MATHEMATISCHES FORSCHUNGSINSTITUT OBERWOLFACH

Tagungsbericht 07/1998

Dirichlet Forms

15.02. bis 21.02.1998

Die Tagung fand unter der Leitung von N. Bouleau (Paris), M. Fukushima (Osaka), N. Jacob (München) und M. Röckner (Bielefeld) statt. Schon im Vorfeld der Tagung wurden neun Kollegen gebeten, einstündige Übersichtsvorträge vorzubereiten. (Diese sind im Bericht gesondert aufgeführt). Teilweise war der weitere Ablauf nach einem Übersichtsvortrag workshop-artig organisiert, die Beiträge waren also (kürzere) Vorträge und Ergänzungen zum Übersichtsvortrag. Natürlich gab es auch weitere, von Übersichtsvorträgen unabhängige Vorträge, aber auch Kurzmitteilungen. Um die Kommunikation von Beginn an zu erleichtern, wurde ein "Conference Reading Room" eingerichtet. Dort konnte jeder Teilnehmer seine für die Tagung relevanten Arbeiten auslegen. Dieser "Conference Reading Room" wurde als eine große Bereicherung betrachtet und intensiv genutzt, um auch unabhängig von Vorträgen Kontakte zu schaffen. Inhaltliche Schwerpunkte lagen bei den Themen

- reflektierte Dirichlet-Formen
- Dirichlet-Formen auf Fraktalen
- Dirichlet-Formen und Sobolev-Räume
- Geometrie und Analysis auf Pfadräumen
- Dirichlet-Formen in der mathematischen Physik
- nichtlokale Dirichlet-Formen und Pseudodifferentialoperatoren
- nichtsymmetrische Dirichlet-Formen und Verallgemeinerungen
- Dirichlet-Formen, innere Geometrie und Wärmeleitungskerne.

Ein weiteres Ziel der Tagungsleitung war es, möglichst viele junge Wissenschaftler zur Tagung einzuladen. Dies war dank der großzügigen Hilfe der Institutsleitung auch möglich. Von den 49 Teilnehmern aus zehn Ländern muß man zehn als prä-oder postdoc Studenten bezeichnen, weitere sechs würde man in Deutschland als "frisch habilitiert" bezeichnen.

A. Übersichtsvorträge

N. BOULEAU

Interpretation of Dirichlet forms in terms of error calculus

By his *Theoria combinationis* (1821) Gauss has to be considered as a founder of error calculus. If $U = F(X, Y, Z)$, and X, Y, Z are erroneous with independent errors of standard deviations $\sigma_1, \sigma_2, \sigma_3$, Gauss—supposing the errors are small—gives the variance of the expected error of U:

$$\sigma_U^2 = \left(\frac{\partial F}{\partial X}\right)^2 \sigma_1^2 + \left(\frac{\partial F}{\partial Y}\right)^2 \sigma_2^2 + \left(\frac{\partial F}{\partial Z}\right)^2 \sigma_3^2. \tag{1}$$

In comparison to formulas given in textbooks in physics for the error ΔU of U which is most often written

$$|\Delta U| = \left|\frac{\partial F}{\partial X}\right| |\Delta X| + \left|\frac{\partial F}{\partial Y}\right| |\Delta Y| + \left|\frac{\partial F}{\partial Z}\right| |\Delta Z| \tag{2}$$

formula (1) has the great advantage to be *coherent*, i.e. if $F = G_1 \circ H_1 = G_2 \circ H_2$, then the error on $G_1 \circ H_1(X, Y, Z)$ is equal to the error on $G_2 \circ H_2(X, Y, Z)$ if they are both computed by (1).
In my lecture I show that local Dirichlet forms theory is a correct mathematical framework to express Gauss' theory of errors. The errors are infinitesimal Gaussian variables. This makes correct the problem of "Gaussianness" of non-linear images of such small Gaussian variables, and gives rise to coherent error calculus. This can be done as well on infinite dimensional spaces as used for stochastic processes.
This insight to Dirichlet forms leads naturally to three conjectures: 1) on representation of the gradient of Lipschitz functions, 2) about regularity of image Dirichlet structures, and 3) about regularity of closable forms on $\mathbb{R}^n$.

D. FEYEL

Sobolev spaces generalizing Dirichlet spaces

Dirichlet spaces arose as natural functional spaces for potential and energy theory. They found their definitive form in the works of Deny, and Deny-Beurling, with the introduction of contractions working in a Hilbert functional space, or equivalently the consideration of symmetric semigroups of submarkovian (pseudo)-kernels on a measurable space. At the opposite Sobolev spaces arose when Leray, Sobolev, Nikodym were lead to the consideration of weak solution of PDEs. After that, they were developed by many authors, in the same spirit,

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for obtaining a kind of weak differential calculus. More recently, Malliavin suggested the introduction of Sobolev spaces on the Wiener space, thanks to a generalized gradient (Sobolev aspect) and used it in the calculus of variations in infinite dimension. This can be done also with the help of the Ornstein-Uhlenbeck semigroup (Dirichlet aspect). This construction easily and usefully extends to an abstract Wiener space. In a more general setting, if $H^{1,2} = W^{1,2}$ is a Dirichlet space, one can define $H^{r,p}$ for $r \in \mathbb{R}$, $p > 1$ by complex inter/extrapolation. If a *carré du champ* exists (Kunita, Roth, Meyer), one can define $W^{r,p}$ as for Riemannian manifolds for r an integer and $p > 1$. The so-called problem ($H = W$), that is to know if $H^{1,p} = W^{1,p}$ for every p (which implies $H^{r,p} = W^{r,p}$ for every integer r) was solved in the affirmative in many cases (Calderon-Zygmund, Meyer, Serrin, Bakry-Emery...). For example this implies the theorem of continuity of divergence. An other tool which naturally arises for Dirichlet and Sobolev spaces is the notion of capacity. It was first defined in the context of Dirichlet spaces, but usefully extends to the framework of Sobolev spaces, especially in infinite dimension (Malliavin, Fukushima, Feyel-La Pradelle...). All the preceding notions extend to the case of Hilbert valued functions and more generally to p-admissible space valued functions. This is involved in studying regularity of solutions of SDE (Malliavin, Nualart, Feyel-La Pradelle...). This is also involved in the problem of density of the image-measure. Under natural conditions, the law of an $\mathbb{R}^n$-valued Sobolev function defined on the Wiener space, is absolutely continuous with respect to the Lebesgue measure (Bouleau-Hirsch). There is a coarea formula "*à la Federer*" expliciting the density (Feyel-La Pradelle). Sobolev spaces on path spaces were also studied (Fang, Bakry, Ledoux) for problems of curvature, hypercontractivity. In an other field of ideas, an other kind of definition has been proposed for Sobolev spaces by Hajlasz. This kind of definition works on an arbitrary bounded metric space endowed with a bounded measure, and extends the usual definitions for classical cases (Riemannian manifolds). The advantage is that it allows very simple proofs of classical inequalities such as Poincaré, Sobolev, John-Nirenberg. All of that, with the ***doubling property*** of Biroli-Mosco, seems to be encouraging for a more general comprehension of hypoellipticity phenomena.

