Emergence of structures on a neuronal dynamic

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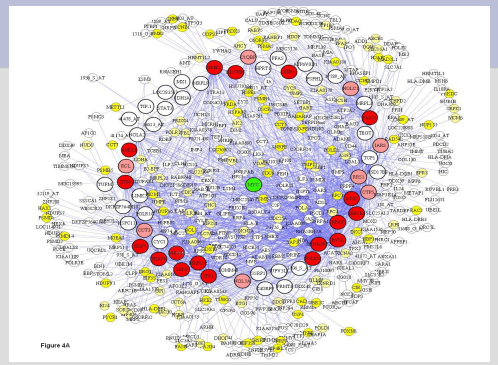
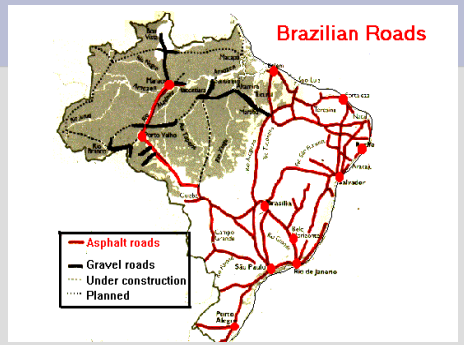
The Problem





How do structures emerge on plastic (adaptive) networks?

We need:

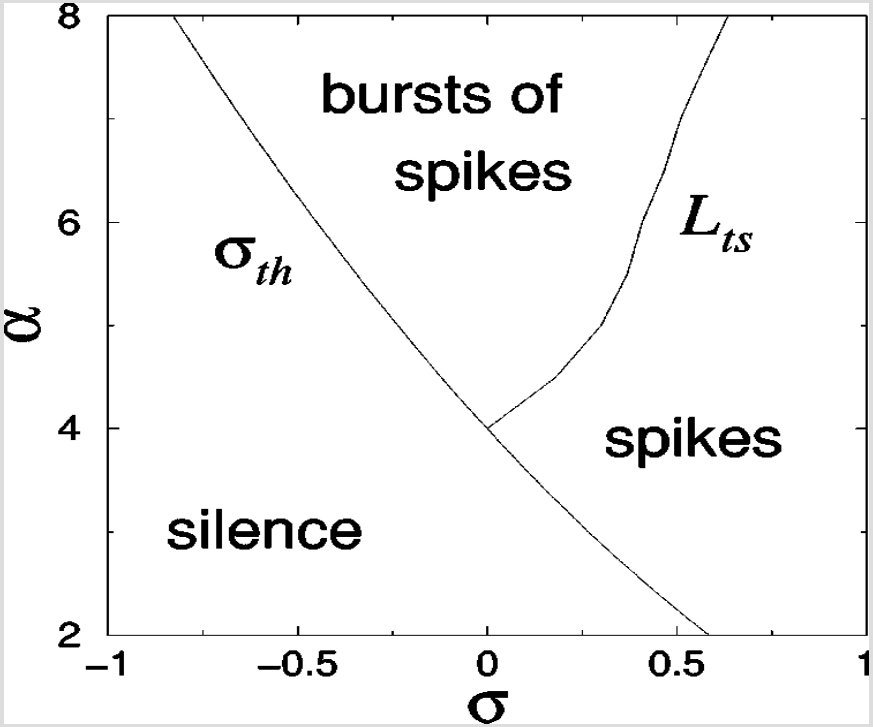
A well known plastic network with a well known plastic rule

