# Network dynamics and functional connectivity in neuronal assemblies coupled to micro-electrode arrays

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#### <u>Connections</u> 10<sup>14</sup> 100.000.000.000.000

(1000:10000 connections each cell)

## Information flow



## Reverse engineering the brain

Why is it important to decode the neuronal information ?

#### Paralysed woman moves robot with her mind

link <u>https://www.youtube.com/watch?v=ogBX18maUiM</u>

### <u>Outline</u>

1. Neuronal networks coupled to Micro-Electrode Arrays (MEAs)



2. Engineered networks coupled to MEAs display complex dynamics







3. Interplay between connectivity and network dynamics







#### Neuronal networks coupled to MEA



Adapted from Poli et al., Frontiers in Neural Circuits, 2015

#### <u>Electrophysiological activity of neuronal networks coupled to</u> <u>micro-electrode array</u>

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#### Robot controlled by neurons

link https://www.youtube.com/watch?v=NZihD9QGqMs

### Great variability of activity patterns

#### **Experimental Evidence:**

#### Cortical networks exhibit different patterns of activity at the same degree of development



#### **Scientific Question:**

How neuronal connectivity shapes dynamics (and vice-versa)?

### Homogeneous vs. Interconnected networks





**Interconnected nets** 







Macis E. et al., J. Neurosci. Meth., 2007 Massobrio & Martinoia, J. Neural Eng., 2008

Number of neurons

#### Homogeneous vs. Heterogeneous networks



#### Rat neurons grown on a computer chip

### fly a simulated aircraft

link https://www.youtube.com/watch?v=1w41gH6x\_30

### The history behind the b-27 media system

link https://www.youtube.com/watch?v=xQBkyo0yuzM

#### <u>Coding of memory in engineered heterogeneous and</u> <u>interconnected neuronal networks reconstructed from</u> hippocampus





#### In vitro hippocampal networks ascribe functions for encoding episodic memories: Pattern Separation of EC axonal inputs transmitted via microtunnels into DG



25 trials at 22 stimulation electrodes in EC (25X22 = 550 columns)

1

Pearson Correlation (r

25 trials at 22 stimulation electrodes

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25X22 =

**550 rows** 

### Pattern Separation of EC axonal inputs and Pattern Completion in CA3



#### Axonal transmission between each pair of four stages

#### of the EC-DG-CA3-CA1 circuit



Poli D. et al., GNB 2018

#### 2D vs. 3D neuronal assemblies (1)



#### 2D vs. 3D neuronal assemblies (2)





#### 3D neuronal assemblies show network burst and random spikes (in vivo like)



Frega M. et al., Sci. Rep. 2014

### Interplay between connectivty and network dynamics





Poli D. et al., Frontiers in Neural Circuits, 2015

### **Topological network properties during development**



#### Interplay between functional and structural connectivty

#### From Functional



- interplay between functional and structural networks
- 2. Topology of a structural network maintained in a functional one

Bullmore and Sporns, Nat. Rev. Neurosci. 2009

Functional connectivity may provides a useful way to infer structural connectivity (especially when structural morphological reference is not available)

### **Scientific Questions:**

Ullo *et al.* Front. in Neuroanatomy 2014

Is it possible to identify functional-effective links that partly reconstruct the network architecture and therefore the topological features? YES

Poli D. et al., J. Neural Eng., 2016





2. Does high-frequency electrical stimulation induce synaptic plasticity ? YES

Chiappalone M. et al., European\_Journal\_of\_Neuroscience , 2008

High-density MEAs with large number of electrodes would

certainly provide a better picture.



1 mm

The high spatial resolution of high-density MEAs would allow a more thorough investigation of the topological architectures of neuronal assemblies

#### <u>Summary</u>

- 1. Reverse engineering the brain.
- 2. Neuronal networks coupled to MEAs show great variability of activity patterns.
- 3. Engineered networks show complex and specific dynamics.
- 4. Heterogeneous and interconnected hippocampal neurons cultured on multichamber devices over MEAs ascribe functions for encoding pattern separation and completion.
- 5. Strong interplay between connectivity and network dynamics.
- 6. Strong interplay between functional and structural connectivity