M. FUKUSHIMA

Quasi-homeomorphisms, smoothness of signed measures and semimartingale characterizations

We are motivated how to understand the normally reflecting Brownian motion on $\bar{D}$ for an open set $D \subset \mathbb{R}^d$. There have been two different levels of approaches to it: q.e. level approach (admitting exceptional sets of zero capacity in every statement) and the everywhere level one (requiring every statement to hold for any starting point $X \in \bar{D}$). The latter one has been taken by Bass-Hsu (for a Lipschitz domain), Beblassie-Toby (for a standard cusp) and by Fukushima-Tomisaki (for a Lipschitz domain with Hölder cusps). In this talk, I formulate the first approach in greatest possible generality. For an open set $D \subset \mathbb{R}^d$, let $\hat{H}^1(D)$ be the closure of $C_0^1(\mathbb{R}^d)\mid_D$ in the space $\hat{H}^1(D)$. $(\frac{1}{2}\mathbb{D}, \hat{H}^1(D))$ is a strong local regular Dirichlet form on $\bar{D}$ and the associated diffusion (X_t, P_x) on $\bar{D}$ is called a modified reflecting Brownian motion ($MRBM$). We prove that the $MRBM$ is a semi martingale (+ some integrability condition) if and only if D is a Caccioppoli set, namely, the partial derivatives of I_D in the distribution sense are signed measures. The key step in the proof is to show that the surface measure arizing in the Gauss formula for a Caccioppoli set is automatically smooth, namely, it charges no set of zero capacity. This sort of assertion was proved by Chen-Fitzsimmons-Williams in a different setting by using a strong Feller property of the associated resolvent. Actually their requirement of strong Feller property can be weakened to Feller property. On the other hand, according to my old result in 1971, any regular Dirichlet space (even any quasi regular Dirichlet space) admits another regular Dirichlet space associated with a Ray resolvent such that the underling spaces are related to each other by a capacity preserving quasi homeomorphism. This means that we lose no generality by assuming that a regular Dirichlet space is of Ray resolvent (and hence Feller resolvent) as far as quasi motions are concerned. This is the way to prove our main assertion.

W. HOH

On pseudo differential operators generating Markov processes

We are interested in generators of Markov processes in $\mathbb{R}^n$. A natural property that characterizes those generators as far as a pointwise theory is concerned, is the positive maximum principle. This principle states that for a linear operator A, and a function φ in its domain, $A\varphi(x_0) \leq 0$, at any positive maximum x_0 of φ. It is satisfied by generators of Markov processes and for generators of Feller processes it characterizes exactly the sub-Markovian property of the semigroup. Now, by a result of Ph. Courrège an operator satisfies the positive maximum principle if and only if it is a Lévy type operator or, equivalently, a pseudo differential operator

$$-p(x, D)u(x) = -\int_{\mathbb{R}^n} e^{ix\xi} p(x,\xi)\hat{u}(\xi)d\xi, \quad u \in C_0^\infty(\mathbb{R}^n),$$

where the symbol $p : \mathbb{R}^n \times \mathbb{R}^n \to \mathbb{C}$ has the basic property that for fixed $x \in \mathbb{R}^n$ the map $\xi \to p(x,\xi)$ is a continuous and negative definite function. We call such symbols negative definite. These symbols do not fit into any known symbol classes, since they are in general even not differentiable w.r.t. the co-variable ξ. Also in the differentiable case they do not satisfy estimates of classical symbol classes. Hence new techniques had to be developed. They rely in an essential way on properties of negative definite functions, for instance on generalized triangle and Peetre inequalities which are valid in this case. In the talk three different approaches how to construct a process associated with $-p(x, D)$ are discussed. First a perturbation approach by N. Jacob generalizing Lévy operators to the

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variable coefficient case. Next the process is constructed by solving the martingale problem. Finally a symbolic calculus was introduced, which is appropriate for negative definite symbols, and used to find associated semigroups. In addition, by several examples it is explained how properties of and estimates on the symbol have immediate probabilistic implications for the process.

YU. KONDRATIEV

Fluctuations in continuous systems: classical and quantum aspects

We discuss a concept of fluctuation spaces in statistical physics of continuous systems. The microdynamics of Glauber type for interacting classical gas can be lifted to macrodynamics of fluctuations. This lifting (as well as a construction of microdynamics) uses the analytic apparat developed in a series of papers by S. Albeverio/Yu.Kondratiev/M. Röckner. An analogous result is also true in the case of interacting quantum gases. In the later case we use an Euclidean loop space representations for the corresponding temperature state of the system considered.

