MATHEMATISCHES FORSCHUNGSINSTITUT OBERWOLFACH

Tagungsbericht 43/1999

Stochastic Analysis

31.10. - 06.11.1999

This meeting was organized by Gerard ben Arous (Lausanne), Jean Dominique Deuschel (Berlin) and Alain-Sol Sznitman (Zürich)).

This meeting had two exceptional moments: First the Oberwolfach prize was awarded to Dr. A. Guionnet for her work on spin glasses and random matrices, and second the solution of a long-standing conjecture was announced by W. Werner reporting on a joint work with G. Lawler and O. Schramm. This conjecture concerns the intersection exponents for Brownian motions in dimension 2, and is a very important first step in the understanding of conformal invariance from microscopic models.

The meeting also focussed on various very active themes of probability, among them random matrices and combinatorics, coalescing random walks or stochastic flow models and their links with different interacting particle systems. In particular the connection of these domains with new tools and ideas of stochastic analysis became substancially more apparent.

New exciting developments in the core domain of stochastic analysis such as relation with PDE, differential geometry, random media, path behavior of Brownian motions and infinite dimensional analysis were also presented.

This report was written by Gesine Reinert

Abstracts

Dominique Bakry
Gradient bounds and Sobolev-type Inequalities

Let L be the generator of a diffusion process; we define the bilinear operators Γ and Γ_2 as

$$\begin{aligned}\Gamma(f,f) &= \frac{1}{2}Lf^2 - 2fLf;\\ \Gamma_2(f,f) &= \frac{1}{2}L\Gamma(f,f) - \Gamma(f,Lf)\end{aligned}$$

We say that L satisfies a curvature-dimension inequality $CD(\rho,\eta)$ iff, $\forall f$,

$$\Gamma_2(f,f) \geq \rho\Gamma(f,f) + \frac{1}{\eta}(Lf)^2 \qquad (CD(\rho,\eta))$$

We say that a kernel K satisfies a Poincare Inequality with constant α iff $\forall f$,

$$K(f^2) \leq K(f)^2 + \alpha K(\Gamma(f,f)) \qquad (Poinc(\alpha))$$

Then, let $P_t = e^{tL}$ be the heat kernel. L satisfies $CD(0,\infty)$ iff P_γ satisfies $Poinc(2t)$. Moreover, L satisfies $CD(0,\eta)$ iff $\mathcal{P}_t$ satisfies $Poinc(2t^2/\eta)$, where $\mathcal{P}_t = \int_0^\infty P_s\mu_t^{(\eta)}(ds)$, where $\mu_t^{(\eta)}$ is the law of the hitting time of 0 for a reversed Bessel process with generator $\frac{\partial^2}{\partial s^2} - \frac{\eta+1}{s}\frac{\partial}{\partial s}$ on $\mathbf{R}_+$ starting from $t > 0$.

J. van den Berg
Asymptotic density in a modified coalescing random walk model

This talk is about joint work with Harry Kesten. We consider a system of particles each of which performs a continuous time random walk on $\mathbf{Z}^d$. The particles interact only at times when a particle jumps to a site at which there are a number of other particles present. If there are j particles present, then the particle which just jumped is removed from the system with probability p_j. We generalize results which Bramson and Griffeath obtained for the basic model (the case $p_1 = 1$): We show that if p_j is increasing in j and if $d \geq 5$ and we start with one particle at each site of $\mathbf{Z}^d$, then $P\{$ there is at lease one particle at the origin at time $t\} \sim C(d)/t$. The constant $C(d)$ is explicitly identified. We think the result holds for every dimension $d \geq 3$ and briefly discuss some special cases for which we have been able to weaken our assumption $d \geq 5$. Our method is considerably different from that by Bramson and Griffeath, and seems substantially more robust. It is based on a rigorous justification of a rather intuitive mean field approximaton of $dp(t)/dt$. It seems applicable to many models of coalescing and annihilating particles.

Jean Bertoin

Clustering statistics for sticky particles with Brownian initial velocity

Based on "Clustering statistics for sticky particles with Brownian initial velocity". To appear in Journal de Mathématiques Pures et Appliquées.