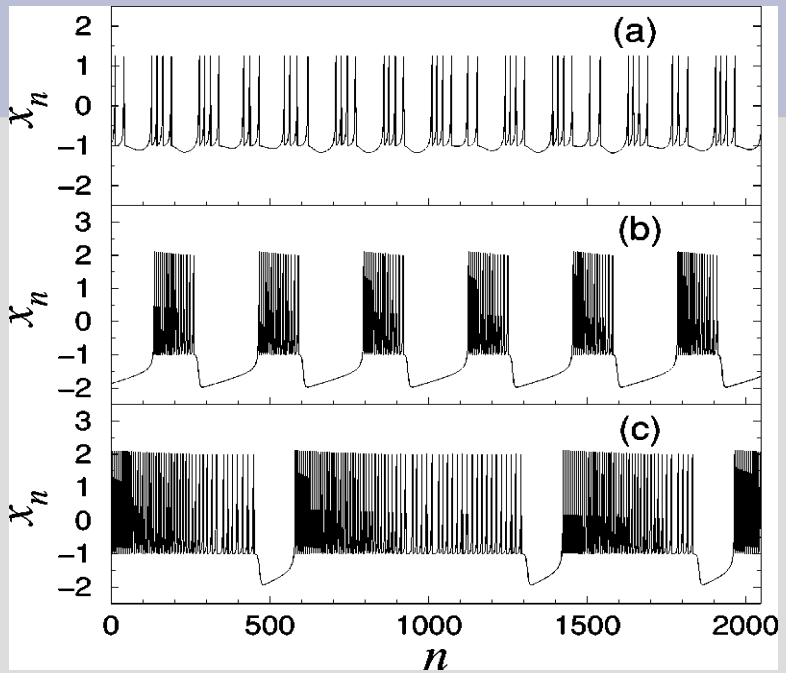
We propose:

CML + spiking-bursting activity + Hebb postulate

Coupled Map Lattice Model

$$x^i_{t+1} = f\left(x^i_t,\ y^i_t + \mu_x W x_t\right)$$
$$y^i_{t+1} = y^i_t - \mu_y\left(x^i_t + 1\right) + \mu_y \sigma + \mu_y W x_t$$



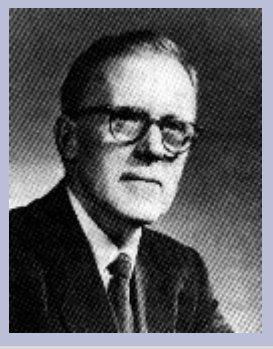


$$f(x,y) = \begin{cases} \alpha(1-x) + y\ , & x \le 0 \\ \alpha + y\ , & 0 < x \\ -1\ , & x \ge \alpha + y \end{cases}$$

$$W x_t = \frac{1}{(N-1)^2} \sum_{i \ne j} w^{ij}\left(x^j_t - x^i_t\right)$$

N. Rulkov, PRE, 65, 041922 (2002)

Hebb's Rule



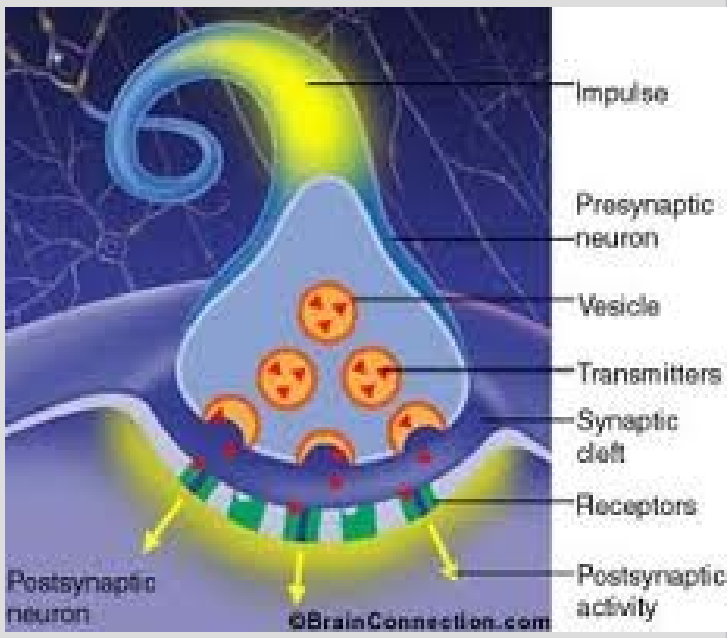
"… When an axon of cell A is near enough to excite a cell B and repeatedly or persistently takes part in firing it, some growth process or metabolic change takes place in one or both cells such that A's efficiency, as one of the cells firing B, is increased."

