Critical Limits in a Bump Attractor Network of Spiking Neurons

AA Vergani† and CR Huyck†

†Middlesex University (London, UK)

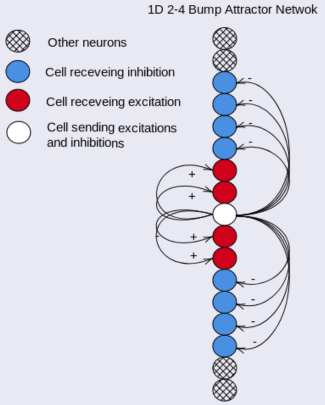
a.vergani@mdx.ac.uk

Contents

1. Introduction
2. The Bump Attractor Network
   - Structure and Function
3. Simulations
   - The neural model
   - The experimental settings
4. Results
   - Activation Patterns
   - Critical Limits
5. Conclusions
   - Final propositions
   - Future works

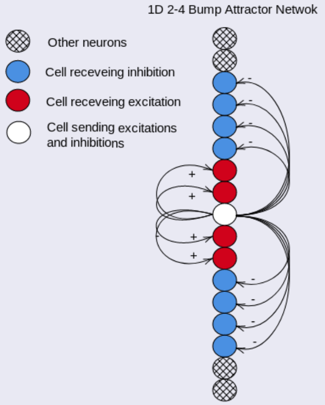
The (stationary) Bump Attractor Network

The proposed structure

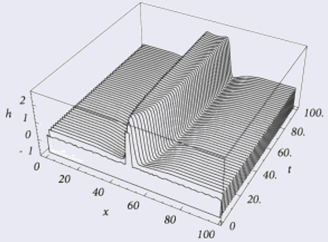


The (stationary) Bump Attractor Network

The proposed structure

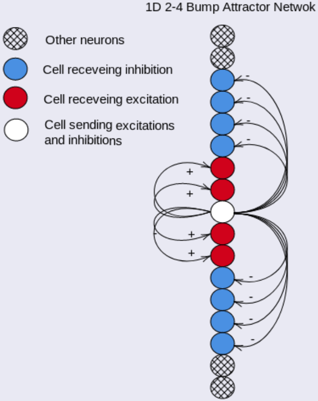


Localized bump of activation

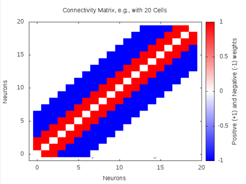


The (stationary) Bump Attractor Network

The proposed structure

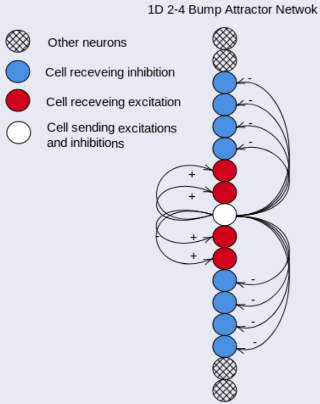


Connectivity, e.g., 20 cells

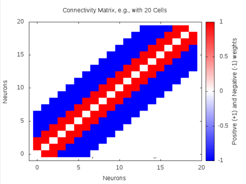


The (stationary) Bump Attractor Network

The proposed structure



Connectivity, e.g., 20 cells



Functions

- Brain Features Selection
- *Winner Takes All (WTA)*
- Concept representation

The neural model

Leaky Integrate and Fire formalism with fixed thereshold

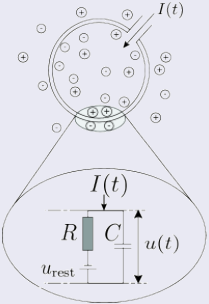
$$\frac{dV_M}{dt} = \frac{(-I_{Leak} - I_{Ex}^{syn} - I_{In}^{syn} + I_{Ext})}{C_M}$$

The neural model

Leaky Integrate and Fire formalism with fixed thereshold

$$\frac{dV_M}{dt} = \frac{(-I_{Leak} - I_{Ex}^{syn} - I_{In}^{syn} + I_{Ext})}{C_M}$$