T. LYONS

Integration against Dirichlet processes

We discussed in way of survey the results, first introduced by Zheng and Lyons, (1988) Asterisque, which lead one to the construction of a stochastic integral

$$\int \omega \circ dX = (M^\omega + \bar{M}^\omega)/2$$

where M^ω, $\bar{M}^\omega$ are $\mathbb{P}_\mu$ martingales with respect to forward and backward filtrations on path space, and X is a conservative process associated to a Dirichlet process $(\mathcal{E}, \mu)$ and ω is a one-form with values in $L^2(\mu)$. We then discussed substantial improvements to these results, initiated by Zheng and Lyons (Proc. Royal Soc. Edinburgh) and continued in the recent paper with Stoica where we consider starting the integral at a point $(\mathbb{P}_0)$ or letting the time go to infinity. We concluded with our (Bass, Hambly, Lyons) main theorem extending the classical Wong-Zakai theorem as follows: Suppose $(\mathbb{R}^d, \mathcal{E}, \mu)$ is a Dirichlet process (continuous paths etc.) and it has uniformly p-variation paths in the sense that

$$\sup_{\substack{x \in \text{support} \\ t < 1}} \frac{\mathbb{E}_x (| X_0 - X_t |^p)}{t} < K, \quad p < 4,$$

(this includes a substantial range of Markov processes). Then denoting $X_t^{(n)}$ to be the piecewise linear dyadic interpolation of X and $Y^{(n)}$ to be the solution to

$$dY^{(n)} = f(Y^{(n)})\, dX^{(n)} \qquad Y_0^{(n)} = a$$

then (providing $f \in \mathrm{Lip}(p+\varepsilon)$) the limit $Y = \lim Y^{(n)}$ exists and provides a meaningful solution to

$$dY = f(Y)\,dX.$$

The methods are from above, and also rely heavily on the "theory of rough paths".

P. MALLIAVIN

Riemannian geometry on path space

(Based on Cruzeiro & Malliavin, *J. Funct. Anal.* (1996), Cruzeiro & Fang, *J. Funct. Anal.*(1997), Kazumi *J. Funct. Anal.* (1997), Fang *JMPA* (1998))
The Itô parallel transport defines on the path space $\mathbb{P}_{m_0}(M)$ of a Riemannian manifold a ***parallelism*** given by a 1-differential form Θ, defined on $\mathbb{P}_{m_0}(M)$, taking its values in $H^1([0,1],\mathbb{R}^d)$. The coboundary $d\Theta$ defines the ***structural equation*** which can be exactly computed:

$$[z_1, z_2](t) = Q_{z_1}(t)z_2(t) - Q_{z_2}(t)z_1(t) \qquad (*)$$

where $z_1, z_2 \in H^1([0,1];\mathbb{R}^d)$, $Q_z(t) = \int_0^t \Omega(\circ dp, z)$, Ω being the curvature tensor of M. This equation $(*)$ allows to proceed toward the computations of infinitesimal geometry, as precise as the finite classical dimension analogue. A Weitzenböck formula is established which leads to a full theory of anticipative stochastic integral on M. The infinitesimal generator of the Driver-Röckner process on $\mathbb{P}_{m_0}(M)$ is explicitly computed.

U. MOSCO

Dirichlet forms and fractals

We discuss relations between "geometry" and "dynamics" on structures—like fractals—that enjoy self-similarity, i.e. invariance under the action of N contractive self-similarities ψ_i; of the structure into itself. More specifically, relation between invariant Lagrangians

$$d\mathcal{L}[u] = \sum_{i=1}^{N} \rho_i\, d\mathcal{L}[u \cdot \psi_i], \quad \rho_i > 0 \qquad (1)$$

—as given in measure valued sense by the theory of Dirichlet forms—and invariant quasi metrics

$$d^2(x,y) = \sum_{i=1}^{N} \rho_i\, d^2\left(\psi_i(x), \psi_i(y)\right) \qquad (2)$$

with *some* ρ_i's as in (1).
We mention connections with subelliptic metrics of Heisenberg group type, "geometric optics" metrics for Dirichlet forms, spaces of homogeneous type of harmonic analysis, and we describe:

- volume growth of balls
- spectral asymptotics of Weyl's type
- Nash, Sobolev, John-Nirenberg and Morrey inequalities
- transition functions

Our conclusion is that - when focussed in the intrinsic Lagrangian metric—the "strange" dynamics of fractals is seen to be governed by "universal", Euclidean-like laws, showing reduction of "dynamics" to (effective) Lagrangian 'geometry'.

I. SHIGEKAWA

Comparison theorem and logarithmic Sobolev inequality

We discuss the following semigroup comparison (or domination) of the form $|\vec{T}_t\theta| \le e^{-\lambda t}T_t|\theta|$. Here $\{T_t\}_{t\ge0}$ is a semigroup acting on scalar functions, and $\{\vec{T}_t\}_{t\ge0}$ is a semigroup acting on vector-valued functions. In this talk, we consider a Riemannian manifold with boundary. $\{T_t\}_{t\ge0}$ is a diffusion semigroup with Neumann boundary condition and $\{\vec{T}_t\}_{t\ge0}$ is a semigroup generated by the Hodge-Kodaira Laplacian $dd^* + d^*d$ acting on p-forms. We think of two kinds of boundary condition for $dd^* + d^*d$: the absolute boundary condition and the relative boundary condition. We generalize the Weitzenböck formula and give a sufficient condition for the semigroup comparison.
Combining the comparison theorem with the commutation theorem, we reformulate the Bakry-Emery criterion for the logarithmic Sobolev inequality.

B. Weitere Vorträge, Beiträge in Workshops und Kurzmitteilungen

S. ALBEVERIO

Geometry of configuration spaces, poisson measures and quantum fields

We present a new approach, based on joint work with Yu. Kondratiev and M. Röckner, to the problem of constructing quantum mechanics for infinitely many degrees of freedom (non relativistic and relativistic quantum fields). We start out by recalling the approach to quantum mechanics via representation theory of Weyl canonical commutation relations *(CCR) ("kinematics")*, together with a representation of the Hamiltonian ("dynamics"). We relate this problem to the representation theory of topological groups G acting on a space with a G-quasi invariant measure. This leads to a natural extension to the study of the corresponding representation theory of Weyl commutation relations in infinite dimensions. Both in finite and in infinite dimensions the Hamiltonian is given as the classical Dirichlet operator associated with the quasi-invariant measure μ which gives the representation space $L^2(\mu)$. We mention the realization of this program in non relativistic quantum theory, with finitely resp. infinitely many degrees of freedom as well as in relativistic quantum field theory, where one has to assure in addition a representation of the Poincaré group in $L^2(\mu)$. The latter problem has been solved only in some models in space dimension 0, 1, but only partially in space dimensions 2 and 3. Fo! r the latter we mention however a recent breakthrough by Gottschalk, Wu and myself, where a local relativistic quantum field model with non trivial S-matrix has been constructed, by tools somewhat related to the ones discussed in the second part of the lecture.
In the second part of the lecture we show how a shift of attention from the representation of CCR to the representation of 'current algebras' gave rise to another type of development. The attention to 'current algebras' was drawn particularly in the late 60s through work in the relativistic domain by Gell-Mann and others and in the nonrelativistic domain by Goldin and others. In this connection we mention also work on the representation theory for the group of mappings Map (M, G) form a manifold M to a Lie-group G and for the groups of diffeomorphisms of a manifold M. Both groups representation have connections with quantum fields, the former with relativistic (resp. euclidean) quantum fields, the latter with nonrelativistic quantum fields. We explain in more details the latter connection. For this we introduce a natural geometry and measure theory on configuration spaces of particles moving on a (non compact) Riemannian manifold. We then construct the tangent bundle to! the configuration space, the gradient and divergence operation, and show their duality in the case of a mixed Poisson measure (Poisson measure plays thus the role of a flat measure over infinite dimensional configuration spaces).
We show how the 'N/V limit' of a second quantized quantum mechanical particle system in a box can be described in terms of this measure. We then extend