We establish a connection between two different models of clustering: the deterministic model of sticky particles which describes the evolution of a system of infinitesimal particles governed by the dynamic of completely inelastic shocks (i.e. clustering occurs upon collision with conservation of masses and momenta), and the random model of the so-called additive coalescent in which velocities and distances between clusters are not taken into account. The connection is obtained when at the initial time, the particles are uniformly distributed on a line and their velocities are given by a Brownian motion.

Robert C. Dalang

Extending the martingale measure stochastic integral with application to spatially homogeneous spde's

in order to describe solutions to the stochastic wave equation in spatial dimensions $d \geq 3$, an extension of Walsh's 1986 stochastic integral is required. We provide such an extension and apply it to show existence and uniqueness of solutions to the wave equation driven by spatially homogeneous Gaussian noise that is white in time. For $d \leq 3$, only standard Lipschitz conditions on the non-linearity are needed, byt or $d > 3$, our approach (jointly with C. Mueller) requires that the non-linearity have a smoothing effect in the space variable.

Amir Dembo

Thick points of Brownian motion and most favourite points for random walks

Denote by $T(x, r)$ the occupation measure of a disc of radius r around x by planar Brownian motion run till time 1, and let $T(r)$ be the maximum of $T(x, r)$ over x in the plane. We find the asymptotic of $T(r)$ as r tends to 0 and furthermore determine the Hausdorff dimension of the set of *thick points* x for which $T(x, r)$ are exceptionally large. As a consequence, we prove a conjecture about planar simple random walk due to Erdos and Taylor (1960): The number of visits to the most frequently visited lattice site in the first n steps of the walk, is asymptotic to $(\log n)^2/\pi$. We also show that for $0 < a < 1/\pi$, the number of points visited more than $a(\log n)^2$ times in the first n steps, is approximately $n^{1-a\pi}$.

We shall complement these results with the corresponding statements for thick points in dimensions $d \geq 3$ and for *thin points* x where $T(x, r)$ are exceptionally small.

This talk is based on a joint work with Y. Peres, J. Rosen and O. Zeitouni.

László Erdős

Lifshits tail in a magnetic field: the threshold case

We obtain the Lifshits tail, i.e. the exact low energy asymptotics of the integrated density of states for the two dimensional magnetic Schrödinger operator with a uniform magnetic field and Poissonian impurities. The single site potential is repulsive and has an asymptotic tail behavior. If this tail is heavier than Gaussian, then the potential energy plays a dominant role in the Lifshits tail. If the tail decays faster than a Gaussian, then the kinetic energy determines the asymptotics.

Our new result concerns the threshold case, where the single site potential is exactly Gaussian. Here classical (pontential energy) and nonclassical (kinetic energy) effects both contribute. The Lifshits tail is

$$\lim_{E\to 0+0} \frac{\log N(E)}{|\log E|} = -2\pi\nu\Big(\frac{1}{B} + \frac{\lambda^2}{2}\Big)$$

where $B = const$ is the magnetic field, ν is the intensity of the Poisson impurities $\{x_i\}$, λ^2 is the variance of the single site potential; $U(x) \sim \exp -(x/\lambda)^2$, and $N(E)$ is the integrated density of states of $(-i\nabla - A)^2 - B + \sum_i U(x - x_i)$ per unit volume below energy $E \geq 0$.

Franco Flandoli

Stochastic models in fluid dynamics

The general purpose of this research is to analyze small-scale structures and possible singularities in $3-D$ fluids by means of probabilistic methods and models. We discuss two directions of investigation.

Following the approach to singularities of Scheffer and Caffarelli-Kohn-Nirenberg, we study the set of singularities for a stochastic Navier-Stokes equation, to see whether the noise has an effect (certain numerical simulations give the impression that the noise may present the emergence of singularities). Up to now it has been possible to prove only that $\mathcal{H}^1(S) = 0$, with probability one, as in C-K-N work (S is the set of singularities, $\mathcal{H}^1$ is the 1-dimensional Hausdorff measure). But for solutions which are stationary in time we prove that for every $t \geq 0$, the set of singularities at time t is empty with probability one. This result holds true also for the deterministic equation.

