Understanding the brain in theory and practice

A series of interactive workshops on building better experiment-theory collaborations in neuroscience

Perez et al. (2021)

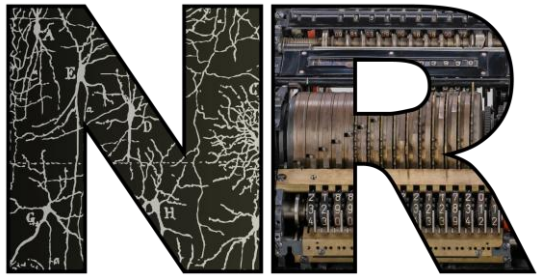
Does heterogeneity help the brain and how could we know if it did?

Dan Goodman

Imperial College London

Department of Electrical and Electronic Engineering

IMPERIAL



neural-reckoning.org

Plan for today

Going to try something a bit different today

Will present some of our ‘pure theory’ research on neural heterogeneity, but…

Brainstorm how this work could be made to work better with experimental research

Discussion will be around these questions (so think about it as you listen):

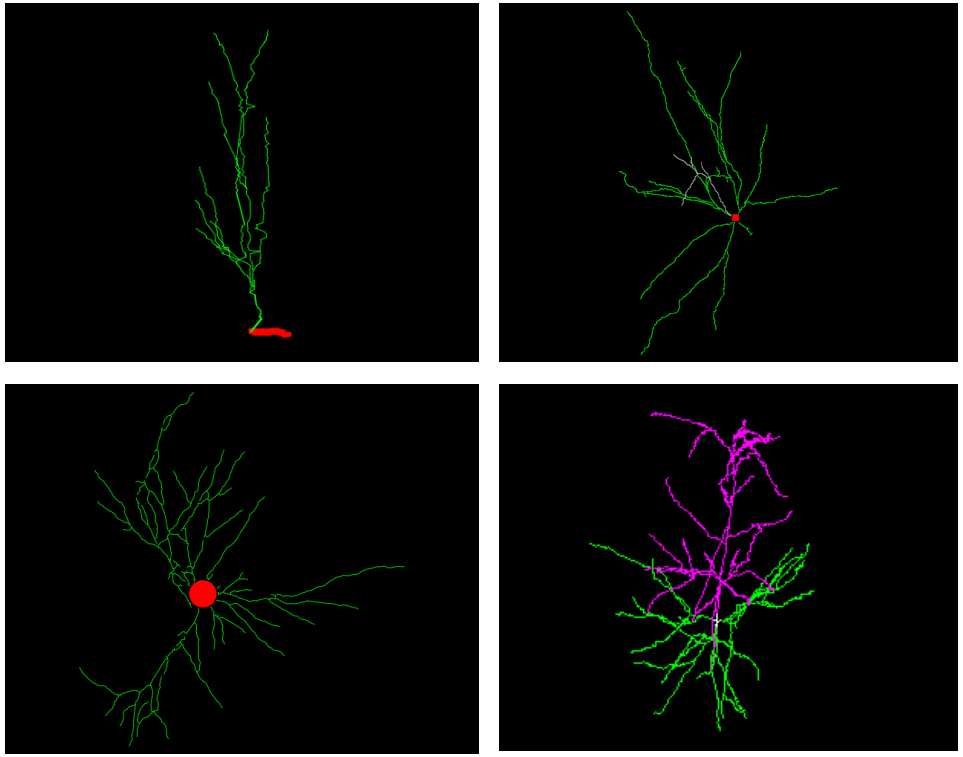
1. Do we learn anything about the brain by evaluating how well models perform tasks?
2. Can we test theories about a multiply redundant brain?
3. How could we experimentally test theories about the function of neural heterogeneity?
4. Can theoretical work that can’t be tested contribute to understanding the brain?

Afterwards – discussion of whether to write an opinion paper based on this series?