Electric circuit

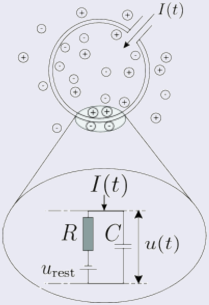


The neural model

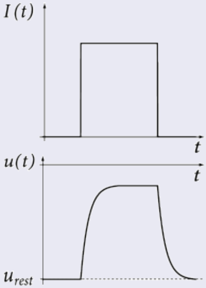
Leaky Integrate and Fire formalism with fixed thereshold

$$\frac{dV_M}{dt} = \frac{(-I_{Leak} - I_{Ex}^{syn} - I_{In}^{syn} + I_{Ext})}{C_M}$$

Electric circuit



Input and Output



The neural model

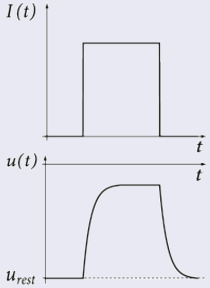
Leaky Integrate and Fire formalism with fixed thereshold

$$\frac{dV_M}{dt} = \frac{(-I_{Leak} - I_{Ex}^{syn} - I_{In}^{syn} + I_{Ext})}{C_M}$$

Some parameters

$C_M = 1.0\text{nF}$
$v_{reset} = -70.0\text{mV}$
$v_{rest} = -65.0\text{mV}$
$v_{thresh} = -48.0\text{mV}$

Input and Output



The neural model

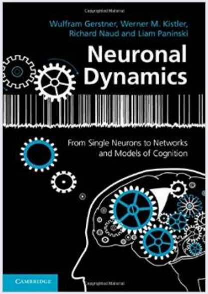
Leaky Integrate and Fire formalism with fixed thereshold

$$\frac{dV_M}{dt} = \frac{(-I_{Leak} - I_{Ex}^{syn} - I_{In}^{syn} + I_{Ext})}{C_M}$$

Some parameters

$C_M = 1.0\text{nF}$
$v_{reset} = -70.0\text{mV}$
$v_{rest} = -65.0\text{mV}$
$v_{thresh} = -48.0\text{mV}$

Gerstner et al 2014



The experimental settings

Procedures

The experimental settings

Procedures

- set-up the **topology** of a 1D bump-attractor network (2-4 connectivity) with 100 cells;

The experimental settings

Procedures

- set-up the **topology** of a 1D bump-attractor network (2-4 connectivity) with 100 cells;
- use a set of **deterministic spike sources**, ranging from 1 to 40 inputs, using a unitary step;

The experimental settings

Procedures

- set-up the **topology** of a 1D bump-attractor network (2-4 connectivity) with 100 cells;
- use a set of **deterministic spike sources**, ranging from 1 to 40 inputs, using a unitary step;
- simulations have been run with a **different combinations** of positive and negative weights, varying from 0.05 to 0.10 (step equal to 0.01);

The experimental settings

Procedures

- set-up the **topology** of a 1D bump-attractor network (2-4 connectivity) with 100 cells;
- use a set of **deterministic spike sources**, ranging from 1 to 40 inputs, using a unitary step;
- simulations have been run with a **different combinations** of positive and negative weights, varying from 0.05 to 0.10 (step equal to 0.01);
- the computational **run-time** used is 300ms;

The experimental settings

Procedures

- set-up the **topology** of a 1D bump-attractor network (2-4 connectivity) with 100 cells;
- use a set of **deterministic spike sources**, ranging from 1 to 40 inputs, using a unitary step;
- simulations have been run with a **different combinations** of positive and negative weights, varying from 0.05 to 0.10 (step equal to 0.01);
- the computational **run-time** used is 300ms;
- the simulation are computed with the **neuromorphic hardware** (SpiNNaker 4-Chips board system - Petrut's seminar Feb 21st)

The experimental settings

Investigating criticalities

The experimental settings

Investigating criticalities

- the critical limits are **special** number of spike sources and the weights combinations

The experimental settings

Investigating criticalities

- the critical limits are **special** number of spike sources and the weights combinations
- the **questions** that are investigated are
  - 1) if the network *ignites* and
  - 2) if it does, do the spike trains have either a stable *persistence*, a *splitting* shape or a *divergent* pattern?

