Mathematisches Forschungsinstitut Oberwolfach

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Stochastic Analysis

October 27th – November 2nd, 2002

The workshop was organised by *Gérard Ben Arous (Courant)*, *Jean-Dominique Deuschel (Berlin)* and *Ofer Zeitouni (Minnesota)*. Twenty-five lectures were given during five morning and four afternoon sessions, an additional evening lecture was presented by Wendelin Werner. The lectures were well-attended, and time between lectures was used for a large number of informal small-group discussions and collaborative work. The 37 participants came from Germany (13), France (10), USA (4), Switzerland (3), UK (3), Japan (2), Israel (1), and Netherlands (1).

The aim of the workshop was to bring together researchers in stochastic analysis, representing many different aspects of the field. In the talks the newest developments were presented and comprehensively reviewed. Topics covered include Brownian motion and diffusion processes, flows, coalescents, coagulation and aggregation, random matrices, Schramm-Löwner evolution, stochastic processes in random environment, spatial branching processes, spatial processes with interaction, and large deviation techniques.

All participants benefited from the excellent working conditions and inspiring atmosphere at Oberwolfach, which made the meeting a great success. It is a pleasure to thank everyone at the MFO for making this possible.

The abstracts below are listed in chronological order.

Abstracts

Mutually catalytic and symbiotic branching

Klaus Fleischmann

The unique existence of a two-dimensional continuum version of the mutually catalytic branching model of Dawson/Perkins/Mytnik (1998) is reported (joint work with *Dawson/Etheridge/Mytnik/Perkins/Xiong*). Open interface problems are surveyed. One of these problems, the compact interface property, is attacked in a one-dimensional continuum setting for a more general model we call symbiotic branching (work in progress with *Alison Etheridge*).

The speed of biased random walk on percolation clusters

Nina Gantert

(joint work with Noam Berger and Yuval Peres, Berkeley.)

We consider biased random walk on supercritical percolation clusters in $\mathbb{Z}^d$. We show that the random walk is transient and that there are two speed regimes: If the bias is large enough, the random walk has speed zero, while if the bias is small enough, the speed of the random walk is positive.

Spectral asymptotics for random matrices

Friedrich Götze

The rate of convergence of the empirical distribution of the eigenvalues of a hermitian matrix with independent random entries to Wigner's half circle law is investigated as well as the convergence of the empirical distribution of the eigenvalues of the covariance matrices of n random p-dimensional random vectors to the Marchenko-Pastur law with p of the order of n. The bounds are explicit of order $O(n^{-1/2})$ and sharp on certain classes of sparse matrices.

Related open problems concerning longest weakly increasing subsequences of random words with limits based on such GUE-ensembles are discussed and first results of limit distributions for random words generated by a Markov chain are presented.

Flows, coalescence and noise

Yves Le Jan

(joint work with Olivier Raimond, Paris)

We are interested in stationary "fluid" random evolutions with independent increments. Under some mild assumptions, we show they are solutions of a stochastic differential equation (SDE). There are situations where these evolutions are not described by flows of diffeomorphisms, but by coalescing flows or by flows of probability kernels.

In an intermediate phase, for which there exists a coalescing flow and a flow of kernels solution of the SDE, a classification is given : All solutions of the SDE can be obtained by filtering a coalescing motion with respect to a sub-noise containing the Gaussian part of its noise. Thus, the coalescing motion cannot be described by a white noise.

Dirichlet processes associated to diffusions

Pierre Mathieu

Let X be a symmetric diffusion process in $\mathbb{R}^d$. We derive sufficient conditions on a function, f, for the stochastic process $f(X(t))$ to be a Dirichlet process. We consider both the elliptic case (joint work with *K. Dupoiron* and *J. San Martin*, Arxiv math.PR/0210118), and the general, non-elliptic, case (See P. Mathieu, Stochastics and stochastic reports, 2001). In this later situation, our main tool are weighted norm martingale inequalities (P. Mathieu, Annales de l'IHP, 1993).

