# List of abstracts

## 1. Maximino Aldana

Pairwise decomposition of complex perturbations in models of genetic networks.

In several cases a big complex perturbation affecting a given dynamical system is composed of simpler perturbations that interact in a non-linear way. For instance, to treat some diseases a cocktail of several antibiotics is prescribed. Each antibiotic can be considered as a "simple" perturbation acting on the organism, and the complete cocktail is the big perturbation whose effect is not just the linear superposition of the constituent antibiotics acting separately. This is because the antibiotics, once inside the organism, interact non-linearly with each other and with the metabolism of the cell. Therefore, knowing the effect that each antibiotic, acting individually, has on the organism is not enough to predict the combined effect of the entire cocktail. The general question we would like to answer is: Under what conditions the effect of a multi-component perturbation can be predicted by knowing the effect of the constituent perturbations acting separately, or in pairs, or in triplets, etc? The very surprising answer is that, under very general conditions, it is enough to know the pairwise interactions between the constituent perturbations to predict the effect of the big multi-component perturbation.

## 2. Tati Alonso Amor

Persistence during visual search

Visual search is a cognitive task that involves a number of underlying properties, one of them being the persistence along the visual paths. Here we studied geometrical and statistical persistence on an experiment where subjects had to nd a number \5" embedded in a cloud of numbers from \1" to \9". The geometrical persistence is analyzed by focusing on both the distribution of saccadic directions and intersaccadic angles, whose probability distributions show a preference of participants towards a reading-like mechanism, whose characteristics and potential advantages for searching/foraging are discussed. To explore the statistical persistence, we performed a Multifractal Dentred Fluctuation Anlysis (MF-DFA) over the magnitude time series, nding that the whole time series seems to exhibit a multifractal behavior arising from the combination of saccades and xations. By inspecting instead the magnitude time series only for xational movements, we found that these exhibit a monofractal behavior with a Hurst exponent close to 0.7, indicating long-range positive correlations. As a whole, we expect that our methodological approach can be used as a way to understand persistence and strategy-planning along visual search, giving an insight on how this task is performed.

## 3. Oshrit Arviv

Neuronal avalanches and near-critical dynamics in stimulus-evoked activity of the human brain

The study addresses several important questions: What is the spatiotemporal organization of stimulus-evoked cortical dynamics in healthy human subjects? Are there deviations from excitation-inhibition balance during evoked activity? What is the relationship between evoked activity and resting-state activity? In recent years, numerous studies have found that the brain at resting-state displays many features characteristic of a critical state. Here we examine whether stimulus-evoked activity can also be regarded as critical. Additionally, we investigate the relation between resting-state activity and stimulus-evoked activity from the perspective of criticality. We found that cortical activity measured by MEG is near critical and organizes as neuronal avalanches at both resting-state and stimulus-evoked activities. Moreover, a significantly high intra-subject similarity between avalanche size and duration distributions at both cognitive states was found, suggesting that the distributions capture specific features of the individual brain dynamics. When comparing different subjects, a higher inter-subject consistency was found for stimulus-evoked activity than for resting-state. During the course of stimulus-evoked activity, time-locked to the stimulus onset, we demonstrate fluctuations in the gain of the neuronal system, and thus short time-scale deviations from the critical state. Nonetheless, the overall near-critical state in stimulus-evoked activity is retained over longer time-scale, in close-proximity and with a high correlation to spontaneous (not time-locked) resting-state activity. Spatially, the observed fluctuations in gain manifest through anti-correlative activations of brain sites involved, suggesting a switch between task-negative (default mode) and task-positive networks and assigning the changes in excitation-inhibition balance to nodes within these networks. Overall, this study offers a novel outlook on evoked activity through the framework of criticality, and proposes that the human brain operates near an optimal dynamical regime for informatioprocessing also when evoked by stimuli.

## 4. Luc Berthouze

Long-range temporal correlations in human brain phase synchronisation

The capacity of the human brain to interpret and respond to multiple temporal scales in its surroundings suggests that its internal interactions must also be able to operate over a broad temporal range. In this talk, I will describe a recently introduced framework for robustly assessing the presence of, and characterising the degree of, long-range temporal correlations in the moment-to-moment fluctuations of the phase difference between pairs of neurophysiological signals. Application of the framework to two classical models of criticality (Ising and Kuramoto) and recently described variants of these models aimed to more closely represent human brain dynamics reveals the parameters at which these systems show evidence of LRTCs in phase synchronisation. This provides a basis for the interpretation of results when the framework is applied to human physiological data. I will report recent results with human simultaneous EEG and EMG data showing that brain resting states show synchronisation patterns with similar temporal structure to that of a system of Kuramoto oscillators just prior to its critical level of coupling, and that finger tapping moves the system away from this pre-critical state towards a more random state. The results are validated by applying the same analysis to data with Gaussian white noise phase difference, recordings from an empty scanner and phase-shuffled time series.
The existence of LRTCs in fluctuations of phase synchronisation suggests that these fluctuations are governed by non-local behaviour. This has important implications regarding the conditions under which one should expect to see LRTCs in phase synchronisation. Specifically, brain resting states may exhibit LRTCs reflecting a state of readiness facilitating rapid task-dependent shifts towards and away from synchronous states that abolish LRTCs.