all these considerations to the case of Ruelle's measures describing Gibbs statcs of classical statistical mechanics. We also discuss the relations with the representation theory of the diffeomorphism groups (and its semidirect product with the abelian group $C_0^\infty(M)$, M being the underlying manifold). We close with raising the question of a possible relativistic extension of these considerations.

D. APPLEBAUM

Lévy processes in Lie groups and symmetric spaces

Lévy processes in Lie groups were first characterised via their infinitesimal generators by Hunt in 1956. More recently they have been described as solutions of stochastic differential operatios driven by Brownian motion and an independent Poisson random measure. They can also be obtained as a limit (a.s.) of Brownian motions with drift interlaced with jumps. When the group G has a compact subgroup K spherically symmetric Lévy processes in the symmetric space G/K are projections of such process in G. In this context, Harish-Chandra's theory of spherical functions allows as to develop a Lévy-Khintchine type formula originally due to Gangolli. Finally, these ideas are extended to general Riemannian manifolds.

R. BASS

Random walks on graphical Sierpinski carpets

In work with M. Barlow, we consider random walks on a class of graphs derived from Sierpinski carpets. We obtain upper and lower bounds (which are non-Gaussian) on the transition probabilities which are, up to constants, best possible. We also extend some classical Sobolev and Poincaré inequalities to this setting.

M. BIROLI

Sum of Dirichlet forms

Consider an open set Ω in $\mathbb{R}^N$, $N \geq 2$, that intersects the hyperplane $\{x_n = 0\}$, and denote $\Sigma = \Omega \cap \{x_N = 0\}$. Denote by D' the gradient in $\mathbb{R}^N$ and by D' the (tangential) gradient on Σ.
Let $a(u, v)$ be the Dirichlet form defined as

$$a(u, v) = \int_\Omega D'u\, D'v\, m(dx) + \int_\Sigma D'u\, D'v\, \sigma(dx) \qquad (*)$$

(m and σ are respectively the Lebesgue measure on Ω and on Σ). After a suitable definition of balls with center $x_0 \in \Sigma$, we prove an Harnack inequality on such a type of balls for positive harmonics of $(*)$. From the above result the Hölder continuity of the harmonics of $(*)$ can be easily deduced.

V. BOGACHEV

Invariant measures of diffusions on manifolds generated by Dirichlet forms

The talk is concerned with the regularity, uniqueness and existence problems for diffusion processes on finite and infinite dimensional manifolds. Connections with weak solutions of elliptic equations are discussed. Perturbations of generators of Dirichlet forms satisfying weak Log-Sobolev inequalities are studied. Related necessary or sufficient conditions for the compactness of the embeddings of the Dirichlet spaces are described.

Z.-Q. CHEN

Fine properties of symmetric stable processes

In this talk, we give lower and upper bound estimates for Green functions and Poisson kernels of a symmetric α-stable process X in bounded $C^{1,1}$ domains in $\mathbb{R}^n$, where $0 < \alpha < 2$ and $n \geq 2$. For this, an exact formula expressing the Poisson kernel of X on a domain D with uniform exterior cone condition in terms of the Green function of X in D is derived. Using these estimates, we prove that the 3G Theorem holds for X on bounded $C^{1,1}$ domains and that the conditional lifetimes for X in a bounded $C^{1,1}$ domain are uniformly bounded. Also given is a simple proof of the boundary Harnack principle for nonnegative functions which are harmonic in a bounded $C^{1,1}$ domain D with respect to the symmmetric stable process. We then show the conditional gauge theorem holds for symmetric α-stable processes on bounded $C^{1,1}$ domains in $\mathbb{R}^n$ where $n \geq 2$. Two of the major tools used to prove this conditional gauge theorem are logarithmic Sobolev inequality and intrinsic ultracontractivity. This talk is based on the following two joint works with Renming Song.

[1] Z. Q. Chen and R. Song, Estimates on Green functions and Poisson kernels for symmetric stable processes. Preprint.
[2] Z. Q. Chen and R. Song, Intrinisic ultracontractivity and conditional gauge for symmetric stable processes *J. Funct. Anal.* **150** (1997), 204–239.

TH. COULHON

Upper and lower estimates for Markov semigroups kernels

Let e^{-tA} be a Markov semigroup acting on $L^2(X,\xi)$, where (X,ξ) is a measure space. One characterizes ultracontractive bounds of the form $\|e^{-tA}\|_{1\to\infty} \leq m(t)$ in terms of Nash type inequalities involving the Dirichlet form (Af,f). Optimal sufficient conditions for lower bounds on $\|e^{-tA}\|_{1\to\infty}$ are also given in terms of anti-Faber-Krahn inequalities. These results are useful for the study of large time behaviour of heat kernels on non-compact Riemannian manifolds, and their discrete time analogue for random walks on infinite graphs.

[1] T. Coulhon: Ultracontractivity and Nash type inequalities. J. Funct. Anal.

141 (1996), 510–593.
[2] T. Coulhon and A. Grigoryan: On-diagonal lower bounds for heat kernels and Markov chains. Duke Math. J. 89 (1997), 133–199.

