Data-driven efficient surrogate-assisted evolutionary method for multi-objective optimization of high-dimensional neural dynamical systems

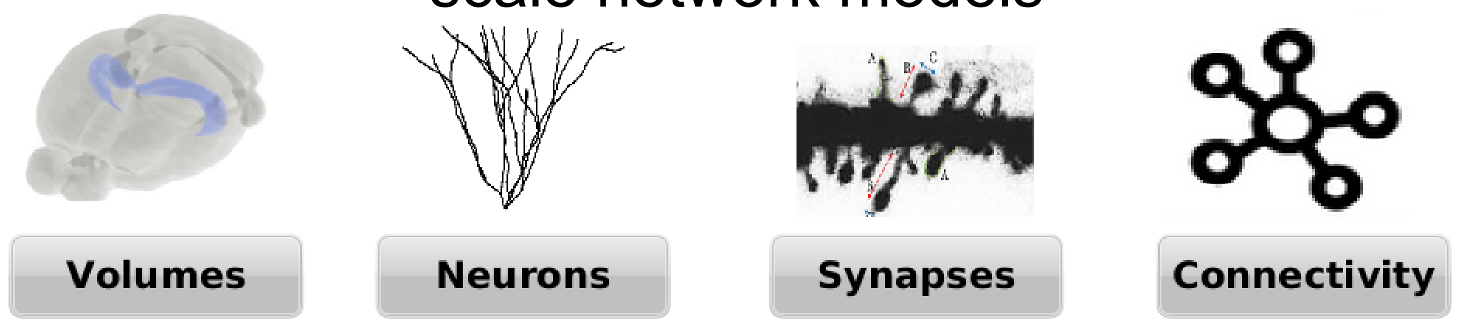
August 3, 2023

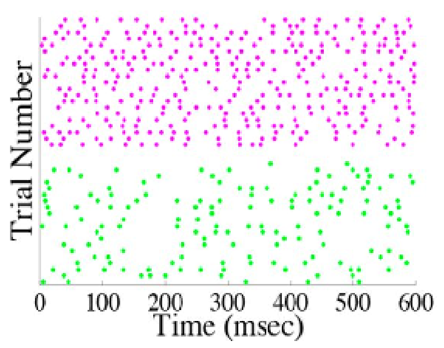
Ivan Raikov, Ivan Soltesz

Stanford University

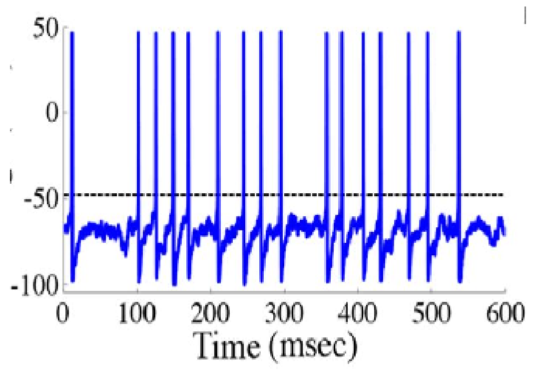
Overview: Biophysical modeling of hippocampal networks at full scale

Parallel, efficient, flexible data storage for large-scale network models

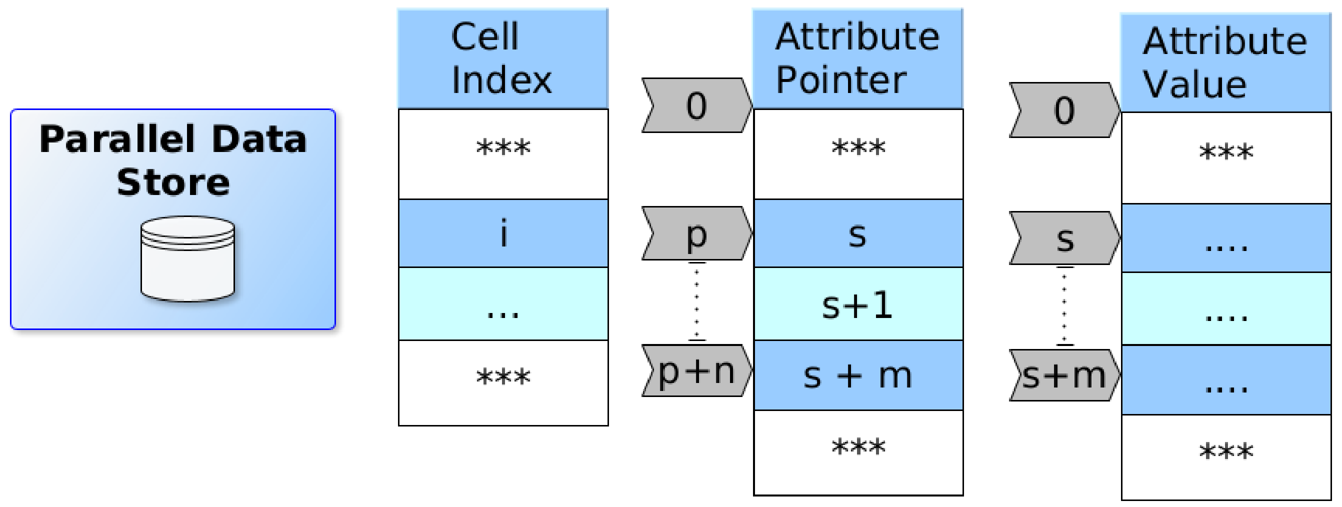




Spikes



Voltage traces

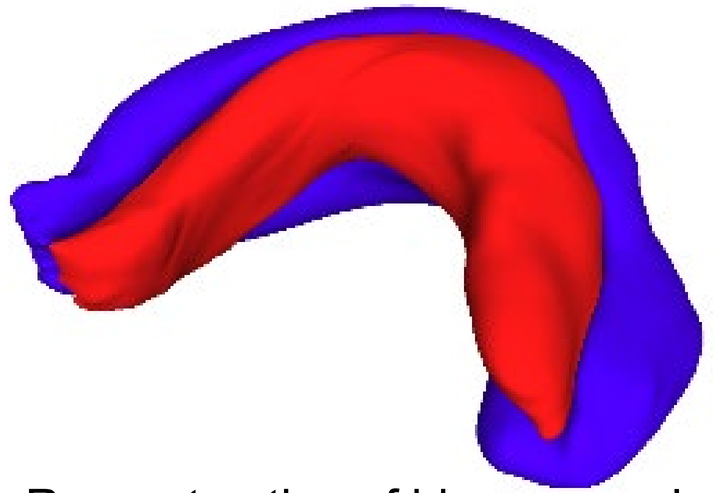


Towards a general framework for modeling large-scale biophysical neuronal networks: a full-scale computational model of the rat dentate gyrus

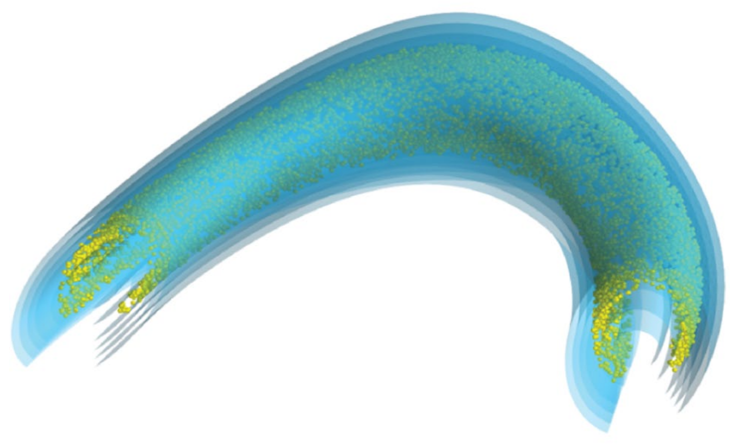
Raikov… Soltesz, 2021.

https://www.biorxiv.org/content/10.1101/2021.11.02.466940v1

Realistic 3D anatomy and topographical gradients of functional and connectivity properties