## 5. Angelo Bifone

Brain anatomical, structural and functional connectivity: a weak link?

Several measures of brain connectivity can be derived from analyses of neuroimaging data. Functional connectivity is often defined in terms of correlated functional responses or spontaneous fluctuations in different brain regions as measured by functional MRI, MEG or EEG. Diffusion Tensor MRI exploits the anisotropic diffusion of water along myelinated fibers to delineate white matter tracts connecting different brain regions and to map brain structural connectivity. Finally, covariance of cortical thickness or grey matter volume has been used to assess the mutual influence of genes or trophic factors in shaping brain anatomy. All these forms of connectivity appear to be organized in coherent patterns that are often represented as networks. The interdependence of these different networks and the factors determining their formation and topology are still largely unknown. How structural connectivity constrains functional connectivity networks, by way of example, remains the subject of investigation, with conflicting results reported in the literature. Here, I will present some recent findings on the neurobiology of brain connectivity and will discuss their implications for the analysis of brain connectivity networks and their interactions.

## 6. Dante Chialvo

The brain: what is critical about it?

## 7. Lucilla de Arcangelis

Correlations in brain activity

Neuronal avalanches are a novel mode of spontaneous brain activity, experimentally found *in vitro* and *in vivo,* which exhibits a robust critical behaviour. Avalanche activity can be modelled within the self-organized criticality framework, including threshold firing, refractory period and activity-dependent synaptic plasticity. The size and duration distributions confirm that the system acts in a critical state, whose scaling behaviour is in agreement with experimental data. Interestingly, the critical behaviour is robust with respect to network features but shows interesting features on modular networks.
The temporal organization of neuronal avalanches can be characterized by the distribution of waiting times between successive events. Experimental measurements in the rat cortex in vitro exhibit a non-monotonic behavior, not usually found in other natural processes. Numerical simulations provide evidence that this behavior is a consequence of the alternation between states of high and low activity, leading to a dynamic balance between excitation and inhibition. This behavior has been verified on a larger scale, i.e., on fMRI data from resting patients, where activity variations with opposite sign are correlated over a temporal scale of few seconds, suggesting a critical balance between activity excitation and depression in the brain.

## 8. Antonio de Candia

Dynamical transition between replay and non-replay of spatio-temporal patterns

Complex collective activity emerges spontaneously in cortical circuits *in vivo* and *in vitro*, such as alternation of up and down states, precise spatiotemporal patterns replay, and power law scaling of neural avalanches. We focus on such critical features observed in cortical slices. We study spontaneous dynamics emerging in noisy recurrent networks of spiking neurons with sparse structured connectivity. The emerging spontaneous dynamics is studied, in presence of noise, with fixed connections. Note that no short-term synaptic depression is used. Two different regimes of spontaneous activity emerge changing the connection strength or noise intensity: a low activity regime, characterized by a nearly exponential distribution of firing rates with a maximum at rate zero, and a high activity regime, characterized by a nearly Gaussian distribution peaked at a high rate for high activity, with long-lasting replay of stored patterns. Between this two regimes, a transition region is observed, where firing rates show a bimodal distribution, with alternation of up and down states. In this region, one observes neuronal avalanches exhibiting power laws in size and duration, and a waiting time distribution between successive avalanches which shows a non-monotonic behavior. During periods of high activity (up states) consecutive avalanches are correlated, since they are part of a short transient replay initiated by noise focusing, and waiting times show a power law distribution.
One can think at this critical dynamics as a reservoire of dynamical patterns for memory functions.
We also study dynamics as a function of number of reshaffled connections, to see effects of topology on network dynamics.

