Fast reconstruction of degenerate populations of conductance-based neuron models from spike times

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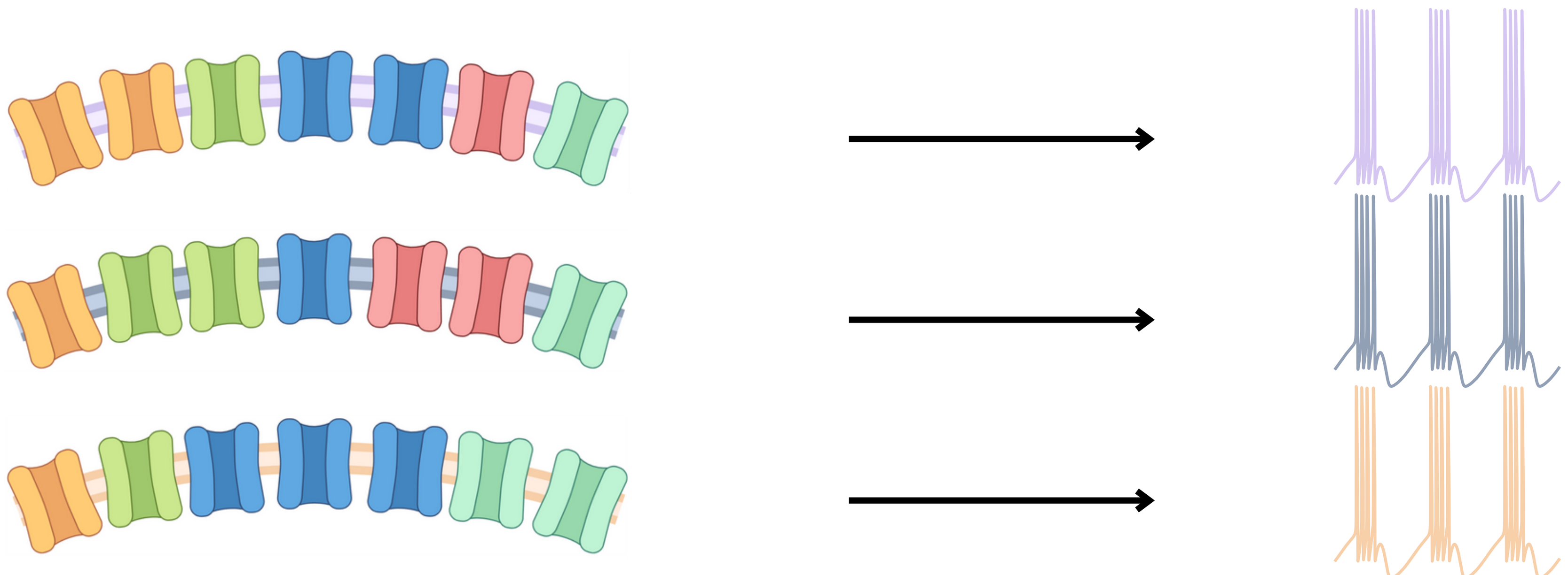
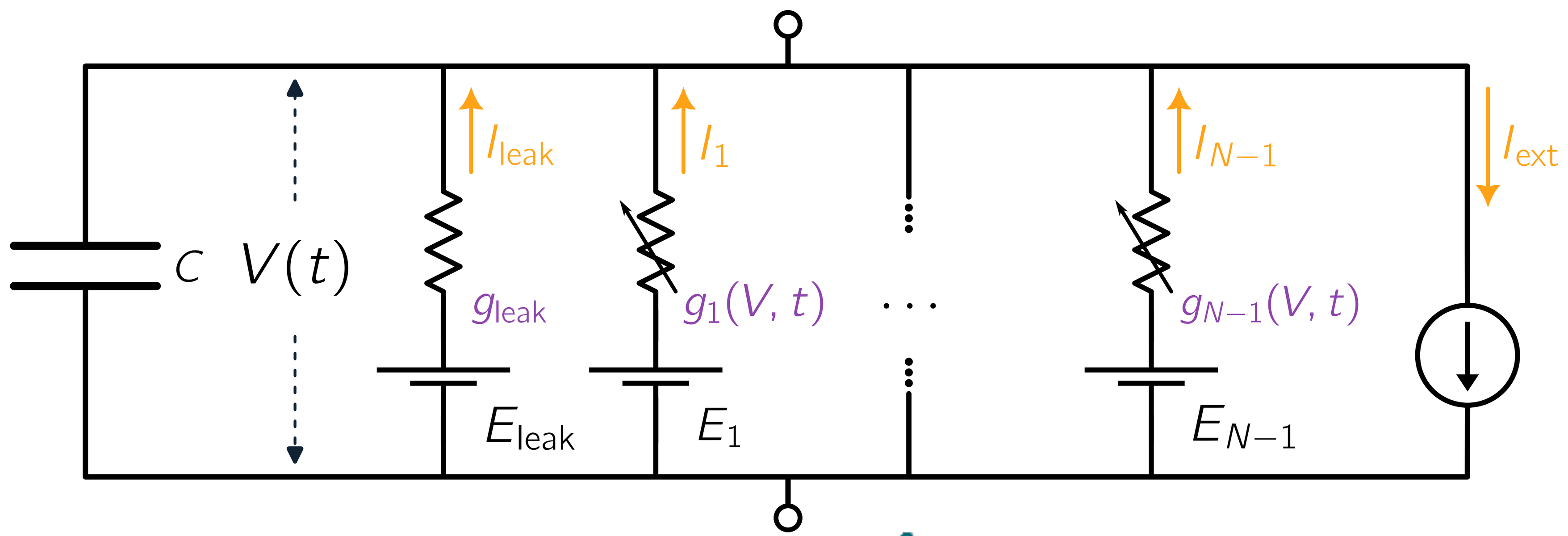
Background & Motivations