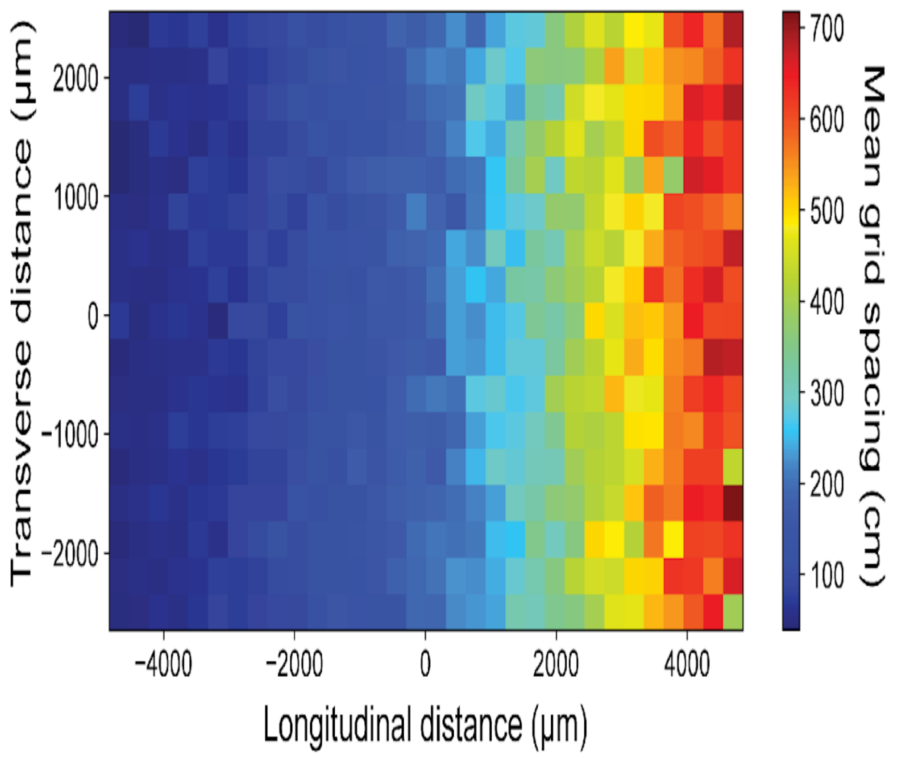


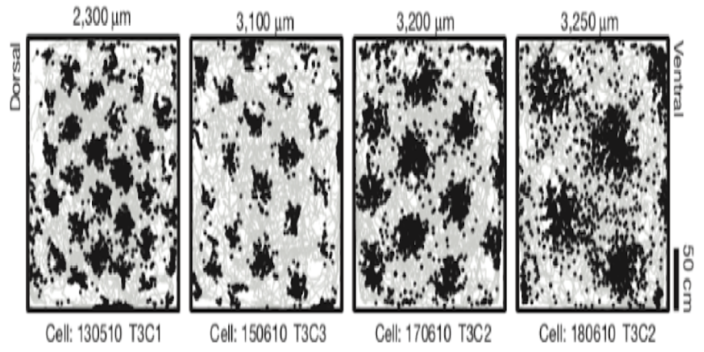
Reconstruction of hippocampal volume



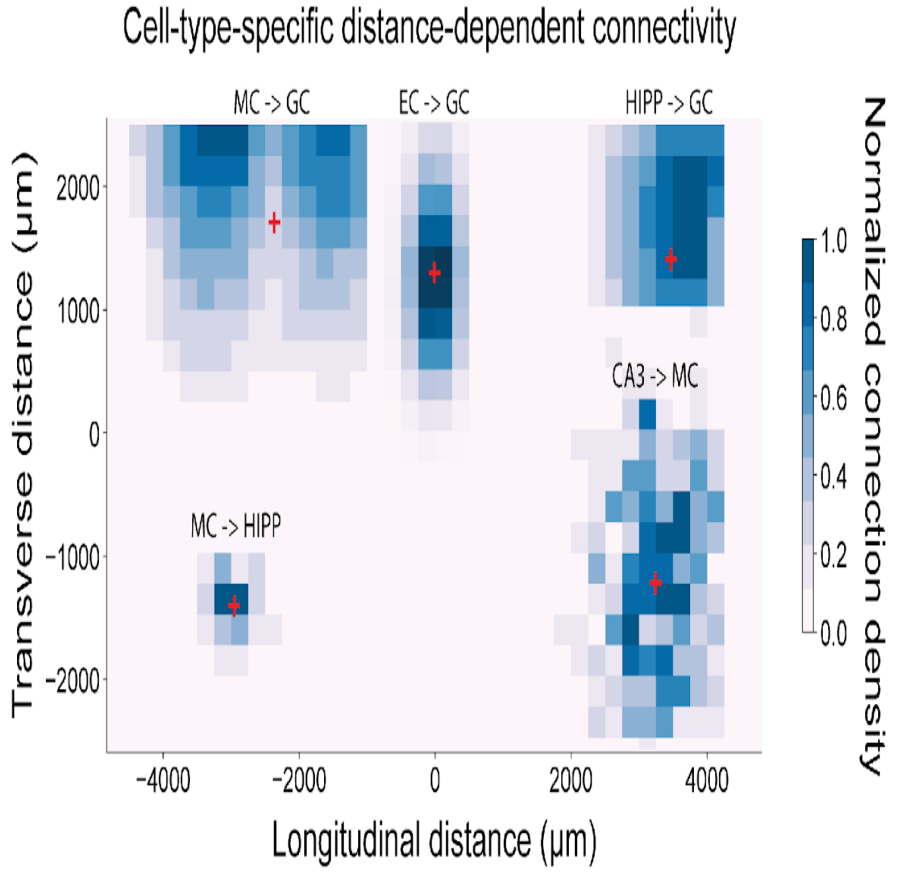
Model of dentate gyrus volume with layer-specific somata distribution

Topography of spatial inputs to the hippocampus from entorhinal grid cells

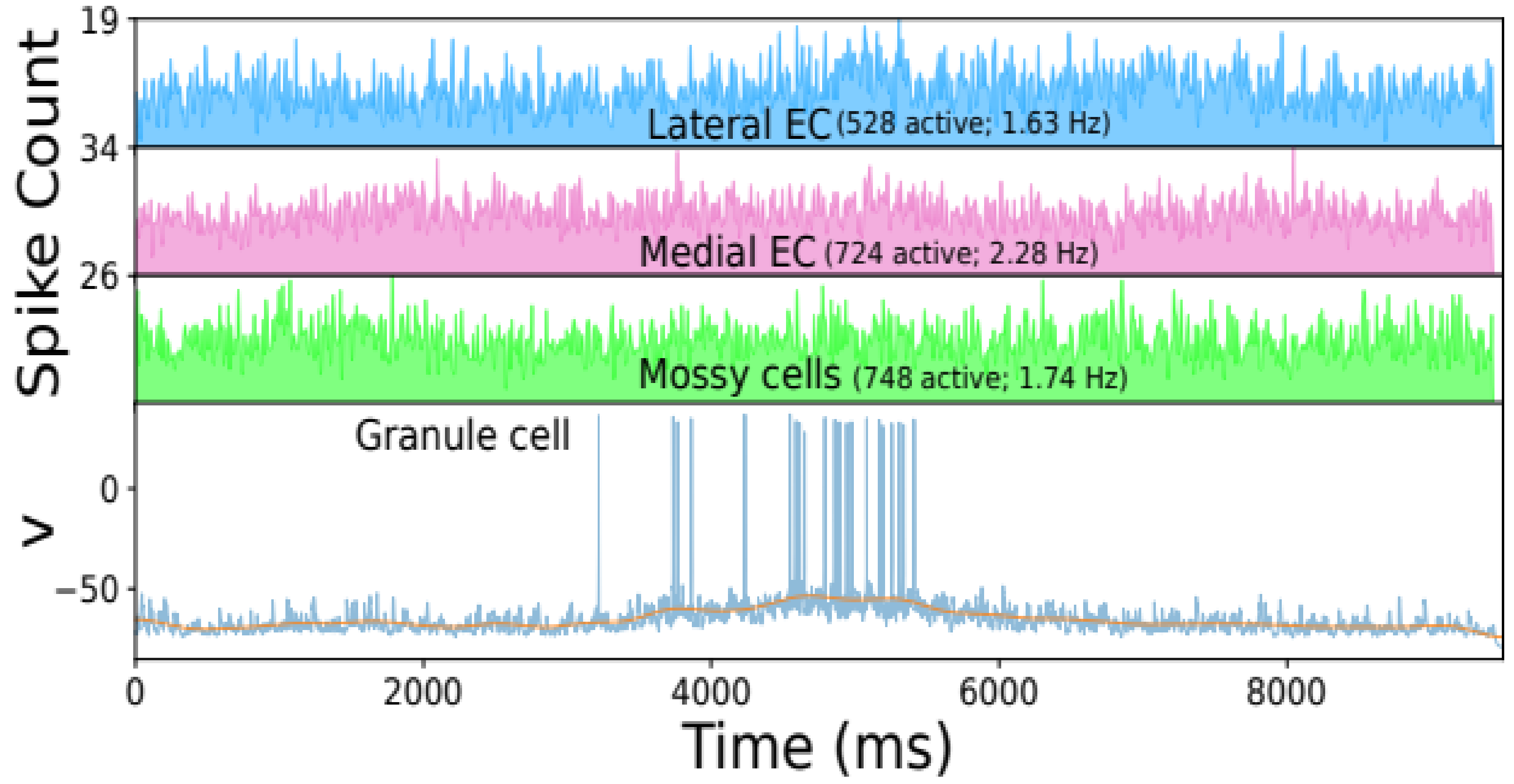


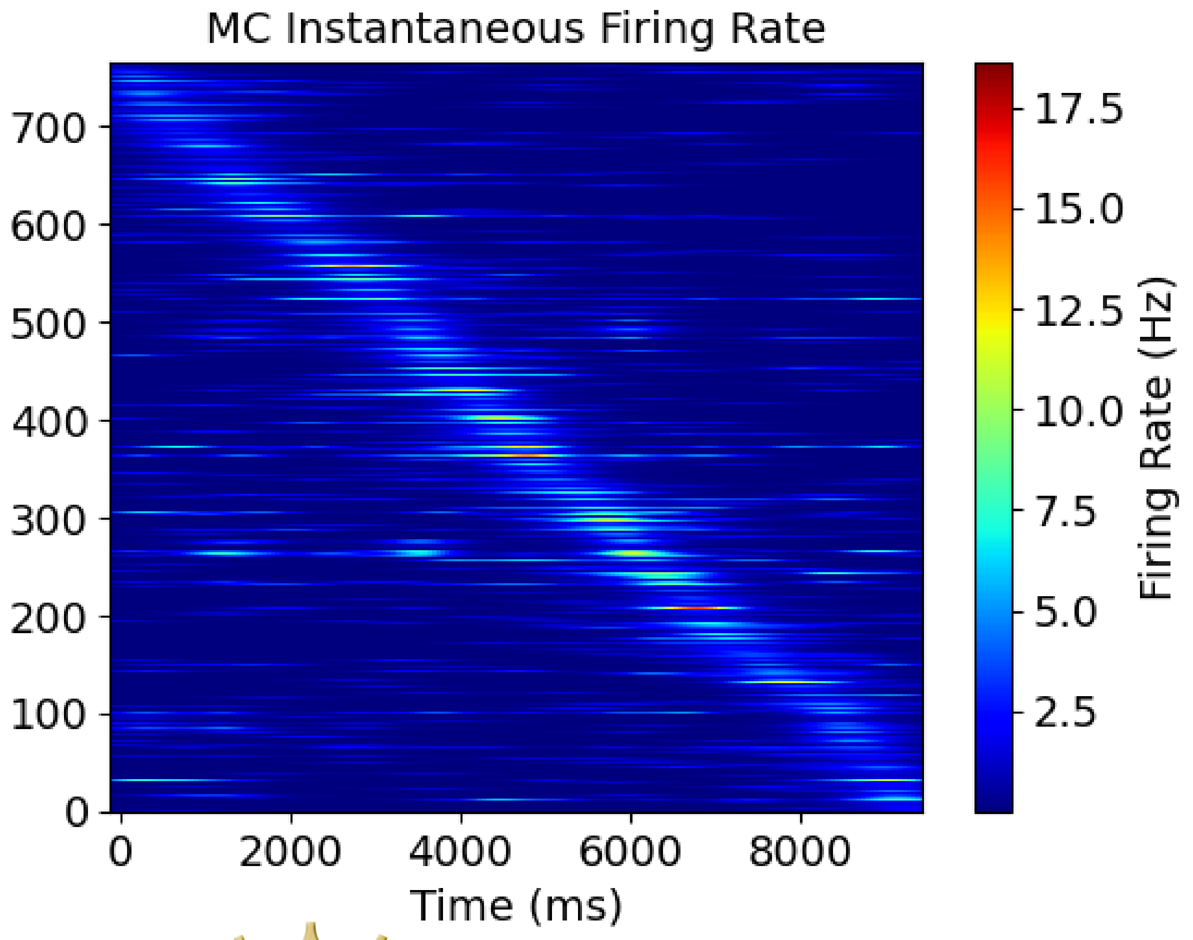


From Stensola et al., *Nature*, 2012.