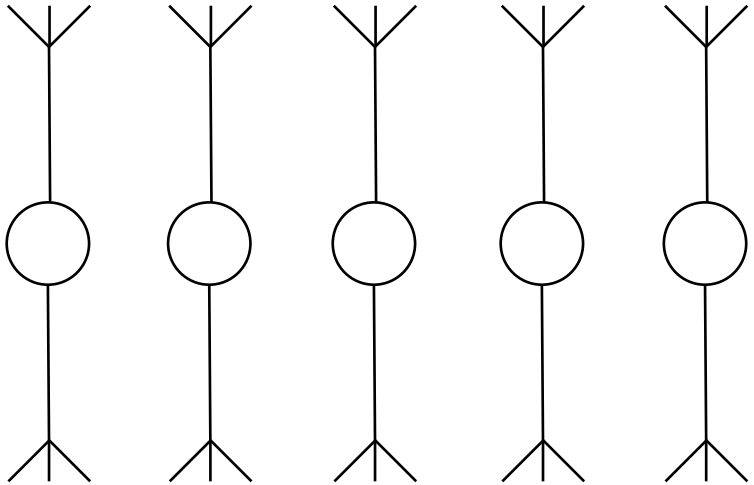
Why is the brain so heterogeneous?

What the brain is like

Some random neurons from neuromorpho.org



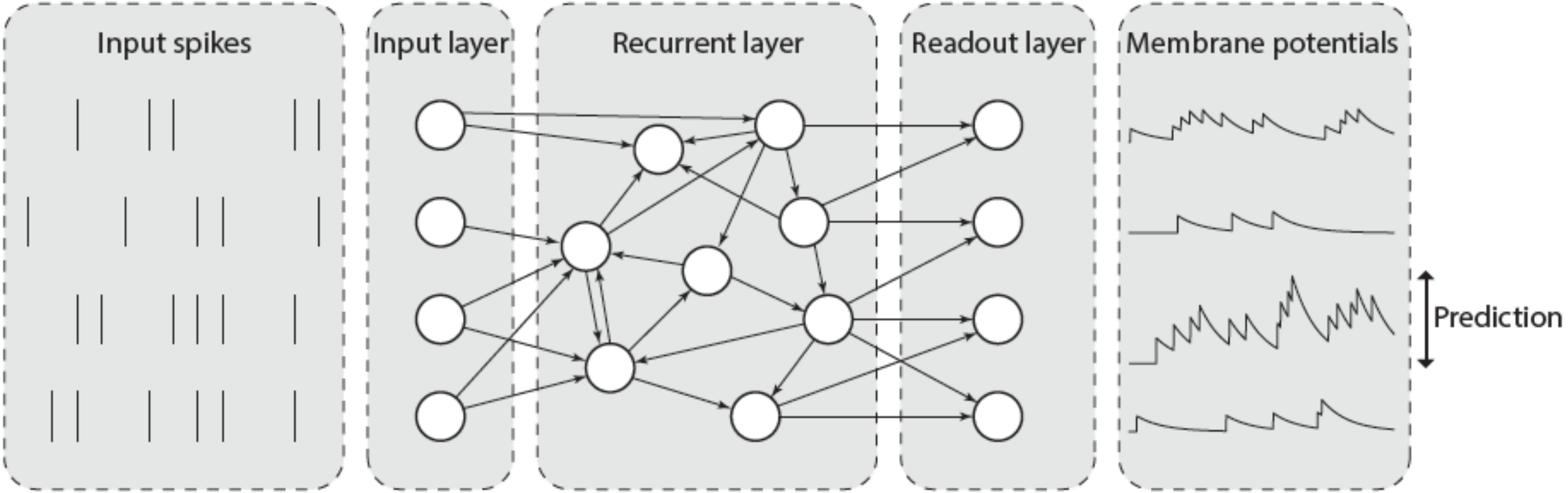
What our models are like