The second problem is an attempt to describe thin filament-like regions of high vorticity by means of trajectories of stochastic processes, following the ideas of A. Chorin who used trajectories of SAW on a lattice. The self energy of a Brownian trajectory $x + W_t$, $t \in [0,T]$, and a translate of it, say, $y + W_t$, with $y \neq x$, is well defined. Formally it is given by the double Stratonovish integral:

$$H_{xy} = 2\frac{\Gamma^2}{8\pi}\int_0^T \left(\int_0^t \frac{1}{|(x+W_t) - (y+W_s)|} \circ dW_s\right) \circ dW_t.$$

We can give a meaning to this integral, showing that it is related to the local time of self intersections of W_t. Using H_{xy}, it is possible to define the energy of a vortex field concentrated over a "cylinder" of Brownian trajectories.

Tadahisa Funaki

Hydrodynamic limit, equilibrium fluctuation for $\nabla\phi$ interface model on a wall and large deviation

We shall report three kinds of results on the Ginzburg-Landau $\nabla\phi$ interface model. Hydrodynamic limit and equilibrium fluctuation will be discussed for the model on a wall. The dynamics on the wall is defined by SDEs of Skorohod type with reflection so that the height variables (i.e. solutions of SDEs) satisfy $\phi_t(x) \geq 0, x \in \Gamma$. Assuming $\Gamma = d$-dimensional lattice torus $(\mathbb{Z}/N\mathbb{Z})^d$, nonlinear PDE with reflection is derived as the limit of macroscopically scaled height variables (joint work with Nishikawa and Otobe). As the limit of their fluctuation fields, in 1-dimension imposing 0-boundary conditions at both edges, stochastic heat equation with reflection (Nualart-Pardoux's SPDE) is obtained in equilibrium (joint work with Olla). Finally, large deviation will be established for the interface model without wall. Dynamic rate functional is specified and the relation with static result obtained by Deuschel-Giacomin-Ioffe will be discussed (joint work with Nishikawa).

F. Götze

Central Limit Theorem and Lattice Point Problems in Euclidean Spaces

The rate of convergence in the CLT in the k-dimensional space on the set of ellipsoids with fixed ratios of axelengths is shown to be of order $O(n^{-1})$ for n i.i.d. summands with finite absolute moments. The proof reduces the problems to bounds for integrals over thetafunction which yield as well a bound of order $O(R^{k-2})$ for the error in the problem of counting the number of lattice points in an ellipsoid of radius R, comparing it to its volume. Both results hold for dimension $k \geq 5$ and provide the optimal rates of approximation in these dimensions. Examples show that in dimensions $k \leq 4$ the rates of convergence are of order $O(n^{-1} \log n)$ or worse.

Alexander Grigor'yan

Heat kernel on manifolds with ends

Let M be a geodesically complete Riemannian manifold, and non-compact. Denote by $p_t(x, y)$ the heat kernel on M. A general problem is to investigate the behaviour of $p_t(x, u)$ in connection with the geometry of M.

Let M be a connected sum of a finite number of other manifolds $M_1, M_2, \dots, M_k$. Given a sharp enought information about the heat kernels $p_t^{(i)}(x, y)$ on M_i, how to estimate $p_t(x, y)$?

The answer is given assuming that $p_t^{(i)}$ admit the Li-Yau type estimate

$$p_t^{(i)} \asymp \frac{1}{V_i(x,\sqrt{t})} \exp\left(-\frac{d_i^2(x,y)}{ct}\right),$$

where $V_i(x,r)$ the volume of a geodesic ball on M_i of radius r, d_i the geodesic distance on M_i. Assume also that V_i satisfies the doubling condition $V_i(x,2r) \leq CV_i(x,r)$. Then we obtain sharp information about $p_t(x,y)$. Here I give only one example. Fix a point $O_i \in M_i$ and set $V_i(r) = V_i(O_i, r)$.