## 9. Andrea Gabrielli

Detecting cluster structure of resting state fMRI brain networks of mice

In this talk we present the results of the study of the fMRI correlation networks obtained from the MRI scan of 41 mice. For each mouse the brain has been partitioned in 54 different regions following a standard neurophysiological atlas. Starting from single voxels fMRI time-series we have obtained the mean time-series for each of the 54 macro regions from which we have constructed the region-region correlation matrix through the evaluation of the region-region Pearson coefficients .
We have focused our analysis on the functional connectivity networks constructed from a large resting state fMRI dataset to assess the presence of percolation thresholds. Specifically, we have applied standard percolation analysis and variations thereof to assess the hierarchical modular structure in this species. Importantly, we have applied novel approaches to this dataset that avoid some of the pitfalls that may affect analysis of functional connectivity networks and mask their topological structure. Indeed, functional connectivity networks are just a representation of correlation matrices often obtained by introducing arbitrary thresholds to make the graph sufficiently sparse and computationally tractable. Specifically, we propose 1) a modified version of the standard percolation analysis that makes it possible to retain the information provided by negative correlations, 2) a novel null model, independent of the choice of a particular threshold and resting exclusively on the information encoded into the correlation matrix. Moreover, we propose the use of an algorithm to calculate the closest correlation matrix to a given symmetric matrix. These methodological developments make it possible to reliably assess the presence of a hierarchically organized modular structure in the mouse brain.

## 10. Ewa Gudowska-Nowak

Seeking for a fingerprint: analysis of point processes in actigraphy recording

Despite numerous studies indicating anomalous temporal statistics and scaling in spontaneous human activitity and interhuman communication, there is muchon-going discussion on the origin and universality of observed statistical laws. Behavioral processes are frequently conveniently characterized in terms of stimulus response approach [1, 2], by adapting a systematically repeated, the same external sensory protocol which allows to estimate the statistics of subject's responses. In a more general attitude, in which brains are conceived as information processing output-input systems [3, 4], the observed self-similar temporal patterns of non-stimulated spontaneous neuronal activity can be determined by analyzing spatio-temporal statistics of location and timing of neural signals. Similar to scale-free uctuations detected in psychophysical time series, also dynamics of collective neuronal activity at various levels of nervou systems exhibit power-law scalings. Remarkable scale-free uctuations and long-range correlations have been detected on long time scales (minutes and hours) in data
recorded with magneto and electroencephalography and have been attributed to the underlying dynamic architec-ture of spontaneous brain activity discovered with functional MRI (fMRI) and de_ned by correlated slow tuations in blood oxygenation level-dependent signals.On the other hand, negative deections in local field potentials recorded at much shorter time scales (milliseconds) have been shown to form spatiotemporal cascades (neuronal avalanches) of activity, whose size (amplitude) and

lifetime distributions are again well described by power laws. These power-law scaling behaviors and fractal properties of neuronal long-range temporal correlations and avalanches strongly suggest that the brain operates near a critical, self-organized state [3] with neuronal interactions shaping both, temporal correlation spectra and distribution of signal intensities. It seems thus plausible to further investigate timing, location and amplitudes of such cascades to gain information about underlying brain dynamics and to identify characteristics of stochastic spatial point processes which can serve as reliable models of the ruling dynamics. Some neurological and psychopathic diseases such asParkinson disease, vascular dementia, Alzheimer disease,schizophrenia, chronic pain and even sleep disorders anddepression are related to abnormal activity symptoms.So far there are many, non-unique evaluative measuresused in clinical practice to determine severity of thesedisorders or the e_ect of applied drugs. The challenge thus remain to what extent correlations during resting state (spontaneous) activity are altered in disease states and whether a set of characteristic parameters can be classi_ed unambiguously to describe statistics of healthy versus unhealthy mind states and spatiotemporal organization of such disrupted brain dynamics. Motor activity of humans displays complex temporal fluctuations [5, 6which can be characterized by scale-invariant statistics, thus documenting that structure and uctuations of such kinetics remain similar over a broad range of time scales. Former studies on humans regularly deprived from sleep or su_ering from sleep disorders predicted change in the invariant scale parameters with respect to those representative for healthy subjects. In these studies we investigate the signal patterns from actigraphy recordings [5] by means of characteristic measures of fractional point processes. We analyze spontaneous locomotor activity of healthy individuals recorded during a week of regular sleep and a week of chronic partial sleep deprivation. Behavioral symptoms of sleep lack can be evaluated by analyzing statistics of duration times during active and resting states, and alteration of behavioral organization can be assessed by analysis of power laws detected in the event count distribution, distribution of waiting times between consecutive movements and detrended uctuation analysis (DFA) of recorded time series. We claim that among di_erent measures characterizing complexity of the actigraphy recordings and their variations implied by chronic sleep distress, the exponents characterizing slopes of survival functions in resting states are most effective in determining biomarkers distinguishing between healthy and sleep-deprived groups.