Equilibrium fluctuations

Stefano Olla

We study the equilibrium fluctuations for the density field for conservative systems of infinitely many particles in continuous space. Positions and velocities of the particles evolve according to the (stochastically perturbed) Newton equations

$$\begin{aligned} d\mathbf{x}_j(t) &= \mathbf{v}_j(t)dt \\ d\mathbf{v}_j(t) &= -\sum_{(i\neq j)} \nabla V(\mathbf{x}_j(t)-\mathbf{x}_i(t))dt + dJ_j(\mathbf{x},\mathbf{v}) \end{aligned} \tag{1}$$

where $dJ_j(\mathbf{x},\mathbf{v})$ is a stochastic noise with eventually some conservation laws.

Stochastic flows and exchangeable coalescents

Jean-François Le Gall

(joint work with Jean Bertoin, Paris VI)

Exchangeable coalescents are Markov processes taking values in the space of all partitions of $\mathbb{N}$, whose semigroup satisfies an exchangeability property. These processes have appeared in the recent work of Pitman, Schweinsberg, Möhle and Sagitov, which was motivated in part by the asymptotics of the genealogy of populations with a fixed size. Special important cases are the Kingman coalescent and the Bolthausen-Sznitman coalescent. We show that exchangeable coalescents are in one-to-one correspondence with flows of bridges, where a bridge is defined as a right-continuous nondecreasing process $(B(r), r \in [0,1])$ with exchangeable increments and such that $B(0) = 0$ and $B(1) = 1$. We also provide a Poissonian construction of flows of bridges analogous to the classical Lévy-Ito construction of Lévy processes.

Coagulation of Brownian particles

James Norris

Consider a system of N particles in $\mathbb{R}^3$, with initial positions $x_1, \dots, x_N$ and initial masses $y_1, \dots, y_N$. The particles perform independent Brownian motions with diffusivities $a(y_i)$ until $|x_i - x_j| \leq N^{-1}(r(y_i) + r(y_j))$ for some pair i, j. At this time, the pair of particles i, j is replaced by a single particle located at their centre of mass and having mass $y_i + y_j$. The evolution then begins afresh. From physical arguments, under certain conditions, it is reasonable to take $a(y) = y^{-1/3}$ and $r(y) = y^{1/3}$. In this situation, assuming spatial homogeneity, Smoluchowski wrote down a system of deterministic equations for the densities of particles having mass $1, 2, \ldots$ which expresses that particles of mass y and y' coagulate at rate

$$K(y, y') = 2\pi(a(y) + a(y'))(r(y) + r(y')).$$

We formulated a generalised version of this system of equations and stated results of existence, uniqueness and regularity. We allow for a continuum of masses and for spatial inhomogeneities. A procedure was then outlined to show convergence of the empirical measure of the particle system to the solution of the differential equations.

Self-attracting Poisson clouds in an expanding universe

Jean Bertoin

We consider the following elementary model for clustering by ballistic aggregation in an expanding universe. At the initial time, there is a doubly infinite sequence of particles lying in a one-dimensional universe that is expanding at constant rate. We suppose that each particle p attracts points at a certain rate $a(p)/2$ depending only on p, and when two particles, say p and q, collide by the effect of attraction, they merge as a single particle $p * q$. The main purpose of this work is to point at the following remarkable property of Poisson clouds in these dynamics. Under certain technical conditions, if at the initial time the system is distributed according to a spatially stationary Poisson cloud with intensity μ_0, then at any time $t > 0$, the system will again have a Poissonian distribution, now with intensity μ_t, where the family $(\mu_t, t \geq 0)$ solves a generalisation of Smoluchowski's coagulation equation.

Metastability in diffusion processes: Precise asymptotics

Anton Bovier
(joint work with M. Eckhoff, V. Gayrard and M. Klein)

We develop a potential theoretic approach to the problem of metastability for reversible diffusion processes with generators of the form $-\epsilon\Delta + \nabla F(\cdot)\nabla$ on $\mathbb{R}^d$ or subsets of $\mathbb{R}^d$, where F is a smooth function with finitely many local minima. We show that in general the exponentially small part of the spectrum is given, up to multiplicative errors tending to one, by the eigenvalues of the classical capacity matrix of the array of capacitors made of balls of radius ϵ centred at the positions of the local minima of F. In particular, in non-degenerate situations, these eigenvalues can be identified with the same precision with the inverse mean metastable exit times from each minimum. Moreover, we prove that these mean times are given, again up to multiplicative errors that tend to one, by the classical *Eyring formula*. These estimates through sharp upper and lower bounds on capacities making use of their variational representation and monotonicity properties of Dirichlet forms. The methods developed here are extensions of our earlier work on discrete Markov chains to continuous diffusion processes.