We can easily record neuronal firing patterns, but not their exact ion channel compositions. How specific channel compositions shape neuronal activity is of great scientific interest.

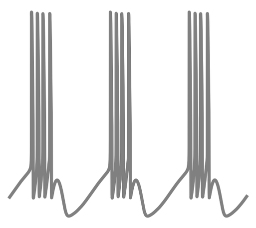


Neurons are degenerate: different ion channel compositions can produce similar firing patterns (Marder et al. 2006).

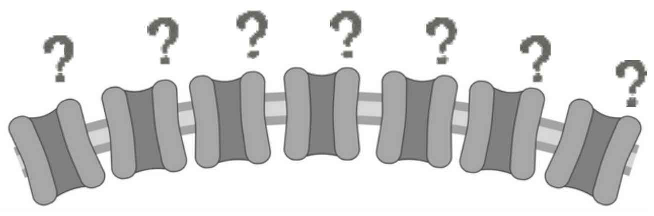


$$C\frac{dV}{dt} + g_{\text{leak}}(V - E_{\text{leak}}) = -\sum_{i\in\mathcal{I}} \overset{?}{\bar{g}_i} m_i^{p_i} h_i^{q_i}(V - E_i) + I_{\text{ext}}$$

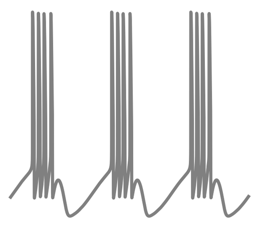
Conductance-based models are biophysically plausible and widely used as *in silico* representations of neurons. Their maximum conductances $\bar{g}_i$ directly reflect the underlying ion channel compositions.