L. DENIS

Product Dirichlet structure and applications to Poisson measure

We consider an $\mathbb{R}^+ \times M$ -valued Poisson measure, where M is a very general measure space. We denote by μ this Poisson measure and its compensator is $dt \otimes dv$. We assume that $M = \bigcup_{i=1}^{\infty} M_i$ with $M_i \cap M_j = \emptyset$ for $i \neq j$ and $\nu(M_i) < \infty$ for all i. We construct a Dirichlet structure (D, E) on $L^2(W, \mathbb{F}, P)$ where $(W, \mathbb{F}, P)$ is the underlying space. We have a criterion of density:

$$F_*(\det\Gamma(F) \cdot P) \ll \lambda_l, \quad F \in D^l$$

where F is the "carré du champ" operator and λ_l is the Lebesgue measure. Finally, we apply this to a stochastic differential equation driven by μ:

$$dX_t = f(X_t)dt + \int_M g(X_S, m)\mu(ds \otimes dm)$$

with $X_0 = x$, and give a criterion of density for $X_t, t > 0$.

A. EBERLE

Uniqueness and non-uniqueness of singular diffusion operators

Uniqueness problems for (not necessarily symmetric) singular diffusion operators on L^p-spaces over finite and infinite dimensional state spaces are discussed. Here, "uniqueness" means that there exists at most one C^0-semigroup on L^p (respectively only one symmetric, sub-Markovian, etc., C^0-semigroup such that its generator extends the diffusion operator, which is a priori defined on a space of "test functions". It is demonstrated how non-uniqueness can be caused by different effects related to boundaries, singularities, and infinite dimensional phenomena. Several new uniqueness results, both for finite and infinite dimensional diffusion operators, are presented. Some of the obtained criteria in finite dimensions are shown to be sharp. A new probabilistic "explanation" for certain L^p uniqueness results will also be given.

M. HINO

Exponential decay of positivity preserving semigroups on L^p

Let (X, m) be a finite measure space and $p \in (1, \infty)$. For positivity preserving semigroups which are also stongly continuons on $L^p(X, m)$, the following problems are discussed in this talk: existence of invariant measures and exponential decay in L^p sense. Sufficient conditions are given by introducing notions of some hyperboundedness condition and some mixing condition. Typical examples are semigroups on a Banach space generated by $-\nabla\sigma\nabla + (b, \nabla\bullet)$, where the Dirichlet form associated with a diffusion part satisfies the logarithmic Sobolev inequality, and a drift part b is relatively small.

F. HIRSCH

Two-parameter Bessel processes

In two papers (PTRF, 95), S. Song and myself introduced a general notion of symmetric multiparameter Markov processes and we showed that it was possible to develop both probabilistic and analytic potential theories related to such processes. In this talk (also based on a joint work with S. Song) I consider the problem of the existence of such a two-parameter process of which the transition semi-groups are both equal to the Bessel semi-group on $\mathbb{R}_+$ of dimension d, where d is a real number ≥ 2. The two-parameter process is obtained as a one-parameter process in the path space of the Bessel process. This leads us to introduce a Dirichlet form on the path space and to prove the existence of an associated diffusion.

K. KUWAE

Reflected space for quasi-regular Dirichlet forms

The reflected Dirichlet space for quasi-regular Dirichlet forms is represented by using of the Beurling-Deny decomposition and the Le Jan type formula for energy measures of continuous, jumping and killing type. The closedness of (active) reflected Dirichlet spaces is discussed without using the first definition by M. Silverstein (1974) and its characterization by Z. Q. Chen (1992). I also show the maximality of the (active) reflected Dirichlet space in the class of extensions in the sense of Silverstein for quasi-regular Dirichlet forms. The maximality is known in the case of strongly local regular Dirichlet forms by Kawabata-Takeda (1998) by use of Chen's characterization. The uniqueness of extensions holds if the 1-capacities of all balls defined by the intrinsic metric are finite and the metric is square integrable with respect to the jumping measure. The conservativeness also assures the uniqueness.

A. DE LA PRADELLE

Stochastic processes and Sobolev spaces

We give simplified proofs of the existence of regular Gaussian processes (as fractional Brownian motion) and a sharpening of the Kolmogorov lemma by the use of fractional Sobolev spaces. (The improvement is in the use of vector valued

Sobolev spaces). We get also a Kolmogorov-Ascoli lemma which says that if a sequence $X_t^n(\omega)$ of processes are uniformly α-Hölder in $L^p(\Omega)$ and tends to X_t in L^p for each t, then X^n tends to X in $L^p(\Omega, \mathcal{J}^{\beta,p})$ $(0 < \beta < \alpha)$ where $\mathcal{J}^{\alpha,p}$ denotes a fractional Sobolev space. If $\Omega = \mathcal{C}([0,1])$, $\mu =$ the Wiener measure and $W^{r,p}(\Omega, \mu)$ the classical Sobolev space associated to the Ornstein-Uhlenbeck operator, we can replace the L^p-norm by the $W^{r,p}$-norm to get stronger results. As an application we extend the well-known support theorem which says that the support of the image measure $X(\mu)$ where X is solution of a certain Stratonovitch S.D.E. (S) is the closure of its skeleton (the image of the Cameron-Martin space by an O.D.E. naturally associated to (S)) for the norm of the Banach space carrying μ. The support of the capacity $c_{r,p}$ associated to $W^{r,p}$, is the closure of the skeleton with respect to the α-Hölder norm $(\alpha < 1/2)$. This is a joint work with D. Feyel.

V. LISKEVICH

On the uniqueness problem for Dirichlet operators

The talk is devoted to the uniqueness problem in L^p for operators associated with classical gradient Dirichlet forms. New results are given both for finite and infinite dimensional cases. The latter has application to the uniqueness of stochastic quantization processes for Euclidean quantum field theory in finite volume.

Z.-M. MA

Stochastic dynamics on configuration spaces over free loop spaces

This talk is based on my recent two joint works with Albeverio, Kondratiev and Röckner. We introduced a metric on configuration spaces which describes the topological structure of configuration spaces in a reasonable way. We developed also a general procedure of lifting Dirichlet forms from downstair spaces to configuration spaces. Under some minor conditions one can check that the lifted Dirichlet forms are quasi-regular and local. Hence one may construct diffusions on configuration spaces via Dirichlet form theory. Applying this mathematical machinery we obtained stochastic dynamics on configuration spaces over free loop spaces, having background from quantum mechanics.

I. McGILLIVRAY

Large time volume of the pinned Wiener sausage

The form of the asymptotic expansion of the expected volume of the pinned Wiener sausage for large time is given. The result is valid for dimensions $d \geq 3$.