Cells that fire together, wire together.

$$w_{t+1}^{ij} = w_t^{ij} + \Delta w_t^{ij}$$

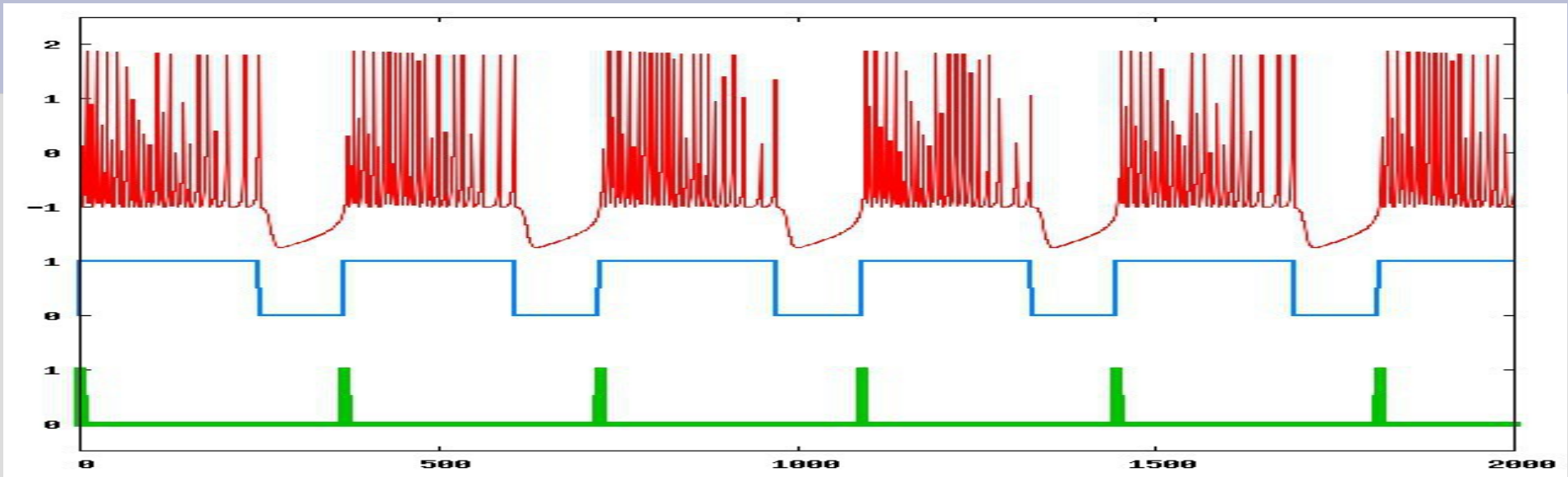
$$\Delta w_t^{ij} = \lambda \Theta(x_t^i) \Theta(x_t^j)$$

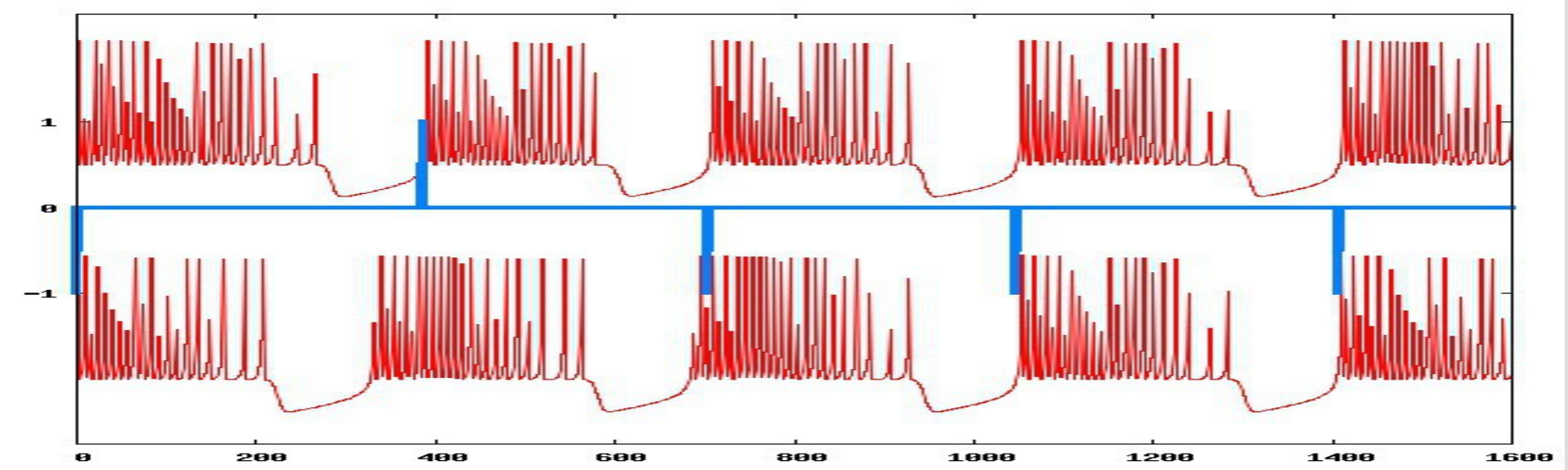
"Associative Learning"