Inverse problem →



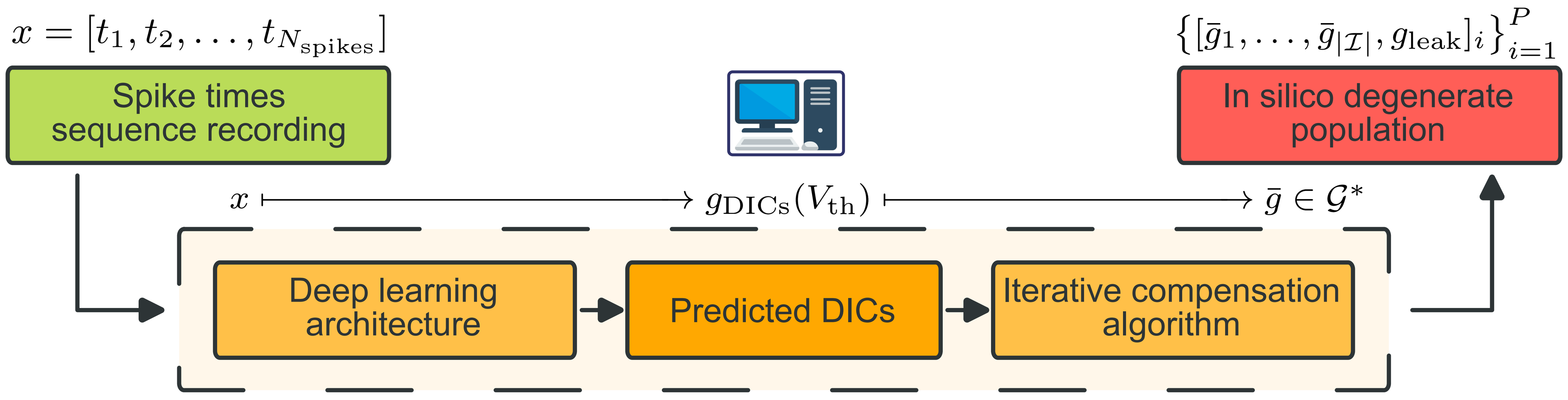
modeling $\approx$



Inverse problem → $[\overset{?}{\bar{g}_1}, \overset{?}{\bar{g}_2}, \ldots, \overset{?}{\bar{g}_{|\mathcal{I}|}}]$

Inferring possible sets of maximum conductances from spike recordings defines a core inverse problem in (computational) neuroscience.

Our approach



We aim to infer the maximal conductances $\bar{g} \in \mathcal{G}$ of a known conductance-based model from recorded spike times x.

