Discrete Breathers in Neural Networks
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Abstract
Localization in non-linear lattices of excitable elements is present in discrete breathers [1], and forms an interesting counterpart to localization of activity in neural systems [4]. We study the behavior of breatherlike excitations in a system of locally interacting integrate-and-fire neurons. Both numerical and analytical results justify the notion of a neural breather, which may form an element of working memory and attention. In particular we consider the stucture of neural breathers in dependence of the parameters of the units, the range of the interaction, delays and refraction. Different ways of adding noise to the system are also considered. As an application of breathers, we discuss networks of spatially distributed breathers, which are a model for communication between prefrontal cortex and other brain regions.

Resynchronization

- Simple breathers are synchronously firing.
- Small differences in the spike times are rapidly canceled out.
- If a whole subpopulation is shifted in their spike times, this disturbance remains.

Internal Noise

Weak noise has no effect, but stronger noise can prevent v from crossing vth.

Proof of Existence of Breathers

For Delays \( \tau > \Delta t \) we get the spike-pattern below exists and is stable for
\[
\epsilon < \frac{2}{\left( v_{th} - v_{wa} + (v_{th} - v_{wa})e^{-\gamma \tau} \right) \left( 1 - e^{-\gamma \tau} \right) (v_{th} - v_{wa})}
\]
Let the crossing of \( v_{th} \) be preserved. 
Return map:
\[
\left( \frac{t_{i+1}}{t_{i+1} + 2} \right) = \left( \frac{t_i}{t_i + 2} \right)
\]
No dependence on the \( v_j \)

Spatially Distributed Breathers

Neural breathers can model
- working memory
- associating e.g. features of visual objects in prefrontal cortex

Model:
- layers with local excitation, global inhibition coupling
- therefore localizing structure
- excitatory coupling \( \gamma \) between the brain regions
IT (object recognition) \( \rightarrow \) PFC (prefrontal cortex)
and PFC \( \rightarrow \) V4 (color processing)

- Breathers only survive, when interacting with the other region.
- With sufficiently large phase difference multiple objects can be memorized.
- Additional breathers with small phase lag are suppressed.

Conclusion and Outlook

- Even in very simple settings, neural breathers exist.
- With leaky integrate and fire neurons, the stability of such breathers can be determined analytically.
- Discreteness is a stabilizing factor.
- Breathers provide a model for feature binding, see [2].
- Stability in the continuous limit is interesting for comparison with other localizing models.
- The feature-binding model is also applicable to the problem of limited memory capacity and attention deficit disorder.
- This model should be set up with more realistic neuron models to get results that are comparable to measurements.

References