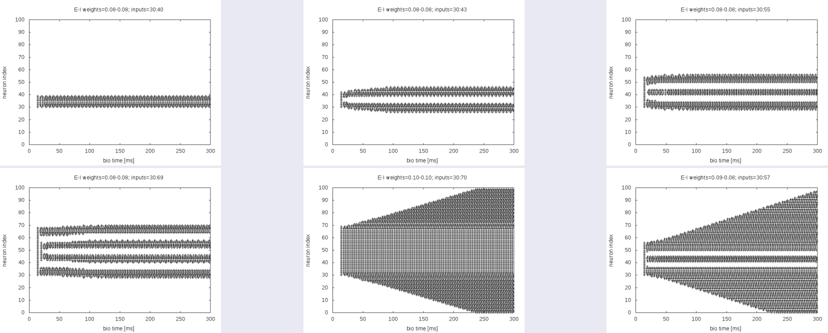
The experimental settings

Investigating criticalities

- the critical limits are **special** number of spike sources and the weights combinations
- the **questions** that are investigated are
  - 1) if the network *ignites* and
  - 2) if it does, do the spike trains have either a stable *persistence*, a *splitting* shape or a *divergent* pattern?
    - $\Longrightarrow$ What are the patterns the network emerges?

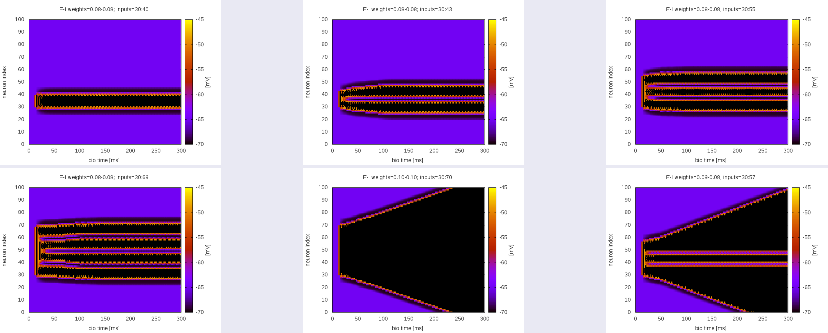
Activation patterns found

spikes



Activation patterns found

voltage



Towards critical limits ...

Example of limits

- Set
  - Ex Weights = 0.08
  - In Weights = 0.08
- Increase inputs
  - from 1 to 40

splitting patterns

1st critical limit:
Minimal sources to ignite the bump attractor network

E-I Weights	**0.05**	**0.06**	**0.07**	**0.08**	**0.09**	**0.1**
0.05	4	4	4	4	5	/
0.06	2	2	2	2	2	2
0.07	2	2	2	2	2	2
0.08	2	2	2	2	2	2
0.09	2	2	2	2	2	2
0.1	1	1	1	1	1	1

2nd critical limit:
Minimal sources to split the network dynamics in 2 streams

E-I Weights	**0.05**	**0.06**	**0.07**	**0.08**	**0.09**	**0.1**
0.05	13	13	12	/	/	/
0.06	15	13	13	12	11	11
0.07	D	15	14	13	13	12
0.08	D	17(+D)	15(+D)	13	13	13
0.09	D	D	D	15(+D)	15(+D)	15
0.1	D	D	D	D	D	D

3rd critical limit: Minimal sources to split the network dynamics in 3/4 streams

E-I Weights	3S	4S
0.06-0.05	25	37
0.07-0.06	26	39
0.08-0.06	26 (+D)	na
0.08-0.07	23 (+D)	na
0.08-0.08	25	39
0.09-0.08	27 (+D)	na
0.09-0.09	25 (+D)	na

e.g., 0.09-0.08

Conclusions

Propositons about the starting firing

Conclusions

Propositons about the starting firing

- **Ignition** can be achieved by a few inputs.

Conclusions

Propositons about the starting firing

- **Ignition** can be achieved by a few inputs.
- It is not enough to ignite the network with only one spike source, except when the excitatory weight has high values, as 0.10.

