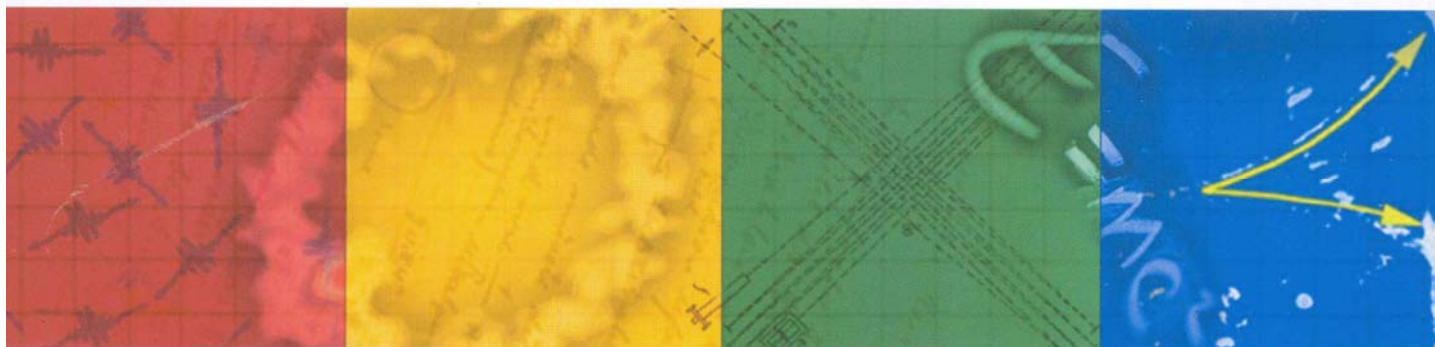"물리와 함께 여는 밝은 미래"

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model simulations, their complex properties are far from being well understood. Here, we show that intriguing complex-periodic (such as period-2, period-4 oscillatory, or chaotic) spiral wave states, can arise in monolayer tissues of cardiac cell culture in vitro, and demonstrate that these different dynamic states can co-exist with abrupt and spontaneous transitions among them - in other words, the medium supports multi-stability. Based on extensive image data analysis, we have confirmed that these spiral waves are driven by their tips tracing complex orbits whose unusual, meandering shapes are formed by delicate interplay between localized conduction blocks and nonlinear properties of the culture medium.

Fp-007 Emergence of a dominant spiral wave from spiral wave competition in a model of inhomogeneous excitable media.

WOO Sung-Jae, HWANG Seong-min, KIM Tae Yun, LEE Kyoung Jin(*CRI Center for Neurodynamics and Dept. Physics, Korea University.*) Spiral waves that form spontaneously on heart tissues are attracting much interest in recent years, as they are believed to be the main cause of ventricular tachycardia -- abnormally fast, yet regular, cardiac rhythms. For a systematic study on their properties, we have recently developed an in vitro cardiac system that can maintain a confluent monolayer of cardiac cells alive for an almost indefinite period of time. Wave activities in this cardiac system can be visualized non-invasively with a home-built optical mapping system. Among various phenomena that arise in the this system, we are attracted to the phenomenon of spiral wave entrainment: in early stages of the tissue culture, many small spiral wavelets compete and evolve into one or a few dominant spiral waves. There is now a substantial amount of evidence that localized inhomogeneities exist and play asignificant role in this competition. Here, we have simulated the so-called 3V-SIM model by Fenton and Karma to show that a realistically implemented spatial inhomogeneities can indeed reproduce the afore-mentioned experimental observations.

Fp-008 Initial flux fluctuations of random walks on regular lattices

SOOYEON Yoon, BYUNG SUN Ahn, YUP Kim(*Kyung Hee Univ., Dept. of Phys..*) We study a characteristic coupling between average flux $<f_i>$ and dispersion σ_i at each site i on 1 and 2-dimensional lattices when random fluctuated incoming walkers from the outside undergoes random diffusion. We assume that variations of the number of walkers, W, define a dynamic variable chosen from an uniform distribution in the interval $[W-\Delta W, W+\Delta W]$. Each walker does M-step random walks from a location which they are initially placed at random on 1, 2-dimensional lattices. After M steps, we measured the average flux vs dispersion at each lattice site. We study the dispersion depends on the average flux as $\sigma \sim <f>^\alpha$. The two scaling regimes are found. One is the regime with $\alpha \simeq 0.5$ and the other is one with $\alpha = 1$.

Fp-009 Surrogate Test on the nonlinearity of EEG

임 규창, 김 수용(*Dept. of Physics, KAIST.*) Although we have no idea of the underlying dynamics of a system, we can obtain a sequence of measurements in time. And a chaotic system has been a strong candidata for a visually stochastic noise signal. However, there is still no direct and secure evidence on the chaoticity or nonlineariy of some examples such as EEG, stock market, etc and in addition, some filtered noise can mimic the chaotic time series by giving a finite numerical result when some nonlinear measures are implemented. So, in this study, we aimed to determine whether EEG is a nonlinear dynamical system or a linear stochastic process by applying the surrogate statistical analysis. Correlation dimension and lyapunov exponents are used to implement the surrogate test. For correlation dimension, there was no statistically significan result but for lyapunov exponent (prediction error) we could some remarkable result, but there is short of universality. So, we tried not a single surrogate but a multivariate surrogate test. The results showed that the rejection of a null hypothesis is explicit for some specific channels. It means that brain system can't be described solely by nonlinear or linear stochastic system, respectively. it"s thought that brain is functioing between two extremes of nonlinearity and linear stochasticity. Although the used algorithms are still under suspicion about its robustness against noise in the signal, this surrogate test can be a useful tool to classify the personality of a time series.

