IberSinc Meeting

Tarragona 6-7 October 2016

PROGRAM

Thursday, October 6

10:00 -10:45 h	**Fabrizio de Vico (Brain and Spine Institute , ICM)** Analysis and modeling of complex brain networks: from static to dynamic approaches
10:45 - 11:10 h	**Coffe Break**
11:10 -13:10 h	**Lluís Hernández-Navarro (U. Barcelona)** Experimental Approaches to Assess Connectivity in Neuronal Cultures
	Ernesto Pereda (U. La Laguna) Comparación de redes funcionales cerebrales en reposo a partir de datos neurofisiológicos de EEG y MEG simultáneos
	Miguel Cornelles (CSIC-UIB) Clasificación automática de tipos de epilepsia a partir de la actividad MEG de sujetos en reposo
	Irene Sendiña-Nadal (URJC-CTB) Self-organizing cultured neural networks: longitudinal tracking and modelling of the underlying network structure
13:10 - 14:10 h	**Lunch**
14:10 - 15:40h	**Thematic Work Group**
15:40 – 16:00 h	**Coffe Break**
16:00- 17:30 h	**Carlos Quintero (U. P. Catalunya)** Characterizing how Complex Optical Signals Emerge from Noisy Intensity Fluctuations
	Dario Zappalà (U. P. Catalunya) Investigating Hilbert frequency dynamics and synchronisation in climate data
	Jeremy Guillon(Brain and Spine Institute , ICM) Title: Multifrequency Brain Connectivity In Alzheimer's Disease
17:30- 18:30h	**Poster mini-charlas & poster session**

Friday, October 7

11 -13 h	**Jordi Soriano (U. Barcelona)** Interplay Activity-Connectivity in Living Neuronal Networks in vitro
	Juan A. Almendral (URJC-CTB) La robustez dinámica en redes correlacionadas
	Nikos Kouvaris (U. Pompeu Fabra) Self-organizing stationary patterns in networks of active elements
	Luce Prignano (U. Barcelona) Mobile Integrate-and-Fire oscillators with minimal interaction rules: does moving faster always enhance synchronization?
13:00 -14:00	**Lunch**

INVITED TALK

Analysis and modeling of complex brain networks: from static to dynamic approaches.

Fabrizio de Vico
Brain and Spine Institute, ICM

Studying the brain as a network has profound implications in the comprehension of the organizational neural mechanisms underlying cognition and disease. As with other complex systems, brain networks have been mainly characterized using static approaches, from the way they are constructed to the way they are analyzed through graph theoretic tools. However, we know that the interactions between spatially remote brain regions can exhibit dynamic changes at multiple time scales affecting the way the brain processes information in healthy and diseased conditions. Hence, static approaches represent an oversimplification of the real phenomenon and there is a pressing need to develop methods for characterizing dynamic brain networks whose connectivity fluctuates over time. Dynamic approaches require advances from the construction of time-varying brain networks to the development of new graph methods for the analysis and modeling of transient network changes. In this talk, I will review some of the recent findings in the nascent field of “dynamic network neuroscience”, highlighting the current challenges and the future directions towards a more realistic understanding of the brain function.

TALKS

Experimental approaches to assess connectivity in neuronal cultures.

Lluís Hernández-Navarro, Javier G. Orlandi and Jordi Soriano.
U. Barcelona

The complexity of the connectivity blueprint in living neuronal circuits has motivated the development of theoretical and computational tools to infer their major characteristics, such as the average number of connections, the distribution of connections, and high-order topological features. In our study we have explored them by analyzing the activity in neuronal cultures, and considered approaches that include the analysis of the network as a dynamical system, percolation, and spin models. For the first approach, we recorded spontaneous neuronal activity and resolved the ignition times for each monitored neuron. The analysis shows that activity takes place in the form of bursts, events of fast activation of all the neurons in a short time window. These bursts occur quasi-periodically along time and initiate in a few, specific locations in the culture, which we call nucleation points. Since the number of nucleation points, as well as the characteristics of the propagating fronts, strongly depend on the circuitry of the network, we can extract interesting properties of the underlying connectivity map. For the second and third approaches, we considered a global bath excitation protocol combined with a progressive weakening of the connections among neurons. This protocol leads to a percolative scenario, in which the largest group of connected neurons defines a giant component that decreases in size as the network is gradually disconnected. At a

critical disconnection degree, the giant component disappears. The properties of this critical point are tightly related with the topology of the circuit, particularly the average number of connections.

