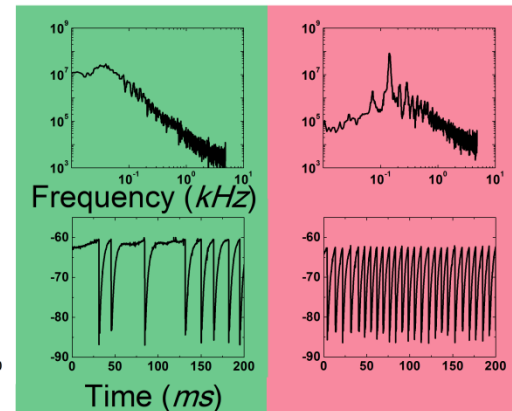
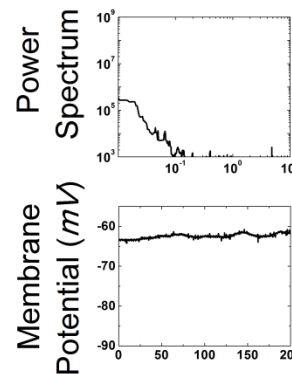


Neuronal dynamics emulation on Spikey

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NICE workshop 2017



Motivation

- ❖ **Neuronal firing activities have attracted a lot of attention.**
 - ❑ The basis for adaptive behavior;
 - ❑ The signs for various neurological disorders.
- ❖ **The “criticality” hypothesis.**
 - ❑ The brain is poised in the critical boundary;
 - ❑ Have been found across multiple species using a variety of measurement technique;
 - ❑ Still exists a hot debate;
 - ❑ Possible solution: constructing a brain-phase diagram;
 - ❑ The emerging neuromorphic chip provide a powerful tool.
- ❖ **Toward better understanding of collective neuronal dynamics.**
 - ❑ provide a new computing paradigm using networks of spiking neurons.

Emulation Settings

The emulation work was done using the neuromorphic chip - Spikey I, developed by University of Heidelberg, Germany.

We constructed a **recurrent network of neurons with sparse and random connections**.

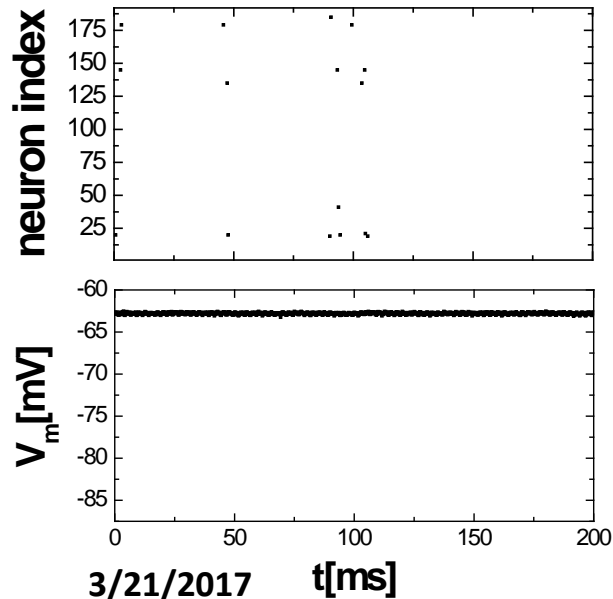
- ❖ A group of **192 neurons** was used.
- ❖ Each neuron was configured to have a fixed number $k = 5$ of presynaptic partners.
- ❖ **Eight (8) randomly chosen neurons** from the whole group were stimulated by an external input modeled as a uniform-time-distributed signal.
- ❖ **The average effect** of these external inputs for triggering neuronal firing was **0**.
- ❖ The neuron's **resting membrane potential** was chosen to be **-65mV**.



