RESEARCH INTERESTS

Meesoon Ha

My research interests have been mostly in the field of statistical physics and related condensed-matter theory topics. In particular, I have been involved in the study of nonequilibrium critical phenomena, phase transitions, and finite-size scaling in one-dimensional (1D) simple dynamic processes, including growing interfaces and driven diffusive particle systems. Most recently I have also been working on equilibrium and nonequilibrium phase transitions in complex networks which are scale-free. I would like to continue general aspects of these intriguing processes as well as expand my work to other related areas of complex systems from a statistical physics perspective.

Master's Thesis Project:

During my M.S. program at Korea University, I worked on kinetic roughening as investigated dynamic properties of 1D nonequilibrium interfaces through a model for growing interfaces. My exact enumeration results of its dynamic recursion relations led to my first publication, "Exact solutions of a restricted ballistic deposition (RBD) model on a 1D staircase" in Phys. Rev. E **51**, 1047 (1995). My advisors and I connected the unusual value of the dynamic exponent z in the RBD model to the well-known dynamic exponent of Kardar-Parisi-Zhang (KPZ) growth by using a time rescaling argument. This proved that the RBD model belongs to the KPZ universality class.

Ph. D. Thesis/Dissertation Project:

My research interests at the University of Washington shifted to the closely related 1D driven diffusive systems. These processes show surprisingly rich and complex behaviors, in particular boundary-induced nonequilibrium phase transitions.

As the first topic, we studied the exact mapping of the RBD model onto a 1D fully asymmetric diffusion reaction model and to the reaction process $A + A \to A$. This was published in J. Phys. A **32**, L495 (1999). In the context of particle dynamics, the RBD process was reinterpreted as a mass-conserving coalescence process where particles of unit mass enter at one edge of chain and coalesce while performing a biased random walk to the opposite open edge. The conserved particle mass acts as a passive scalar in the $A + A \to A$ process. This allowed us to formulate a comprehensive scaling theory.

After that, I started working on a variation of the most celebrated model describing driven diffusive processes, namely the asymmetric simple exclusion process (ASEP).

The model, originally proposed by C.T. MacDonald and his coworkers in Biopolymer **6**, 1 (1968), consists of particles hopping unidirectionally with hard-core exclusion along a 1D lattice. Due to conservation of the particle current, the rates of incoming or outgoing particles at the boundaries drive the system to non-trivial stationary states. The resulting phase diagram shows phase transitions with continuous and discontinuous changes in the average density of particles.

Initially, the model was studied in the early 1990-ties in the mean-field (MF) approximation, followed by numerical simulations, and then extended to complete analytic solutions of the stationary state by solving specific versions of the model. The full time evolution, of the ASEP is exactly soluble, by the Bethe ansatz technique, in case of periodic boundary conditions. The model is a special line in the general phase diagram of the 1D well-known XXZ spin 1/2 quantum chain Hamiltonian, and also in the so-called six-vertex model of 2D equilibrium critical phenomena. For other, but only very specific, boundary conditions the exact form of the stationary state of the ASEP can be obtained from the so-called matrix product ansatz technique.

Traffic jams appear in the above ASEP type driven diffusive systems in the presence of local inhomogeneity, e.g., a slow bond, where the hopping rate is reduced. Queuing phase transitions have been reported in lots of exact or numerical studies of the ASEP. The scaling properties of such transitions, however, remained somewhat unclear and unresolved (and the above exact methods seem to fail in those cases).

In our own studies, we focused on the scaling properties of these queuing phenomena. In our published paper in Phys. Rev. E last year, we “confined the traffic jam to a garage” and introduced a new version of the ASEP where instead of a slow bond or reservoirs on both open ends, the road starts and terminates in the same garage. This leaves us two control parameters, the total car density and the exit probability. Due to the fact that the garage has an infinite parking capacity, macroscopic occupation of the garage is quite similar to a traffic jam on the road. Queuing transitions are thus related to dynamic analogues of Bose condensation, in terms of macroscopic occupancy at the garage. Our early results were presented at the 2001 APS March meeting and at the international summer school (entitled Fundamental Problems in Statistical Physics X) in Germany that same year. This project led to my third publication, “Macroscopic car condensation in a parking garage” in Phys. Rev. E **66**, 036118 (2002).