D. Hebb, The organization of behavior. New York: Wiley & Sons, (1949)

Time Evolution





Our Model

$$f(x,y)=\begin{cases}\alpha(1-x)+y\ , & x\le 0\\ \alpha+y\ , & 0<x\\ -1\ , & x\ge\alpha+y\end{cases}$$

$\alpha=6.5$

$$x^i_{t+1}=f\left(x^i_t,\ y^i_t+\frac{\mu_x}{N}\sum_j w^{ij}_t\left(x^j_t-x^i_t\right)\right)$$

$$y^i_{t+1}=y^i_t-\mu_y\left(x^i_t+1\right)+\mu_y\sigma+\frac{\mu_y}{N}\sum_j w^{ij}_t\left(x^j_t-x^i_t\right)$$

$\mu_x=1.0$

$\mu_y=0.001$

$\sigma=-0.25$

$$w^{ij}_{t+1}=w^{ij}_t+\Delta w^{ij}_t$$

$$\Delta w^{ij}_t=\lambda\,\delta\left(x^i_t\right)\Theta\left(x^j_t\right)\left(1-2\,\Theta\left(x^j_{t-\tau}\right)\right)$$

Parameters

(λ,τ)

Order Parameters

Dynamic

$$S_t = 4\left(\frac{1}{N}\sum_i \Theta(x_t^i)\right)\left(1-\frac{1}{N}\sum_i \Theta(x_t^i)\right)$$

$$S = \frac{1}{T}\sum_{t=1}^{T} S_t \qquad \sigma_S = \frac{1}{T}\left(\sum_{t=1}^{T}(S_t - S)^2\right)^{1/2}$$