Three Phases

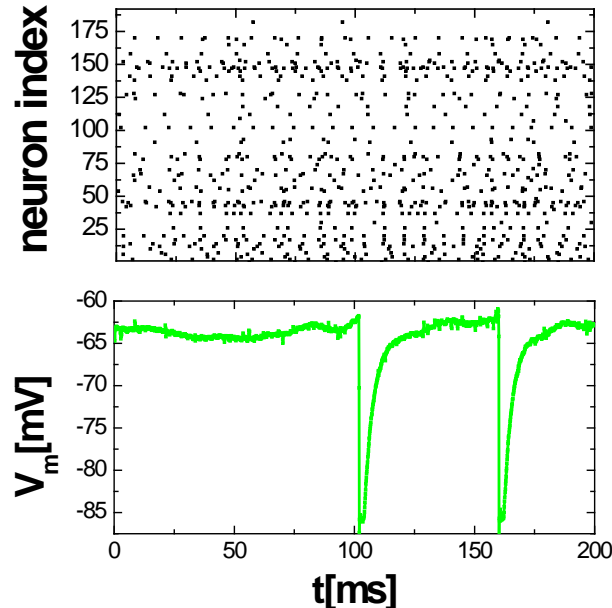
T-phase

- Few firing activities during the emulation;
- The whole dynamical system seems to be “silent”.



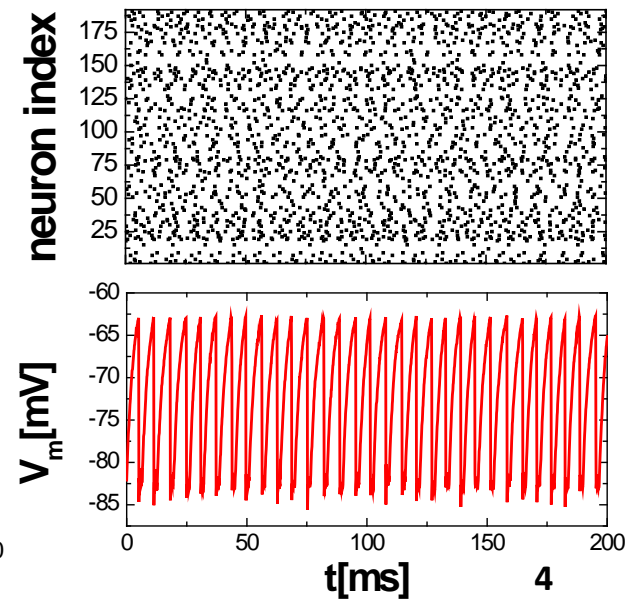
N-phase

- Intermittent firing activities;
- Closely resemble to the normal healthy brain behavior.

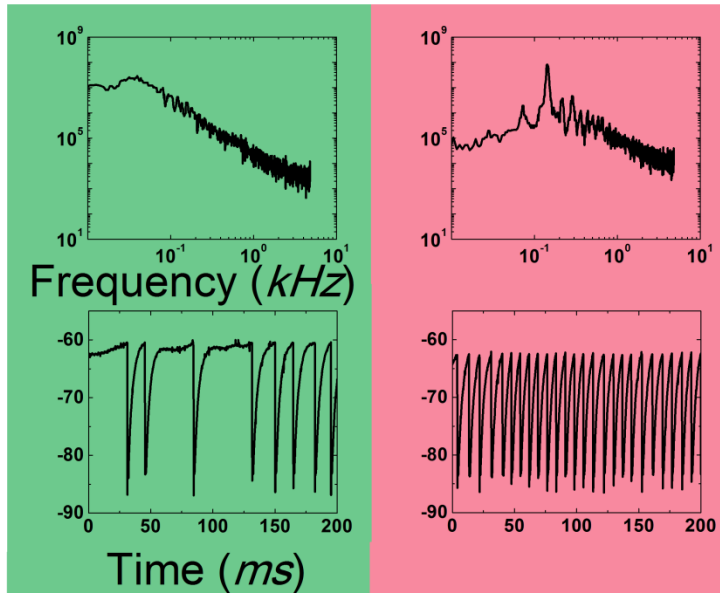
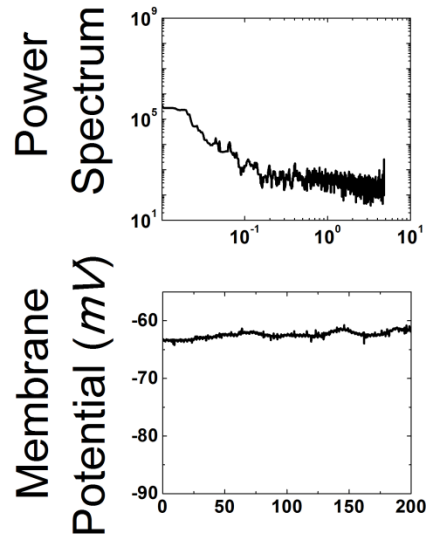