Conclusions

Propositons about the starting firing

- **Ignition** can be achieved by a few inputs.
- It is not enough to ignite the network with only one spike source, except when the excitatory weight has high values, as 0.10.

Propositions about 2S splitting and diverging

Conclusions

Propositons about the starting firing

- **Ignition** can be achieved by a few inputs.
- It is not enough to ignite the network with only one spike source, except when the excitatory weight has high values, as 0.10.

Propositions about 2S splitting and diverging

- The **splitting behaviour** with two streams is related to similar weights or with **greater negative weights** than positive ones (*ihinbition matters*).

Conclusions

Propositons about the starting firing

- **Ignition** can be achieved by a few inputs.
- It is not enough to ignite the network with only one spike source, except when the excitatory weight has high values, as 0.10.

Propositions about 2S splitting and diverging

- The **splitting behaviour** with two streams is related to similar weights or with **greater negative weights** than positive ones (*ihinbition matters*).
- To the contrary, **the diverging behaviour** is related to **greater positive weights** than negative ones (*excitation matters*).

Conclusions

Propositons about 3S/4S splitting with divergence

Conclusions

Propositons about 3S/4S splitting with divergence

- The spike train patterns with **multiple streams** (3 and 4) seem related with the **size of the input window**.

Conclusions

Propositons about 3S/4S splitting with divergence

- The spike train patterns with **multiple streams** (3 and 4) seem related with the **size of the input window**.
$\Longrightarrow$ *The more inputs ignite the bump network, the more (could be) the streams within the splitting behaviour*

Conclusions

Propositons about 3S/4S splitting with divergence

- The spike train patterns with **multiple streams** (3 and 4) seem related with the **size of the input window**.
  $\Longrightarrow$ *The more inputs ignite the bump network, the more (could be) the streams within the splitting behaviour*
- The weights that determine the **streaming with divergence** are at the **boundary** between the weight condition underlying the splitting and the divergent patterns.

Conclusions

Propositons about 3S/4S splitting with divergence

- The spike train patterns with **multiple streams** (3 and 4) seem related with the **size of the input window**.
  $\Longrightarrow$ *The more inputs ignite the bump network, the more (could be) the streams within the splitting behaviour*
- The weights that determine the **streaming with divergence** are at the **boundary** between the weight condition underlying the splitting and the divergent patterns.
  $\Longrightarrow$ *It's an intermediate situation close to both the pattern possibilities.*

Future works

Next directions

Future works

Next directions

- Different 1D topologies, e.g., line, ring, knots

Future works

Next directions

- Different 1D topologies, e.g., line, ring, knots
- From 1D to 2D, 3D or nD network

Future works

Next directions

- Different 1D topologies, e.g., line, ring, knots
- From 1D to 2D, 3D or nD network
- Neural model with adaptation

Future works

Next directions

- Different 1D topologies, e.g., line, ring, knots
- From 1D to 2D, 3D or nD network
- Neural model with adaptation
- From static weights to learning

Future works

Next directions

- Different 1D topologies, e.g., line, ring, knots
- From 1D to 2D, 3D or nD network
- Neural model with adaptation
- From static weights to learning
- Bump Attractor with Hopfield network

Future works

Next directions

- Different 1D topologies, e.g., line, ring, knots
- From 1D to 2D, 3D or nD network
- Neural model with adaptation
- From static weights to learning
- Bump Attractor with Hopfield network
- Thermodynamics in dynamical systems

Future works

Next directions

- Different 1D topologies, e.g., line, ring, knots
- From 1D to 2D, 3D or nD network
- Neural model with adaptation
- From static weights to learning
- Bump Attractor with Hopfield network
- Thermodynamics in dynamical systems
  - $\Longrightarrow$ *Description vs Explanation*

Cheers

Thank you for the attention!

Reference for other details

Vergani and Huyck 2020
Critical Limits in a Bump Attractor Network of Spiking Neurons
Preprint on Researchgate

Useful links

- Images of simulation results
- Playlist video on Youtube