How Can Spiking Networks Remain Resilient Under Degeneration?

Simachew Mengiste[1], Ad Aertsen[2], Demian Battaglia[1], Arvind Kumar[3]

[1]FunSy – University of Strasbourg; [2]BCF – University of Freiburg; [3]KTH – Royal Institute of Technology

Problem and Questions

- Degeneration progressively removes synapses and neurons, but circuit activity can remain stable before complete network failure.
- We ask which structural factors preserve weakly active, irregular dynamics under damage.
- We also ask whether degeneration-induced changes in rate, variability, and synchrony can be predicted from weighted connectivity.

Central idea

Structural loss does not directly determine dynamical failure. Degeneration is filtered through inhibitory organization: how much inhibition is available, and where it is recruited in the architecture.

Computational Ingredients

Healthy baseline

Weakly active asynchronous-irregular firing is matched before damage is applied.

Neuron model

Excitatory and inhibitory leaky integrate-and-fire spiking neurons.

Architectures

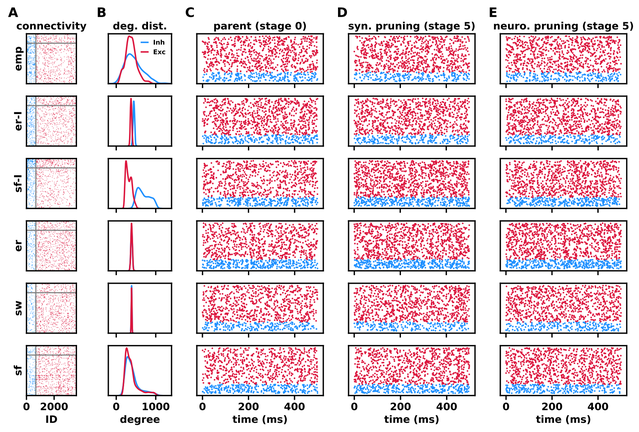
Empirical microcircuit and synthetic controls matched for size and density.

Degeneration

Synaptic and neuronal loss applied as staged pruning strategies.

Model System

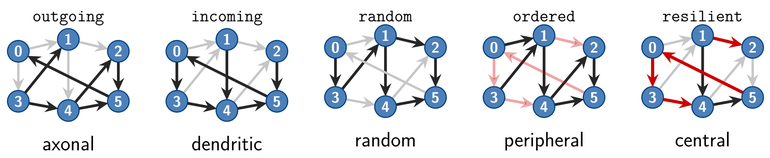
- Empirical layer-4 cortical microcircuit compared with `er`, `sw`, `sf`, `er-I`, and `sf-I`.
- All networks preserve size, E/I composition, and total synapse count.
- Inhibition-promoting controls test whether resilience reflects special placement of inhibitory influence.



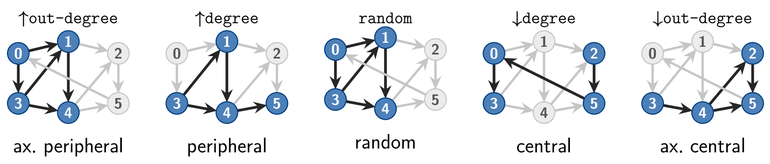
Synaptic and Neuronal Loss Rules

- Degeneration proceeds in nine stages; each stage removes 10% of the remaining synapses or neurons.
- Synaptic rules abstract diffuse synapse loss, dendritic/axonal damage, and targeted loss of strong connections.
- Neuronal rules test random loss, hub-targeted disruption, and selective loss of strong broadcasters.