Theorem 1 *Assume that all M_i's satisfy the Li-Yau estimate and $V_i(r) \asymp r^{\alpha_i}, \alpha_i > 2$. Then, for all $x \in E_i, y \in E_i, i \neq j$, such that $|x| > 1, |y| > 1, t > 1$, we have*

$$p_t(x,y) \asymp \left(\frac{1}{t^{\alpha_j/2}|x|^{\alpha_i-2}} + \frac{1}{t^{\alpha_i/2}|y|^{\alpha_j-2}} + \frac{1}{t^{\alpha}|x|^{\alpha_i-2}|y|^{\alpha_j-2}}\right) \exp\left(-\frac{d^2(x,y)}{ct}\right),$$

where $\alpha = \min_i \alpha_i$. Here, $E_i = M_i \setminus K, |x| = dist(x,K)$.

Alice Guionnet
Large Random Matrices

In the talk, we review some results on large random matrices. We begin by presenting a few domains of probability where large random matrices appear, precise the natural questions one asks in such domains and some known answers; the domains we investigate are random environment models (spin glasses), communication theory, hydrodynamics, quantum physics and free probability. This talk ends on a short state of the art.

Frank den Hollander
On the volume of the intersection of two Wiener sausages

For $a > 0$, let W_1^a and W_2^a be the a-neighborhoods of two independent infinite-time standard Brownian motions in $\mathbb{R}^d$ starting at 0. It is well known that $P(|W_1^a \cap W_2^a| < \infty) = 1$ for all $a > 0$ if and only if $d \geq 5$. We show that

$$\lim_{t\to\infty} t^{-\frac{d-2}{d}} \log P(|W_1^a \cap W_2^a| \geq t) = -I_d^{\kappa_a} \in (-\infty, 0)$$

and derive a variational representation for the rate constant, which depends on d and on κ_a, the Newtonian capacity of the ball with radius a. We show that the optimal strategy behind this large deviation behavior is time-inhomogeneous: W_1^a and W_2^a "form a Swiss cheese" during the time window $[0, c^*t]$ and then wander off to infinity in different directions. Here c^* is a critical time horizon that comes out of the variational representation for $I_d^{\kappa_a}$. It turns out that at time c^*t the two Wiener sausages cover part of the space, leaving random holes whose sizes are of order 1 and whose density varies on scale $t^{1/d}$ according to a certain optimal profile.

Joint work with M. van den Berg and E. Bolthausen.

Kurt Johansson

Random growth and random matrices

Recently connections have been established between a certain directed growth model in 1+1 dimension and discrete orthogonal polynomial ensembles, which are analogous to the classical orthogonal polynomial ensembles in random matrix theory like GUE. The model is equivalent to the totally asymmetric simple exclusion process in one dimension with a certain initial configuration. This generalizes previous work by Baik, Deift and Johansson on longest increasing subsequences in random permutations.

Achim Klenke

Interacting Fisher–Wright Diffusions in a Catalytic Medium

(joint work with Andreas Greven and Anton Wakolbinger)

We study the longtime behaviour of interacting systems in a randomly fluctuating (space–time) medium and focus on models from population genetics. There are two prototypes of spatial models in population genetics: spatial branching processes and interacting Fisher–Wright diffusions. Quite a bit is known on spatial branching processes where the local branching rate is proportional to a random environment (catalytic medium).

Here we introduce a model of interacting Fisher–Wright diffusions where the local resampling rate (or genetic drift) is proportional to a catalytic medium. For a particular choice of the medium, we investigate the longtime behaviour in the case of nearest neighbour migration on the d–dimensional lattice.

While in classical homogeneous systems the longtime behaviour exhibits a dichotomy along the transience/recurrence properties of the migration, now a more complicated behaviour arises. It turns out that resampling models in catalytic media show phenomena that are new even compared with branching in catalytic medium.

Claudio Landim

Asymptotic behavior of tagged particles nad equilibrium fluctuations of the asymmetric simple exclusion

We consider the asymmetric simple exclusion process starting from the equilibrium product measure ν_α. We prove that the density field under diffusive scaling converges in dimension $d \geq 3$ to a generalized Ornstein-Uhlenbeck process. We relate the equilibrium fluctuations of the density field to the central limit theorem of a second class particle. This indicates that in dimension the correct scaling is $N^{3/2}$ and suggests that the limit field should be invariant by the scaling $Y(t,x) = \sqrt{a}Y(ta^{3/2}, ax)$. While it is expected that $E_{1/2}[X_t^2] = t^{4/3}$, we prove that $t^{5/4} \leq E_{1/2}[X_t^2] \leq t^{3/2}$.

