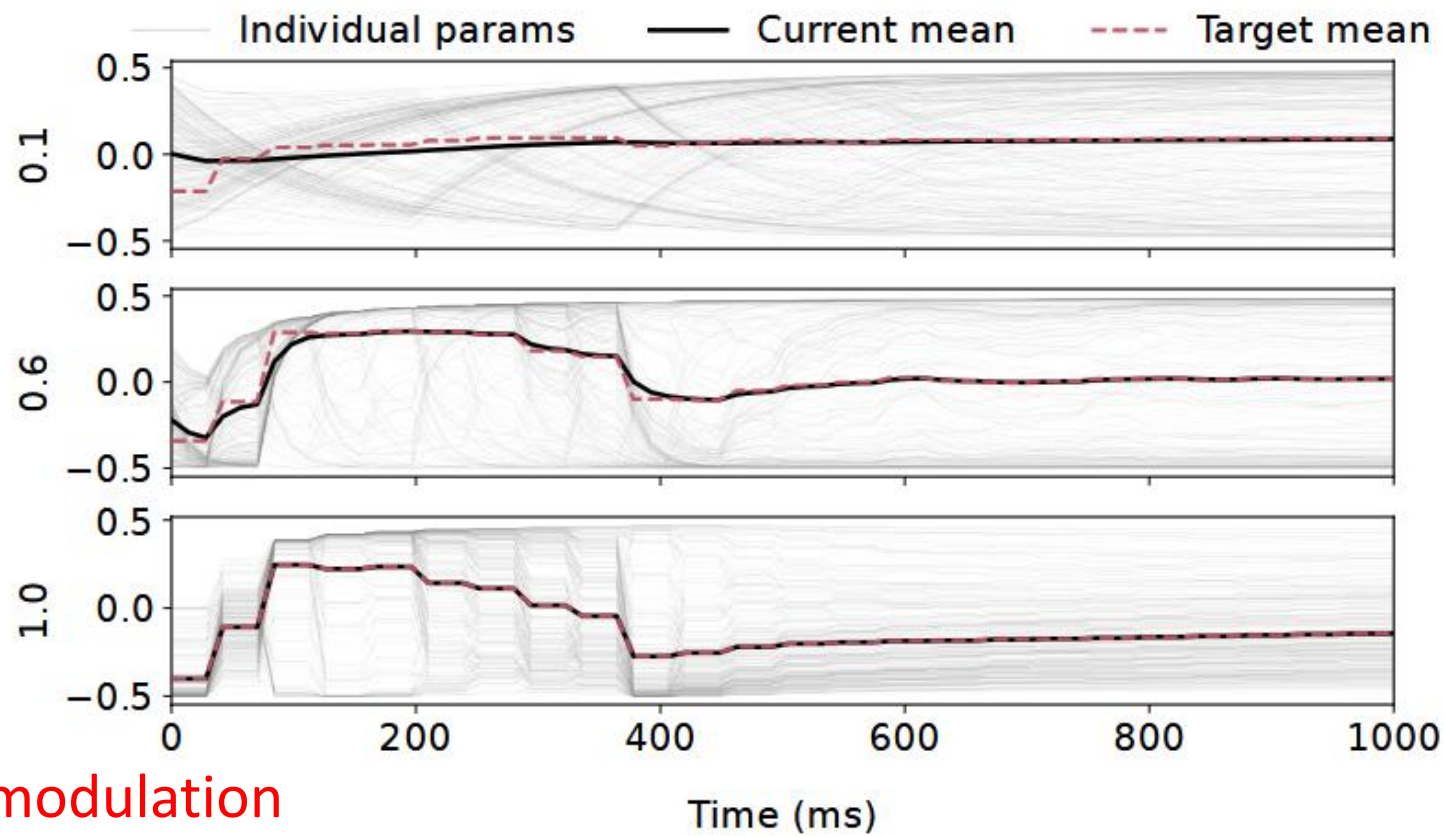


Slow modulation

Diffusion Factor, λ

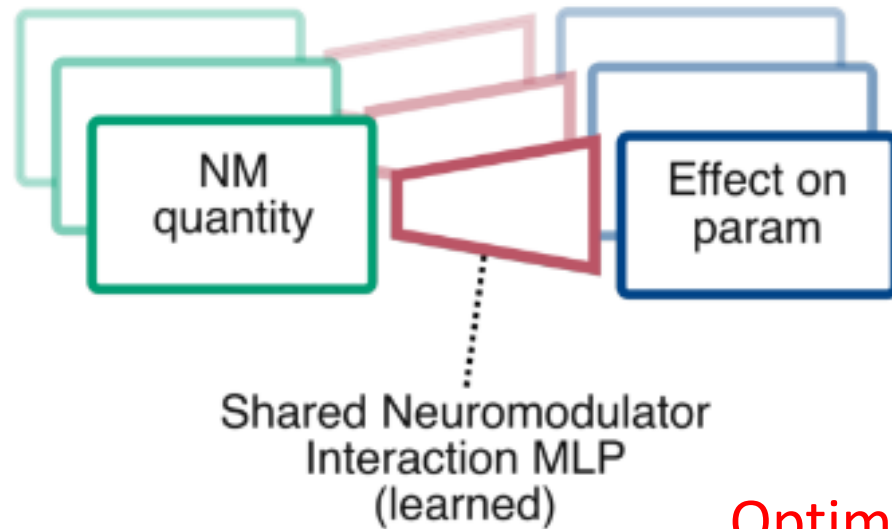