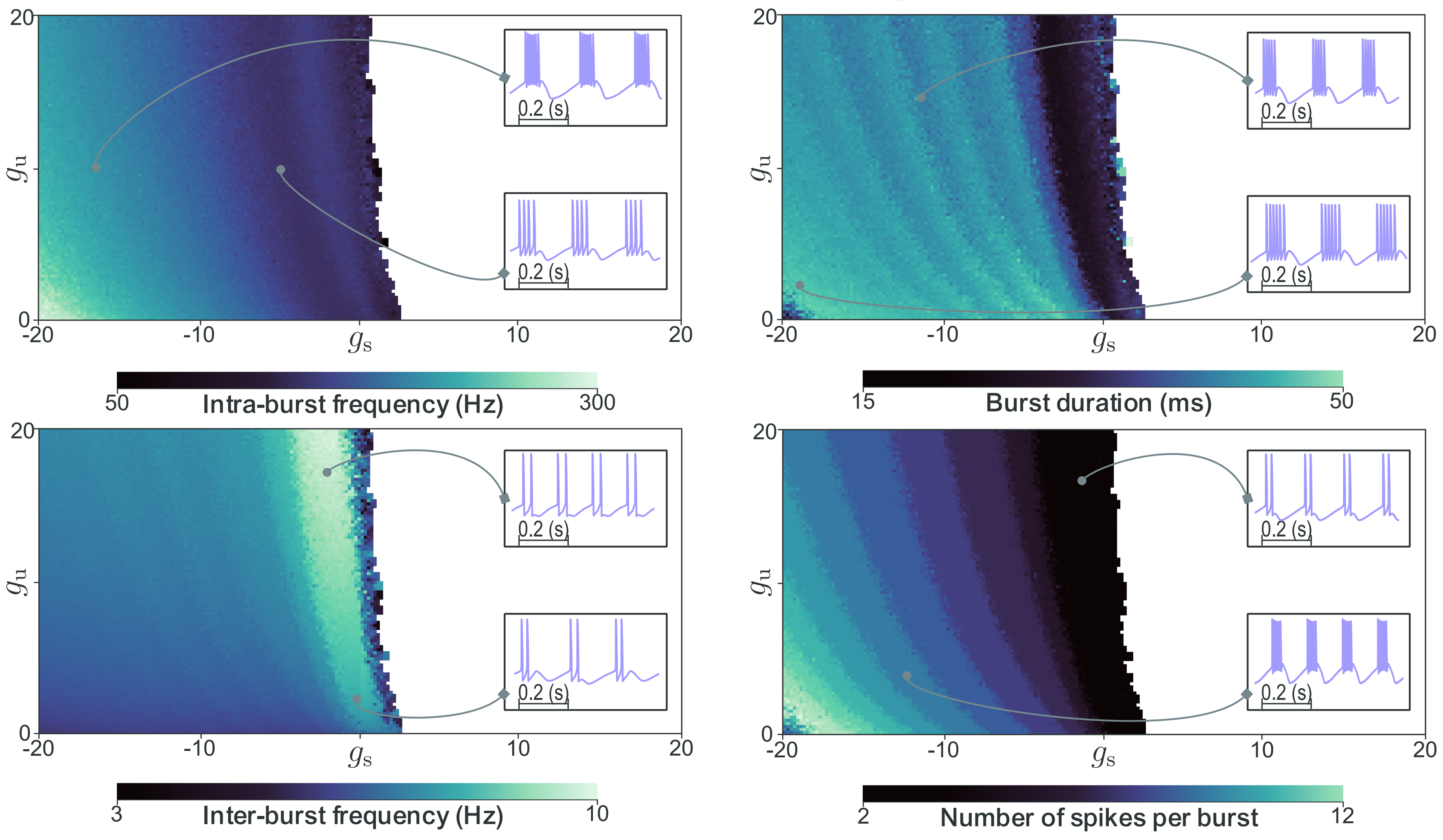
Because many conductance sets can reproduce the same firing pattern, the solutions form a degenerate subspace $\mathcal{G}^*(x) \subset \mathcal{G}$.

To reduce this high-dimensional problem, we use Dynamic Input Conductances (**DICs**; Drion et al. 2015), a low-dimensional descriptor of firing dynamics.

We show that DICs are convenient intermediate representation to study neuronal degeneracy.

Our method predicts DICs from spike times, then generates multiple compatible conductance vectors $\bar{g} \in \mathcal{G}^*(x)$, efficiently exploring the degenerate solution space.

Activity descriptors vary smoothly across the DIC space



DICs can be computed from the vector of maximal conductances, and conversely, one can construct maximal conductance vectors compatible with target DICs (Fyon et al. 2024). The slow and ultra-slow DICs (g_s, g_u) shape the neuron firing pattern.

We solve the inverse problem in the DIC space.