Upper tails and large deviations for Brownian intersection local times

Wolfgang König

(joint work with Peter Mörters, Bath)

We consider several Brownian motions in $\mathbb{R}^d$ with $d \geq 2$ until the exit time from a bounded domain or until time infinity. The main object of interest is the intersection of their paths. On this set there is a natural (random) measure, the intersection local time, ℓ. We are interested in the behaviour of ℓ in the limit of diverging intersection mass in a given compact subset U of B.

More precisely, we derive the logarithmic asymptotics of the probability of the event $\{\ell(U) > a\}$ as $a \to \infty$, in terms of a variational problem and a second time in terms of non-linear eigenvalues of the Green's operator resp. the Laplace operator. Furthermore, we describe the limiting shape of the intersection local time, i.e., the measure $\ell/\ell(U)$, conditional on $\{\ell(U) > a\}$, in terms of a large-deviation principle. We illustrate this principle in terms of the famous Donsker-Varadhan principle and discuss all the results and conjectures.

Thick and thin points for Brownian intersection local times

Peter Mörters

Let S be the intersection of two independent Brownian paths in $\mathbb{R}^3$ endowed with the natural measure, the intersection local time ℓ. In the first part of the talk, based on joint work with *Wolfgang König (Berlin)*, we study thick points for ℓ, we show that, almost surely,

$$\dim\big\{x \in S \,:\, \limsup_{r \downarrow 0} \frac{\ell(B(x,r))}{r \log\log(1/r)^2} = a\big\} = 1 - \theta\sqrt{a},$$

where θ is a finite constant characterised by a natural variational problem. In the second half of the talk, based on a joint project with *Achim Klenke (Köln)*, we discuss thin points and sketch a prof that, almost surely, for all $a \geq 1$,

$$\dim\big\{x \in S \,:\, \limsup_{r \downarrow 0} \frac{\log \ell(B(x,r))}{\log r} = a\big\} = \frac{\xi}{a} + 1 - \xi,$$

where $\xi = \xi_3(2,2)$ is the intersection exponent for two packets of two Brownian motions in dimension three.

Branching Brownian motion and Poissonian traps

Frank den Hollander

(joint work with Janos Engländer)

In this talk we consider a branching Brownian motion on $\mathbb{R}^d$ with branching rate β in a Poissonian field of spherical traps whose locally finite intensity measure ν is such that $d\nu/dx \sim \ell/|x|^{d-1}$ as $|x| \to \infty$. The process starts with one particle at the origin. The annealed probability that none of the particles hits a trap ("hard killing") until time t is shown to decay like $\exp[-I(\ell,\beta,d)t + o(t)]$ as $t \to \infty$, where the rate constant $I(\ell,\beta,d)$ is computed in terms of a variational problem. It turns out that this rate constant exhibits a crossover at a critical value $\ell_c = \ell_c(\beta,d)$. Various properties of the process conditional on survival ("optimal survival strategy") are derived. In contrast, the annealed probability that at least one of the particles does not hit a trap ("soft killing") until time t is shown to decay to a strictly positive limit.

Degenerate Poisson equation and applications

ETIENNE PARDOUX
(joint work with A. Yu. Veretennikov, Leeds)

Let $L = \frac{1}{2}\sum_{i,j} a_{ij}\frac{\partial^2}{\partial x_i \partial x_j} \sum_i b_i(x)\frac{\partial}{\partial x_i}$ be the generator of a diffusion process $\{X_t\}$ with values in $\mathbb{R}^d$. We assume that the coefficients are locally Lipschitz, a is bounded and possibly degenerate, $\langle b(x), x\rangle \to -\infty$ as $|x| \to \infty$ (this gives positive recurrence), and a "local Doeblin condition" (see Veretennikov, Theory of Prob. and Appli. 2000) holds (this gives irreducibility). Under these assumptions, the process $\{X_t\}$ has a unique invariant probability measure μ which integrates all polynomials.