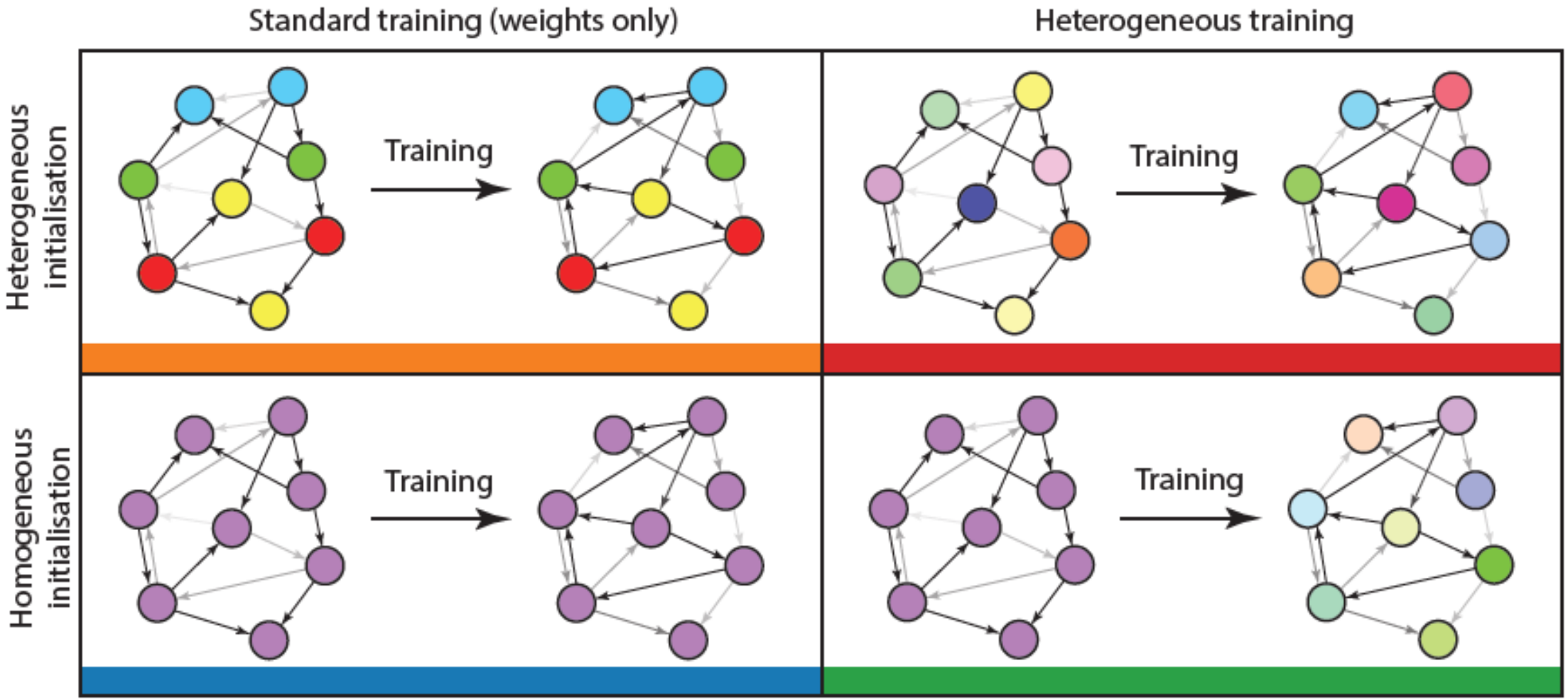
This study

Replace single value of τ with different for each neuron
Let the network learn τ as well as weights
Compare performance on different tasks