Spatial selectivity in a biophysically realistic setting

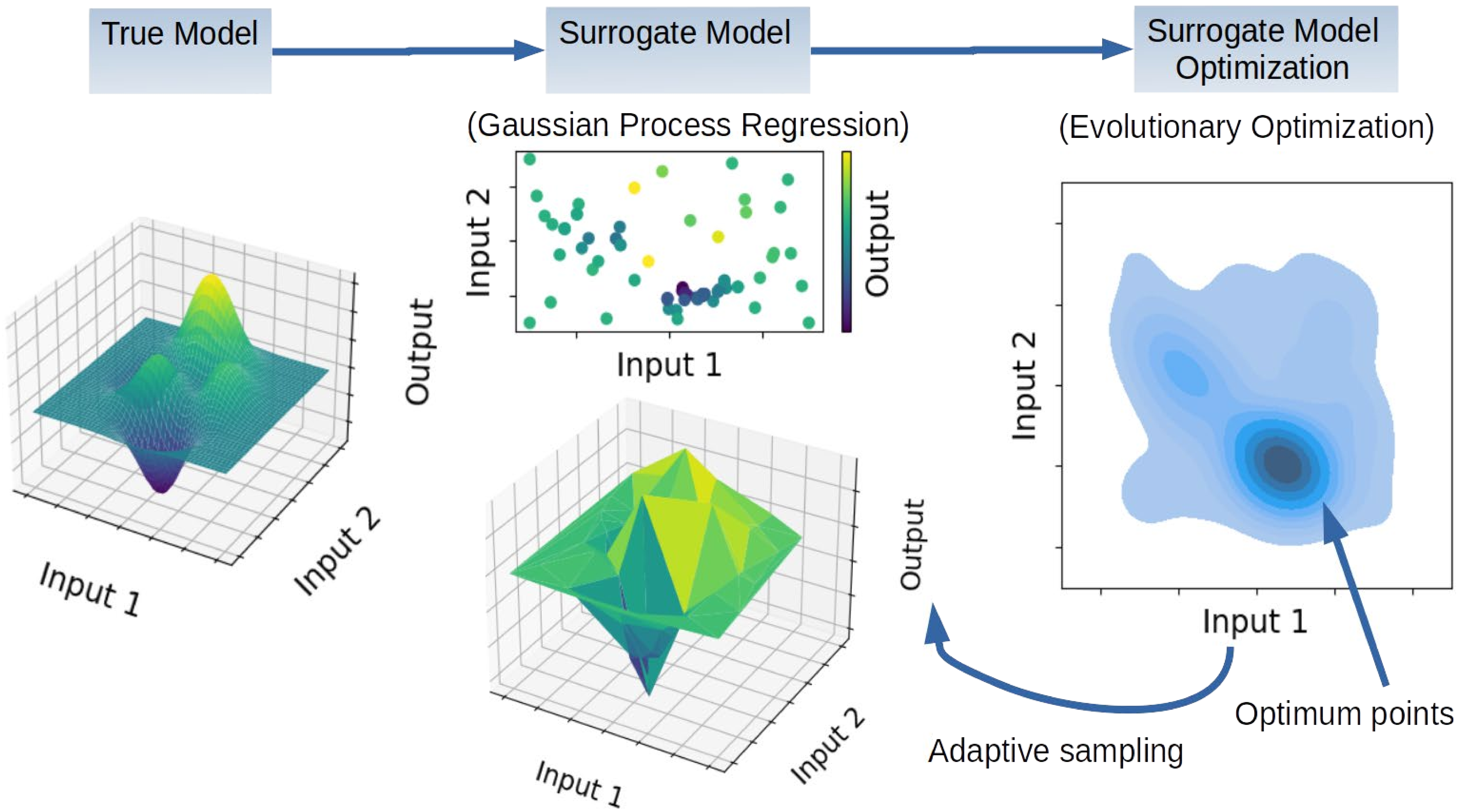




FRONTERA

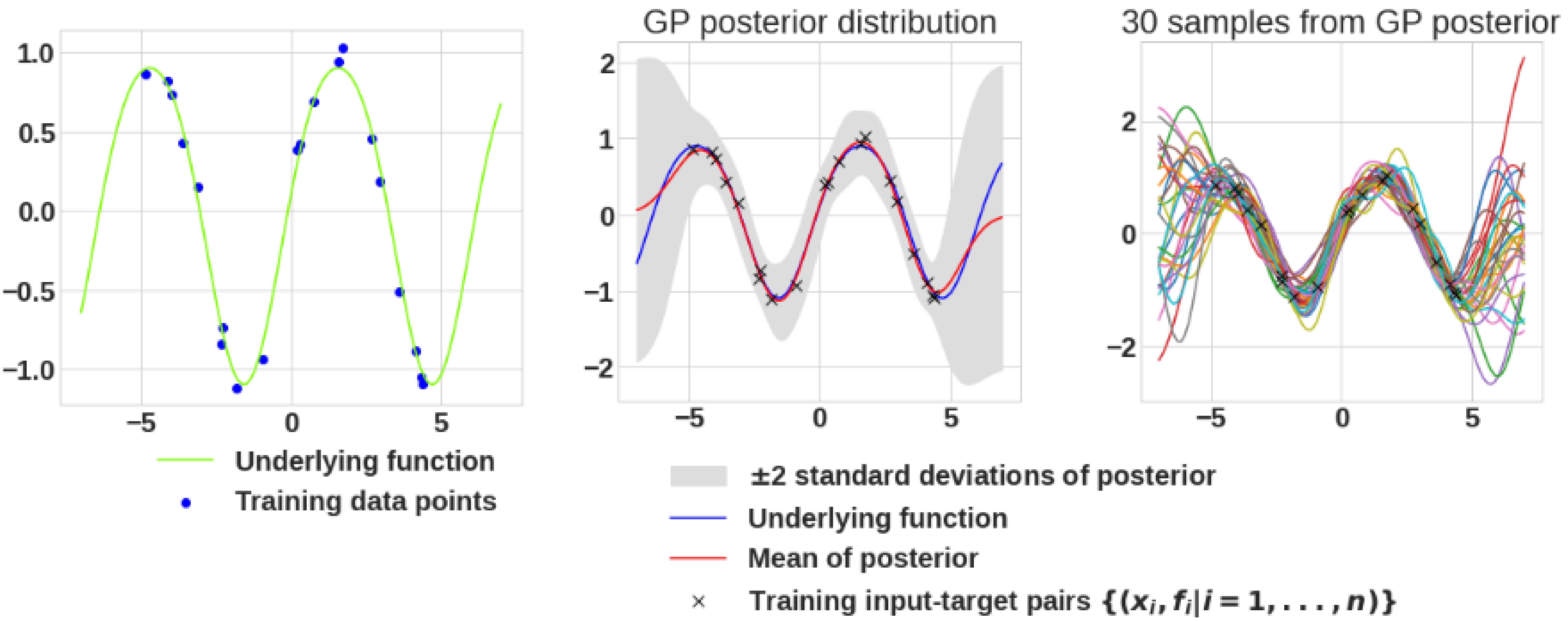
Stanford MEDICINE

Surrogate-assisted optimization overview

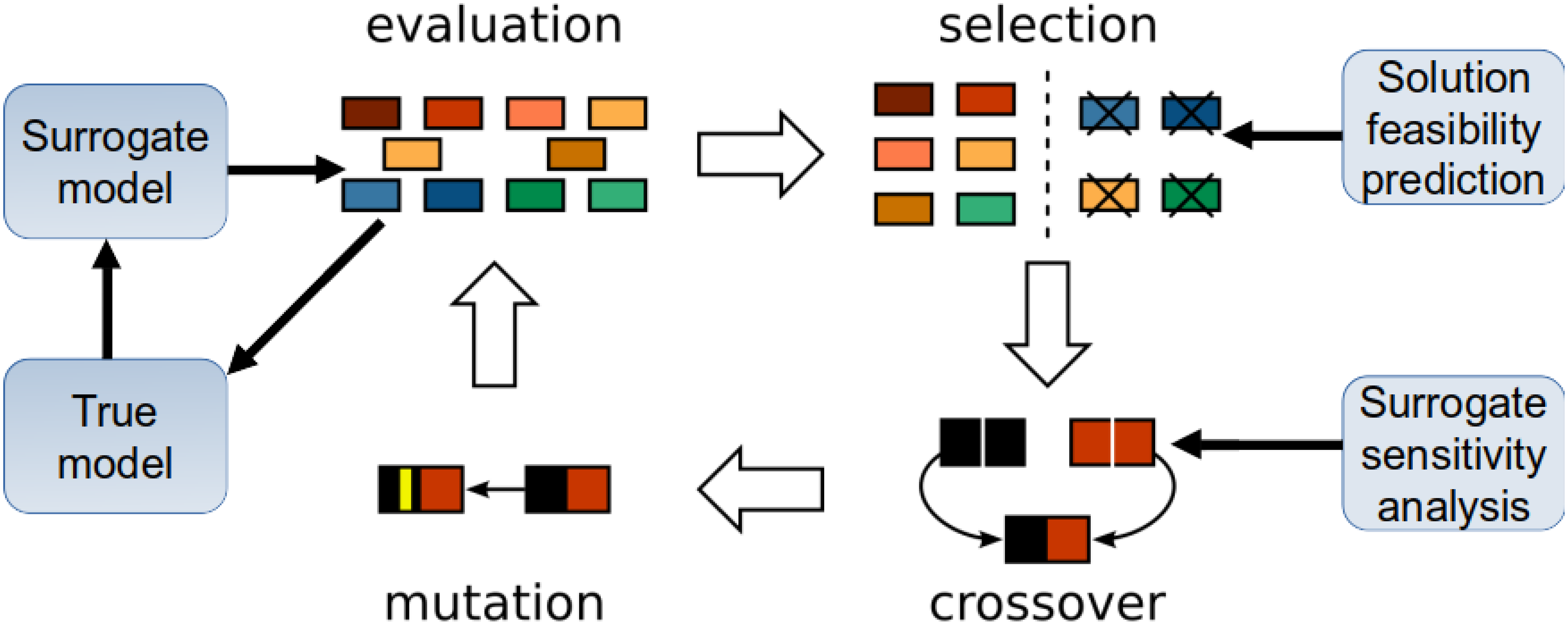


Gaussian Process Regression for Surrogate Modeling

Gaussian processes provide methods for regression modeling by defining a conditional probability distribution over a number of functions that represent a given collection of points.



Surrogate-Assisted Optimization With Evolutionary Algorithms



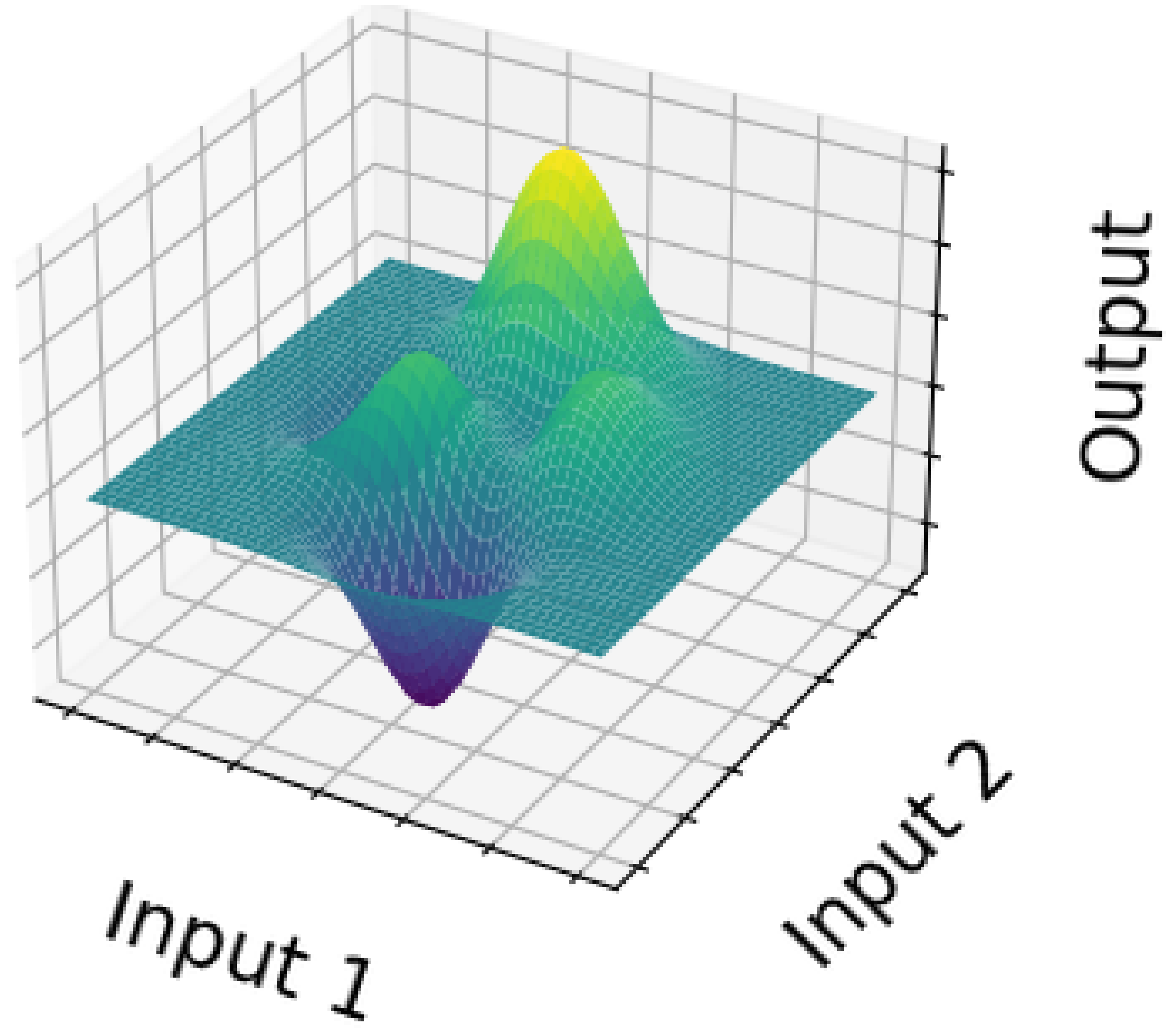
https://www.strong.io/blog/evolutionary-optimization