V. METZ

Homogenization on a fractal

We consider the Vicsek fractal E for three reasons: 1. It can be constructed by successive cutouts from $[0,1]^2$ similar to the Cantor discontinuum—this may be viewed as polluting the homogeneous material $[0,1]^2$; 2. the usual construction of a Dirichlet form on E by a converging sequence of discrete Dirichlet forms on 'grids' is also polluted, this time by random weights on the edges (random conductances); 3. it is known that E carries a one-parameter-family of different homogeneours (pure) media (Dirichlet forms). Despite all these facts the usually scaled renormalization map renders a sequence of discrete Dirichlet forms that Mosco-converges to a homogeneous one (a 'pure' one that is invariant under the scaled renormalization map), if the expected effective resistance across the cornerpoints of $[0,1]^2$ are finite. Under stronger assumptions on the effective resistances and the conductances the corresponding Markov chains converge weakly to a Markov process that is defined by a 'pure' Dirichlet form.

G. MOKOBODZKI

Gradients des fonctions lipschitziennes et formes de Dirichlet sur R^p

1) On caractérise des mesures bornées m sur R^p qui interviennent dans la conjecture de BOULEAU et HIRSCH sur les espaces de Dirichlet par la propriété (P) suivante
(P)-Pour toute suite $(\varphi_n) \subset C_b^1(R^p)$ vérifiant
$\|\nabla\varphi_n\|_\infty \leq C$ pour tout n, et $lim_{n\to\infty}\|\varphi_n\|_\infty = 0$
-Pour tout champ de vecteurs, $X \in L^2(m, R^p)$
$lim_{n\to\infty}\langle X, \nabla\varphi_n\rangle_{R^p} = 0$ au sens faible dans $L^2(m)$
La conjecture de BOULEAU et HIRSCH équivaut à dire que les mesures m vérifiant (P) sont absoluement continues par rapport à la mesure de Lebesgue sur R^p.
2) On donne des applications des méthodes ulilisées à la représentation des gradients des fonctions Lipschitziennes pour une large classe de mesures qui contrôlent les formes de Dirichlet sur R^p dont le domaine contient $C_b^1(R^p)$

A. NOLL

Capacity in Abstract Hilbert Spaces

We introduce the notion of capacity in abstract Hilbert spaces. It is proved that the spectral shift of a self-adjoint operator which is subjected to a domain perturbation can be estimated in terms of this capacity. The obtained results are finally applied to higher-order partial differential operators.

H. ÔKURA

Skew product, subordination and recurrence of symmetric Markov processes

An explicit formula for the Dirichlet form of a subordinated symmetric Markov process is given, and it is also noted that subordination preserves cores of Dirichlet forms. Some global properties of subordinated Markov processes are also studied. Especially, recurrence criteria and global capacitary inequalities are given. The recurrence criteria for subordinated processes are described in the terms of *rate functions*, which have been introduced by the present author in the earlier work on the recurrence criteria for skew product of symmetric Markov processes. Consequently, every recurrent symmetric Markov process admits a recurrence-preserving subordination. As a typical example, it is shown that the process subordinated to the skew product process $(B_t^{(1)}, B_{l(t)}^{(2)})$ by a β-stable subordinator is recurrent if and only if $\beta \geq 3/4$, where $B_t^{(1)}, B_t^{(2)}$ are independent one-dimemsional Brownian motions, and $l(t)$ is the local time of $B_t^{(1)}$ at the origin.

H. OSADA

Gibbs measures on path space and related Dirichlet form

I construct infinite volume (φ, ψ)-Gibbs measure μ on $W = C(\mathbb{R} \to \mathbb{R})$, where $\varphi = \varphi^{[a]}$ and $\psi = \psi(x, a)$ are free and interaction pair potentials, respectively, φ is assumed to be

$$\varphi(a) = | a |^q + \gamma(a), \quad q \geq 2$$

and

$$\operatorname{ess.sup}_{a \in \mathbb{R}} \frac{|\gamma'(a)|}{1 + |a|^{q-2}} < \infty.$$

$$\psi(x, a) = \rho(x)\lambda(a) = \rho(|x|)\lambda(|a|) \text{ satisfies } \quad \rho \geq 0, \int \rho \, dx < \infty,$$

ρ is decreasing, and λ is convex. We also prove the uniqueness of translation invariant Gibbs measures when

$$\int_{\mathbb{R}} |x| \rho(x) \, dx < \infty. \tag{*}$$

We also give an example of non-uniqueness when (*) does not hold. In the second part of the talk, we construct the classical Dirichlet form on $L(W, \mu)$ and discuss about the spectral gap.

Y. OSHIMA

On the recurrence of some time inhomogeneous Markov processes and related topics

In this talk, we are concerned about a condition for recurrence as well as certain ratio limit theorem of time inhomogeneous Markov processes (or chains). Let

$(E^{(t)}, F^{(t)})_{t\geq 0}$ be a family of Dirichlet forms and $\mathbb{M} = (X_t, P_{(s,x)})$ and $\hat{\mathbb{M}} = (\hat{X}_t, \hat{P}_{(s,x)})$ be the Markov processes associated with $(E^{(t)}, F^{(t)})$ in the sense

$$(\frac{\partial}{\partial s}p(s,\cdot;t,\varphi), \psi) = E^{(s)}(p(s,\cdot;t,\varphi), \psi),$$

$$p(t,x;t,\varphi) = \varphi, \quad \forall\varphi \in L^2(m_t), \quad \forall\psi \in F^{(s)}.$$

We define the recurrence of $\mathbb{M}$ in the following three senses;

(s) $\int_s^\infty I_c(X_t)\,dt = 0$ or ∞ a.s. $P(s,x)$,

(w) $P_{(s,x)}(\sigma_c < \infty) = 0$ or 1,

(m) $E_{(s,x)}\left(\int_s^\infty I_c(X_t)\,dt\right) = 0$ or ∞.