Methods: model architecture



Methods: training



Methods: tasks

Visual

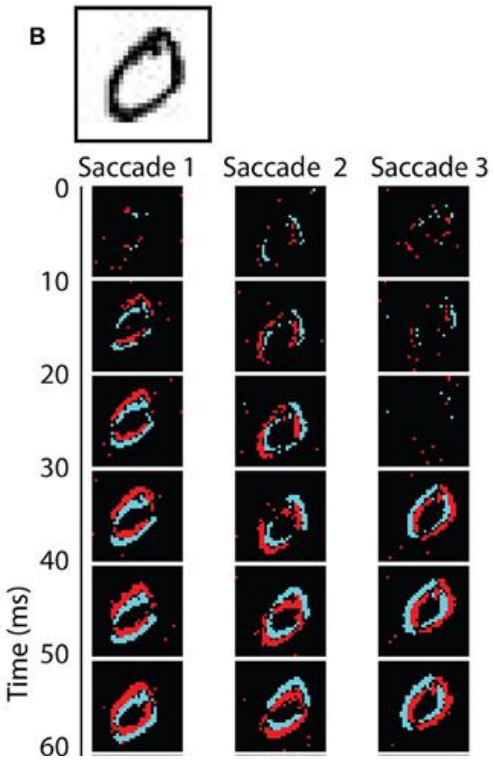
Auditory

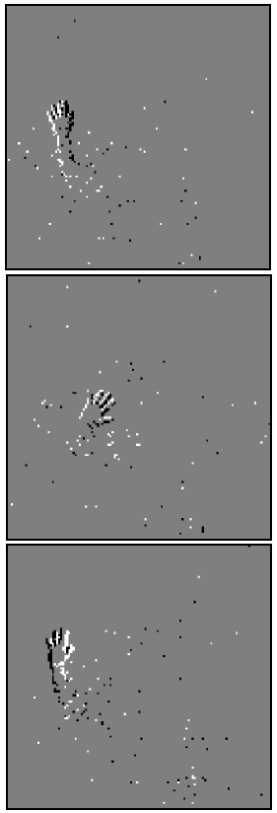
N-MNIST

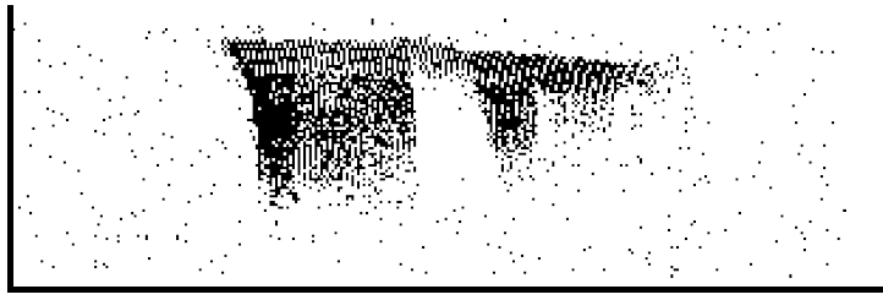
F-MNIST

DVS128

SHD and SSC



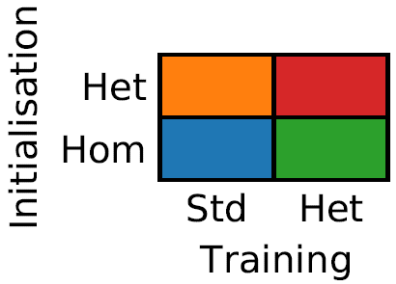


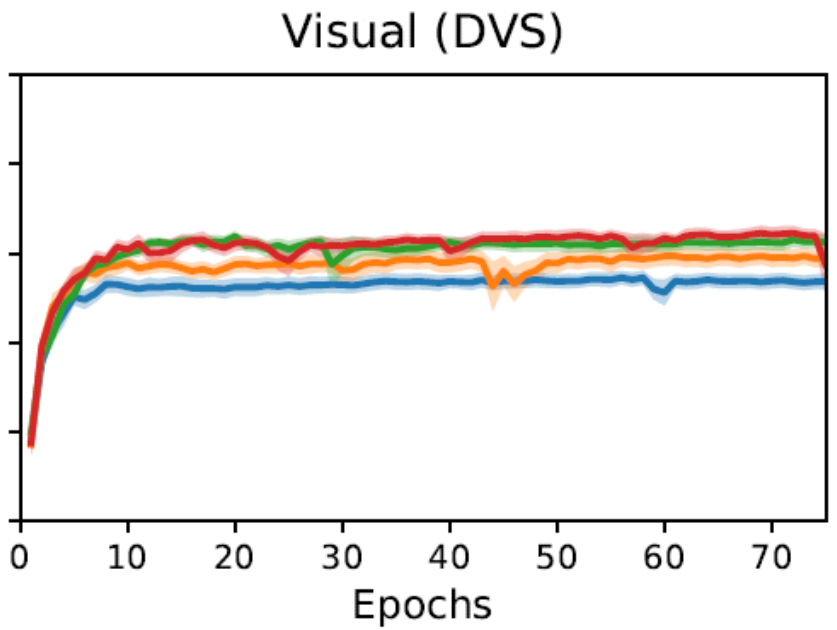


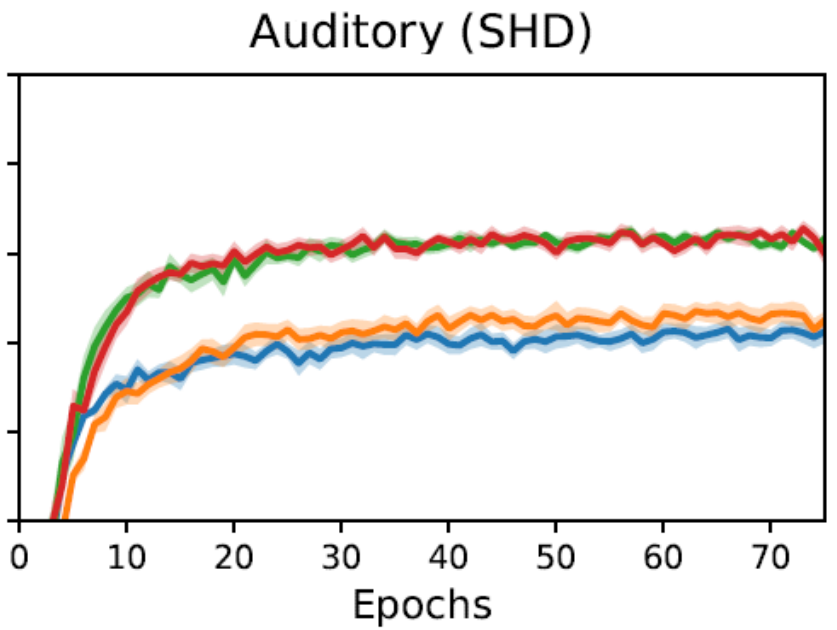
Increasing temporal structure