Comparación de redes funcionales cerebrales en reposo a partir de datos neurofisiologicos de EEG y MEG simultáneos.

Ernesto Pereda, Ricardo Bruña, Maria J. Alvarez, Inmaculada C. Rodrigez, Rosa Jurado and Ana M. Sion.

U. La Laguna

La estimación de las redes funcionales cerebrales a partir de registros no invasivos de la actividad electromagnética de las neuronas es un tópico actual de gran interés. Aunque tanto la MEG como especialmente el EEG carecen de la resolución espacial de la resonancia magnética (RM), sí poseen en cambio una excelente resolución temporal, y pueden registrarse (especialmente el EEG) de manera mucho más sencilla y menos costosa. En este trabajo combinamos la información de RM estructural con registros simultáneos de EEG y MEG en reposo para comparar las redes, en el espacio de sensores, obtenidas con ambas modalidades de datos neurofisiológicos. Para la caracterización de las redes usamos índices de sincronización de fase en función de la frecuencia. Encontramos que, para cierta combinación de frecuencias y parámetros de reconstrucción de las redes, la información proporcionada por ambas modalidades es diferente. En la ponencia discutiremos tanto las posibles implicaciones de este resultado como, sobre todo, métodos alternativos y más refinados para comparar los dos tipos de redes utilizando herramientas de la teoría de grafos que permitan estudiar con detalle las diferencias, a diferentes escalas, entre redes complejas con el mismo número de nodos

Clasificación automática de tipos de epilepsia a partir de la actividad MEG de sujetos en reposo.

Miguel Cornelles Soriano, Guiomar Niso, Silvia Ortín, Sira Carrasco, María Gudín, Claudio Mirasso and Ernesto Pereda

CSIC - UIB

El objetivo de este trabajo es el clasificar de forma automática (aprendizaje supervisado) diferentes tipos de epilepsia. Para ello, se ha realizado el análisis de señales de magnetoencefalografía (MEG) procedentes de sujetos divididos en tres grupos: sujetos con epilepsia focal, sujetos con epilepsia generalizada y sujetos control. El sistema de aprendizaje automático debe ser capaz de clasificar los distintos sujetos en sus correspondientes grupos a partir de la actividad cerebral registrada por MEG cuando los sujetos están en reposo y con los ojos cerrados. Cada uno de los tres grupos en este estudio está formado por catorce sujetos y las señales MEG proceden de períodos sin convulsiones epilépticas. Los datos MEG de cada sujeto se han registrado durante diez minutos, de los que se han extraído cuarenta segmentos de cinco segundos para cada sujeto. Este estudio se ha centrado en el análisis de las series temporales procedentes de 102 magnetómetros, los cuales están distribuidos espacialmente

para medir la actividad en distintas zonas. Para el análisis de las señales MEG en el dominio de la frecuencia, se ha considerado el rango frecuencial (4, 38 Hz) con una resolución de 2 Hz.

El método de aprendizaje automático que se ha explorado es conocido como máquinas de aprendizaje extremo, consistentes en una red neuronal con una capa oculta y con conexiones seleccionadas aleatoriamente. Cabe destacar que, en nuestro caso, la dimensionalidad de la entrada es mayor que la de la propia red. El entrenamiento de este tipo de redes se centra en obtener los pesos de la capa de salida a partir de una simple regresión lineal. En el caso del problema aquí considerado, el número total de sujetos es algo limitado (catorce sujetos en cada uno de los tres grupos) para utilizar técnicas de machine learning. Por eso y para maximizar la cantidad de información utilizada en la fase de entrenamiento, se ha optado por usar la técnica de leave-one-out cross-validation. De esta manera se ha realizado el test una vez con cada sujeto, usando el resto de sujetos para el entrenamiento previo del que está excluido el sujeto de test. Los resultados finales son entonces un promedio de los errores cometidos con cada sujeto.