11. Michael Herrmann

Critical Swarms for Optimization and Exploration

Particle swarm optimization is a metaheuristic algorithm that was inspired by the flocking behaviour of birds and schooling of fish. It has been proposed to find reasonable solutions in a wide range of applied problems. We study the properties of the algorithm in the framework of random dynamical systems which, due to the quasi-linear swarm dynamics, yields analytical results for the stability properties of the particles. This analysis goes beyond existing approaches that were restricted to deterministic versions of the algorithm, while it is possible now to clarify the nontrivial effect of the noise and its usefulness in applications to optimisation problems. Such considerations predict a relationship between the parameters of the algorithm that marks the edge between convergent and divergent behaviours. Comparison with simulations confirms that the algorithm performs best near this margin of instability.

12. Pierre Le Doussal

Avalanches in disordered systems

13. Tomoki Kurikawa

Spontaneous neural activity shaped through learning memories.

Neural activity without explicit stimuli is not stationary but exhibits non-trivial dynamics, as known as spontaneous activity. Recent experimental results demonstrate that it is not just stochastic, but exhibits structured spatio-temporal pattern. Although spontaneous neural activity is often studied in relationship with functional connectivity or neural avalanches, possible relationship between its dynamics and cognitive functions still remains elusive.

To better understand this point, in particular, with regards to memory, we proposed a viewpoint, “memories-as-bifurcations,” that differs from the traditional “memories-as-attractors” viewpoint. According to the memories-as-bifurcations viewpoint, memory is recalled when the spontaneous neural activity is changed to an appropriate output activity pattern, upon application of an input, through a bifurcation in dynamical systems theory, as a result of modification of the flow structure in the neural dynamics. Learning, then, is a process that helps create neural dynamical systems such that a target output pattern is generated as an attractor upon a given input.

From this viewpoint, we built simple network models which learn (hierarchical) input/output associations. We then found that learning process shapes such spontaneous activity that transits over neural patterns having similarity with learned patterns, as is consistent with experimental observations. With increasing the input strength, the spontaneous activity is modified to the activity for the learned pattern associated with the applied input. Functional role of the spontaneous neural activity is discussed accordingly.

## 14. Anna Levina

Assessing network state from its subsampling

Since critical neuronal avalanches were first discovered in the recordings from cortical slices and cultures, self-organized criticality (SOC) became an important topic for neuroscience. The appeal of the criticality hypothesis for the brain lays in its promise to explain a fundamental principle of brain architecture. It also presents an opportunity to relate neuronal circuits to better studied physical systems. To assess state of the simulated system we can use the full information about its activity, however in the data obtained from the brain recordings we always have to deal with subsampling introduced by our inability to record every single neuron in the brain. Here we discuss the changes in avalanche size distribution caused by subsampling, and how it is possible to recover information about the whole network dynamics from its subsampling. We use the methods from statistical physics, and discuss scaling laws for subsampled systems. To prove generality of our approach we apply the obtained result to different models of critical avalanches, that produce distribution from different universality classes. We support our results with mathematical models.

## 15. Klaus Linkenkaer Hansen

Critical brain dynamics and its perceptual implications

Several lines of evidence have pointed to the presence of critical dynamics in neural networks at different levels of organization, where activity tends towards the balance between order and disorder. Different computational models have been created that each exhibit some aspect of this critical behavior. These were used to hypothesize that the critical state is optimal for information processing such as memory storage or response to stimuli. To investigate the relationship between critical-state dynamics and oscillations in the processing of stimuli, we used a previously developed neuronal network model that exhibits neuronal avalanches on short timescales and long-range temporal correlations of oscillations on long timescales (Poil et al., 2012). By altering the excitatory/inhibitory connectivity balance, networks with sub-, critical or super-critical dynamics were created. These networks were probed with varying intensities of stimulation, and their responses analyzed in terms of the dynamic range of post-stimulus phase locking and how post-stimulus effects were modulated by the amplitude of pre-stimulus oscillations.Our results indicate that networks with critical oscillations show the largest dynamic range of post-stimulus phase locking and, interestingly, that critical networks exhibit the most reliable pre-stimulus amplitude dependence of post-stimulus response. These results show that critical networks go through periods of being more or less sensitive to stimuli based on their ongoing activity, which could be important for attentional mechanisms. To test the predictions derived from the model, we studied the relationship between criticality of neuronal oscillations and post-stimulus phase locking in source modeled M/EEG data of healthy participants performing a threshold-stimulus detection task. We observed that individual differences in phase locking can be understood in terms of individual differences in critical brain dynamics. The promise of “critical brain dynamics” for explaining individual variation in brain functioning is discussed.

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For background literature and information about the speaker, see:
https://www.researchgate.net/profile/Klaus_Linkenkaer-Hansen
http://www.cncr.nl/research_teams/neuronal_oscillations_and_cognition/

## 16. Hernan Makse

Percolation and cascading in a brain network of networks: two conundra, one solution.