Network

Nodes degree

Characteristic length

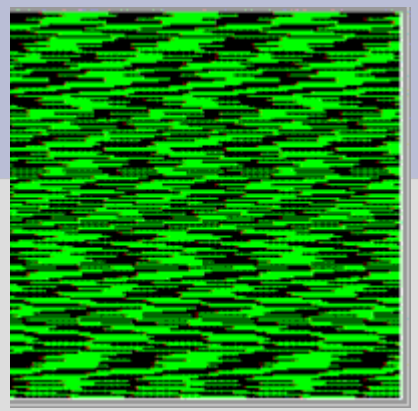
Clustering Coefficient

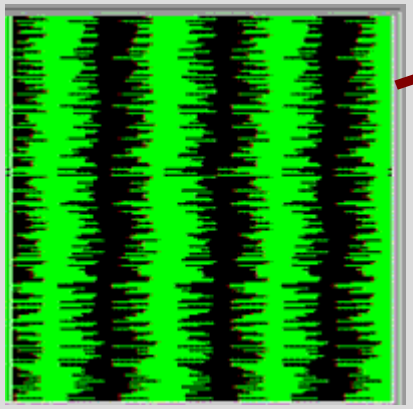
Max. Modularity

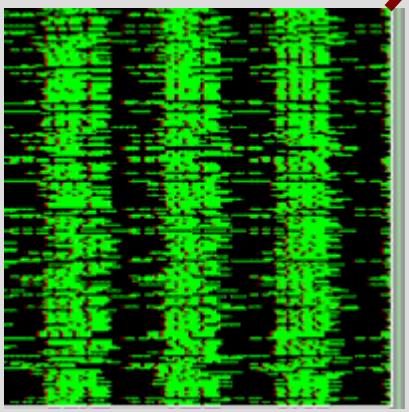
Fired

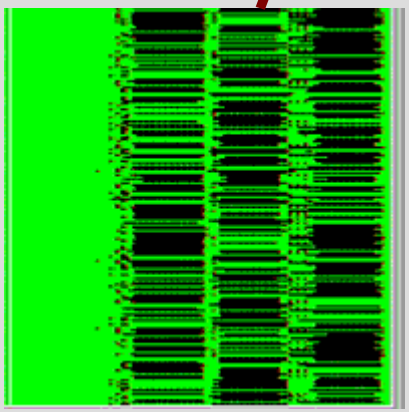
Silence

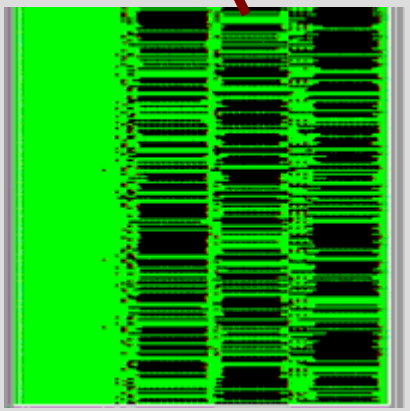