Cuando se usan técnicas de aprendizaje automático basadas en redes neuronales con conexiones seleccionadas aleatoriamente, se eligen una serie de pesos aleatorios que hacen un mapeo entre los datos de entrada y la propia red neuronal. En principio cualquier conjunto de pesos es capaz de realizar la tarea, pero en la práctica hay cierta variación en los resultados cuando se usan pesos distintos. El problema de seleccionar el conjunto de pesos óptimo es un problema abierto ya que los pesos con un mejor resultado de clasificación en la fase de entrenamiento no tienen por qué resultar en la mejor clasificación en la fase de test. Por eso es útil utilizar un método de ensamble estadístico, en el que se obtienen resultados para distintos conjuntos de pesos aleatorios y se combinan de alguna manera estos resultados para obtener un resultado mejor que las realizaciones individuales. En nuestro caso de clasificación de tipos de epilepsia, se ha comprobado que el resultado de clasificación mejora, para los mismos parámetros, del 60% al 70% de aciertos tras combinar 50 sistemas con pesos distintos. Para combinar los distintos resultados, basta con tomar por ejemplo el voto de la mayoría. Al comprobar los resultados de usar máquinas de aprendizaje extremo con ensambles, se ha visto que la clasificación entre sujetos control y el resto de sujetos con epilepsia era muy bueno para unos ciertos parámetros del sistema. Sin embargo, esos mismos parámetros no son los mejores para distinguir entre sujetos con epilepsia focal y focal generalizada. En consecuencia, se ha adoptado un esquema de clasificación en dos etapas para mejorar el resultado final. El esquema final ha consistido en una primera etapa que realiza la división entre sujetos control y el resto de sujetos, y en una segunda etapa que clasifica los sujetos con epilepsia focal y focal generalizada.

El acierto promedio (*accuracy*) del clasificador final es del ~81%. A la vista de la matriz de confusión, se observa que el clasificador es muy bueno para distinguir la condición de sujeto control y bastante bueno para distinguir la epilepsia generalizada frente al resto. Sin embargo, interpreta de manera incorrecta varios sujetos del conjunto de epilepsia focal. Estos resultados se han obtenido utilizando como entrada al sistema las matrices de densidad espectral relativa para cada segmento. Cuando se han usado otros tipos de datos de entrada (densidad espectral absoluta, índices de sincronización en fase), siguiendo el mismo procedimiento aquí descrito, los resultados son peores.

Self-organizing cultured neural networks: longitudinal tracking and modelling of the underlying network structure.

Irene Sendiña-Nadal, Daniel de Santos-Sierra, I. Leyva, Juan Almendral, Sarit Anava, Amir Ayali and Stefano Boccaletti.

U. Rey Juan Carlos – CTB

We analysed the morphological evolution of assemblies of living neurons from locust ganglia, as they self-organize from collections of separated cells into elaborated, clustered, networks. In particular, we designed and implemented a graph-based unsupervised image segmentation algorithm with a very low computational cost. The processing automatically retrieves the whole network structure from large scale phase-contrast images taken at high resolution throughout the entire life of a cultured neuronal network. The network structure is represented by a mathematical object (the adjacency matrix) in which nodes are identified neurons or neurons' clusters, and links are the reconstructed connections between them. The algorithm is also able to extract all other relevant morphological information characterizing neurons and neurites. More importantly and at variance with other segmentation methods that require fluorescence imaging from immunocytochemistry techniques, our measures are non invasive and entitled us to carry out a fully longitudinal analysis during the maturation of a single culture. In turn, a systematic statistical analysis of a group of topological measures grants us the possibility of quantifying and tracking the progression of the main networks characteristics during the self-organization process of the culture. Our results point to the existence of a particular state corresponding to a small-world network configuration, in which several relevant graphs' micro- and meso-scale properties merge. Finally, we identified the main physical processes taking place during the cultures morphological transformations, and embedded them into a simplified growth model that quantitatively reproduces the overall set of experimental observations.

Characterizing how complex optical signals emerge from noisy intensity fluctuations

Carlos Quintero, J. Tiana-Alsina, M. Carme Torrent and Cristina Masoller.

U. P. Catalunya

Identifying transitions to complex dynamical regimes is a fundamental open problem with many practical applications. Semiconductor lasers with optical feedback are excellent testbeds for studying such transitions, as they can generate a rich variety of output signals. Here we apply three analysis tools to quantify various aspects of the dynamical transitions that occur as the laser pump current increases. These tools allow to quantitatively detect the onset of different regimes and can be used for identifying the operating conditions that result in specific dynamical properties of the laser output. They can also be valuable for analyzing regime transitions in other complex systems.