The human brain is organized in functional modules. Such an organization presents a basic conundrum: Modules ought to be sufficiently independent to guarantee functional specialization and sufficiently connected to bind multiple processors for efficient information transfer. It is commonly accepted that small-world architecture of short paths and large local clustering may solve this problem. However, there is intrinsic tension between shortcuts generating small worlds and the persistence of modularity, a global property unrelated to local clustering. Here, we present a possible solution to this puzzle. We first show that a percolation process defines a brain network of networks of hierarchical self-similar modules made of strong links interconnected via weak ties. Weak ties are precisely organized as predicted by theory maximizing information transfer with minimal wiring cost. Such a design suggests a natural solution to the paradox of efficient information flow in the highly modular structure of the brain. We test our theoretical predictions in functional brain networks (in task and resting state). Furthermore, weak interconnecting ties are provided by network hubs implying that the resulting system of correlated networks is stable and robust to failure in contrast to NoN theoretical predictions in uncorrelated systems with one-to-one interdependencies.

## 17. Amos Maritan

Practice makes critical

Recently, evidence has been mounting that biological systems might operate at the borderline between order and disorder, i.e., near a critical point. A general mathematical framework for understanding this common pattern, explaining the possible origin and role of criticality in living adaptive and evolutionary systems, is still missing. We rationalize this apparently ubiquitous criticality in terms of adaptive and evolutionary functional advantages. We provide an analytical framework, which demonstrates that the optimal response to broadly dfferent changing environments occurs in systems organizing spontaneously through adaptation or evolutionto the vicinity of a critical point. Furthermore, criticality turns out to be the evolutionary stable outcome of a community of individuals aimed at communicating with each other to create a collective entity.

References

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## 18. Joaquín Marro

Is the mind a complex of phase transitions?

This talk will illustrate how brain functions, including high-level ones setting up the mind, may be understood on well-defined grounds when one assumes analogy with scenarios that physics classifies as (non-equilibrium) phase transitions and critical phenomena. It suggests models that identify basic mechanisms and help in interpreting observations. This analogy also allows for comparison of data obtained from brains in different stages of evolution, and suggests experiments to detect significant changes of brain dynamics.

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## 19. Gustavo Martinez-Mekler

Is Fertilization Critical?

Fertilization is one of the fundamental processes of living systems. In previous work [1] we introduced a logical regulatory network for the signaling pathway of [Ca2+] concentration oscillations in the flagella of sea urchin sperms, triggered by chemicals surrounding the oocyte. These oscillations modify sperm navigation [2]. Several predictions from the model were subsequently confirmed experimentally leading to a better understanding of the electrophysiology of the flagellum membrane, the action of drugs and chemotaxis [3-4]. Here we show that the network dynamics operates at a critical regime, where robustness and evolvablity coexist. Furthermore, based on criticality as well as non-chaoticity, we reduce the network. Comparison with network reduction based on attractor landscape arguments and correlation calculations is encouraging. Network redundancy is also addressed. The similarity of the reduced discrete network with a system of differential equations model built stepwise is reassuring. Our findings are relevant to the discussion of the role of criticality in essential biological processes and may be of significance to evolution.

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drugs on sea urchin spermatozoa motility. PLoS ONE 9(8): e104451

## 20. Ludovico Minati

Could networked electronic chaotic oscillators be a useful analogy of collective brain dynamics?

Recent years have been characterized by the discovery of certain fundamental principles concerning the organization of brain networks (such as small-world topology) and the dynamical processes which they support (such as criticality), together with the formulation of hypotheses regarding their biological relevance. However, despite advances in neuroimaging and neurophysiology techniques, our ability to record neural activity at high spatiotemporal resolution and to map the underlying structural connectome remains rather constrained. Together with the sheer size of mammalian brain networks, this drives the adoption of a multi-scale approach, wherein brain complexity is jointly investigated at the micro-, meso- and macro-scales attempting to discover scale-invariant features. Within this framework, here we shall consider the potential relevance of experimental networks of chaotic electronic oscillators as a putative model of brain dynamics. This approach appears well-suited to micro-scale investigation, wherein observation and manipulation of networks comprising few tens or hundreds of nodes is of interest, and may complement numerical simulation. Some recently-discovered single-transistor oscillator circuits which can generate strikingly complex activity in spite of their topological simplicity will be presented, and it will be shown that cluster synchronization leads to the formation of communities on an experimental ring of diffusively-coupled units. A provocative analogy between this setup and phenomena observed from resting-state functional MRI data will then be discussed, whereby in both contexts, despite profound differences in scale and dynamics, non-linear structure and low-frequency fluctuations selectively appear for “hub” network nodes. A related CMOS circuit suitable for implementing very large-scale neuromorphic networks in silicon will then be introduced. Finally, recent experimental evidence of spontaneous emergence of remote and lag synchronization of amplitude fluctuations in a ring of reconfigurable analog oscillators will be shown, with a discussion of potential implications for understanding and modelling the mismatch between structural and functional brain connectivity.