C-phase

- A constant oscillatory firing behavior;
- The firing activities never stops.



Power Spectra



T-phase: a sharp decrease at low frequency on power spectra (left column);
N-phase: 1/f noise-like spectra (middle column);
C-phase: 1/f noise-like spectra superimposed by equidistant peaks (right column) representing periodic dynamics.

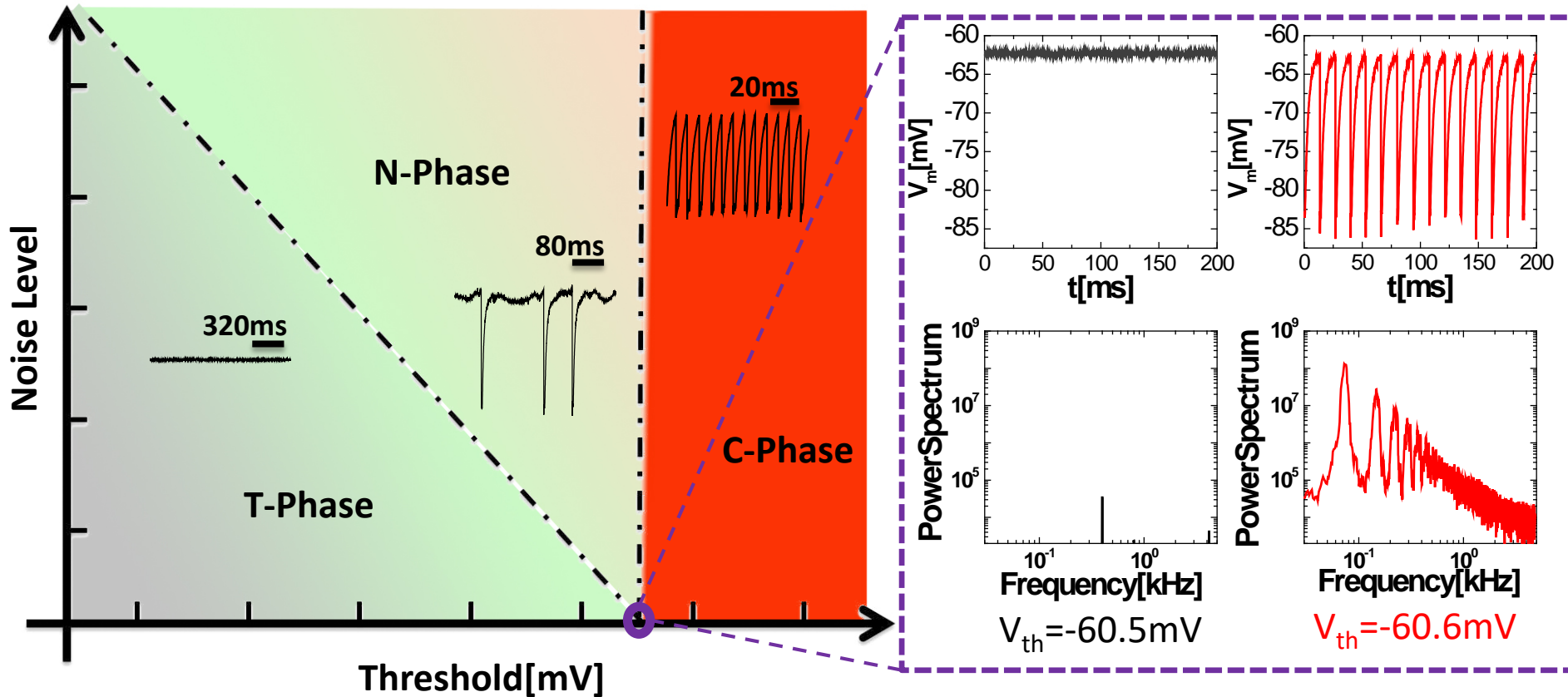