Instant modulation

Reset parameter traces

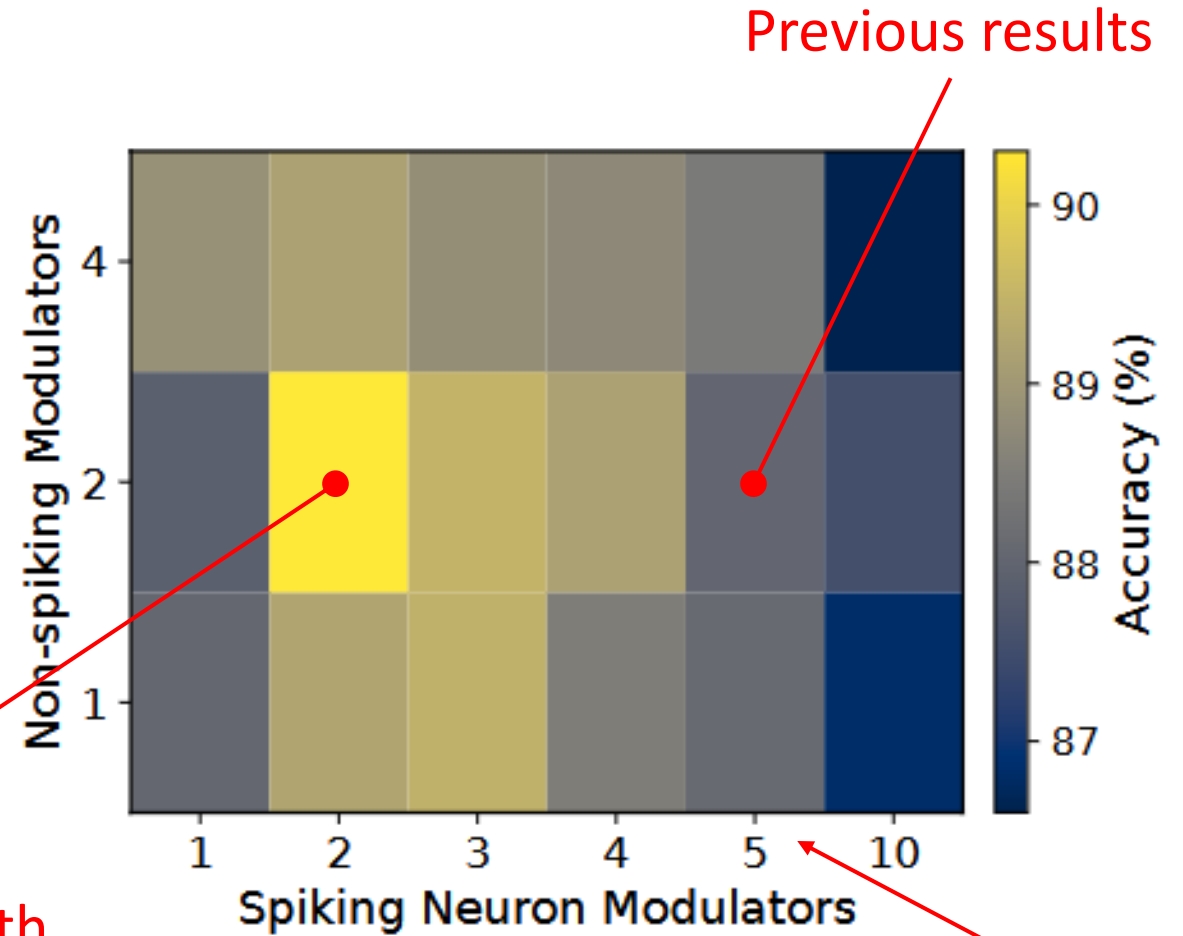


A small number of neuromodulator types is best