## 21. Miguel A. Muñoz

Information-based fitness and the emergence of criticality in living systems

Empirical evidence suggesting that living systems might operate in the vicinity of critical points, at the borderline between order and disorder, has proliferated in recent years, with examples ranging from spontaneous brain activity to flock dynamics. However, a well-founded theory for understanding how and why interact- ing living systems could dynamically tune themselves to be poised in the vicinity of a critical point is lacking. Here we use tools from statistical mechanics and information theory to show that complex adaptive or evolutionary systems can be much more efficient in coping with diverse heterogeneous environmental conditions when operating at criticality. Analytical as well as computational evolutionary and adaptive models vividly illustrate that a commu- nity of such systems dynamically self-tunes close to a critical state as the complexity of the environment increases while they re- main noncritical for simple and predictable environments. A more robust convergence to criticality emerges in coevolutionary and coadaptive setups in which individuals aim to represent other agents in the community with fidelity, thereby creating a collective critical ensemble and providing the best possible tradeoff be- tween accuracy and flexibility. Our approach provides a parsimo- nious and general mechanism for the emergence of critical-like behavior in living systems needing to cope with complex en- vironments or trying to efficiently coordinate themselves as an ensemble.

## 22. Maciej Nowak

Collective correlations of Brodmann areas from random matrix theory denoising of fMRI data

We study collective behavior of Brodmann regions of human cerebral cortex using functional Magnetic Resonance Imaging (fMRI) and Random Matrix Theory (RMT). The raw fMRI data is mapped onto the cortex regions corresponding to the Brodmann areas with the aid of the Talairach coordinates. Principal Component Analysis (PCA) of the Pearson correlation matrix for 41 different Brodmann regions is carried out to determine their collective activity in the idle state and in the active state stimulated by tapping. The collective brain activity is identified through the statistical analysis of the eigenvectors to the largest eigenvalues of the Pearson correlation matrix. The leading eigenvectors have a large participation ratio. This indicates that several Broadmann regions collectively give rise to the brain activity associated with these eigenvectors. We apply random matrix theory to interpret the underlying multivariate data.

## 23. Matias Palva

Functional significance of neuronal criticality in human cognition

Signs of criticality, such as several forms of power-law scaling behaviour, appear ubiquitous in neuronal systems *in vivo* but the functional implications of criticality have remained elusive. Theoretically, a system operating at a critical point has maximal representational and information transfer capacity, and also exhibits a balance between internal robustness and susceptibility to reconfiguration in the face of external stimuli. However, until recently, it has remained unclear how the neuronal scaling laws are related to power-law scaling in human behaviour and whether neuronal criticality is functionally significant for cognitive operations and behavioural performance.
We have used magnetoencephalography (MEG) with cortically-constrained source modelling to assess the dynamics of ongoing brain activity during the resting state as well as during the performance threshold-stimulus detection tasks (TSDTs). These data revealed that the scaling laws of both neuronal avalanches and long-range temporal correlations (LRTC), both during both resting and task states, were correlated with the scaling laws of behavioural dynamics. Importantly, these correlations were limited to well delineated brain systems in a sensory-modality-specific manner. Hence, neuronal criticality appears to be a trait-like and brain-system specific phenomenon that underlies the scale-free behavioral dynamics. In follow-up studies, we found that behavioural scaling in TSDTs was test-retest reliable but uncorrelated with scaling in a comparable discrimination task, which corroborates the notion that they indeed are trait-like and functional-system specific. We also observed that the inter-areal network structures of avalanche dynamics and LRTC were co-localized with those of functional connectivity measured with phase and amplitude correlations. This both further supports the idea of neuronal criticality being modular and shows that the cortical domains of shared critical dynamics overlap with the modularity of the human functional connectome. I will also discuss other ongoing work assessing the functional implications and control parameters of neuronal criticality in the human brain.

