Non-perturbative effects and renormalization in non-parametric Bayesian statistical inference

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Bayesian statistical inference is a framework which enables us to make effective inference combining our knowledge with observed data. For example, digital communication is one of its most fruitful results and indispensable to our life today. Moreover, it gives a foundation of statistical physics, and plays a key role for us to approach systems with infinitely many degrees of freedom. This can be understood from the point of view of probability and information theories.

In this presentation, we discuss the properties of Bayesian statistical inference of the systems with infinitely many degrees of freedom. For this purpose, we adopt the density estimation model by Bialek, Callan and Strong as an example. Non-linearity of the model leads to distinguished improvement of its performance, which is proved by a non-perturbative analysis we developed. The analysis has successfully predicted non-trivial scaling behavior of the model, and made it clear that renormalization in Bayesian statistical inference depends on a distribution of transmitted information through observed data, which is consistent with Shannon's communication theory.
From human mobility to complex networks

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A range of applications, from predicting the spread of human and electronic viruses to city planning and resource management in mobile communications, depends on our ability to understand the mobility of individuals. Furthermore, the structure of social network is also strongly influenced by the location and the mobility of the individual nodes. Here I will study the mobility pattern of anonymized mobile phone users, aiming to understand the statistical characteristics of human trajectories and the impact of the mobility on the underlying social network. I will show that human mobility follows reproducible scaling laws, which, however, deviate from the standard Levy flight or random walk based predictions. I will discuss a simple model that can account for the observed anomalies in the scaling behaviour. Finally, I will discuss potential applications, from the spread of mobile viruses to predictability, problems that rely on a deep understanding of the statistical laws that govern human mobility.
Glassy dynamics and random walks on complex energy landscapes

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We present a simple mathematical model of glassy dynamics seen as a random walk in the network of minima taken as a representation of the energy landscape. We show that a finite temperature glass transition exists if and only if a specific relation holds between the energy of the minima and their number of neighbors. We also examine the relaxation and aging dynamics of the system, and rationalize some results presented in the recent literature. Our approach gives a broader perspective to previous studies that focused on particular examples of energy landscapes obtained by the study of small systems, and shows how the tools developed in complex network theory can be put to use in this context.
New paradigm in the simulation of stochastic reaction networks

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Stochastic reaction networks are widespread in physical, chemical and biological systems. These networks are commonly simulated by Monte Carlo methods such as the Gillespie algorithm.

In this talk I will present two novel equation-based methods for the analysis of stochastic networks. The multiplane method is a dimensional-reduction method based on the master equation. The moment equations method consists of a closed set of equations for the first and second moments of the distribution of population sizes of the reactive species. For a broad class of applications, these methods are superior over Monte Carlo simulations. The equations are linear, stable and converge fast, providing accurate results without the need for statistical analysis of large sets of data. Applications to interstellar chemistry and biological networks will be discussed.
Heterogeneous pair approximation for voter models on networks

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For models whose evolution takes place on a network it is often necessary to augment the mean-field approach by considering explicitly the degree dependence of average quantities (heterogeneous mean-field). We introduce the degree dependence in the pair approximation (heterogeneous pair approximation) for analyzing voter models on uncorrelated networks. This approach gives an essentially exact description of the dynamics, correcting some inaccurate results of previous approaches. The heterogeneous pair approximation can be applied in full generality to many other processes on complex networks.
Quarantine on Dynamic Networks

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While network research has offered great insight into problems of resource allocation, infrastructure construction, and physical and social health, much of the prior research has been conducted on networks where network topology remains constant with time. Real world networks are seldom static however, thus we introduce a timescale for the network topology, separate from the timescale of the transport dynamics.

We investigate Erdős-Rényi and power law networks, and present both simulated and theoretical results. We find that the critical exponents differ from the previously expected behavior in a static network, with the degree of difference proceeding smoothly as a function of the topological timescale. In addition we provide a rescaling to show that this behavior is universal.
Spectral dimension of a class of fractal lattices

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Abstract

The probability that a nearest neighbour random walker is at the origin on a given structure, as $t \to \infty$, is known to scale as $t^{-\bar{d}/2}$, where $\bar{d}$ is a scaling parameter which depends on the geometry of the structure. Knowledge of the parameter $\bar{d}$ gives useful information concerning the properties of the system and is used in condensed matter physics, chemistry and in other areas where diffusive phenomena occur.

It is accepted that $\bar{d} = 2d_f/d_w$, for lattices with defined fractal dimension $d_f$ and random walk dimension $d_w$. However, it is possible to find examples of fractal lattices for which $\bar{d} \neq 2d_f/d_w$. In this talk we present the analytical calculation of $\bar{d}$ for a class of "fractal trees" that do not follow the standard rule $\bar{d} = 2d_f/d_w$. 
Random walk and modularity in directed networks

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The modularity is the most widely used quality function of community identification in networks. However, the modularity has not been defined thoroughly in directed networks while many real-world networks are directed ones, such as World-Wide-Web, citation networks, and gene regulatory networks.