Results: performance

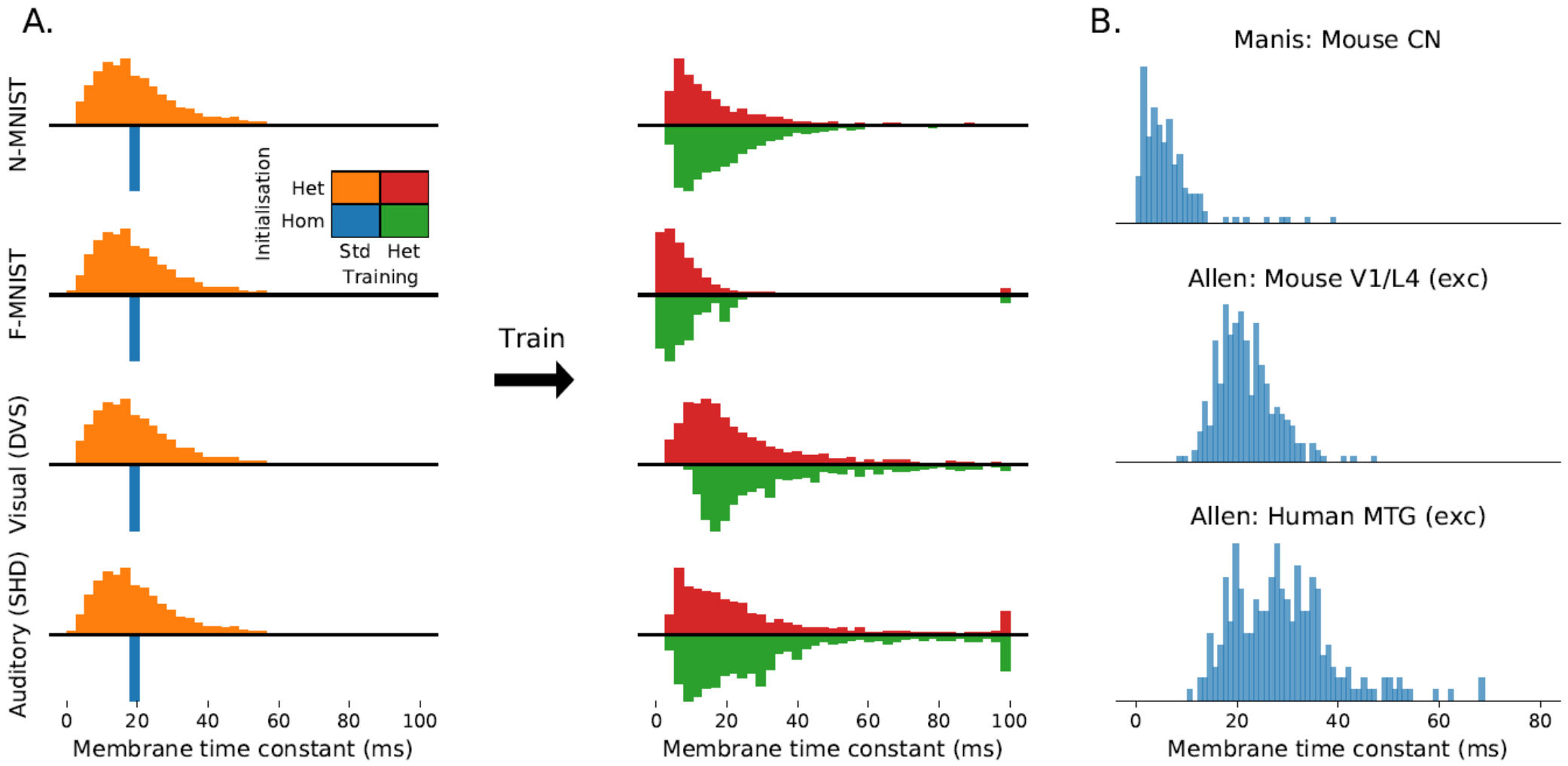
Initialisation	Training	N-MNIST	F-MNIST	DVS128	SHD	SSC
Homog.	Standard	97.4±0.0	80.1±7.4	76.9±0.8	71.7±1.0	49.7±0.4
Heterog.	Standard	97.5±0.0	87.9±0.1	79.5±1.0	73.7±1.1	53.7±0.7
Homog	Heterog.	96.6±0.2	79.7±7.4	81.2±0.8	82.7±0.8	56.6±0.7
Heterog.	Heterog.	97.3±0.1	87.5±0.1	82.1±0.8	81.7±0.8	60.1±0.7
	Chance level	10.0	10.0	10.0	5.0	2.9