Let now $f \in C(\mathbb{R}^d)$ satisfy $|f(x)| \le (1+|x|)^\beta$ and $\int f(x)\mu(dx) = 0$. We show that

$$u(x) := \int_0^\infty E_x f(X_t)\,dt$$

is a continuous function which satisfies the Poisson equation $Lu + f = 0$ in an "integral sense" (as well as in the viscosity sense of Crandall–Lions), and it is the unique such solution which satisfies $|u(x)| \le C(1+|x|)^{\beta+2}$ and $\int u(x)\mu(dx) = 0$.

We then discuss the application of this result to diffusion approximation, and to periodic homogenisation.

Averaging versus Chaos in Turbulence?

HOUMAN OWHADI

The turbulence phenomenon has been addressed through two main theoretical axes. Along the first one, the flow is considered as a random vector field and averaging (space, time, ensemble) is employed to obtain statistical order. With the second one the flow is assumed to be stationary and deterministic, then its evolution obtained by renormalizing Navier Stokes equations from its transport properties along the framework of dynamical systems and chaos. In this paper we start from the second point of view by examining deterministic stationary incompressible flows which can be decomposed over an infinite number of spatial scales without separation between them. It appears that a low order dynamical system related to local Reynolds numbers can be extracted from these flows and it controls their transport properties. Its analysis shows that these flows are strongly self-averaging and super-diffusive: the delay $\tau(r)$ for any finite number of passive tracers initially close to separate till a distance r is almost surely anomalously fast ($\tau(r) \sim r^{2-\nu}$, with $\nu > 0$). This strong self-averaging property is such that the dissipative power of the flow compensates its convective power at every scale. However as the circulation increase in the eddies the transport behaviour of the flow may (discontinuously) bifurcate and become ruled by deterministic chaos: the self-averaging property collapses and advection dominates dissipation. When the flow is anisotropic a new formula describing turbulent viscosity is identified.

Reflected Brownian motion: Skorohod equation and Lyapunov exponent

Krzysztof Burdzy

If $D \subset \mathbb{R}^2$ is a Lipschitz domain with the Lipschitz constant less than 1 then the Skorohod equation defining the reflected Brownian motion in D has a unique strong solution. (Joint work with *R. Bass* and *Z. Chen*.)

Let X_t and Y_t be reflected Brownian motions in $D \subset \mathbb{R}^2$ driven by the same Brownian motion. Then $\text{dist}(X_t, Y_t) \to 0$ as $t \to 0$, a.s., if D satisfies one of the following assumptions:

(i) ∂D is a finite union of polygons, or
(ii) ∂D is the union of 2 graphs of Lipschitz functions with the Lipschitz constant less than 1, or
(iii) D is a smooth domain with at most one hole.

(Joint work with *Z. Chen* and *P. Jones*.)

Large time asymptotics of barycentres of Brownian motions on Hyperbolic spaces

Xue-Mei Li
(joint work with M. Arnaudon)

We consider the large time behaviour of a mass driven by a flow. We also look in detail the asymptotic of independent Brownian particles on hyperbolic spaces. It is shown that the barycentre of two such particles with equal weights converges in a certain sense to a Brownian motion of variance two on the limiting geodesics of that connecting the Brownian particles. The barycentre of 3 or more independent Brownian particles converges almost surely to the conformal barycentre of the measure sitting on the corresponding limit points on the boundary as given by Buseman functions.

Regularity and irregularity of $(1+\beta)$-stable super-Brownian motion

Leonid Mytnik
(joint work with Edwin Perkins)

We establish the continuity of the density of $(1+\beta)$-stable super-Brownian motion $(0 < \beta < 1)$ for fixed times in $d = 1$, and local unboundedness of the density in all higher dimensions where it exists. We also prove local unboundedness of the density in time for a fixed spatial parameter in any dimension where the density exists, and local unboundedness of the occupation density (the local time) in the spatial parameter for dimensions $d \geq 2$ where the local time exists.

Microscopic variational approach to some asymmetric interacting systems

Timo Seppäläinen

Certain one-dimensional asymmetric particle systems and models of moving interfaces in multiple dimensions can be constructed so that a variational equation is satisfied at the path level. This variational formulation involves countably infinitely many realizations of the process, coupled through common Poisson clocks. The variational representation is useful for studying scaling limits and fluctuations. We illustrate this with results for models such as exclusion type processes and Hammersley's process.