Surrogate Optimization Case Study: Peaks function (1)

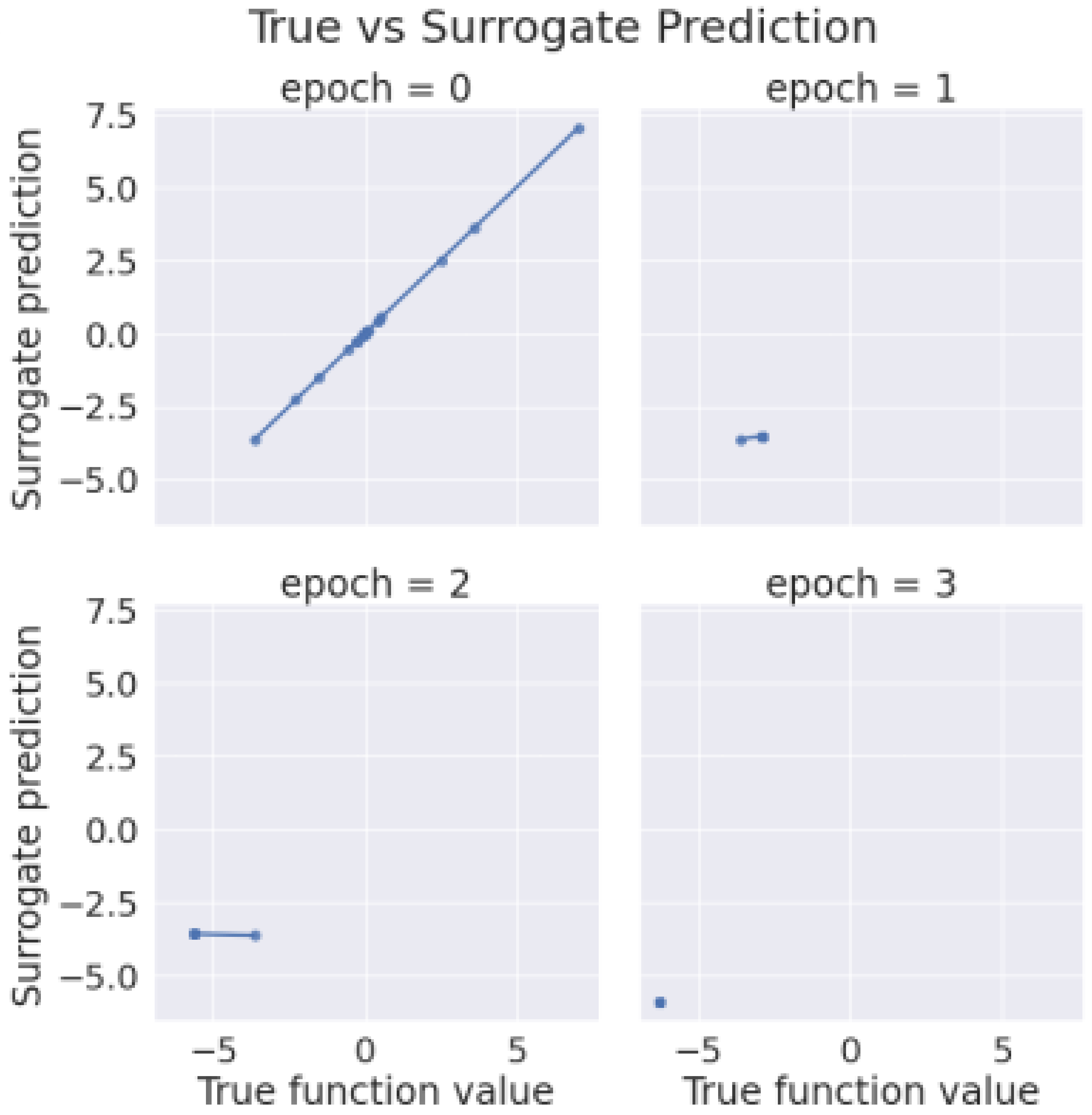
Objective: find the minimal value(s) of the function

$$z = 3(1-x)^2 e^{-x^2-(y+1)^2} - 10\left(\frac{x}{5} - x^3 - y^5\right)e^{-x^2-y^2} - \frac{1}{3}e^{-(x+1)^2-y^2}.$$

A



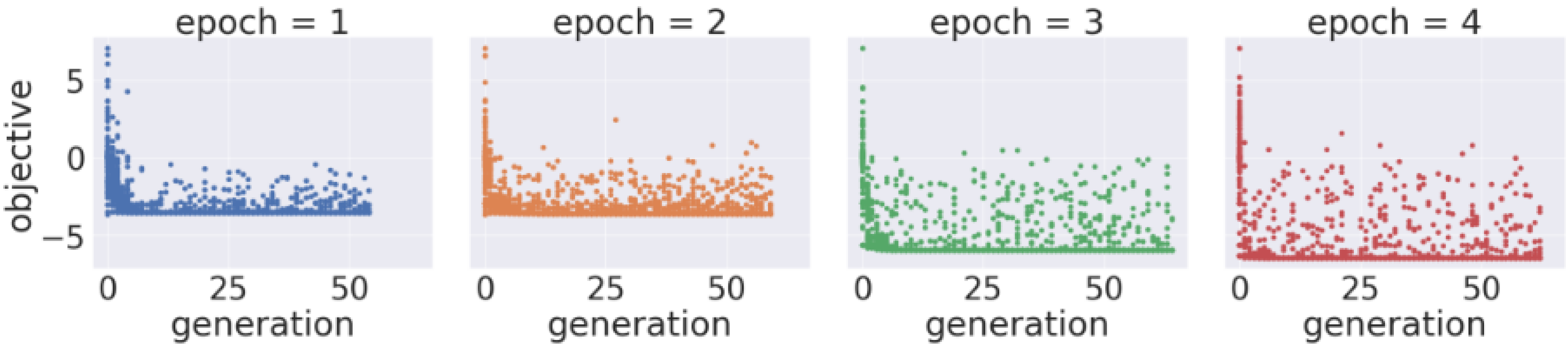
B



Surrogate Optimization Case Study: Peaks function (2)

Objective: find the minimal value(s) of the function

$$z = 3(1-x)^2 e^{-x^2-(y+1)^2} - 10\left(\frac{x}{5} - x^3 - y^5\right)e^{-x^2-y^2} - \frac{1}{3}e^{-(x+1)^2-y^2}.$$

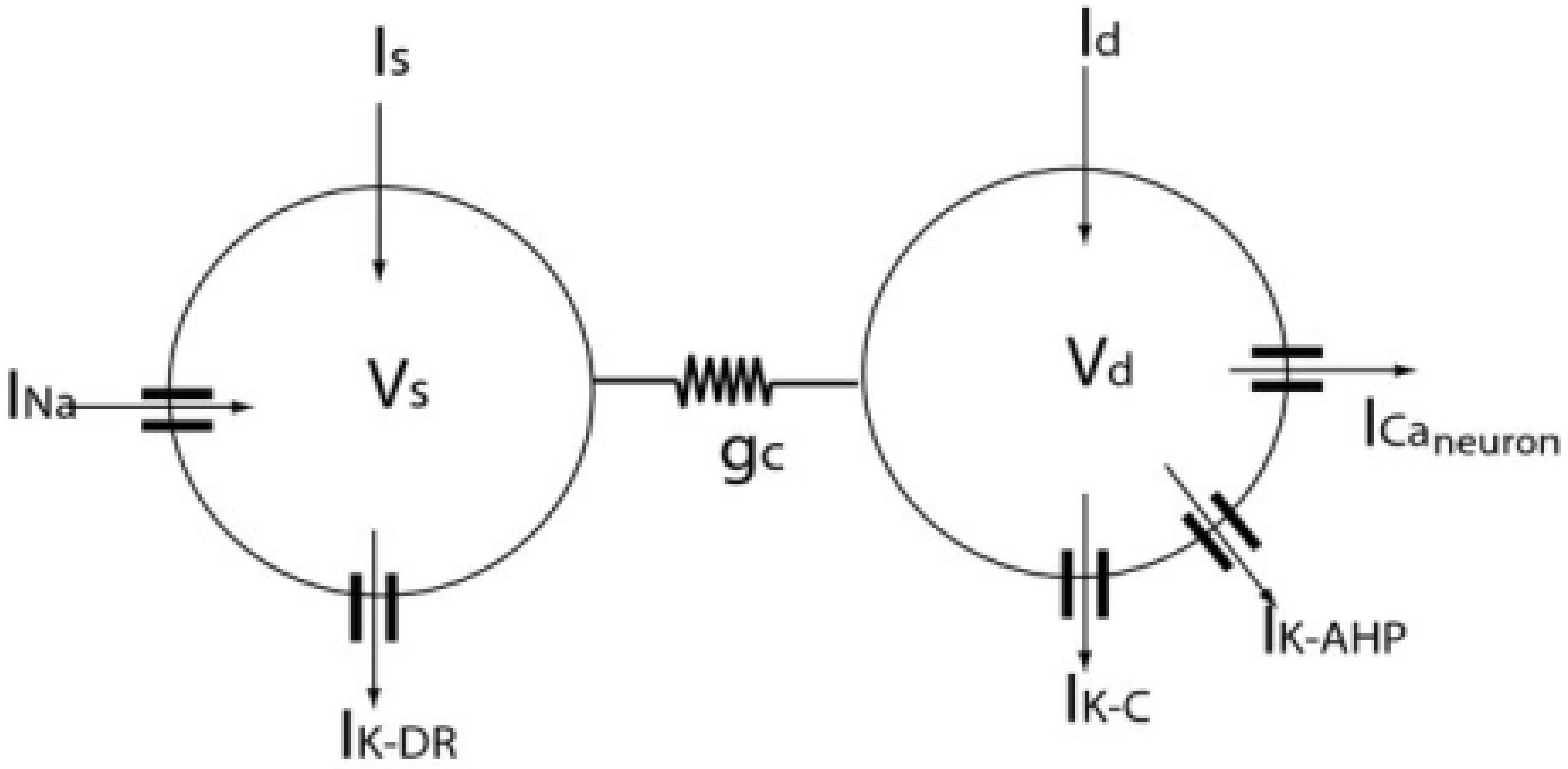


B)