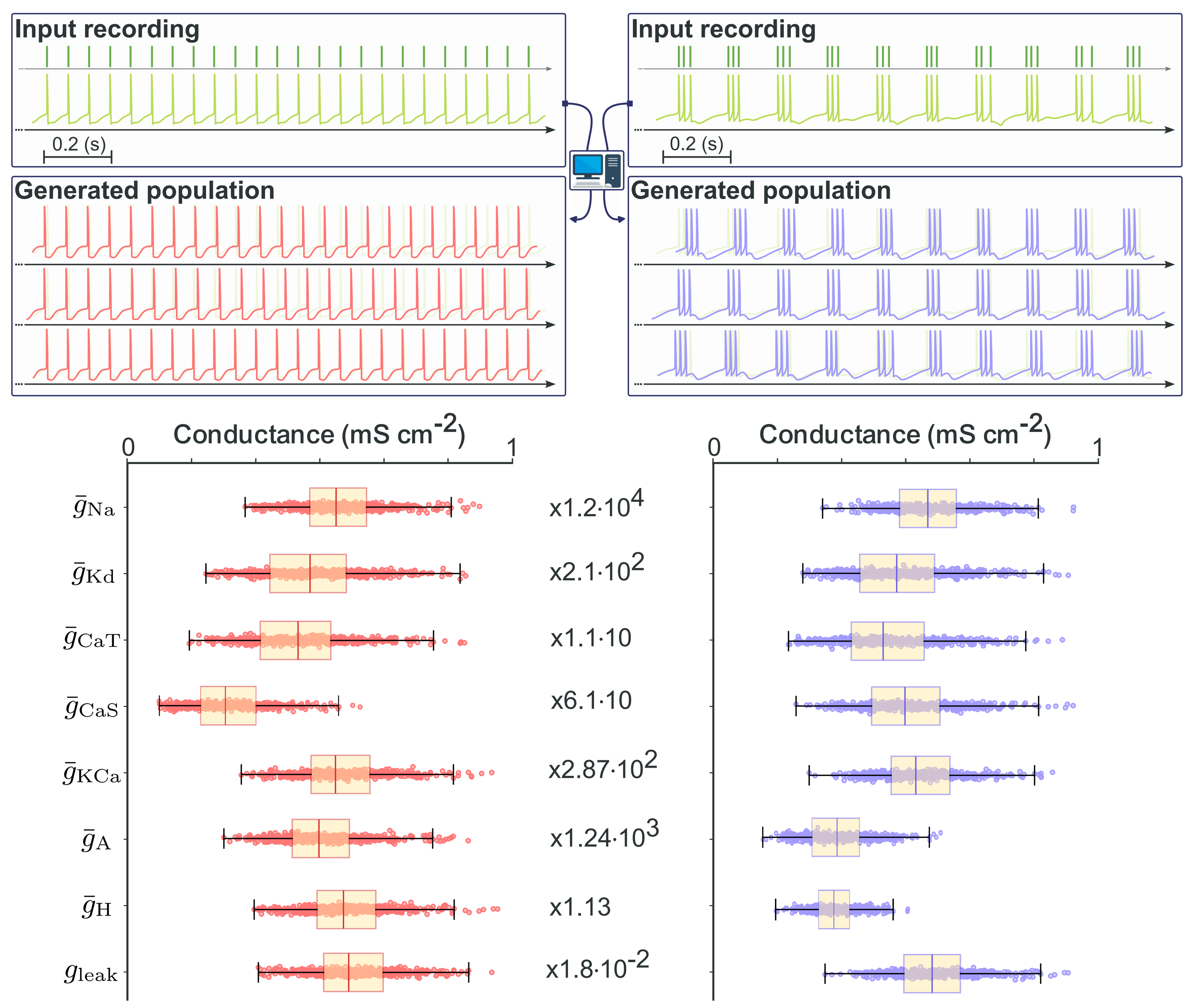
TL;DR

We introduce a method to reconstruct populations of conductance-based neuron models from spike times.

Using deep learning with Dynamic Input Conductances, the method captures neuronal degeneracy (where different sets of conductances can produce similar firing patterns) by generating diverse models that reproduce observed activity.

The approach is accurate, robust, runs on standard lab hardware, and includes an open-source graphical tool for experimentalists.

We can construct degenerate populations from spike times



Our method reconstructs populations that reproduce the input spike activity while spanning diverse underlying conductance configurations, capturing population-level degeneracy

We reconstruct populations and reveal population-level degeneracy.

Conclusion & Perspectives

DICs link spike timing to conductance variability, enabling fast reconstruction of degenerate neuron populations and supporting future experimental and neuromodulation applications.

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You can find our preprint on arXiv (QR code)
arXiv:2509.12783R