A rigorous approach towards the understanding of matrix models

Alice Guionnet

We investigate the limit behaviour of the spectral measures of matrices following the Gibbs measure for two matrix models such as the Ising model on random graphs, Potts model on random graphs, matrices coupled in a chain model or induced QCD model. The partition functions of such models are given by matrix integrals of the following form

$$Z_N(P) = \int e^{-N\,\mathrm{tr}\,(P(A_1^N,\cdots,A_d^N))}\, dA_1^N \cdots dA_d^N$$

with some polynomial function P of d-non-commutative variables and the Lebesgue measure dA on some well chosen ensemble of $N \times N$ matrices such as the set of $N \times N$ Hermitian (resp. symmetric, resp. symplectic) matrices. The corresponding Gibbs measures are given by

$$\mu_P^N(dA_1^N \cdots dA_d^N) = \frac{1}{Z_N(P)} e^{-N\,\mathrm{tr}\,(P(A_1^N,\cdots,A_d^N))}\, dA_1^N \cdots dA_d^N.$$

In this talk, we investigate the problem of the first order asymptotics of matrix integrals with AB interaction, including the Ising model described by $P(A,B) = P(A)+Q(B)-AB$. One of the main result we shall give is the following theorem.

1) For a Hermitian (or symmetric) $N \times N$ matrix A, we denote $\mu_A^{(N)} = N^{-1}\sum_{i=1}^N \delta_{\lambda_i(A)}$ the spectral measure of A when $(\lambda_1(A), \cdots, \lambda_N(A))$ denotes the eigenvalues of A. Then, if (A,B) follows μ_{Ising}^N, $(\mu_A^{(N)}, \mu_B^{(N)})$ converges almost surely towards a unique couple (μ_A, μ_B) of probability measures on $\mathbb{R}$.
2) (μ_A, μ_B) are compactly supported with finite non-commutative entropy

$$\Sigma(\mu) = \iint \log|x-y|d\mu(x)d\mu(y).$$

3) There exists a couple $(\rho^{A\to B}, u^{A\to B})$ of measurable functions on $\mathbb{R}\times(0,1)$ such that $\rho_t^{A\to B}(x)dx$ is a probability measure on $\mathbb{R}$ for all $t \in (0,1)$ and $(\mu_A, \mu_B, \rho^{A\to B}, u^{A\to B})$ are characterized uniquely as the minimizer of a strictly convex function under a linear constraint.

In particular, $(\rho^{A\to B}, u^{A\to B})$ is a solution of the Euler equation for isentropic flow with negative pressure $p(\rho) = -\pi^2 3\rho^3$ such that, for all (x,t) in the interior of $\Omega = \{(x,t) \in \mathbb{R}\times[0,1]; \rho_t^{A\to B}(x) \neq 0\}$,

$$\begin{aligned} \partial_t \rho_t^{A\to B} + \partial_x(\rho_t^{A\to B} u_t^{A\to B}) &= 0 \\ \partial_t(\rho_t^{A\to B} u_t^{A\to B}) + \partial_x\left(\frac{1}{2}\rho_t^{A\to B}(u_t^{A\to B})^2 - \frac{\pi^2}{3}(\rho_t^{A\to B})^3\right) &= 0 \end{aligned}$$

with the probability measure $\rho_t^{A\to B}(x)dx$ weakly converging towards $\mu_A(dx)$ (resp. $\mu_B(dx)$) as t goes to zero (resp. one). Moreover, we have in the sense of distributions that

$$P'(x) - x - \frac{\beta}{2}u_0^{A\to B}(x) - \frac{\beta}{2}H\mu_A(x) = 0, \quad \text{and } Q'(x) - x + \frac{\beta}{2}u_1^{A\to B}(x) - \frac{\beta}{2}H\mu_B(x) = 0,$$

where $H\mu$ stands for the Hilbert transform of the probability measure μ.

Laplace method approach on Gibbs measures with the long range interactions

TAIZO CHIYONUBU

In this talk, I report some of the outcomes in my recent effort of investigating the validity of the Laplace method in the asymptotic problems which appear in various fields of mathematics and mathematical physics.