Investigating Hilbert frequency dynamics and synchronization in climate data

Dario Zappalà and Cristina Masoller
U. P. Catalunya

A recent study demonstrated that, in a class of networks of oscillators, the optimal network reconstruction from dynamics is obtained when the similarity analysis is performed over time series obtained by Hilbert transform. In spite of the fact that this transform has been widely used to analyse output signals of many complex systems, it has not yet been employed to construct climate networks. For these reasons, in this work we analyse large climate datasets of SAT (Surface Air Temperature) using Hilbert transform to compute frequency time series, with the goal of inferring new information about underlying climate interactions and dynamics – for example, signatures of frequency synchronisation.

We work on daily SAT time series, from year 1979 to 2015, in 16380 grid points over the Earth surface. From each SAT time series we calculate the anomaly time series and also, by using the Hilbert transform, we calculate the frequency time series. By plotting the map of the average frequency in every grid point, we extract relevant information about SAT dynamics in different regions of the world.

Then, we calculate autocorrelations of frequency and anomaly series. With these results we plot autocorrelation maps, that allow to uncover geographical regions with different memory properties. In a second step, to find correlations between sites, we compute the zero-lag cross correlations (CC). According to statistical considerations, we put a threshold on the CC matrices (both from SAT anomalies and from Hilbert frequencies) and we build two undirected networks from the two derived series. Then, we analyse network topology, finding which nodes are most connected and exploring their long-range connections. A comparison between the two networks shows which new information can give us the approach based on frequency analysis.

Ultimately, our results suggest that, in fact, Hilbert transform and frequency series are a valid tool to build a climate network and give additional information about correlations, teleconnections and patterns of similar dynamical behaviour. As an example of our results, we report in Figure 1 the map of average frequency. It can be seen that most of the extratropics have an average frequency which corresponds very well to the expected value, i.e. the inverse of the period of the annual solar cycle (12 time steps, giving an angular frequency of $2\pi/12 \approx 0.52$ rad/month). Additionally, there are key tropical areas that diverge from this value: a wide zone in the Pacific Ocean with characteristic dynamics due to El Niño and another one in the Indian Ocean with different dynamics due to monsoons.

Multifrequency Brain Connectivity In Alzheimer's Disease

Jeremy Guillon, Frabrizio de Vico.
Brain and Spine Institute, ICM

Abstract : The brain can be seen as a complex network consisting of a set of regions (nodes) interacting with each other (links). The nature of these interactions can be different and multiple connectivity can be computed from the same subject (individual), each of them describing a different anatomical or functional aspect. For example, it has been shown that brain connectivity are supported by different frequency bands, which are often interrelated.

We propose a graph theoretic approach to characterize brain connectivity, not as a single network but as a set of networks gathered in a multilayer network configuration called a multiplex, from which new topological measures can be extracted in order to compare populations. We built frequency-band specific networks and studied the participation coefficient, a centrality measure that was generalized to the multiplex case, on MEG recordings obtained from 25 Alzheimer diseased (AD) patients and 25 healthy control (HC) subjects in resting state condition. We showed that the multiplex methodology gave complementary information as compared to single-layer approaches in detecting regional differences between populations. Furthermore, when combined together, the singlelayer and multiplex methodologies provide increased classification accuracy thus opening the way towards a new generation of predictive diagnostics in AD.

Interplay activity-connectivity in living neuronal networks in vitro

Javier G. Orlandi, Sara Teller, Clara Granell, Sergio Gómez, Manlio de Domenico, Àlex Arenas, Jaume Casademunt and Jordi Soriano.
U. Barcelona

Neuronal cultures offer a versatile platform to investigate spontaneous activity in small, accessible living neuronal assemblies. Different culturing techniques allow for the exploration of very different structural configurations which, in turn, shape radically different dynamics. In this talk we will introduce two particularly attractive configurations, a first one formed by a homogeneous distribution of neurons over a substrate, and a second one formed by interconnected aggregates of neurons. By monitoring the spontaneous dynamics in these networks under diverse conditions, we will illustrate how important is the wiring among neurons, the intrinsic neuronal dynamics and noise to shape collective behavior. We will also discuss under which conditions we could observe a fully synchronous regime.