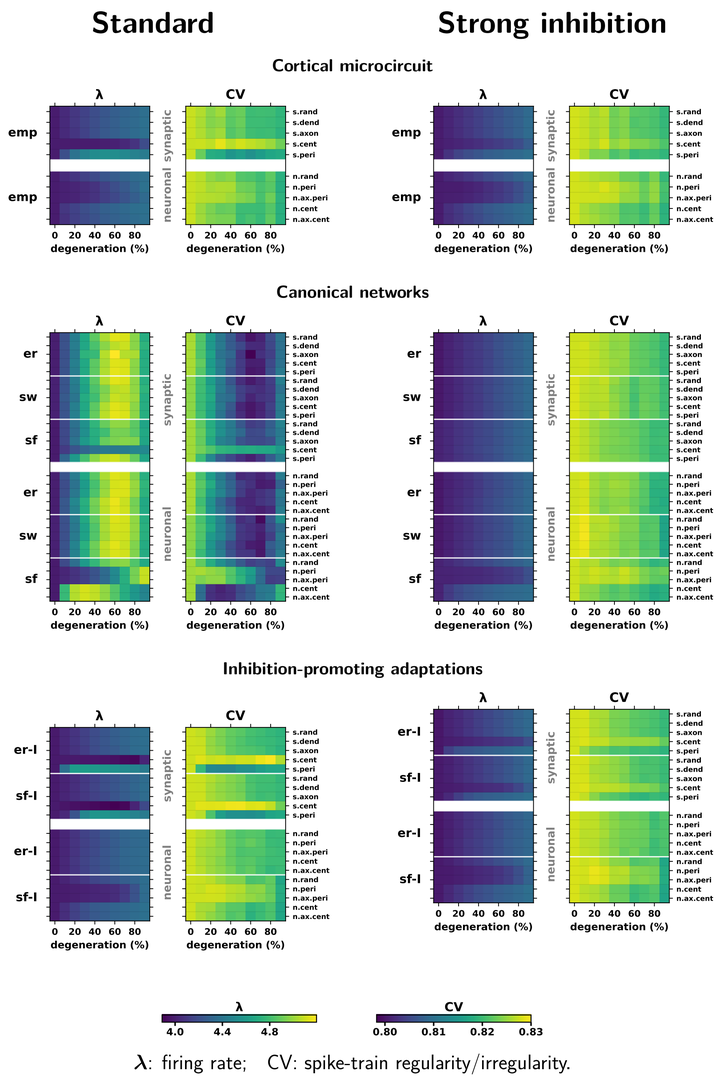
Synaptic pruning



Neuronal pruning



Inhibition Shapes Resilience



λ: firing rate; CV: spike-train regularity/irregularity.

- Under moderate inhibitory strength, `emp`, `er-I`, and `sf-I` remain closer to the baseline regime.
- Generic `er`, `sw`, and `sf` networks show larger changes in firing rate, variability, and synchrony.
- With stronger inhibition, all network classes can be stabilized.

Two routes to resilience

Inhibitory architecture

Inhibitory hubs, preserved E/I subpopulation densities, or enriched excitatory drive onto inhibitory neurons recruit inhibition efficiently.

Inhibitory gain

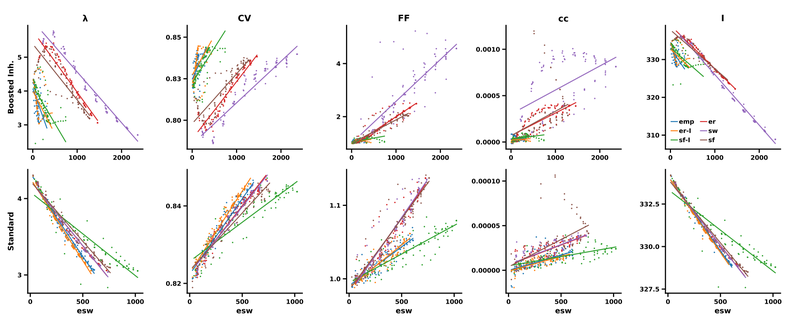
Even less favorable architectures can be stabilized when inhibitory synapses are made strong enough.

Mechanistic interpretation

Architecture does not create an absolute resilient category. It changes the inhibitory gain required to preserve stable activity under degeneration.