Our study of another variation of the ASEP with a bond defect was motivated by the experiments of Prof. J. Timonen, whose group showed experimentally that slow combustion of paper fronts belongs to the KPZ universality class. Prof. Timonen visited Seattle from September to December, 2002. In his experiments, he observed faceting in the presence of a columnar defect. In direct analogy, we considered the ASEP with open boundary conditions and a defect bond in the middle of the road to model such faceting phenomena. we find not only the same faceting, but also clarify the existence of a continuous faceting transition. This has remained somewhat of a puzzling problem for a decade. Based on my detail numerical analysis, Prof. Timonen's group worked on a experimental paper and we wrote a theoretical paper, respectively: "Effect of a columnar defect on the shape of slow-combustion fronts" in Phys. Rev. **68**, 051103 (2003) and "Queuing transitions in the asymmetric simple exclusion process" in Phys. Rev. **68**, 056122 (2003).

Postdoctoral Project:
I joined Prof. Hyunggyu Park's group at KIAS and investigated the universality class of the pair contact process with diffusion (PCPD) in terms of a 1D cyclically coupled model with a controllable long-term memory as my first postdoctoral topic. The PCPD has attracted considerable interest recently, due to a possibility of a new universality class distinct from well-established directed percolation (DP) and directed Ising (DI) classes of absorbing phase transitions. Although various scenarios are suggested based on numerical and field-theoretical results, its critical properties have not been clarified yet. A few years ago, Prof. Jae Dong Noh at the Chungnam National University and Prof. Hyunggyu Park at KIAS pointed out that the long-term memory in the PCPD model is the main source of this new universality class and suggested a possibility of continuously varying critical exponents depending on the memory strength. Through this DP-based cyclically coupled model study where we could directly control not only the memory strength but also its lifetime power-law decaying tail exponent, we confirmed that the long-term memory effect is indeed the main source of novel critical phenomena characterized by continuously varying exponents as claimed in the generalized PCPD model study. Our numerical results support that the universality class of the PCPD model is clearly distinct from two well-established DP and DI classes, due to the long-term memory of diffusive solitary particles, which is consistent with Dr. Su-Chan Park's recent work with Prof. Hyunggyu Park, *driven PCPD*. This work (KIAS preprint No. P04052) will be submitted to a proper journal soon.

As the second topic at KIAS, I extended one of my Ph.D. Dissertation topics, a 1D traffic-type parking garage model, with nonlocal hopping, in collaboration with Prof. Hyunggyu Park and my former Ph. D.adviser, Prof. Marcel den Nijs at the University of Washington. This variation let us study both periodic and open ASEP with nonlocal hopping. From a fundamental perspective, the central issues are its new structures of the nonequilibrium steady states, dynamic pathways to these states, and scaling properties of new and/or old dynamic phase transitions. Introducing nonlocal skids of particles in the ASEP with probability p, promotes clustering and coarsening towards a new phase, namely Empty-Road (ER), we showed that the steady state undergoes nonequilibrium phase transitions into this ER phase from three conventional local-hopping phases (Condensed, Maximal-Current, and Normal) observed in my earlier publication, Phys. Rev. E **66**, 036118 (2003), at a finite value of p_c. We also numerically and analytically (up to the pair mean-field (MF) approximation level) established that these new transitions can be both discontinuous and critical. The first-order plane originates from a clustering instability, and a novel tricritical line separates this from a critical plane. Summing up our numerical results and MF-based arguments, we found that scaling properties on this critical plane are nontrivial as well and clustering with inhomogeneity plays a crucial role in this. One part of this work (KIAS' preprint No. P04053) is on process of final writing. Some other details and the symmetric case are under investigation.

More recently I have been involved in the study of finite-size scaling of equilibrium and nonequilibrium phase transitions on complex networks. In this work, we numerically check the mean-field results of critical exponents of Ising model (corresponding to equilibrium case) and two typical toy model of an epidemic (corresponding to nonequilibrium case), CP and its variant (Susceptible-Infected-Susceptible), on static scale-free networks with various range of power laws in their degree distributions. In this study, to check hyperscaling relations is the core part and we will also check the cutoff dependency on exponents as a side part. This work is in collaboration with Prof. Hyunsuk Hong at Chunbuk National University.

Future Outlook

During my first and second years at KIAS, I devoted myself to generic aspects of how macroscopic phenomena emerge in 1D nonequilibrium systems from microscopic rules, which has contributed to my understanding of how various boundary conditions, local/global inhomogeneities, and long-term memories give rise to critical phenomena and nonequilibrium phase transitions. In addition, last year I expanded my research area to complexity since the long-term goal of my research is the contribution to the advance of the theory of complex systems. As the first step, I have been working on finite-size scaling of critical phenomena and phase transitions in complex networks, so-called scale-free networks.

In future, I expect that my analytical and numerical tools/methods developed in my past and present research topics would be also valuable in understanding complex systems in physics and biology, where the study of their underlying principles is important. In that perspective, the modeling and/or numerical simulations of some specific real systems strongly attract my attention.