	X	Y	Z
True minimum	0.3061	-1.5306	-6.3898
Surrogate minimum	0.1	-1.5632	-6.3001

Stanford MEDICINE

Surrogate optimization of biophysical neuron models based on the Pinsky-Rinzel model formalism

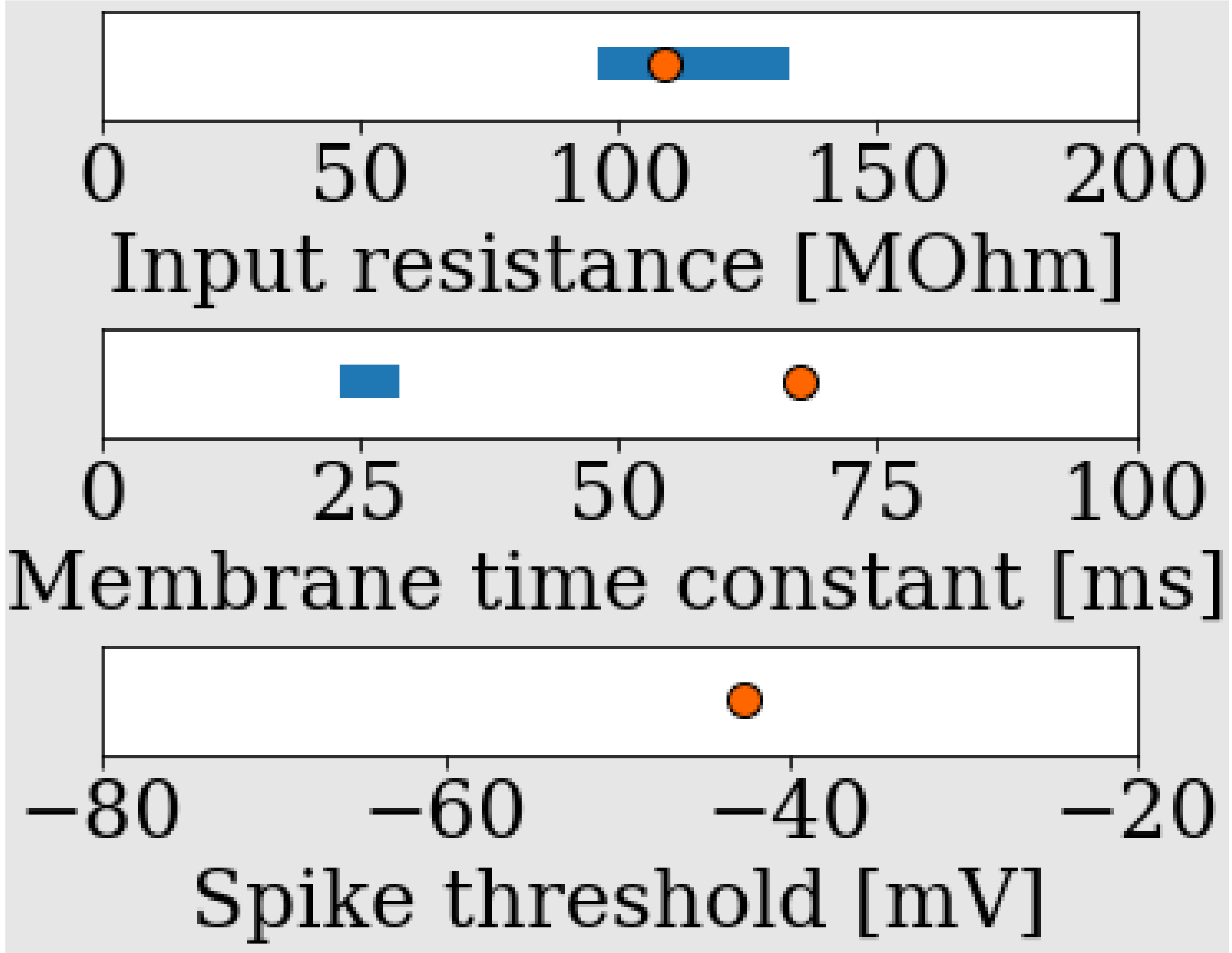


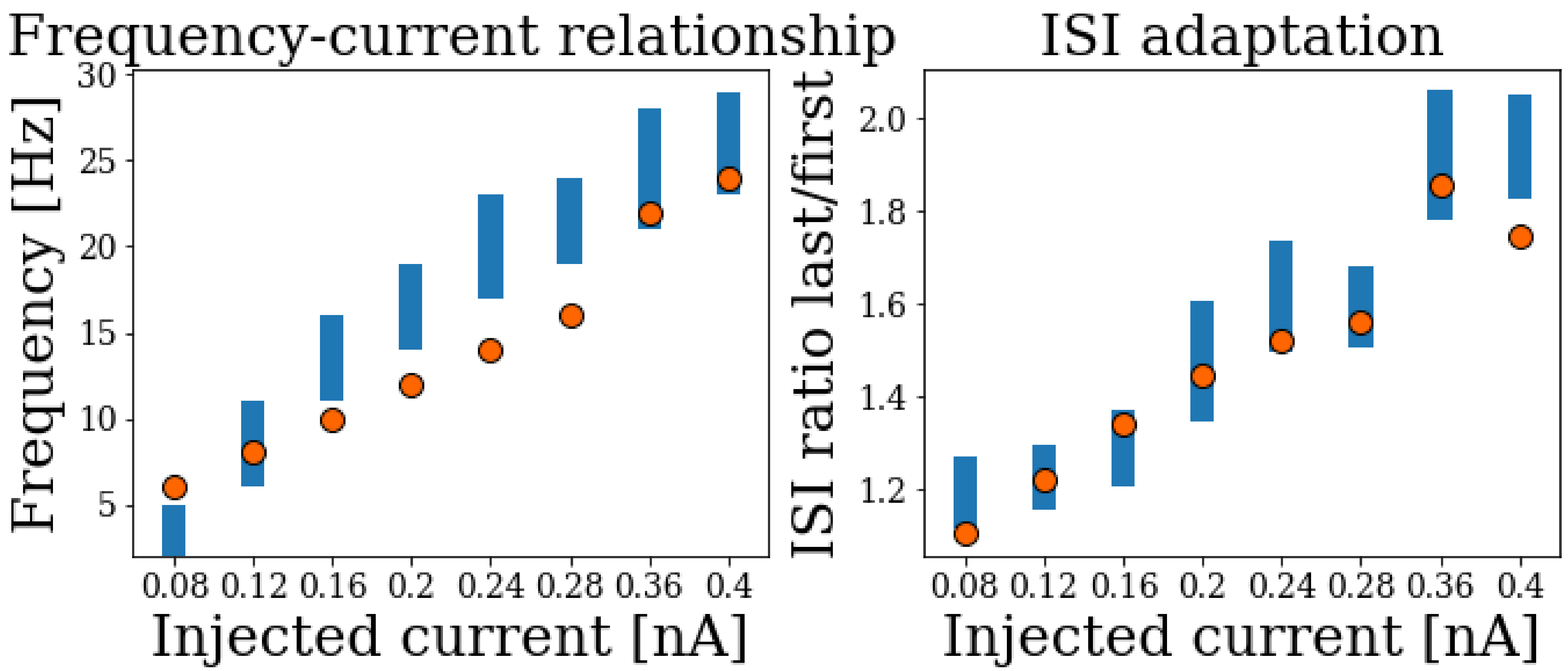
$$
\begin{aligned}
C_m V_s' &= -I_{\text{Leak}}(V_s) - I_{\text{Na}}(V_s, h) - I_{\text{K-DR}}(V_s, n) \\
&\quad + (g_c/p)(V_d - V_s) + I_s/p \\
C_m V_d' &= -I_{\text{Leak}}(V_d) - I_{\text{Ca}}(V_d, s) - I_{\text{K-AHP}}(V_d, q) \\
&\quad - I_{\text{K-C}}(V_d, Ca, c) - I_{\text{Syn}}/(1-p) \\
&\quad + (g_c/(1-p))(V_s - V_d) \\
&\quad + I_d/(1-p) \qquad (1)
\end{aligned}
$$

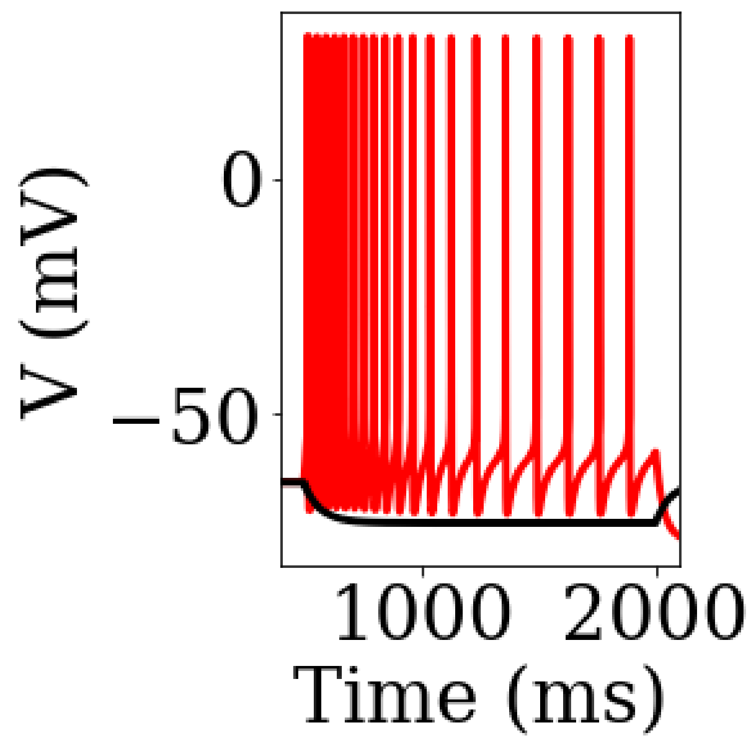
P. F. Pinsky, and J. Rinzel, "Intrinsic and network rhythmogenesis in a reduced Traub model for CA3 neurons." J. Comput. Neurosci. 1994