❖ Standard power-spectrum analysis

Due to the limitation of the total number of neurons and measuring technique in Spikey chip, standard power-spectrum analysis has first been applied to single neuron recordings.

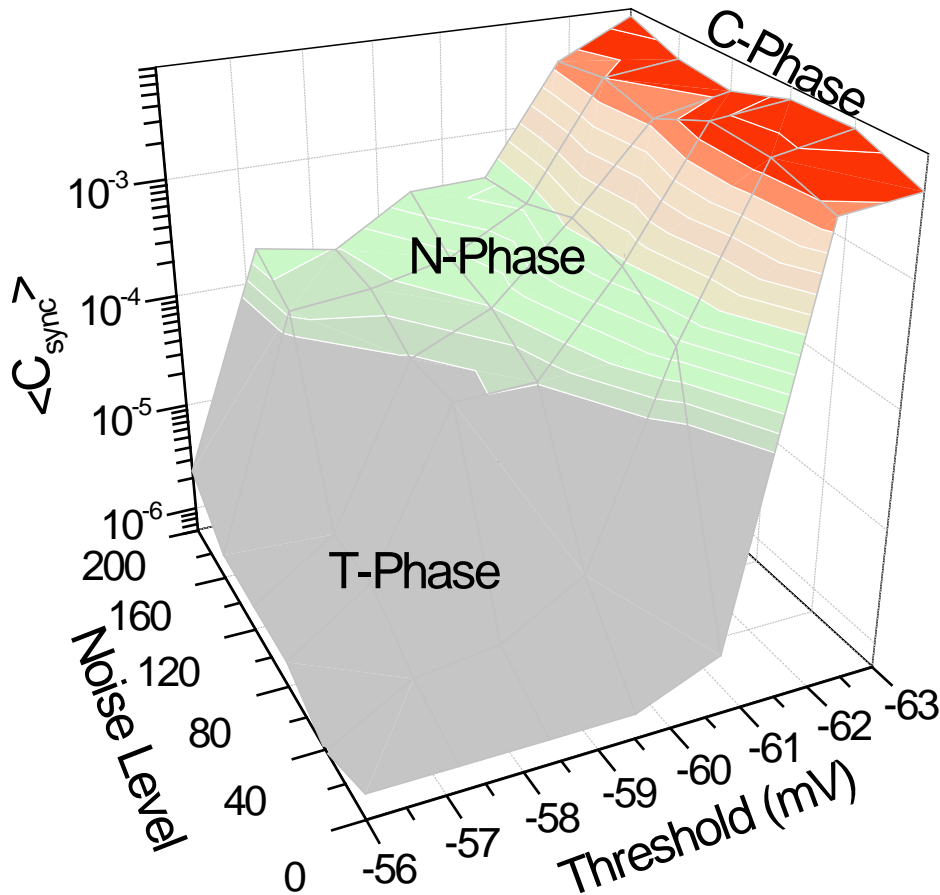
$$x(f) = \int_{-\infty}^{+\infty} e^{-2\pi i f t} x(t) dt,$$

$$S_{xx}(f) = |x(f)|^2.$$

Phases Diagram (Power Spectra)



Phases Diagram (Order Parameter)