## 24. Dietmar Plenz

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## 25. José Soares de Andrade Junior

Resilience and Synchronization of Brain Networks

Interconnected networks are ubiquitous in nature. Many organisms and biological systems often interact with each other, exchanging nutrients and information in an e_cient way through this type of structures. Nevertheless, a number of human built interconnected networks are susceptible to cascading failures, as in the case of power grids, which can eventually lead to large scale blackouts. In the _rst part of the talk we show why interconnected natural networks, such as the neuronal network of the brain, are more stable and resilient to failure than networks created by humans, such as the Internet. In the second part, we focus on the dynamical properties of the interconnected brain network by analysing the role of its hubs on the global synchronization of the system

## 26. Jordi Soriano Fradera

Clustered Neuronal Cultures: Complex Dynamics, Resilience and Adaptability in a Dish

Major dynamical traits of a neuronal network are shaped by its underlying circuitry. In several neurological disorders the deterioration of brain's functionality and cognition has been ascribed to the loss of specific connectivity pathways or a change in the topological properties of the brain's circuits. To deepen in the understanding of the activity-connectivity relationship, neuronal cultures have emerged as remarkable systems given their accessibility and easy manipulation. A particularly attractive configuration of these in vitro systems consists in an ensemble of interconnected clusters of neurons. These clustered neuronal networks exhibit a complex dynamics in which clusters fire in small groups, shaping communities with rich spatiotemporal properties. In our experiments we monitor spontaneous activity using calcium fluorescence imaging, which allows the detection of neuronal firing events with both high temporal and spatial resolution. The detailed analysis of the recorded activity in the context of network theory, information theory and community analysis allows the quantification of important properties such as the functional connectivity of the network, its relation to the structural one, and the structure and stability of the observed modules. Additionally, the networks can be also perturbed in a physical or chemical way, offering a unique scenario to study the resilience of the network to damage and the role of ‘hub’ nodes. The combination of all these approaches is helping to develop models to quantify damage upon network degradation, with promising applications for the study of neurological disorders in vitro.

## 27. Bernardo Spagnolo

Environmental Noise and Nonlinearity in the Brain and beyond

The interplay between environmental noise sources and nonlinearity in three different biological systems is investigated. (i) The phenomena of dissonance and consonance in a simple auditory sensory model are considered. We propose a theoretical analysis with a probabilistic approach to investigate the interspike intervals (ISI) statistics of the spike train generated by the interneuron in the deeper layer. We find that at the output of the interneuron, inharmonious signals give rise to blurry spike trains, while the harmonious signals produce more regular, less noisy, spike trains. The regularity is introduced as the quantity linearly connected with informational entropy. We show that consonant chords influencing the auditory system produce regular spike trains (low entropy) at the systems output, in contrast to dissonant chords, which result in irregular spike trains (high entropy). Theoretical results are compared with numerical simulations. (ii) The noise driven translocation of short polymers in crowded solutions and driven by an oscillating force is analyzed as a second biological system. The dynamics is numerically investigated by solving a Langevin equation in a two-dimensional domain. The mean first translocation time of the center of inertia of polymers shows a nonmonotonic behavior, with a minimum, as a function of the number of the monomers and as a function of the frequency of the oscillating forcing field. (iii) The evolutionary dynamics of cancerous cell populations in a model of Chronic Myeloid Leukemia (CML) is investigated as a third system. A Monte Carlo approach is applied to model the cancer development and progression by simulating the stochastic evolution of initially healthy cells which can experience genetic mutations and modify their reproductive behavior becoming leukemic clones. We study how the patient response to the therapy changes when the drug is assumed with an intermittent time scheduling. We fnd that an intermittent therapy (IT) could also represent a valid choice in patients with high risk of toxicity, despite the retard on the complete restoring of healthy cells.

## 28. Sebastiano Stramaglia

Network approach for bringing together brain structure and function

Understanding the relation between functional anatomy and structural substrates is a major challenge in neuroscience. To study at the aggregate level the interplay between structural brain networks and functional brain networks, a new method will be described; it provides an optimal brain partition --emerging out of a hierarchical clustering analysis— and maximizes the “cross-modularity” index, leading to large modularity for both networks as well as a large within-module similarity between them . The brain modules found by this approach will be compared with the classical Resting State Networks, as well as with anatomical parcellations in the Automated Anatomical Labeling atlas and with the Broadmann partition.

## 29. Ruedi Stoop

Fundamental physics principles generating power laws in bioinformatics and neuroscience

The study of complex networks has pursued an understanding of macroscopic behavior by focusing on power-laws in microscopic observables. Here, we uncover that two universal fundamental physical principles are at the basis of the generation of power-law complex networks.These principles together predict the generic emergence of deviations from ideal power laws, which were previously discussed away by reference to the thermodynamic limit. The ‘rich get richer’ principle expresses that for the formation of ensembles attractive forces generally valid over decades of spatial extensions (in physics involving mass, charge,..) are required. It is this principle that generates the celebrated power laws observed in the distribution of mesoscopic network indicators, such as network degree or weight distribution and on neuronal avalanche size distributions. A second fundamental universality principle of physics is, however, active at the same time, but has passed unnoticed so far. It is the principle that real-world connectivity requires space, and that this space is limited. This saturation principle of the connectability is equally present during the formation of networks, and the question that we address her is, what are its traces will be. This question has not been answered so far.Our approach proposes a paradigm shift in the physics of complex networks, toward the use of power-law deviations to infer meso-scale structure from macroscopic behavior.As an explicit example, we will discuss the nonlinear physics happening within the mammalian cochlea from a network point of view, which will give rise to a novel paradigm of a dynamical activation network. This network, that may be seen as an evolutionary ancestor of the mammalian brain, shows in contrast to the latter under very well defined experimental conditions, power-law distributions of the sizes of the activation networks that are elicited by random stimulations. We will describe what happens to the power-law distributions if the network learns to listen to particular sounds, and we will interpret the changes observed in the context of the thermodynamic formalism of dynamical systems.