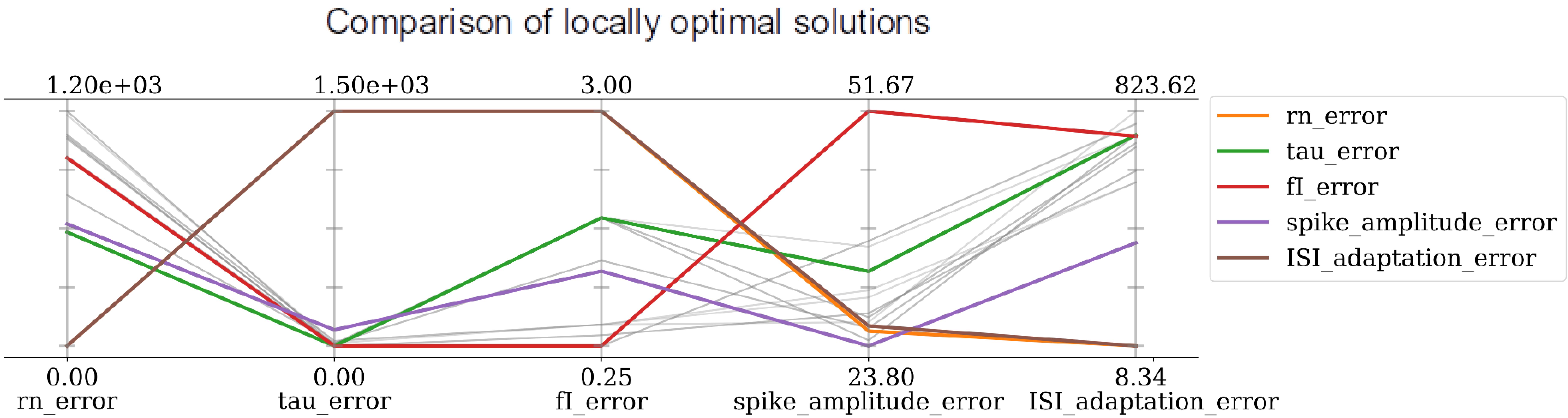
L.A. Atherton, L. Y. Prince, K. Tsaneva-Atanasova. Bifurcation analysis of a two-compartment hippocampal pyramidal cell model. J Comput Neurosci. 2016

Surrogate optimization of Pinsky-Rinzel models of neurons in the dentate gyrus: Mossy Cell

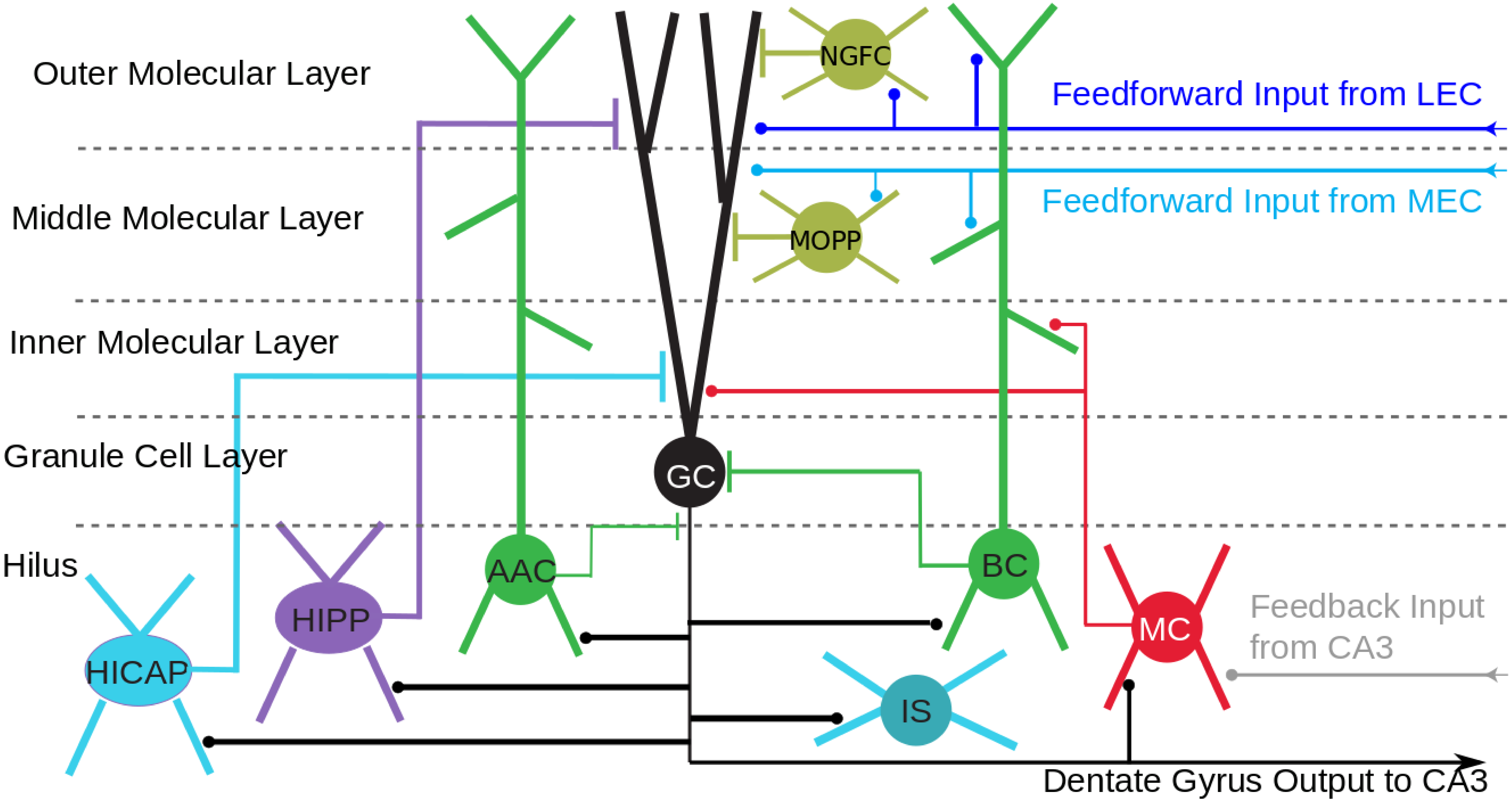








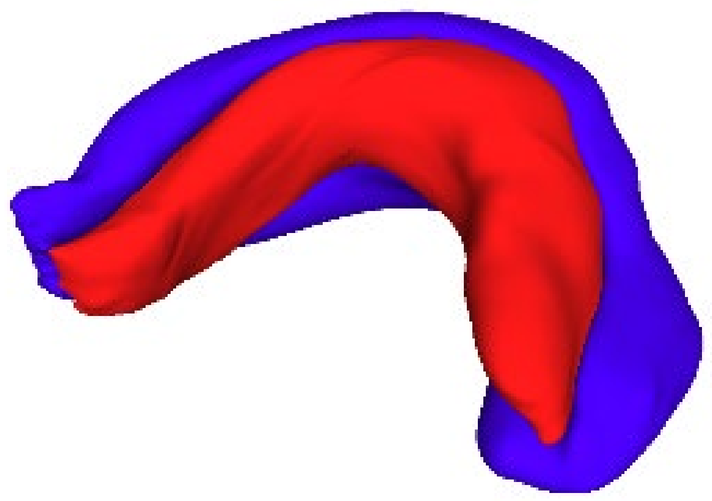
Surrogate optimization of a model of a network of the dentate gyrus (1)



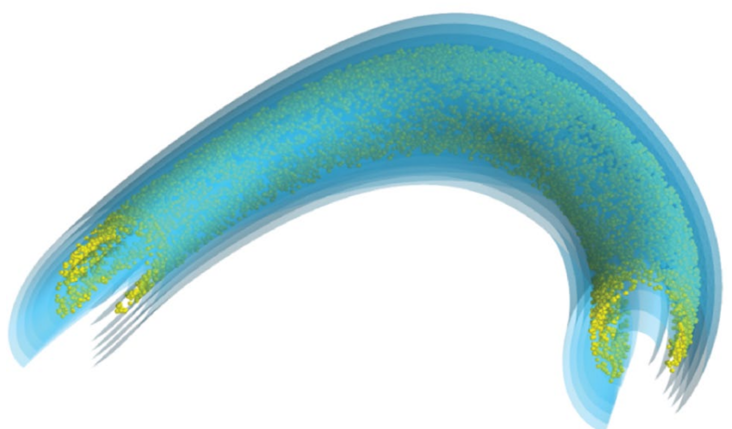
Optimization targets:

- GC selectivity (SNR)
- GC firing rate
- GC fraction active
- MC selectivity (SNR)
- MC firing rate
- MC fraction active
- IN firing rates: AAC, BC, HICAP, HIPP, IS, MOPP, NGFC

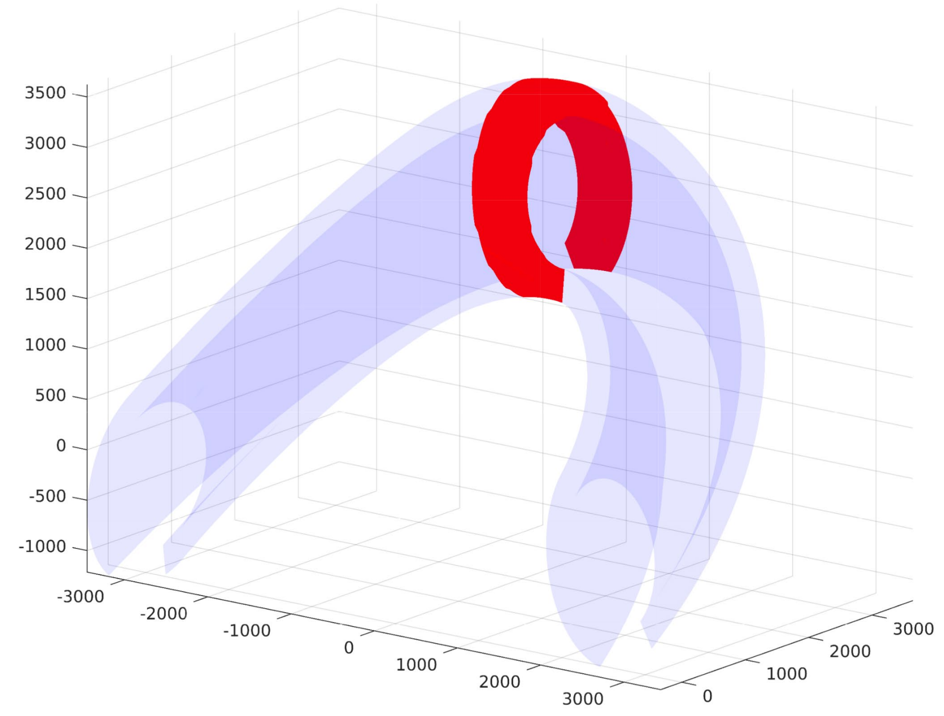
Surrogate optimization of a model of a network of the dentate gyrus (2)