We give general criteria for the recurrence in (s) and (w) sense and apply it to get a condition for (s)-recurrence of a diffusion process corresponding to $E^{(t)}(\varphi,\psi) = \int_{R^d} \nabla\varphi\cdot\nabla\psi\Gamma(t)\,dx$ on $L^2(dx)$ as well as $E^{(t)}(\varphi,\psi) = \int_{R^1} \varphi'\psi'\rho^2(s,x)\,dx$ on $L^2(\rho^2(s,x)\,dx)$.
In the second part of this talk, we give a weak version of a ratio limit theorem of a time inhomogeneous (s)-recurrent Markov chain $\{p_i^j(x,dy)\}$. It says that, for suitable functions f and g, the number of i such that

$$\left| \frac{\sum_{i\leq j\leq k} p_i^j f(x)}{\sum_{i\leq j\leq k} p_i^j g(x)} - \frac{\alpha(f)}{\alpha(g)} \right| > \varepsilon$$

for some $k \leq n$ is of smaller order than n with respect to some measure, where

$$\alpha(f) = \lim_{n\to\infty} \frac{1}{n}\sum_{i=1}^{n} \int f(x)\,dm_i(x).$$

J. PICARD

Applications of a duality formula on the Poisson space

We explain how a duality formula on the Poisson space can be applied to study the evolution of some interacting particles which are not moving but can appear and disappear. In particular, we give conditions for the existence of reversible measures and Gibbs measures.

M. PONTIER

Dirichlet forms on Poisson space

The aim of this work was initially defined with Axel Grorud: to obtain a simple condition on a random variable L in order to enlarge the current filtration $\{\mathcal{F}_t\}$, that is to say $\mathcal{G}_t = \bigcap_{s>t} \mathcal{F}_s \vee \sigma(L)$. The enlarged filtration $\mathcal{G}$ represents an insider trader's point of view of the market. L is the insider trader's anticipating knowledge of the market, $\mathcal{F}$ is the filtration of the prices. The first tool is a Dirichlet form to study the conditional probability law of L given $\mathcal{F}_t$; then a condition is given on L such that this probability law is absolutely continuous with respect to Lebesgue measure. Thus, Jacod's hypothesis H' is satisfied, and the second tool is Jacod's result on enlargement of filtrations. Finally, the initial enlargement of filtrations allows us to compare $\mathcal{F}$ and $\mathcal{G}$-martingales. This work does not present new results, but it collects known results by Bichteler, Graveraux and Jacod and of Bouleau and Hirsch. A Dirichlet structure is built on a Poisson probability space, and the link is done with a stochastic variations calculus of variation.

Z. QIAN

Harnack inequality for diffusion operators

In this talk, I report the joint work with D. Bakry (Toulouse, France) on Harnack inequality. For any elliptic operator we may associate concepts of dimension and Ricci curvature, and we establish several Harnack inequalities via dimension and a lower bound for the Ricci curvature. These are new when the lower bound of the Ricci curvature is positive, and are improvements of Li-Yau's estimate for negative curvature.

[1] D. Bakry and Z. Qian, Harnack inequalities on a manifold with positive or negative Ricci curvature, to appear in 'Revista Math. Iberoam'.

M. RÖCKNER

Rademacher's theorem on configuration space

We consider an L^2-Wasserstein type distance ρ on the configuration space Γ_X over a Riemannian manifold X, and we prove that ρ-Lipschitz functions are contained in a Dirichlet space associated with a measure on Γ_X satisfying some general assumptions. These assumptions are in particular fulfilled by a large class of tempered grandcanonical Gibbs measures with respect to a superstable lower regular pair potential. As an application we prove a criterion in terms of ρ for a set to be exceptional. This result immediately implies, for instance, a quasi-sure version of the spatial ergodic theorem. We also show that ρ is optimal in the sense that it is the instrinsic metric of our Dirichlet form. Furthermore, applications towards the development of a potential theory on Γ_X are given.

C. SABOT

Density of states and holomorphic dynamics in $\mathbb{P}^k$: the example of the interval $[0, 1]$

We study the asymptotic repartition of eigenvalues of a Brownian motion on $[0, 1]$ time-changed by a random time associated with a self-similar measure on $[0, 1]$ (this is a particular example of a diffusion on a finitely ramified fractal). We show that this involves a meromorphic map on $P^2_{\mathbb{C}}$ (the complex projective space of dimension 2). This map is explicite and the study of its dynamics gives non-trivial results on the structure of the density of states. Precisely, we prove that, at the exception of the usual Brownian motion (where the change of time is associated with the Lebesgue measure), the density of states charges no point and its support is included in a Cantor subset of $\mathbb{R}_+$. This is a natural extension of the work of Rammal and Fukushima-Shima on the spectral properties of the Sierpinski gasket. The main features of the method can be generalized to all finitely ramified fractals but the study of the dynamics of the meromorphic map is diff! icult in general.

R. L. SCHILLING

Feller processes and function spaces

Let $\{X_t\}_{t\geq 0}$ be a Feller process on $\mathbb{R}^n$ whose generator $(A, D(A))$ is a pseudo-differential operator $-p(x, D)$ with symbol $p : \mathbb{R}\times\mathbb{R} \to \mathbb{C}$. (Due to a result by Ph. Courrège this will be the case if the test functions $C_c^\infty(\mathbb{R}^n) \subset D(A)$.) We assume throughout that p has *bounded coefficients*, i.e. $\sup_x |p(x, \xi)| \leq c\,(1 + |\xi|^2)$, and satisfies the condition $|\mathrm{Im}\, p(x, \xi)| \leq c_0 \,\mathrm{Re}\, p(x, \xi)$. We show that under these conditions

$$\lim_{t\to 0} t^{-1/\lambda} \sup_{s\leq t} |X_s - x| = 0 \quad \text{or} \quad \infty \qquad \text{a.s. } \mathbb{P}^x$$

according to $\lambda > \beta^x_\infty$ or $\lambda < \delta^x_\infty$ where $\beta^x_\infty, \delta^x_\infty$ are the (polynomial) growth exponents of the symbol $p(x, \xi)$ as $|\xi| \to \infty$. Similar re. ults do hold for large times $t \to \infty$. If $B^s_{p,q}(\mathbb{R})$ is the Besov space with parameters $0 < p, q \leq \infty, s > 0$, we show that almost all ($\mathbb{P}^x$) trajectories

$$\{\mathbb{R} \ni t \mapsto (1 + t^2)^{-\mu/2} X_{t\vee 0}(\omega)\} \in B^s_{p,q}(\mathbb{R})$$

whenever $s > (\frac{1}{p} - 1)_+, \mu > \frac{1}{p} + \frac{1}{\beta_0}$, and $s \cdot \max\{p, q, \beta^y_\infty\} < 1$ for all $y \in \mathbb{R}^n$ are satisfied. (Note that the latter result holds, in particular, for Lévy processes.)