La robustez dinámica en redes correlacionadas

Juan A. Almendral
U. Rey Juan Carlos - CTB

Desde sus inicios, la robustez de una red ha sido uno de los temas centrales de la teoría de redes complejas. Dado que una red depende de las interacciones entre sus unidades, los fallos de esas unidades y/o de los enlaces pueden dar lugar al colapso global de toda la red. Por ejemplo, un accidente en una línea de energía de una red eléctrica puede causar un apagón a

gran escala, o la necrosis de algunas células en una red biológica puede inducir trastornos graves en los seres vivos.

Para prevenir tales daños globales en una red, se han desarrollado dos marcos teóricos para comprender la robustez y la vulnerabilidad de dicha red. La robustez estructural indica la tolerancia a fallos de la conectividad de una red evaluando su componente gigante, es decir, el tamaño de la componente conexa más grande. Este marco se ha aplicado a redes cuyos nodos son estáticos. Por otro lado, la robustez dinámica se centra en la tolerancia a fallos del comportamiento dinámico global de una red en la que los procesos dinámicos juegan un papel importante para su correcto funcionamiento.

La robustez estructural y dinámica de las redes complejas se ha estudiado en redes homogéneas y heterogéneas con diferentes distribuciones de grado. Sin embargo, la distribución de grado no especifica de forma única la topología de la red. Es decir, las redes con la misma distribución de grado pueden tener diferentes tipos de topología. Entre las cantidades que miden en qué se diferencian dos topologías con la misma distribución de grado, aquí nos centramos en el asortatividad. La asortatividad de una red indica cómo el grado de un nodo se correlaciona con los grados de sus nodos vecinos.

Estudiamos la robustez dinámica de redes correlacionadas (asortativas y disasortativas) cuyos osciladores están acoplados difusivamente. Nuestro análisis numérico de redes correlacionadas cuyas distribuciones de grado siguen una ley de Poisson o una ley de potencias muestra que la asortatividad mejora la robustez dinámica pero el impacto de la disasortatividad depende de otros detalles de la conectividad de la red.

Self-organizing stationary patterns in networks of active elements

Nikos Kouvaris
U. Pompeu Fabra

Theoretical investigations of networks of diffusively coupled bistable elements have shown that they can support stationary self-organized activity patterns. In this talk I will report for the first time results of experiments with networks of coupled electrochemical bistable elements that not only confirm such theoretical predictions, but also prove their high robustness. In the experiments, networks with various topologies (i.e., regular and irregular trees) could be constructed by locally coupled electrochemical units with bistable individual dynamics. By applying initial activation to different (subsets of) nodes in such networks, we could observe subsequent spreading or retraction of activation over the networks and formation of different stationary activity patterns. The final stationary patterns depended sensitively on the architecture of the networks and the initial conditions. The agreement with the theoretical predictions was excellent, even though the bistable dynamics of electrochemical elements was based on a complex, and not yet completely known, mechanism and the local coupling between the elements in a network was not strictly diffusional.

Mobile Integrate-and-Fire oscillators with minimal interaction rules: does moving faster always enhance synchronization?

Luce Prignano, Albert Beardo, Oleguer Sagarra and Albert Díaz-Guilera
U. Barcelona

In this work we analyse the emergence of synchronization in a population of mobile Integrate-and-Fire oscillators with minimal interaction rules: each oscillator interacts, on average, with only one unit (neighbour) at once. By proposing different rules for the selection of the neighbour, we bridge phenomenologies detected in a variety of previous models. In order to characterize the interaction rules that give and give not rise to a non-monotonic dependence of the average synchronization time on the velocity of the moving units, we perform an extensive analysis of the properties of the connectivity patterns.

Additionally, we propose a tentative extremely simple method for predicting whether a given hypothetical model would display such non-monotonic behavior.

POSTERS

Entropy of cortical slow spontaneous activity to characterize mouse models of neuropsychiatric disorders.