## 30. Laurens van Kessenich

tba

## 31. Giuseppe Vitiello

Bessel Functions in Mass Action Modeling of Memories and Remembrances

Data from experimental observations of certain brain functions, such as impulse responses of cortex to electric shocks (average evoked potentials), related with the coexistence of pulses and wave modes in the dynamics of a class of neurological processes (Freeman K-sets), present functional distribution reproducing the Bessel function behavior. This suggests the possibility to replace ordinary differential equations, typically used to model data bases concerning such processes, with couples of damped/ampli¯ed oscillators which provide time dependent representation of spherical Bessel equation. The root loci of poles and zeros of the equation solutions are shown to conform to solutions of K-sets. One advantage of the present formalism is that some light is shed on the problem of ¯lling the gap between the behavior at cellular level and the macroscopic dynamics involved in the tra±c between the brain and its environment. Breakdown of time-reversal symmetry in each of the (damped and amplified) oscillators is related with the cortex thermodynamic features. This is proposed to be a possible mechanism to deduce lifetime of recorded memory.

## 32. Alexander Zhigalov

Human connectome and propagation pathways of neuronal avalanches

The human connectome is a comprehensive map of how brain regions are mutually connected with each other and revealing its structure is fundamentally important for understanding neuronal communication and brain dynamics. The connectome has been initially seen as a static network of structural and functional connections in the human brain but recent studies have revealed considerable fluctuations in the connectivity patterns. However, it has remained unclear how the static and dynamic patterns of functional connectivity are related to the actual dynamical states of the brain and the associated patterns of propagating activities.

Criticality has been suggested as an organizing principle for governing neuronal dynamics. Dynamical states near criticality are manifested in power-law scaling laws of neuronal activity cascades, “neuronal avalanches”, at fast (10-3 – 10-1 s) time-scales [5, 6] as well as in fractal-like temporal structures of slow neuronal fluctuations with power-law long-range temporal correlations (LRTCs) at slow (101 – 103 s) time-scales. It is plausible to assume that critical dynamics and the functional connectome are intimately linked but the nature of this relationship has remained unclear. While computational modelling suggests that the functional resting-state network architecture emerges when the system is poised to a critical state, there are no empirical studies addressing this relationship.

We set out to assess the relationship between the static functional connectivity and the two facets of criticality: propagation pathway of neuronal avalanches and inter-areal correlations of LRTC scaling exponents.

We assessed the relationship between critical dynamics and functional connectivity by using both intracranial stereo-electroencephalography (SEEG) and source-reconstructed MEG resting-state recordings of meso- and macroscopic level, respectively, brain activity. We compiled connectomes of avalanche propagation patterns that capture the critical dynamics at fast time-scales, and connectomes of cross-subject correlations of regional scaling exponents of LRTCs that reflect dynamics at slow time-scales. This yields a novel view into how small brain regions coalesce into larger domains/modules operating in shared dynamic states. These indices of inter-areal dynamical relationships were then compared with static functional connectomes, namely, phase-phase and amplitude-amplitude correlations of ongoing neuronal oscillations.

First, we addressed the graph theoretical properties of the avalanche propagation connectome. The results showed that functional segregation and network resilience are maximized at criticality, as indexed by clustering coefficient ($CC = 0.08$, $p < 0.026$; *t-test*, unequal variance) and assortativity coefficient ($AC = 0.68$, $p < 0.025$; *t-test*, unequal variance). Second, we quantified the edge-level similarity between the static connectomes and both the avalanche propagation and LRTC connectomes. The similarities were greatest in the $\alpha$ (8-14 Hz) and $\beta$ (14-30 Hz) frequency bands and were largely above the chance level (confidence interval, 99.99%) throughout the spectrum. Finally, we assessed the similarity between subgraphs of static and dynamic connectomes. The spectral profiles of subgraph similarities resembled those of edge similarities, suggesting that the connectomes are composed of shared principal modules. These data show that neuronal avalanches propagate predominantly along the pathways observed also in the estimates of static functional connectivity and that there is a salient similarity between inter-areal relationships defined by dynamics and connectivity.