J. F. Le Gall

Some new results on the voter model and coalescing random walks

(joint with M. Bramson and T. Cox)

We discuss some recent results concerning the asymptotic behaviour of the classical voter model or systems of coalescing random walks. These asymptotics are described in terms of the measure-valued process known as super-Brownian motion. As a first example, suppose that one starts the voter model in $\mathbf{Z}^d (d \geq 3)$ with opinion 0 at every site of the lattice, except for the origin which has opinion 1. Let U_t be the (random) set of sites which have opinion 1 at time t. Then the scaled sets $\frac{1}{\sqrt{t}}U_t$, conditioned by $\{U_t \neq \emptyset\}$, converge in distribution towards a random compact set distributed according to the canonical measure of super Brownian motion. By duality one gets a similar result for coalescing random walks in $\mathbf{Z}^d$, considering now the set of starting points of the walks which are at the origin at time t. As an application we derive the asymptotic behavior of the probability that one of the walks started in $\sqrt{t}\Omega$ (Ω open set in $\mathbf{R}^d$) is at the origin at time t.

Yves Le Jan

Integration of Brownian vector fields

(with O. Raimond)

We present an extended notion of strong solutions to SDE's driven by Wiener processes. They are not always given by flow of maps but by flows of Markovian kernels, which means splitting can occur. Coalescent flows also appear as solutions of these SDE's. Conditions are given under which coalescence and splitting occur or not. The case of isotripic Sobolev flows is studied on spheres and euclidean space. An interesting phase diagram is given in terms of the two parameters (differentiability index and compressibility) which determine the Sobolev norm on vector fields. It shows splitting is related to hyperunstability and coalescence ot hyperstability. Scaling invariant Brownian vortices (isotropic) can also be constructed. This work was inspired by works of Gawedzki et al on turbulent advection of a possive scalar.

Hirofumi Osada
Melting convergence and diffusion on bubbles

We introduce a method to construct diffusions on "singular" sets such as $\mathbf{R}^d$ ($d \geq 2$), Sierpinski carpets and random fractals called bubbles (although $\mathbf{R}^d$ is not singular). By using this we construct non-degenerate diffusions on these spaces and their rather exotic properties such as infinitesimal spectral dimensions $\neq d$. In case of $\mathbf{R}^d$ we prove the convergence of a family of these exotic diffusions to the standard Brownian motion, which is the melting convergence in the title. We hope the same thing can be proved for Sierpinski gaskets and bubbles.

Gesine Reinert
Stein's method for epidemic processes

Stein's method has been proven to be a powerful tool for deriving bounds in distributional approximations. Here we use it to give an explicit bound on the distance of a general, not necessarily Markovian epidemic model to its deterministic approximation (mean-field approximation). For a fixed population size, the average path behaviour is described using the empirical measure. In particular we thus obtain asymptotic expressions for classical epidemiological quantities.

The bound on the distance is inversely proportional to the square root of the population size (as expected from Gaussion approximations for simpler models). Moreover it grows exponentially in time, a phenomenon to be expected from the distribution of the duration of the epidemic for simpler models, but yet widely ignored.

Michael Scheutzow
On the dispersion of stochastic flows

(joint work with David Steinsaltz and Mike Cranston)

It has been conjectured by R. Carmona (Princeton) that under "reasonable" conditions the diameter of the image of a ball (say) under a stochastic flow on $\mathbf{R}^d, d \geq 2$ grows linearly almost surely. We show that the conjecture holds true for stochastic flows without drift under boundedness, Lipschitz and non-degeneracy assumptions on the quadratic variation of the martingale field driving the flow. This class of flows contains essentially all isotropic Brownian flows. The upper bound (i.e. the fact that the image grows at most linearly) even holds without the non-degeneracy condition and with an additionaly bounded and Lipschitz drift vector field. The question is motivated by applications in oceanography.