Results: distribution of time constants



The conclusions we want to make

Would like to conclude that:

- Heterogeneity is valuable in terms of task performance, energy efficiency, robustness
- Likely that the brain makes use of heterogeneity in these ways
- Possible that evolution has (optimally) tuned heterogeneity for this

But can we make these conclusions?

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But:

- How much does it matter that we only try one architecture?
- Only 5 tasks?
- The brain has to do a lot more than this!
- But what else can we do apart from limited tests such as these?

But can we make these conclusions?

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But:

- The brain has many mechanisms that can achieve the same thing
- Indeed in our models we have seen that we can achieve the same results using several mechanisms:
  - Tunable (or even random) axonal delays
  - Neuromodulation
  - A low dimensional, slow memory state
- So can we conclude the brain uses heterogeneity?

Sun et al. (2025)

AlKilany and Goodman (2026)

Sun et al. (2026)

But can we make these conclusions?

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But:

- Just because the brain has this mechanism available, doesn't mean it's tuned for it
- Does the similarity of the time constant distributions tell us anything?
- If not, how could we experimentally test this idea?
- Wouldn't we need to create an alternative reality and re-run evolution to test it?
- If we can't test it, can it tell us something about the brain anyway?

Thanks!

Nicolas Perez
Heterogeneity
Now @ DeepMind

Perez et al. (2021)

Abdal AlKilany
Neuromodulation

AlKilany and
Goodman (2026)

And thank you for listening to me expressing my existential doubts about my work ❤️

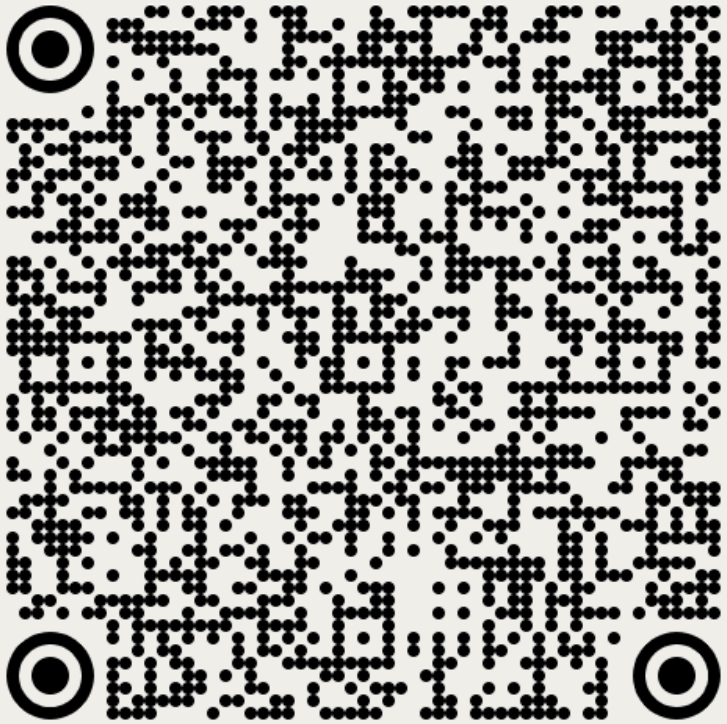
Pengfei Sun
Delay-based SNNs

Sun et al. (2025)

Sun et al. (2026)

Before networking + food

Please complete this survey from the Crick Networking Fund (5m)



Come and find one of the organisers if you’re interested in discussing / contributing to an opinion paper

Group discussion (1h)

Potential outline

Introduce yourselves

- Do we learn anything about the brain by evaluating how well models perform tasks?
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