We propose a generalized form of modularity in directed networks by introducing a new quantity LinkRank, which is the probability that a random walker passes through a particular link during the random walk, and it can be shown that this generalized form is consistent with the original modularity in undirected networks. An immediate advantage of this generalized modularity is that the various algorithms developed to optimize modularity in undirected networks can be applied to directed networks by optimizing our generalized modularity.

Also, a directed model network, which can be used as a benchmark network in further community studies, is proposed to verify our method. Our method is supposed to find communities effectively in citation- or reference-based directed networks.
Local interaction and traffic jam
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We use a cellular automaton approach to investigate the traffic flow pattern on a single lane. The free-flow phase, the synchronized phase, and the jammed phase are observed and the transitions among them are studied as the vehicular density $\rho$ is slowly varied. If $\rho$ is decreased from well inside the jammed phase, the flux $J$ follows the lower branch of the hysteresis loop, implying that the adiabatic decrease of the vehicular density is not an efficient way to drive the system back into the synchronized phase or into the free-flow phase. We propose a simple way to help the system to escape out of the jammed phase, which is based on the local information of the velocities of downstream vehicles.
A Condition for Cooperation in a Game on Complex Networks

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We study a condition of favoring cooperation in a prisoner’s dilemma game on complex networks [1]. There are two kinds of players: cooperators and defectors. Cooperators pay a benefit \( b \) to their neighbors at a cost \( c \), while defectors only receive benefit. The game is done under weak selection and death-birth update. Although it has been well recognized that \( b/c > \langle k \rangle \) is the condition of favoring cooperation [2], we find that \( b/c > \langle k_{nn} \rangle \) is a much better approximate condition. We also show that among the representative networks-regular, random, and scale free-a regular network favors cooperation the most, while a scale-free network favors it the least. In an ideal scale-free network, cooperation is unfeasible. Whether a scale-free network favors cooperation depends on the details of the games.

We examine the impact of credit default swaps (CDS) on defaults and losses in a stylized economic system, composed of interconnected heterogeneous networks of corporates, banks and insurers. We analyse such a system using a stochastic setting, which allows us to exploit limit theorems to exactly solve the contagion dynamics for the entire system. The analysis shows that CDS, when used to expand banks’ loan books (arguing that CDS would offload the additional risks from banks’s balance sheets), can actually lead to greater instability of the entire network in times of economic stress, by creating additional contagion channels. This can lead to considerably enhanced probabilities for the occurrence of very large losses and very high default rates in the system.
Universality class of random search in scarce environments

M. G. E. da Luz, C. L. Faustino, M. L. Lyra, E. P. Raposo and G. M. Viswanathan
We analyze search dynamics and some statistical properties of an autonomous random walker whose sole source of energy are search targets that are themselves diffusing random walkers. We study how the rate of survival searchers varies with the target density via numerical simulations. We report that superdiffusion of both organisms confers substantial rate of survival advantages in the limit of low densities. Moreover, we observe a continuous phase transition for several searches strategies, where the rate of survival is the good order parameter. We calculate the critical densities which depends on the parameters of diffusion adopted by the organisms. We also obtain the critical exponents $\beta/\nu$ and $\nu$ for the transition, where both exponents are independent of the diffusion adopted, suggesting a universality of critical exponents.
Physics and phase transitions in parallel computational complexity
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Though work at the interface between physics and computational complexity has centered largely on NP-hard problems, there are also many interesting questions to be addressed within complexity class P of tractable problems. These questions are brought into relief by considering problems from the point of parallel computation. The talk will begin with a review of parallel computational complexity: the PRAM and Boolean circuit family models of computation, the classes P and NC and the notion of P-completeness. I will then discuss recent work with Cris Moore and Stephan Mertenson phase transitions in the circuit value problem.
Fracture of frictional granular materials using cohesive-friction random fuse model

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This paper presents an efficient algorithm for simulating the fracture of disordered granular materials using the cohesive-friction random fuse model (CFRFM). Fracture behavior of many disordered granular materials is dominated by interfacial failure response that is characterized by decohesion followed by frictional sliding response. To capture such an interfacial failure response, we introduce a CFRFM model, wherein the cohesive response of the interface is represented by a linear stress-strain response until a failure threshold, which is then followed by a constant response at a threshold lower than the initial failure threshold to represent the interfacial frictional sliding mechanism. Using this model, we study scaling of fracture surface roughness and fracture strength distributions.
A dynamical potential model to financial markets and exact derivation of GARCH model

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By analysing high frequency financial market data we already discovered various evidences which clearly show deviation from a simple random walk assumption. One of the most interesting finding is the existence of a kind of velocity potential acting for market prices in addition to the random forces [1]. The shape of potential is usually described by a time dependent quadratic function changing its shape with a characteristic time scale about a few hours in the case of foreign exchange markets. In special cases of bubbles or crashes we can observe an asymmetric higher order potential function supporting directional motions [2]. In the continuum limit the above price motion can be reduced to a generalized Langevin equation in 1 dimensional space with a fluctuating viscosity which can take a negative value [3].