Edmond Geraud-Aguilar, Patricia Castaño-Prat, Lorena Perez-Mendez and Maria V. Sanchez-Vives
IDIBAPS

Slow waves are a type of cortical activity characterized by periods of active and silent neural periods, called Up and Down states, respectively, and this activity can be observed during deep sleep and under anesthesia. We have previously observed that the coefficient of variation of slow waves is often altered in transgenic models of neuropsychiatric diseases. Here we explored whether entropy, a measurement of variability of the cortical signal, could be a sensitive measure to differentiate between wild-type and transgenic mice. We hence measured the entropy of the population firing rate (log(MUA)), calculated separately for Up and Down states in wild-type and transgenic mouse models of Alzheimer's disease, by computing an approximation of the Sinai-Kolmogorov entropy. For this, we used the multiscale entropy (MES; based on the sample entropy), which depends on four parameters: the embedded dimension (m), the tolerance (r), the length of the time series and the scale factor (SF). In order to classify each mouse strain using entropy, we identified the best parameters: we found a statistic by the bootstrap method that compares and classifies both strains, and from which we obtain a p-value. We did this by computing MES, fixing m to 2, varying r from 0.01 to 0.78 by 0.04 steps, and varying SF from 1 to 20 by steps of 1; we thus obtained a 20x20 matrix of p-values, from which we chose the minimum, providing us with the SF and r that give us the best characterization of each strain. Although the computing is time expensive, this method allows better classifying each mouse strain using entropy.

Spatiotemporal modulation of cortical slow oscillations by weak DC electric fields.

Lorena Perez-Mendez, Julia Weinert, Pol Boada-Collado, Maurizio Mattia and Maria V. Sanchez-Vives.
IDIBAPS

Cortical slow oscillations are the predominant activity pattern during deep sleep or anesthesia and are characterized by an alternation (< 1Hz) of active periods, when the network fires (Up states) and silent periods, when the networks remain quiescent (Down states). Furthermore, during Up states the neuronal activity synchronizes in high frequencies (15-90 Hz) and they have been shown to propagate as slow waves along the cortical. We recently used an in vitro model of slow to study the effects of weak DC electric fields on the temporal domain of slow oscillations and found a striking correlation between linearly increasing electric field intensity and slow oscillation frequency due to a modulation of sub-threshold activity during Down states.
We hypothesized that this modulation of excitability should also have a substantial influence on the propagation behavior of slow oscillations. Therefore, we obtained simultaneous recordings with a 16 channel multielectrode-array and used an algorithm based on the timelags of Up state onsets to analyze propagation properties. Furthermore, we simulated our results with a computational model of leaky integrate-and-fire neurons. We found a steady linear increase of horizontal propagation speed with increasing electric fields, while vertical speed reached a peak and dropped for higher electric field intensities, which was due to a fine tuning of horizontal excitatory connectivity.

Multistability in the time-delayed Mackey-Glass model

Pablo Amil, Cecilia Cabeza, Cristina Masoller and Arturo Martí
U. P. Catalunya

Multistability in the long term dynamics of the Mackey-Glass (MG) delayed model is analyzed by using an electronic circuit capable of controlling the initial conditions. The system's phase-space is explored by varying the parameter values of two families of initial functions. The evolution equation of the electronic circuit is derived and it is shown that, in the continuous limit, it exactly corresponds to the MG model. In practice, when using a finite set of capacitors, an excellent agreement between the experimental observations and the numerical simulations is manifested. As the delay is increased, different periodic or aperiodic solutions appear. We observe abundant periodic solutions that have the same period but a different alternation of peaks of dissimilar amplitudes and propose a novel symbolic method to classify these solutions.

Analysis of the effects of periodic forcing in the spike rate and spike correlation's in semiconductor lasers with optical feedback.

Carlos Quintero, Taciano Sorrentino, M. Carme Torrent and Cristina Masoller

U. P. Catalunya

We study the dynamics of semiconductor lasers with optical feedback and direct current modulation, operating in the regime of low frequency fluctuations (LFFs). In the LFF regime the laser intensity displays abrupt spikes: the intensity drops to zero and then gradually recovers. We focus on the inter-spike-intervals (ISIs) and use a method of symbolic time-series analysis, which is based on computing the probabilities of symbolic patterns. We show that the variation of the probabilities of the symbols with the modulation frequency and with the intrinsic spike rate of the laser allows to identify different regimes of noisy locking. Simulations of the Lang-Kobayashi model are in good qualitative agreement with experimental observations.