Fp-010 Hopf Bifurcations in Symmetrically Coupled Period-Doubling Systems

LIM Woochang, KIM Sang-Yoon (강원대 물리학과.) We consider two symmetrically coupled period-doubling systems. Aperiod-doubling transition

to chaos in each subsystem may be replaced by a quasiperiodic transition to chaos. This replacement is done when a symmetric antiphase orbit with time shift of half aperiod loses its stability via a Hopf bifurcation, instead of aperiod-doubling bifurcation. We investigate this type of Hopf bifurcations in two symmetrically coupled logistic maps. A daughter orbit born via a Hopf bifurcation may be characterized in terms of its rotation number ν (i.e., the average rotation rate around a mother orbit point per period of the mother antiphase orbit). For irrational ν, a symmetric quasiperiodic attractor, surrounding the unstable antiphase orbit, emerges. On the other hand, for rational ν (=r/s, s and r: coprimes) anomalous Hopf bifurcations occur as follows. For even r, the Hopf bifurcation creates one symmetry-conserved pair of symmetric periodic attractor and saddle, while for odd r it creates two symmetry-broken pairs of asymmetric periodic attractors and saddles. These symmetric and asymmetric periodic attractors exist in the mode-locked Arnold tongues emanating from the Hopf bifurcation line in the parameter space. Furthermore, bifurcations inside these Arnold tongues are discussed. Similar results are also obtained in symmetrically coupled multidimensional period-doubling systems such as the coupled Henon maps, coupled pendula, and coupled Rossler oscillators.

Fp-011 **Interior-Crisis Route to Strange Nonchaotic Attractors in Quasiperiodically Forced Systems** LIM Woochang, KIM Sang-Yoon(강원대 물리학과.)
As a representative model for quasiperiodically forced period-doubling systems, we consider the quasiperiodically forced logistic map, and investigate the dynamical mechanism for the interior-crisis route to intermittent strange nonchaotic attractors. Using the rational approximation to the quasiperiodic forcing, it is shown that a new type of interior crisis occurs for a three-band smooth torus via a phase-dependent saddle-node bifurcation when it collides with a ring-shaped unstable set which has no counterpart in the unforced case. This interior crisis results in the birth of a single-band strange nonchaotic attractor, exhibiting intermittency. Characterization of such intermittent strange nonchaotic attractors is made in terms of the avergae time between bursts and the local Lyapunov exponents.

Fp-012 경락에서의 생체신호에 대한 비선형 분석 유 승훈, 김 연진[1], 김 장일[2], 윤 옥자, 남 성우[3], 노 유
헌[4], 배 기홍, 한 상준(중앙대학교, 물리학과. [1]*Nanjing University of TCM, Dep. Acupuncture.* [2]연세대학교, 물리학과. [3]연세대학교, 생명공학과. [4]중앙대학교, 의과대학 해부학교실.) 인체에 대한 침구치료에서의 자극과 반응에 대한 연구는 주로 f-MRI를 이용한 영상진단법과 해부학적 연구방법등에 의해서 그동안 연구되어 왔다. 본 연구에서는 특정 경혈에 침구자극을 주고 동일 경락 내에서 얻은 생체신호와 다른 경락에서 얻는 생체신호를 비선형 분석하여 그 특성을 정량화 하였으며, 이를 통하여 동일 경락 내에 있는 생체신호의 동력학적 특성의 유사성을 조사하여 경락의 실체를 밝히고자 하였다.

Fp-013 **Morphological Properties and Cytosolic Calcium Oscillations in {\it In Vitro} Cortical Neural Networks** JEONG Byeongha, KO Tae-Wook, KIM Gi-Ho, LEE Kyoung-Jin(고려대학교 물리학과 신경망동력학연구센터.)
We have quantified the changes in the structures (e.g., cell density, neurite density and morphology, connection motifs) of cortical neural networks {\it in vitro} over several days as they grow and become mature in a dish. At the same time, we have characterized the cytosolic calcium oscillations of the neuronal cell populations and their synchronization based on a confocal imaging. Our analysis indicates that calcium spikes and the degree of their synchronization increase rather dramatically while the morphology of the cellular network changes only gradually. Based on the results of our pharmacological investigations and computer model studies, we believe that long-range electrical connectivities are the key component conferring an almost instantaneous synchronization.

Fp-014 **Instability of defensive alliances in the six-species predator-prey model on complex networks** LIU Jianbin, 김 범준(아주대학교)
A simple model of a food web composed of six species is studied in the viewpoint of the spatial interaction structure. Each species has two predators and two preys, and it was previously known that the defensive alliances of three cyclically predating species self-organize in the two-dimensional regular structure and protect each other from the invasion of other species. The alliance becomes unstable either as the high mutation rate is allowed or as the rewiring probability is increased in the Watts-Strogatz network constructed in two dimensions. An order parameter to detect the inter-alliance symmetry breaking is suggested and used to