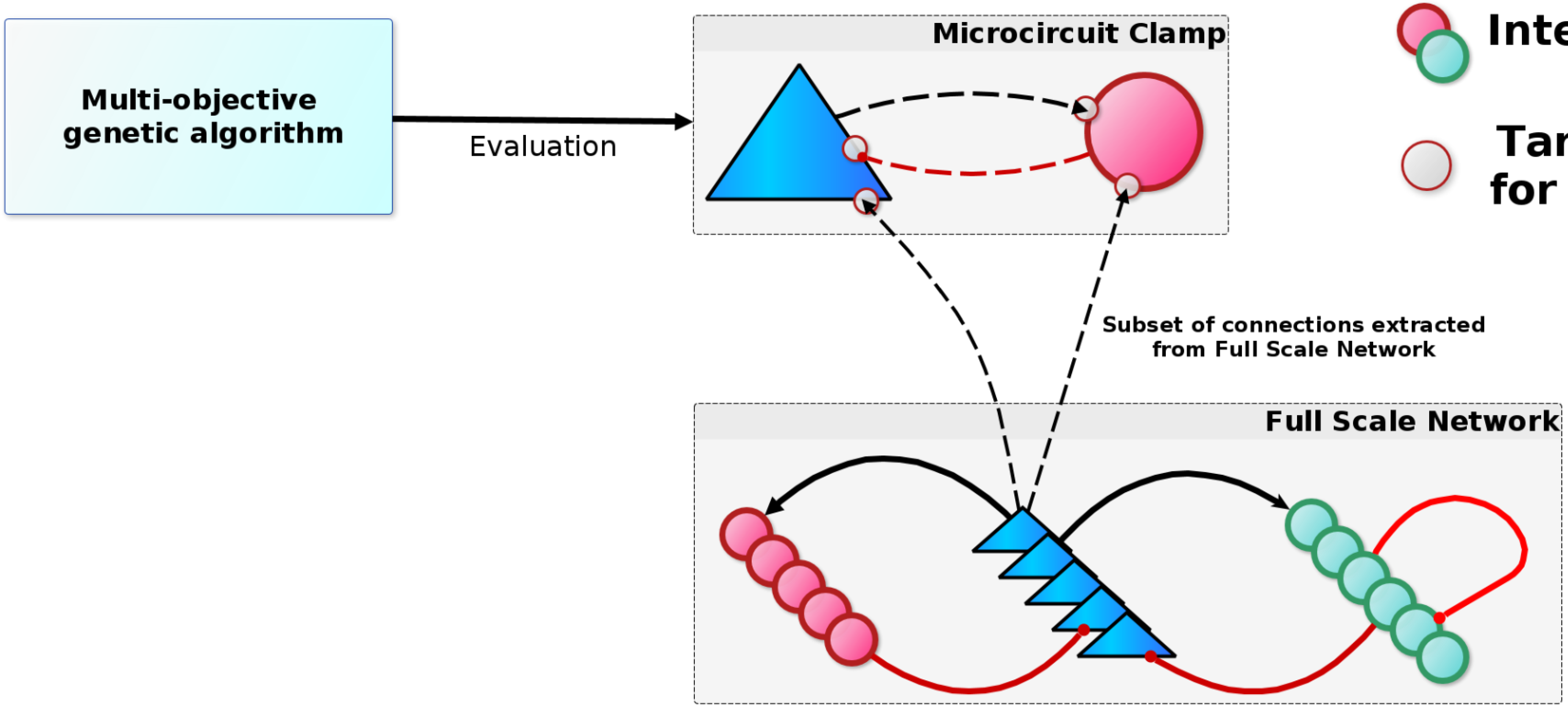


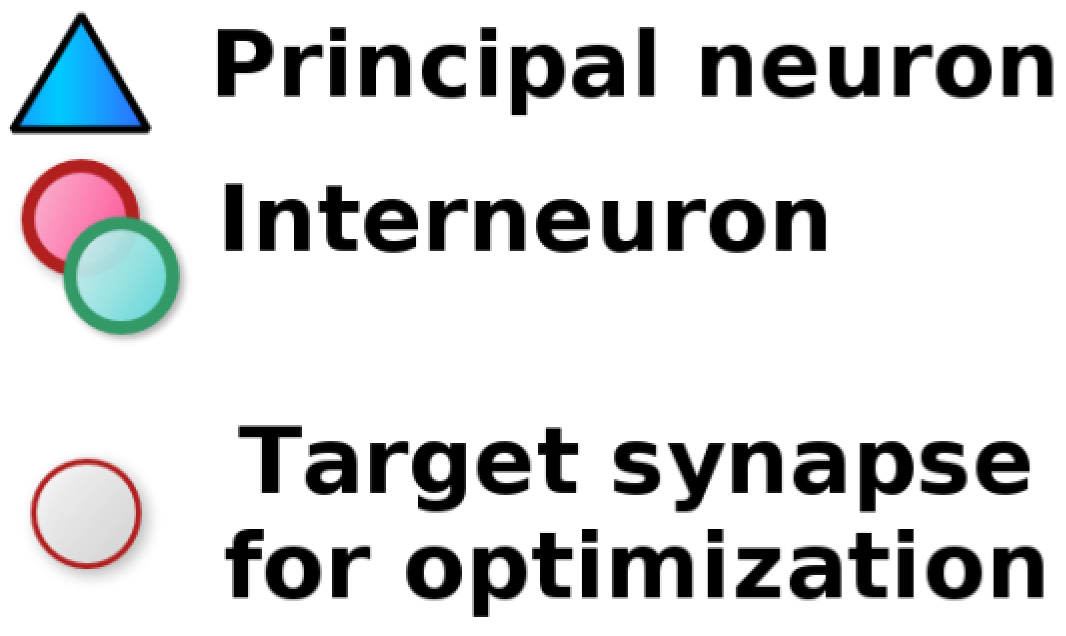
Reconstruction of hippocampal volume



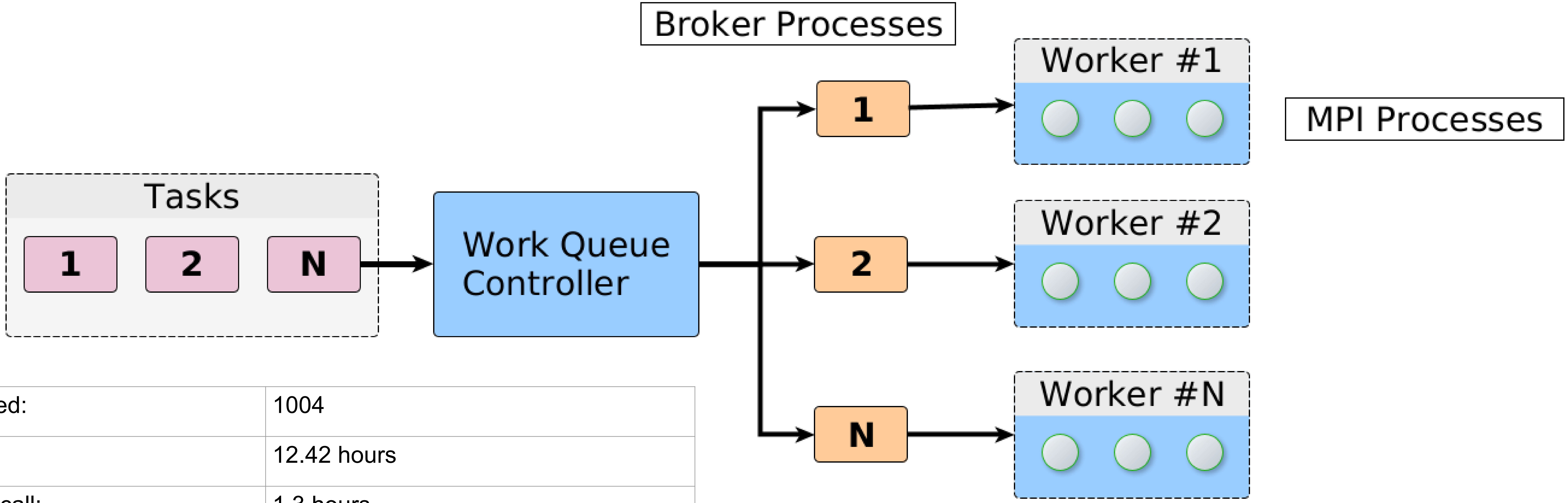
Model of dentate gyrus volume with layer-specific somata distribution







Surrogate optimization of a model of a network of the dentate gyrus (3)

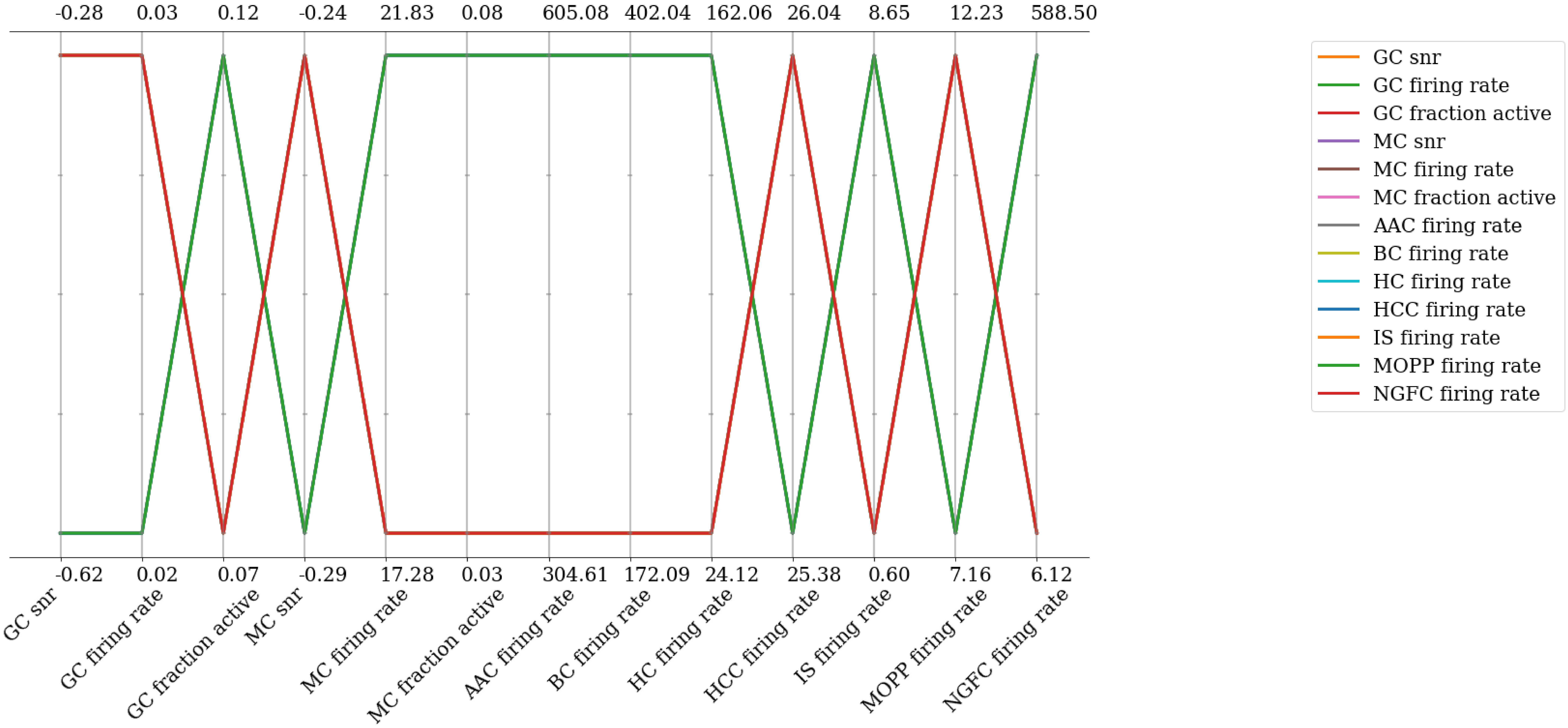


Results collected:	1004
Total walltime:	12.42 hours
Mean time per call:	1.3 hours
Std. dev. of time per call:	0.19 hours
Mean calls per worker:	7.8 [min 7 max 9]
Number of processes:	28544 (1024 nodes; 223 processes per worker)
Number of workers:	127

