The Global COE Program

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Bilateral International Exchange Program (BIEP, invite) report

Send report to: Your responsible Professor in Kyoto University

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(Year/Month/Day) 2009/11/26

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Research Project

Title	On Non-universal aspect of Earthquake recurrence patterns
Duration	2009/9/8-2009/12/5

Please summarize your activities and results during your stay in Kyoto University.
Also please describe how your stay has been beneficial to the graduate students in the institute. You can add a sheet, if you need more space.
You can also write any comments and requests to the GCOE program.

Here I briefly report my activities during the three-month visit in Nonlinear Dynamics Group, Physics Department, Kyoto University. The report is organized as follows: 1. Research studies. 2. Academic Activities. 3. Other activities.

1. Research Studies.

1-1. Collaboration with Prof. Shinomoto: On Non-universal aspect of Earthquake recurrence patterns

The aim of our collaboration work is to understand the spatial variation of earthquake recurrence patterns on the entire Earth, and to relate them with tectonic boundary types. For this purpose, we carried out a series of data analysis, together with the collaboration with Prof. Shinomoto's PhD students Takahiro Omi and Nanae Matsuno.

Earthquakes result in large scale motions of tectonic plates. Though it is always difficult to foretell the time, space and magnitude of individual earthquakes, it is possible to capture the characteristics of an entire sequence of earthquakes. Many studies have been focused on the universal aspect of earthquake recurrence times, i.e., the universality in distribution of inter-earthquake intervals under rescaling processes of region size, magnitude cutoff and mean event rate. These imply a universal mechanism underlying the generation of earthquakes.

However, the plate boundaries that generate earthquakes are not homogeneous, but are classified into several types such as divergent, convergent, and transform. It is possible that the fine temporal patterns of event occurrence differ between spatial regions, reflecting internal conditions for causing events.

In order to closely examine the temporal characteristics of earthquake occurrences, we applied a metric of local variation of event-intervals Lv, which was previously designed for analyzing the irregularity of neuronal spike trains (Shinomoto et al., Neural Computation 2003; Shinomoto et al., PLoS Comput Biol 2009). It is defined as: $Lv = \frac{3}{n-1}\sum_{i=1}^{n-1}\left(\frac{I_i - I_{i+1}}{I_i + I_{i+1}}\right)^2$, where I_i and I_{i+1} are the i^{th} and $i+1^{st}$ adjacent recurrence times, and n is the total number of interocurrence intervals. This metric intrinsically captures the local variation of a sequence of events via calculating the instantaneous variability of inter-event intervals: The term $\left(\frac{I_i - I_{i+1}}{I_i + I_{i+1}}\right)^2 = 1 - \frac{4I_i I_{i+1}}{(I_i + I_{i+1})^2}$ represents the cross-correlation between consecutive intervals I_i and I_{i+1}, each rescaled with the instantaneous earthquake rate $2/(I_i + I_{i+1})$. For a sequence of perfectly regular intervals (where intervals are identical), Lv metric returns zero, while it takes value of *1* for a Poisson random series of events where inter-event intervals are independently exponentially distributed. This metrics captures the

regularity of a sequence of events, while eliminating nonstationarity by rescaling intervals with the momentary rate.

By applying the Lv metric to sequences of earthquakes occurring in different areas, we revealed several facts listed below: First of all, we found that the irregularity of earthquake occurrence depends on the mean rate. Next, we examined the regional difference of the intrinsic irregularity, after removing this overall trend. It is found that the divergent boundaries exhibit temporal patterns even more highly correlated than those of convergent and transform boundaries. In addition, there is a strong tendency for the regions of the similar degree of irregularity to cluster on the world map. These facts indicate that the temporal occurrence of earthquakes reflects underlying mechanical conditions, not only the known classification of the tectonic boundaries, but also some unknown factors.

Now we are writing a joint paper on this topic. We will continue our collaboration till the paper is published, and even further after.

1-2. Collaboration with Prof. Nakao: Coupling-induced synchronization.

We analytically and numerically investigated the synchronization behavior of coupling-induced over-damped Stuart-Landau oscillators (described as $\dot{\omega}_i = \mu\omega_i - |\omega_i|^2 \omega_i - iC|\omega_i|^2 \omega_i$). We firstly simulated two coupled over-damped Stuart-Landau oscillators, each of which has a negative parameter of μ (which means that they are over-damped when isolated) and extended it to many coupled over-damped oscillators in simulation. We found that coupling can make over-damped oscillators to (re-)synchronize with each other. Later, we revealed analytically the conditions and patterns for N over-damped oscillators to synchronize, both for positive coupling and for negative coupling. Results showed that for positive coupling, the group size can tune the system into complete synchronization; and for negative coupling, the synchronization patterns subject to a simple condition of zero-mean field.

This work may have relevance with population-driven synchronization and revealed a new class of synchronization by negatively coupling over-damped oscillators.

2. Academic Activities

I have given 4 presentations in Nonlinear Dynamics Group. It includes,

(a) One open seminar in Nonlinear Dynamics Group, where I presented a work I was involved *a possible population-driven synchronization on cicada chorus*. Related information can be found here, http://www.ton.scphys.kyoto-u.ac.jp/nonlinear/seminar-list/2009.09.30.html

(b) One presentation of my current research on Seismology to Israeli professor Ido Kanter, who visited Prof. Shinomoto's group. I also discussed with him on this work and received informative suggestions.

(c) One Journal Club presentation, where I introduced a paper of my group in Fudan University: *Heterogeneous Preferences, Decision-Making Capacity and Phase Transitions in a Complex Adaptive System*

(d) One lecture in Reading Club to Prof. Shinomoto's students, on chapters in the book

entitled *Spikes*.

By these 4 presentations we exchanged studies and ideas, in a relatively formal way.

3. Other activities

(a) During my stay, I tried and finally made to get familiar with the students and colleagues here. We had numerous communications both on research topics and on casual ones. The discussions were beneficial for both sides, during which we activated each other both in thoughts and in attitudes towards life.

(b) Not only did we communicate in office, we even had a wonderful party in Prof. Shinomoto's home, where Israeli professor Ido Kanter and his wife, Prof. Nakamura (Kansai University), Prof. Nakao, Prof. Shinomoto's students and I joined. In this party, Prof. Shinomoto held a mini music concert by his children and his students (including me!). Please refer to a photo in the Appendix part for the wonderful party.

Acknowledgement:

I would like to express my gratitude to Prof. Shinomoto and Prof. Nakao, for their supervisions during the three months. I would also like to say thanks to all the students and colleagues in Nonlinear Dynamics Group for the numerous discussions and their friendliness. Thank Ms. Nishikawa very much for preparing documents and caring my daily life. Finally, thank GCOE committee for providing me this great opportunity, such that we can have fruitful collaboration that is beneficial for both sides.

Appendix: Prof. Shinomoto's home party (2009.11.22)