Dynamics Phase Diagram

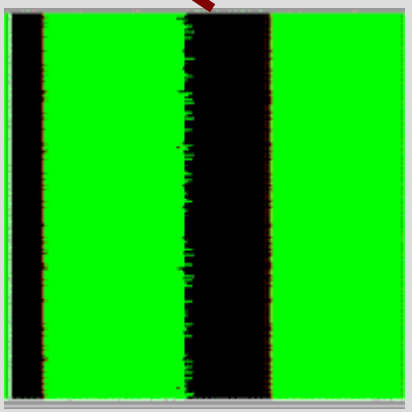


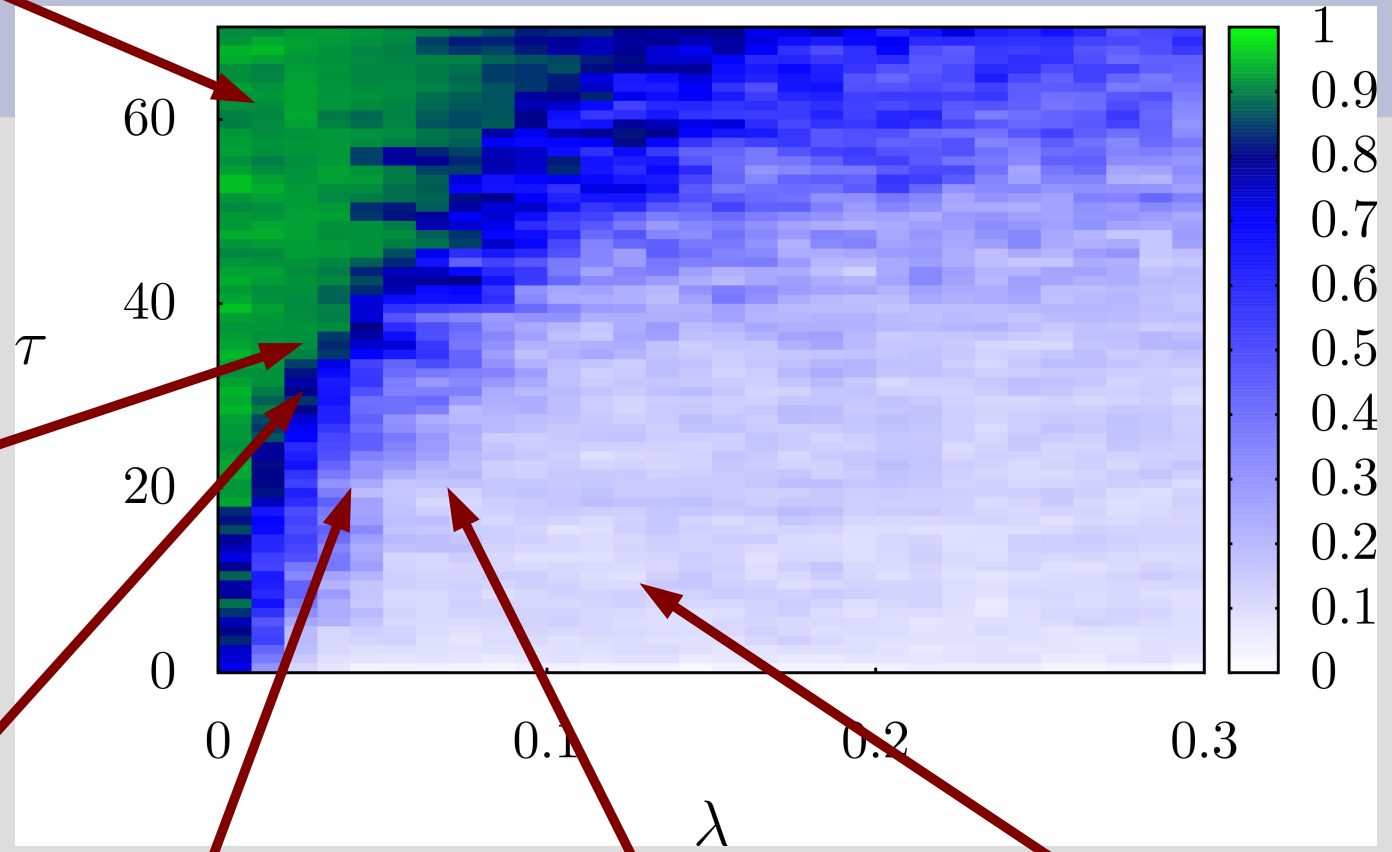




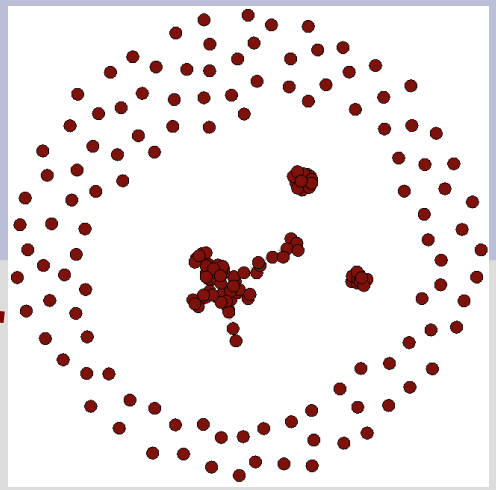


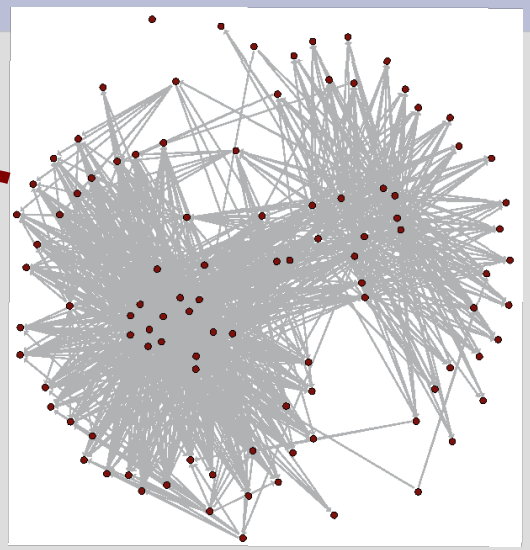


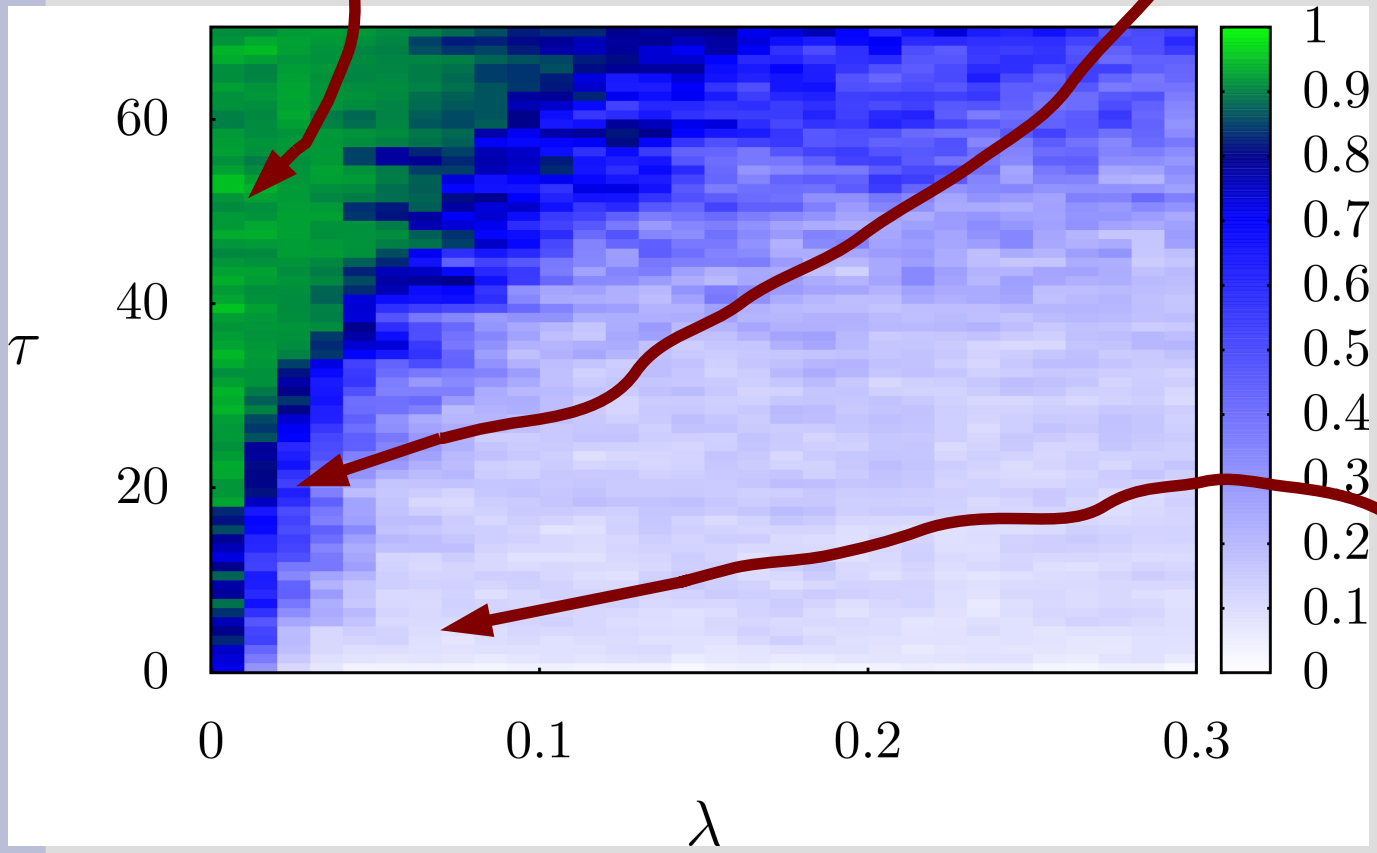


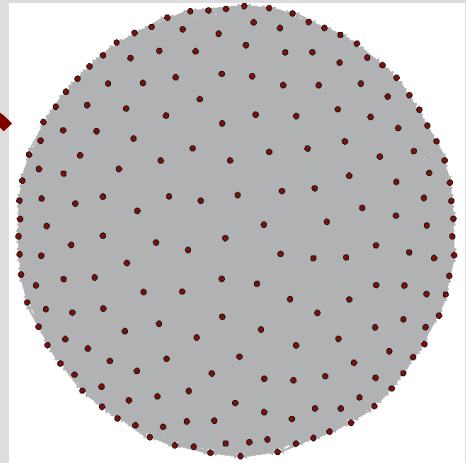


Network Phase Diagram









Conclusions

In our model

- **We found that complex networks emerge around the transition between unconnected and highly connected networks**

- **A certain degree of exclusion in the interactions is necessary for the emergence of complex structure in plastic networks**

Thank you