B. SCHMULAND

Some exceptional sets in configuration space

The canonical Dirichlet form of Albeverio, Kondratiev, and Röckner is used to find exceptional sets in the space of locally finite configurations on $\mathbb{R}^d$. The underlying probability measure is either a mixed Poisson measure or a Gibbs measure associated with a superstable pair potential.

M. L. SILVERSTEIN

Suppose that absorption preceeds subordination

Suppose that you define a process on a subdomain D of $\mathbb{R}^n$ by subordinating the absorbed Brownian motion on that domain. This differs from the usual absorbed subordinated process in those jumps which correspond to time intervals when Brownian motion exits and returns before killing.

S. SONG

The symmetry of a one-dimensional diffusion process and the Siegmund duality

We propose to study the Siegmund's duality problem for any one-dimensional regular diffusion process using Dirichlet form theory. Let us reformulate Siegmund's original definition: Let (P_t) be the Markov transition semigroup of a regular one-dimensional diffusion. We call *Siegmund's dual* $(\widehat{P}_t)$ of the semigroup (P_t) the family of operators defined by the relation $\langle b, \widehat{P}_t f\rangle = \langle dP_t[Tb], f\rangle$ where f is a positive function, b is a bounded measure, and Tb is the distribution function of the measure b. We then prove that $(\widehat{P}_t)$ is a Markovian semigroup, symmetric with respect to the measure $ds(x)$, strongly continuous in $L^2(ds)$. We give the exact domain of its generator. It happens that, if the generator of (P_t) is $\frac{d}{dm}\frac{d}{ds}$ (with certain boundary conditions), the generator of $(\widehat{P}_t)$ is $\frac{d}{ds}\frac{d}{dm}$ (with some boundary conditions). We have answered thus the Siegmund's conjecture for any regular one-dimensional diffusion process.

W. STANNAT

Generalized Dirichlet forms and applications

Let L be a nonsymmetric operator of type $Lu = \sum_{ij} a_{ij}\partial_i\partial_j u + \sum_i b_i\partial_i u$ on an arbitrary open subset $U \subseteq \mathbb{R}^d$. We analyze L as an operator on $L^1(U,\mu)$ where μ is an invariant measure, i.e., a possibly infinite measure μ satisfying the equation $L^*\mu = 0$. We explicitely construct, under mild regularity assumptions, a maximal solution $(L, \mathcal{D}(L))$ of $(L, C_0^\infty(U))$ generating a sub-Markovian C_0-semigroup in $L^1(U,\mu)$. We completely characterize those cases in which there exists exactly one maximal extension on $L^1(U,\mu)$. Our results imply in particular that the generalized Schrödinger operator

$$\Delta u + 2\varphi^{-1}\langle\nabla\varphi, \nabla u\rangle, \quad u \in C_0^\infty(\mathbb{R}^d),$$

is L^1-unique in $L^1(\mathbb{R}^d, \varphi^2 dx)$ if and only if the corresponding Friedrichs extension is conservative. Using the theory of generalized Dirichlet forms which is a new framework for the analysis of non-symmetric differential operators on finite and infinite dimensional state spaces extending the classical theory of Dirichlet forms, we construct associated diffusion processes.

P. STOLLMANN

Localization for random Dirichlet forms

Localization is a phenomenon occuring in disordered media and refers to pure point spectrum in a certain energy region for random operators. We discuss this phenomenon for a family of Laplacians on random domains. Such models are referred to as random quantum wave guides in the mathematical physics literature. As a preparatory step, we prove Lifshitz asymptotics of the integrated density of states. For our specific model, this requires a detailed analysis of domain perturbations. This is joint work with F. Kleespies (Frankfurt/M.).

K. TH. 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 forms as a Γ-limit of certain non-local Dirichlet forms defined in terms of the metric d and the reversible measure m. The second problem is how to define and approximate the energy of a map with values in a metric space N. This leads to the question whether $\frac{1}{2t}\mathbb{E}_m[d^2(f(X_0), f(X_t))]$ 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 if either X_t is Brownian motion on $\mathbb{R}^n$ (with arbitrary f, N, d) or the space (N, d) has nonnegative curvature (with arbitrary M, X_t, f).

M. TOMISAKI

Superposition of symmetric diffusion processes

Let us consider the following Dirichlet form:

$$E(u, v) := E^+(u^+, v^+) + E^-(u^-, v^-) + E^\Gamma(\gamma u, \gamma v)$$

$$u, v, \in D(E) = \{u \in H^1(\mathbb{R}^d); \gamma_+ u = \gamma_- u = \gamma u \in \mathbb{F}^\Gamma\}$$

where $(E^+, H^1(\mathbb{R}^d_+))$ and $(E^-, H^1(\mathbb{R}^d_-))$ are Dirichlet forms corresponding to uniformly elliptic second order partial differential operator with $C^{1,\lambda}$ coefficients; $\Gamma = \{(x_1, \ldots, x_d) \in \mathbb{R}^d; x_d = 0\}$, and $(E^\Gamma, \mathbb{F}^\Gamma)$ is a Dirichlet form on $L^2(\Gamma)$ which corresponds to an integro-differential form of $C^{1,\lambda}$-class; $u^+ = u|_{\mathbb{R}^d_+}$ and $u^- = u|_{\mathbb{R}^d_-}$.We then show that there is a Feller process associated with $(E, D(E))$.

J. YING

Perturbation of Markov semigroups

In the context of general Markov processes, we introduce so-called additive functionals of Kato class, and discuss the semigroup perturbed by them. The main tools include bivariate Revuz measures and switching identity, which generalizes the classical Revuz formula. We also take symmetric Markov processes as a special case to discuss and formulate the perturbation of the associated Dirichlet form.

T. S. ZHANG

Generalized Feynman-Kac semigroups, associated quadratic forms and asymptotic properties

In this paper, we study the Feynman-Kac semigroup

$$T_t f(x) = E_x[f(X_t)exp(N_t)]$$

where X_t is a symmetric Lévy process and N_t is a continuous additive functional of zero energy which is not necessarily of bounded variation. We identify the corresponding quadratic form and obtain large time asymptotics of the semigroup. The Dirichlet form theory plays an important role in the whole paper.

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