Neuromodulator Release Model

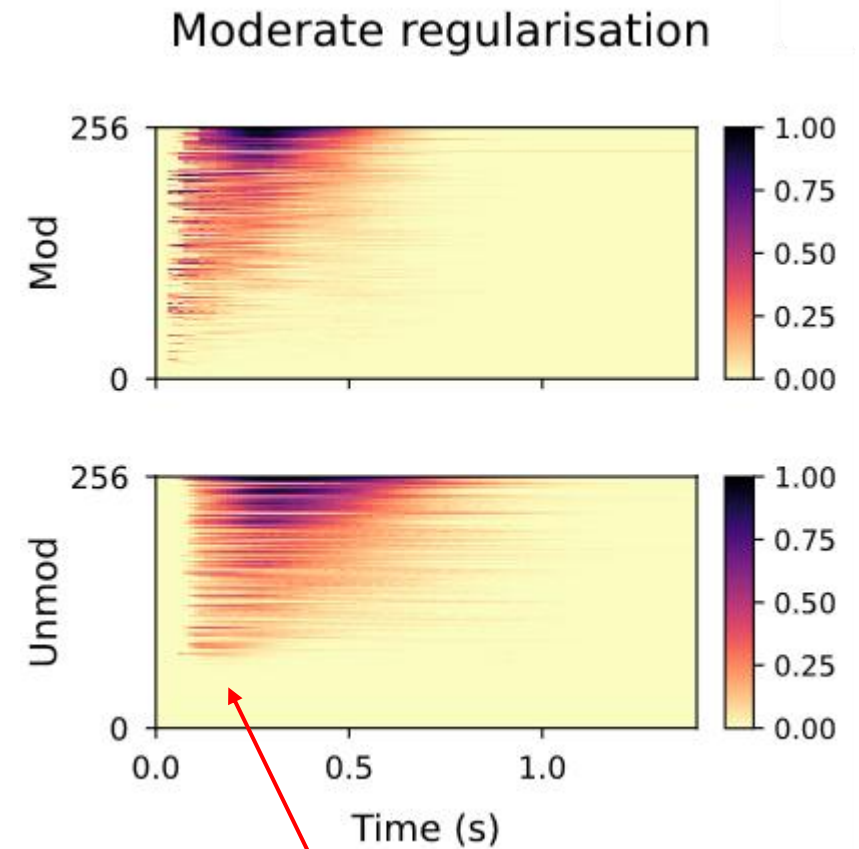
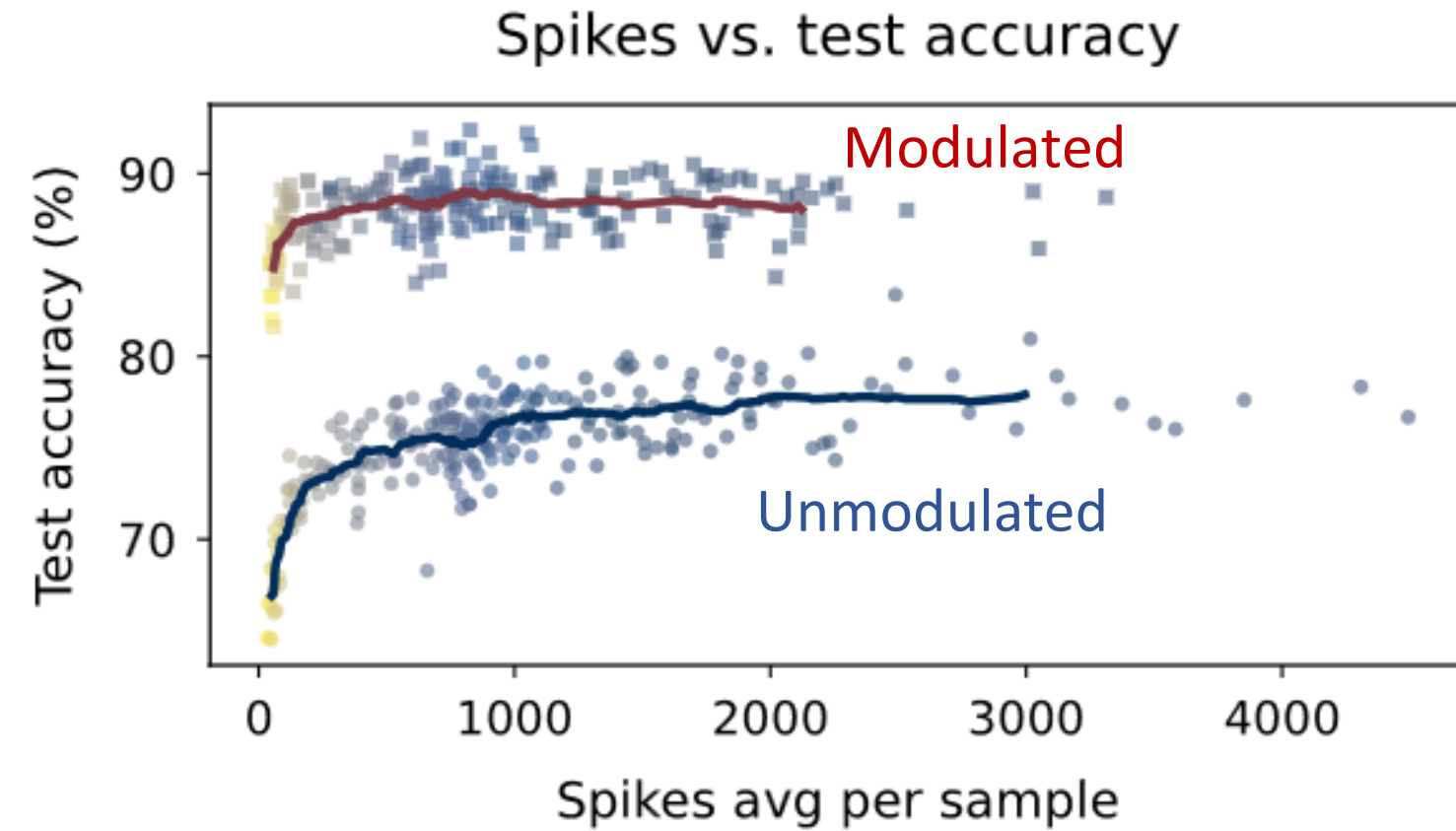