The talk consists of two parts. In the first part I present an asymptotic evaluation of $E[\exp(-\frac{1}{2}\sum_{i,j=1}^{n} V(X_i, X_j))]$ up to the factor $(1 + o(1))$, where $\rho_n = (1/n) \cdot \sum_{i=1}^{n} \delta_{X_i}$ and $X_i,\ i = 1, 2, \ldots$ are the real-valued *i.i.d.* variables with a compactly supported density, in the case $J[\nu] = \int V d\nu d\nu$ has a minimum point.

In the second part, I give a remark on the 1973 result of Gallavotti & Marchioro on the integral

$$I(g, \omega) = \int_{\mathbb{R}^n} \exp\left\{-\frac{g^2}{2}\sum_{i\neq j}^{1,n} \frac{1}{(x_i - x_j)^2} - \frac{\omega^2}{2}\sum_{i=1}^{n} x_i^2\right\} dx_1 \cdots dx_n.$$

SLE, Restriction, and Representations

WENDELIN WERNER

We describe (this is joint work with *Greg Lawler* and *Oded Schramm*) all random sets satisfying the "restriction property". The SLE process with parameter 8/3 turns out to play a prominent role (it is the only random simple curve satisfying the restriction property). Among other things, this gives a heuristic justification to the fact that this SLE could be the scaling limit of self-avoiding walks. We then (this is joint work with *Roland Friedrich*) show how the restriction property is related to highest-weight representations of the Lie Algebra of vector fields on the unit circle. Various identities appearing in conformal field theory turn up in this setting.

Some Examples of Diffusive Random Walks in Random Environment

ALAIN-SOL SZNITMAN

(joint work with E. Bolthausen and O. Zeitouni)

We consider a special class of multi-dimensional random walks in random environment for which we are able to prove in a non-perturbative fashion both a law of large numbers and a quenched central limit theorem. As an application we provide new examples of diffusive random walks in random environment. In particular we can construct examples of diffusive walks which are small perturbations of the simple random walk and evolve in an environment where the static drift does not vanish.

Multiple space-time scale analysis of population models

ANDREAS GREVEN

We consider a number of population models featuring multiple type populations, type interaction and a complex geographical structure. Main examples are Moran models, Fleming-Viot processes, mutually catalytic branching, total-mass dependent branching etc. In order to build up a system with interacting components, where the interaction occurs at different time scales we describe the first step in this program, namely the analysis of the mentioned system in the original and in a fast time scale. It is an important task in the context of population models to incorporate the genealogical structure inherent in these models into this multi-scale analysis which we can do for Moran models. Through the procedure of building block averages and passing to a fast time scale one obtains a limiting dynamics of the blocks, which is determined by a non-linear map. Important models are fixed points or fixed shapes of this map.

Catalytic Branching and the Brownian Snake

ACHIM KLENKE

We construct a catalytic super process X (measure-valued spatial branching process) where the local branching rate is governed by an additive functional A of the motion process. These processes have been investigated before but under restrictive assumptions on A. Here we do not even need continuity of A. The key is to introduce a new time scale in which motion and branching occur at a varying speed but are continuous.

Another aspect is to consider X in the generic time scale of the branching - and not of the motion process. This allows to give an explicit construction of X using the Brownian snake. As a by-product this yields an almost sure approximation by the corresponding branching particle systems.

Stochastic resonance

PETER IMKELLER

We consider a dynamical system describing the motion of a particle in a double well potential with a periodic perturbation of very small frequency, and an additive stochastic perturbation of amplitude ϵ. It is in stochastic resonance if the solution trajectories amplify the small periodic perturbation in a 'best possible way'. Systems of this type first appeared in simple energy balance models designed for a qualitative explanation of global glacial cycles. Large deviations theory provides a lower bound for the proportion of the amplitude and the logarithm of the period above which quasi-deterministic periodic behaviour can be observed. However, to obtain optimality, one has to measure periodicity with a measure of quality of tuning such as spectral power amplification favoured in the physical literature. In a situation where the potential switches discontinuously between two spatially antisymmetric double well states we encounter a surprise. Contrary to physical intuition, the stochastic resonance pattern is not correctly given by the reduced dynamics described by a two state Markov chain with periodic hopping rates between the potential minima which mimic the large (spatial) scale motion of the diffusion. Only if small scale fluctuations inside the potential wells where the diffusion spends most of its time are carefully eliminated, the Markov chain gives the correct picture.

Edited by Peter Mörters

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