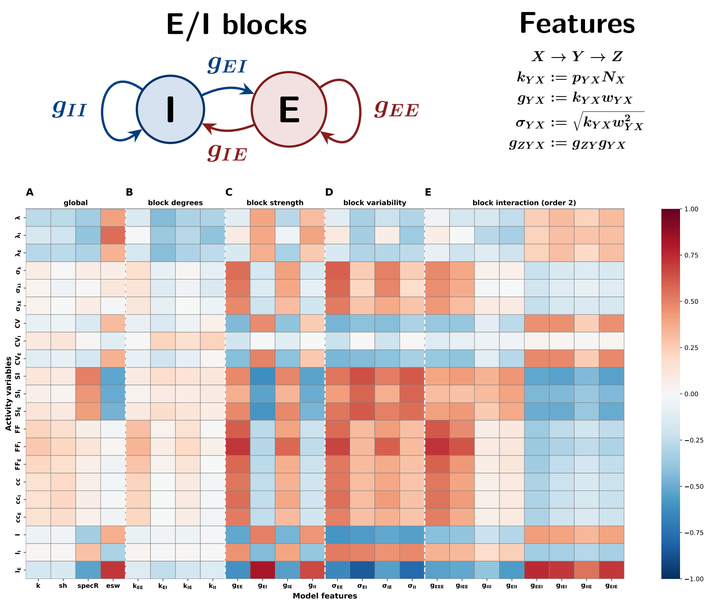
ESW Organizes Within-Class Drift

- ESW, the *effective synaptic weight* of a neuron, is its net presynaptic strength.
- With globally inhibitory weighted coupling, ESW provides a simple first proxy for inhibitory dominance.



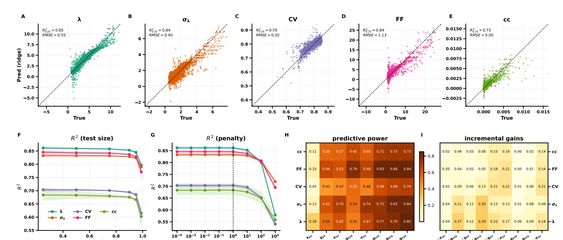
- ESW organizes firing rate and synaptic current trajectories well within network classes.
- However, similar ESW values can still support different variability, irregularity, and synchrony across architectures.

Structure–Activity Correlations



- Purely topological summaries are weakly related to activity changes.
- Weighted E/I coupling features show stronger and more structured correlations with rate, variability, and synchrony.
- These weight-aware variables motivate the multivariate predictor below.

Predictive Structural Features

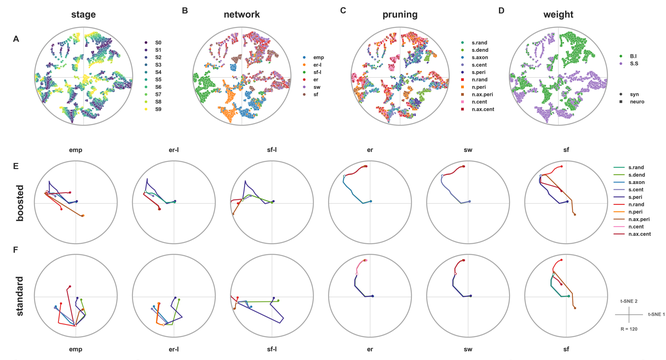


- The multivariate model extends ESW from one global weighted sum to subpopulation-resolved E/I coupling.
- Mean weighted interactions, their fluctuations, and second-order terms substantially improve prediction across rate, variability, synchrony, and irregularity.

Prediction message

The relevant structure is not just how many links remain, but which weighted E/I interactions survive degeneration.

Activity-Space Summary



Low-dimensional activity projections summarize how network states drift jointly across rate, variability, and synchrony. They suggest a broad organization by architecture and inhibitory regime, with pruning rules shaping more local trajectories.

Implications and Outlook

- Circuits may be especially vulnerable when degeneration weakens inhibitory control or disrupts how inhibition is recruited.
- Maladaptive sprouting may restore connection number while blurring the inhibitory organization needed for stable dynamics.
- Boosting inhibition, or improving its recruitment, may stabilize activity under structural loss.
- Future tests should vary cell-type vulnerability, sprouting rules, lesion tempo, baseline state, and disease-specific constraints.

mengiste@unistra.fr