Optimal
performance with
fewer modulator
types



Number of spiking neuron parameters = 5

Can use many fewer spikes (lower energy cost)



Wasted neurons (never active)



Conclusions

- Can add neuromodulation to SNNs
- Easy to implement and train (GitHub code with tutorials)
- Improves performance, parameter efficient
- Allows strong spike regularisations (useful for neuromorphic)
- Generate hypotheses for biological brains

Thanks to



Abdal AlKilany
P4-3 (ground floor)
Wed 14:00-15:30

And thanks to you!



Lab poster advert

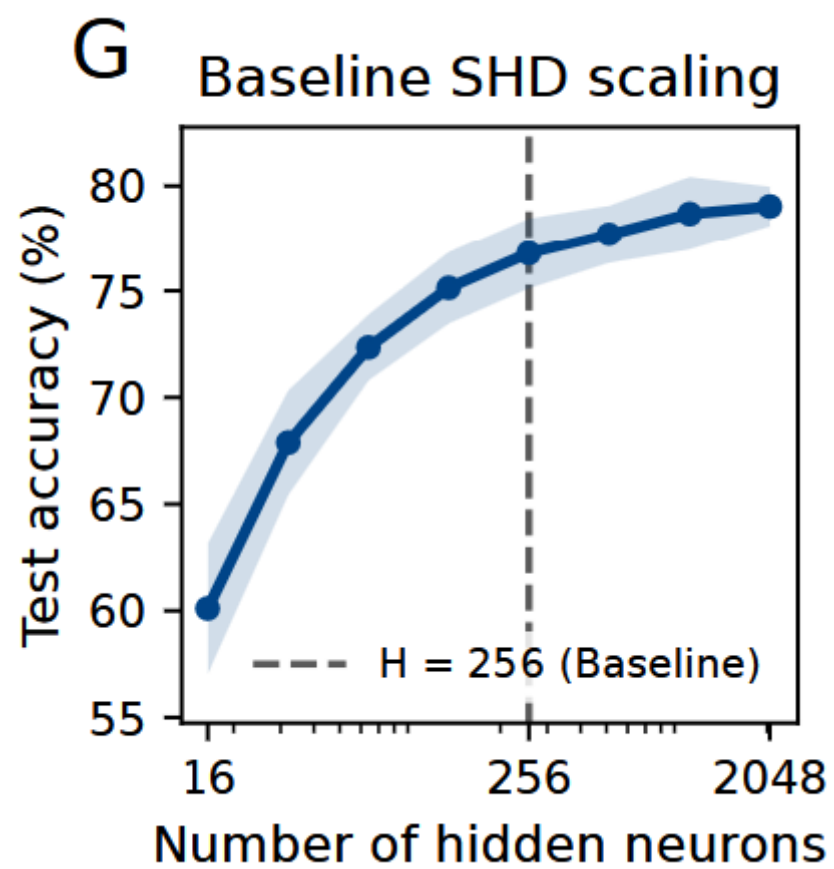


Yishu Zhang
P1-44 (first floor)
Tue 16:30-18:00
**Do heterogeneous brains
remember better?**



Nicolas Dundov
P4-38 (first floor)
Wed 14:00-15:30
**Blood and modularity: a brain-inspired
approach to functional disentangled
neural representations**

Backup slides



F

Parameter count vs accuracy