S. Shlosman
Variational problems of stat. mechanics and of combinatorics

The Wulff construction gives a solution to the problem of finding a shape which encloses a given volume and which has the least surface energy. It turns out that the resulting Wulff shape is also the asymptotic shape of a region occupied by one phase of the Ising model subject to the canonical constraint.

We show that a similar construction exists for finding the asymptotic shape of large combinatorical objects, like Young diagrams and planar partitions.

Alexander Soshnikov
Universality at the Edge of the Spectrum in Wigner Random Matrices

We prove universality at the edge for rescaled correlation functions of Wigner random matrices in the limit $n \to \infty$. As a corollary we show that, after proper rescaling, the 1st, 2nd, 3rd, etc. eigenvalues of Wigner random hermitian (resp. real symmetric) matrix weakly converge to the distributions established by Tracy and Widom in the G.U.E (G.O.E.) cases.

Wilhelm Stannat
Spectral properties of (non-symmetric) Fleming-Viot operators

We present three results on spectral properties of Fleming-Viot (FV) operators with general mutation (and no selection or recombination). The corresponding processes can be obtained as the limit of sequences of Markov chains of Wright-Fisher type and can therefore be interpreted as diffusion approximations for the random evolution of a population with a given mutation. FV-processes are (apart from the Dawson-Watanabe processes) the best studied class of measure-valued diffusions. Let the space of types be a compact metric space and the mutation operator be the generator of a Feller semigroup with a unique invariant measure. Under these assumptions the corresponding FV-operator itself has a unique invariant measure. Our first result states that if the semigroups generated by the mutation operator converge to equilibrium with exponential rate then the semigroup generated by the corresponding FV-operator converges to its unique invariant measure with the same exponential rate. Our second result states that FV-operators determine a logarithmic Sobolev inequality if they are symmetric and the space of types is finite. This implies in particular that the corresponding semigroups are hypercontractive. Our third result states that semigroups corresponding to FV-operators with bounded mutation are not hypercontractive if the space of types is infinite.

Karl-Theodor Sturm
Dirichlet forms and harmonic maps

In this talk, two problems and partial solutions related to generalized harmonic maps between singular spaces were presented.

The first problem is how to construct a reversible diffusion process X_t on a given metric space (M, d). The solution consists in constructing a regular local Dirichlet form as a Γ-limit of certain non-local Dirichlet forms defined in terms of the metric d and the reversible measure m, see [1].

The second problem is how to define and approximate the energy of a map f with values in a metric space N. This leads to the question whether

$$\frac{1}{2t}\mathbb{E}_m\left[d^2(f(X_0), f(X_t))\right]$$

as a function of t is always decreasing in t (or whether at least it converges for $t \to 0$). Affirmative answers can be given either if X_t is BM on $M = \mathbb{R}^m$ (with arbitrary f, N, d) or if the space (N, d) has nonnegative curvature (with arbitrary M, X_t, f), see [2].

References.

[1] K.T.Sturm: *Diffusion processes and heat kernels on metric spaces.* Ann. Prob. **26** (1998), 1-55

[2] K.T.Sturm: *Monotone approximation of energy functionals for mappings into metric spaces I.* J. reine angew. math. **486** (1997), 129-151

Boris Tsirelson
Toward stochastic analysis beyond the white noise

Some interrelated topics are outlined:

(*probability*) Stochastic flows: smooth and singular
(*computer science*) Boolean functions: stable and sensitive
(*analysis*) Continuous tensor products: Fock and non-Fock
} parent topics

(*interdisciplinary*) Noises: classical and non-classical } child topic

Stochastic flows are a natural source of interesting examples (models) for the other topics. A recent progress, made mostly by Jon Warren, could be of interest for quantum field theory. For an extended abstract, visit my site:
`www.math.tau.ac.il/~tsirel`

WENDELIN WERNER

The value of Brownian intersection exponents

We discuss joint work with Greg Lawler and Oded Schramm. We give the ideas of the proof of the following results (that had been conjectured by Theoretical physicists): If B and B' denote two planar brownian motions started from different points in the plane then the probability that the two traces $B[0,t]$ and $B'[0,t]$ are disjoint up to time t, decays like $t^{-5/8}$ when $t \to \infty$. Other related results, and the link with conjectures concerning critical planar percolation are also discussed.

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