Based on this background we consider a diffusion process of a particle in temporarily changing viscosity. We derive a Fokker-Planck equation from the Liouville equation which includes the case of negative viscosity. It is shown that the time evolution equation of variance becomes the famous GARCH model in financial technology in a special case. We solve the steady state distribution of the values of variance and show that the velocity distribution generally has symmetric power law tails. This result is consistent with the empirical law that the distribution of market price difference in short time scale generally follows a power law.

Although the GARCH model is successful in the reproduction of this power law distribution, we show that the GARCH model cannot explain the other empirical law of abnormal diffusion of market prices. The reason of this failure is due to the simplification of the assumption of white noise behaviour of viscosity fluctuation. The PUCK model can take into account the effect of finiteness of correlation time of viscosity fluctuation, and the abnormal diffusion can also be explained successfully.

References
Scaling laws between population and facility densities

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We investigate the ideal relation between the population and the facility densities within the framework of an economic mechanism governing microdynamics. In previous studies based on the global optimization of facility positions in minimizing the overall travel distance between people and facilities, it was shown that the density of facility $D$ and that of population $\rho$ should follow a simple power law $D \sim \rho^{2/3}$. In our empirical analysis, on the other hand, the power-law exponent $\alpha$ in $D \sim \rho^\alpha$ is not a fixed value but spreads in a broad range depending on facility types. To explain this discrepancy in $\alpha$, we propose a model based on economic mechanisms that mimic the competitive balance between the profit of the facilities and the social opportunity cost for populations. Through our model, we show that commercial facilities driven by the profit of the facilities have $\alpha = 1$, whereas public facilities driven by the social opportunity cost have $\alpha = 2/3$. 
Scaling in the global spreading patterns of pandemic Influenza A and the role of control: empirical statistics and modeling

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The pandemic of influenza A (H1N1) is a serious on-going global public crisis. Understanding its spreading dynamics is of fundamental importance for both public health and scientific researches. In this talk, I would like to investigate the spreading patterns of influenza A and find the Zipf’s law of the distributions of confirmed cases in different levels. Similar scaling properties are also observed for severe acute respiratory syndrome (SARS) and bird cases of avian influenza (H5N1). To explore the underlying mechanism, a model considering the control effects on both the local growth and transregional transmission is proposed, which shows that the strong control effects are responsible for the scaling properties. Although strict control measures for interregional travelers are helpful to delay the outbreak in the regions without local cases, our analysis suggests that the focus should be turned to local prevention after the outbreak of local cases. This work provides not only a deeper understanding of the generic mechanisms underlying the spread of infectious diseases, but also an indispensable tool to decision makers to adopt suitable control strategies.
Record-breaking temperatures reveal a warming climate

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In current media coverage the occurrence of record-breaking temperatures and other extreme weather conditions is often associated with global climate change. However, record breaking events occur at a certain rate in any stationary random process, and the question whether the known increase in global mean temperature is sufficient to significantly influence this rate has so far not been conclusively answered. We present a mathematical analysis of records drawn from independent random variables with a drifting mean to show that, to leading order, the change in the record rate is proportional to the ratio of the drift velocity to the standard deviation of the underlying distribution. We apply the theory to time series of daily temperatures for given calendar days, obtained from historical climate recordings of several hundreds of European and American weather stations as well as re-analysis data. The sensitivity of the analysis is enhanced by comparing the actual time series to the time-reversed process. We conclude that the change in the mean temperature has increased the rate of record breaking events in a moderate but significant way. For the European station data covering the time period 1976-2005, we find that about 6 of the 18 high temperature records observed on average in 2005 can be attributed to the warming climate.
Installing Sources to Satisfy Consumers - A Statistical Physics Approach

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We consider transportation networks in which resources are provided from the surplus nodes to satisfy the resource consumption of the deficient nodes with a minimum total transportation cost. In the optimal source location problem, some deficient nodes are converted to source nodes with an additional installation cost per node. The solution to this problem is relevant to optimal power control in wireless sensor networks. When the installation cost decreases, the fraction of installed source nodes increases in discrete fractions, resembling the Devil’s staircase and corresponding to different clusters of consumer nodes surrounded by the source nodes. Frustration arises due to the choices of locating the installed source nodes, and numerous suboptimal configurations emerge, resembling typical glassy behavior.

We use the cavity approach to analyze the problem, but unlike most constraint satisfaction problems involving discrete variables, our problem involves continuous current variables. The one-step replica symmetry breaking (1RSB) solution involves solving a stable distribution of functionals, which is in general infeasible. Nevertheless, we obtain small closed sets of functional cavity fields and demonstrate how simple recursions of probabilities render the 1RSB solution feasible. The physical results in the replica symmetric (RS) and the 1RSB frameworks are thus derived and their stabilities are examined. Applications to power control in wireless sensor networks will also be discussed.