❖ Order parameter construction

The order parameter construction follows the function,

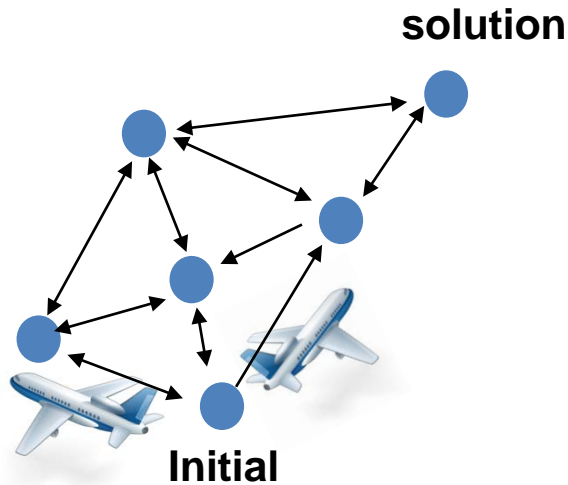
$$C_{i,j}(\tau) = \frac{1}{\tau} \int_{t_0}^{t_0+\tau} \delta_i(t) \delta_j(t) dt,$$

where $\delta_i(t)$ is 1 if neuron i is spiked at time t , and 0 otherwise.

| Phase | Typical $\langle C_{sync} \rangle$ |
|---------|------------------------------------|
| T-phase | $< 10^{-6}$ |
| N-phase | $\sim 10^{-4}$ |
| C-phase | $> 10^{-3}$ |

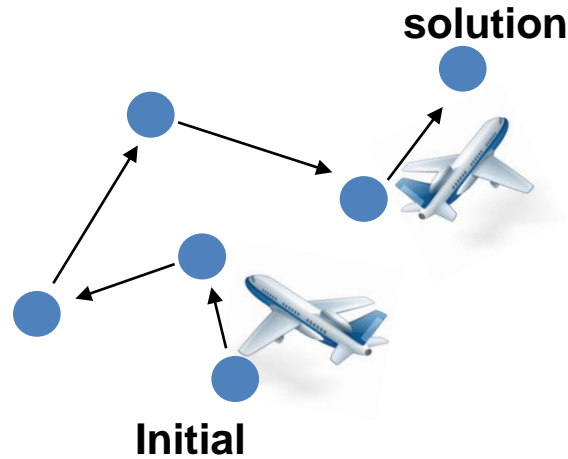
Computing

Thermal equilibrium



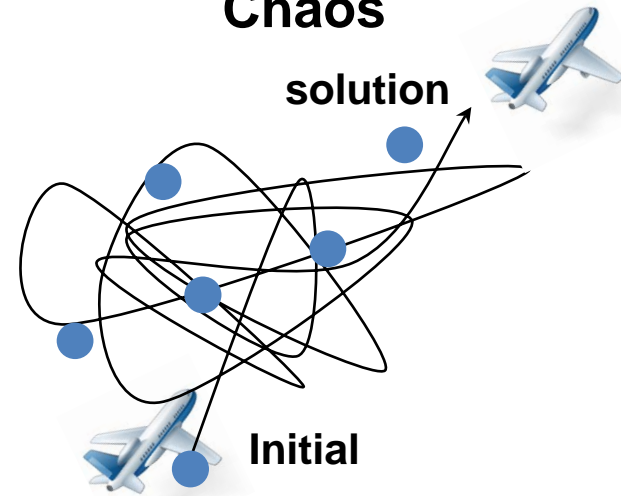
- Many-stop flight with revisiting the solutions (slow search)

N-dynamics



- Many-stop flight without revisiting
- Intermittent dynamics
- Jumping between attractors (local minima)

Chaos



- Non-stop flight over possible solutions (bad for sampling)
- Continuous, fast dynamics
- Difficult to track

| | T | N | C |
|--------------------------|---|---|---|
| Sampling | + | + | - |
| Non-revisiting solutions | - | + | + |