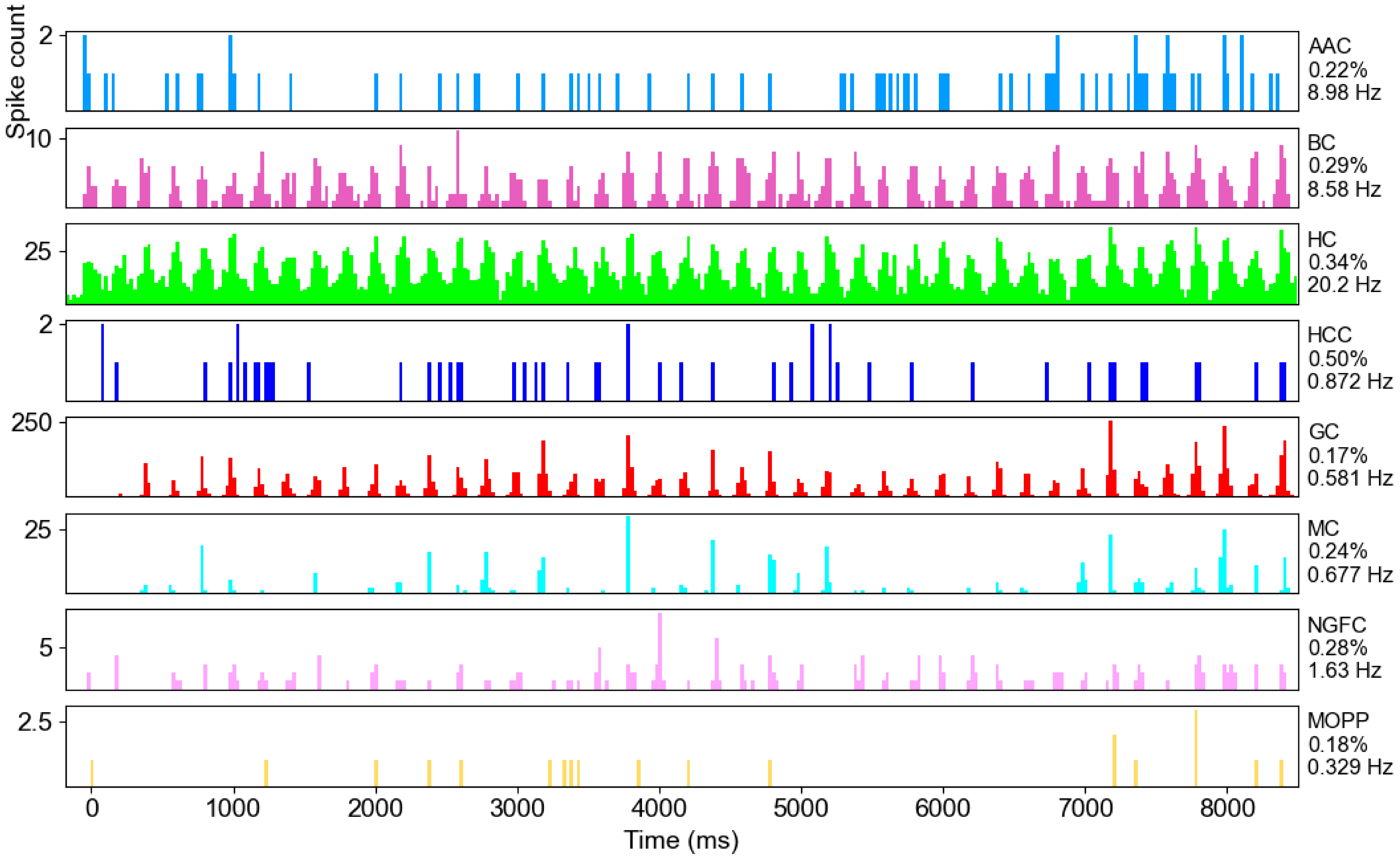
Distributed work queue based on mpi4py

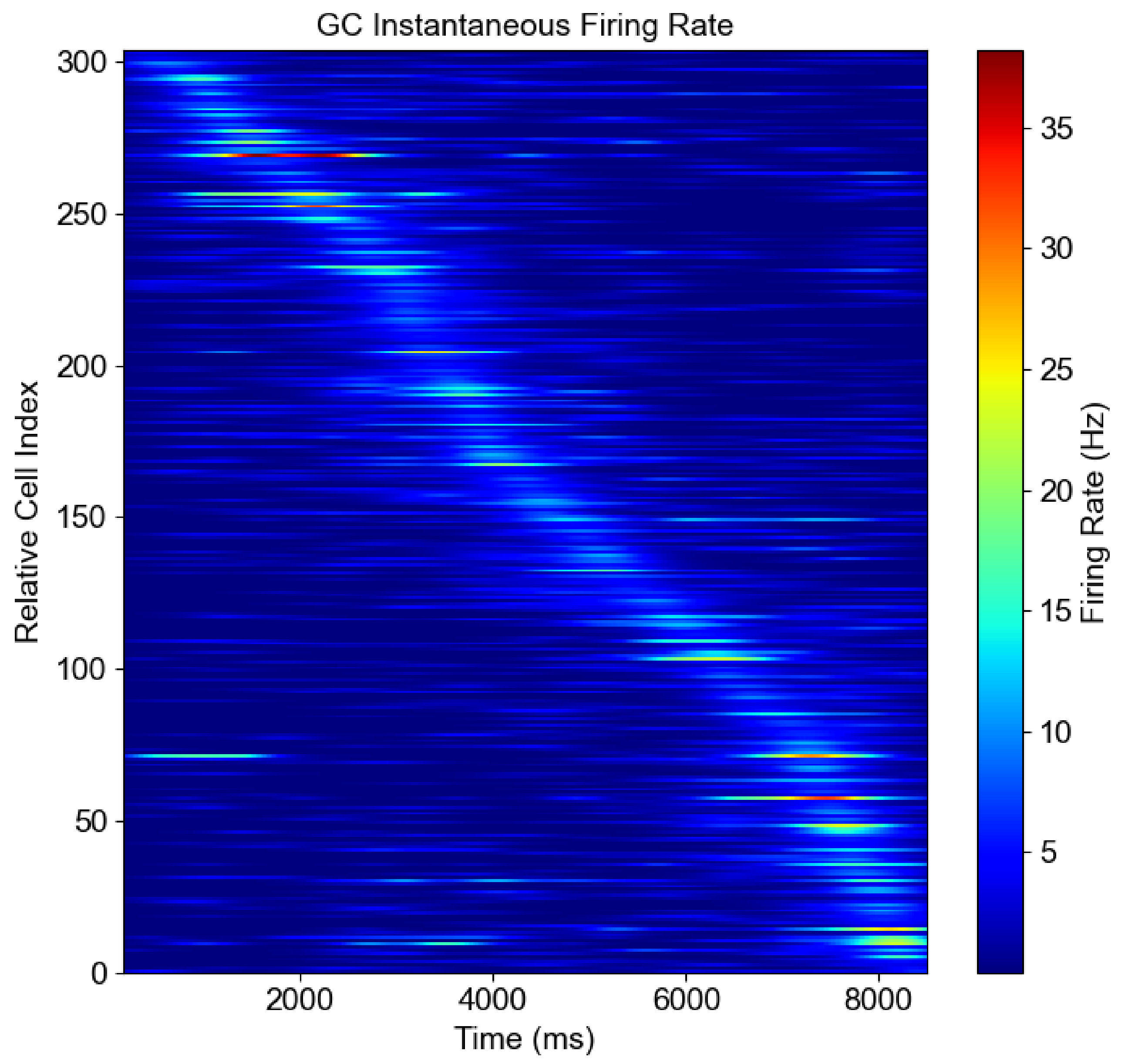
https://github.com/iraikov/distwq

Surrogate optimization of a model of a network of the dentate gyrus (4)

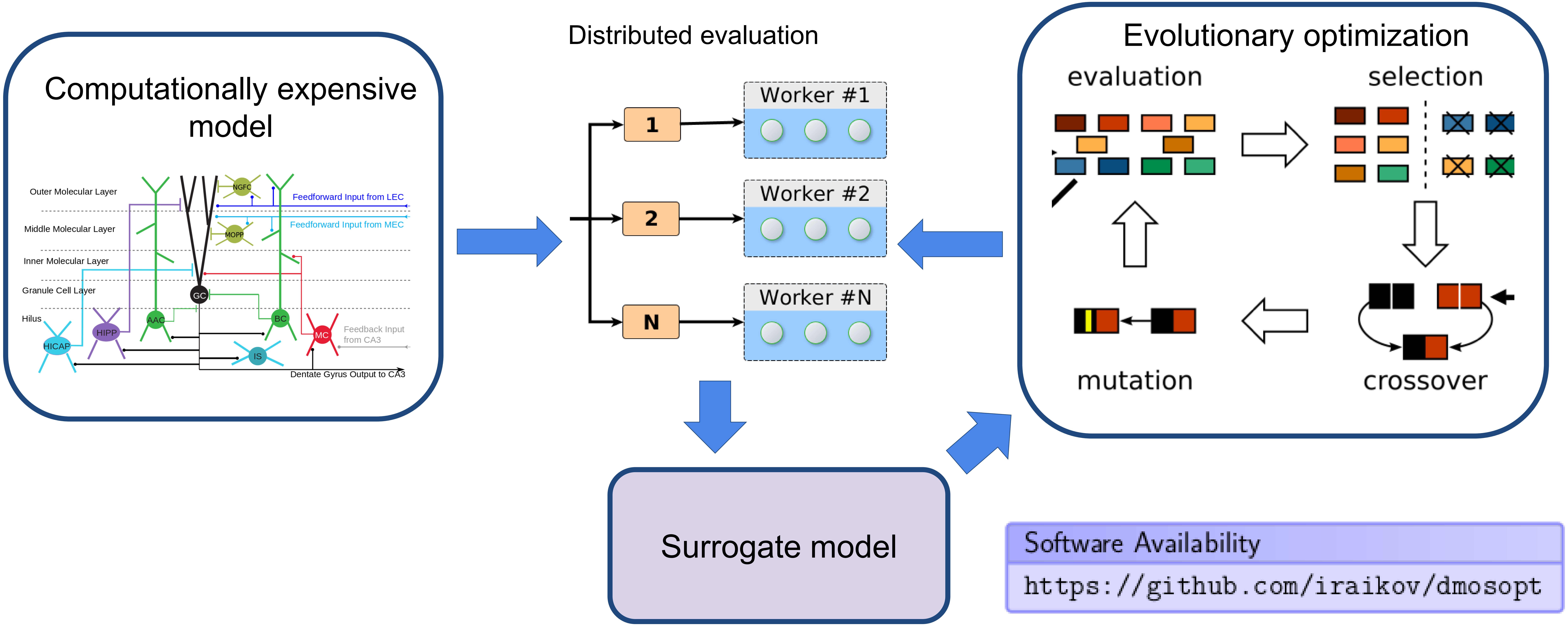


Surrogate optimization of a model of a network of the dentate gyrus (5)





Summary



Software Availability
`https://github.com/iraikov/dmosopt`

Distributed surrogate assisted optimization toolbox: https://github.com/iraikov/dmosopt

Prannath Moolchand

Ivan Raikov

Ivan Soltesz

NIH BRAIN 1U19NS104590-01

Towards a Complete Description of the Circuitry Underlying Sharp Wave-Mediated Memory Replay

NIH BRAIN 1U19NS104590-01

Towards a Complete Description of the Circuitry Underlying Sharp Wave-Mediated Memory Replay