Mathematisches Forschungsinstitut Oberwolfach

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Mini-Workshop:

Partial Differential Equations

August 5th – August 11th, 2001

The present meeting was organized by L. C. Evans (Berkeley), S. Müller (MPI Leipzig) and Ernst Kuwert (Freiburg). The idea was to bring together people in nonlinear partial differential equations working on problems motivated by geometry and physics.

The central issue in most talks is the regularity, or rather the singular structure, of the solutions. In many cases, like for example for Yang-Mills connections, minimal surfaces, harmonic maps and for the Ginzburg-Landau functional, the set of singularities is studied via geometric measure theory. Other techniques include convex integration, stochastic pertubations and of course a priori estimates, like for example in the case of wave maps. A number of talks concerned problems motivated by applied physics, such as non-Newtonian fluids, combustion theory, 2D limits of 3D elasticity, fluid mixtures and micromagnetics. However, techniques of geometric type play an important role also there.

The program contained 24 talks presenting new developments and results. It was important that there was still enough time for informal talks and discussions. The participants of the workshop came from Germany, U.S.A., Italy, France, Switzerland, Sweden, United Kingdom, Japan and Turkey.

The following abstracts are in chronological order.

Abstracts

Quantization, Bubbling and Regularity Issues for Yang-Mills Fields and Harmonic Maps

Tristan Rivière
(joint work with Gang Tian)

We consider J-holomorphic maps from an almost complex 4-manifold into any given algebraic varieties which are in the Sobolev Space $W^{1,2}$ and which are locally approximable by smooth maps. We prove that the singular set of such maps is made of isolated point singularities.

Global Solutions for some Oldroyd Models of Non-Newtonian Flows

Nader Masmoudi
(joint work with Pierre Louis Lions)

We consider some Oldroyd models of non-Newtonian flows consisting of a strong coupling between incompressible Navier-Stokes equations and some transport equation for an extra part of the stress tensor. We prove global existence of weak solutions in dimension 2 or 3. The existence proof relies upon showing that some defect measures are equal to 0 and hence enforcing weak convergence to a strong one. This allows for a passage to the limit in the nonlinear terms.

A Singular Limit Arising in Combustion Theory: Fine Properties of the Free Boundary

Georg S. Weiss

The equation $\partial_t u_\varepsilon - \Delta u_\varepsilon = -\beta_\varepsilon(u_\varepsilon)$ in $(0,\infty) \times \mathbb{R}^n$, where β_ε converges to the Dirac measure concentrated at 0 with mass 1/2, has been used as a model for the propagation of flames with high activation energy. For initial data that are bounded in $C^{0,1}(\mathbb{R}^n)$ and have a uniformly bounded support, we study non-negative solutions in the Cauchy problem in $(0,\infty) \times \mathbb{R}^n$ as $\varepsilon \to 0$. We show that each limit of u_ε is a solution on the free boundary problem $\partial_t u - \Delta u = 0$ in $\{u > 0\} \cap (0,\infty) \times \mathbb{R}^n$, $|\nabla u| = 1$ on $\partial\{u > 0\} \cap (0,\infty) \times \mathbb{R}^n$ (in the sense of domain variations and in a more precise sense). For a. e. time t the graph of $u(t)$ has a unique tangent cone at $\mathcal{H}^{n-1}$ - a=2Ee. $x \in \mathbb{R}^n$. The free boundary $\partial\{u(t) > 0\}$ is up to a set of vanishing $\mathcal{H}^{n-1}$ measure the sum of a countably $n-1$-rectifiable set and of the set on which $|\nabla u|^2$ vanishes in the mean. The non-degenerate singular set is for a. e. time a countably $n-1$-rectifiable set. As key tools we introduce a monotonicity formula and, on the singular set, an estimate for the parabolic mean frequency.

Irregular Solutions to Strictly Quasiconvex Parabolic Equations

Marc Oliver Rieger

In a joint work with Stefan Müller (MPI for Mathematics in the Sciences) and Vladimír Šverák (University of Minnesota) we study regularit y questions for nonlinear parabolic equations. We prove existence of irregular solutions for parabolic equations of the type

$$\begin{aligned} u_t(x,t) - \operatorname{div} DF\big(\nabla u(x,t)\big) &= f(x,t), \\ u(x,0) &= 0, \end{aligned}$$

where F is a strongly quasiconvex function and f H"older continuous. In fact we construct a solution u which is Lipschitz continuous, but no where $\mathcal{C}^1$. Moreover u satisfies the condition $\operatorname{div} DF(\nabla u) = 0$ a. e. The proof uses the method of convex integration and constructions inspired by the theory of microstructures and is based on recent work of Stefan Müller and Vladimír Šverák for elliptic problems.

Uniqueness Issues of Motion by Mean Curvature

Aaron Nung Kwan Yip

We describe some approaches to study motion by mean curvature with stochastic perturbations. Emphasis is put on the effects of noise on the non-uniqueness phenomena of the motion. We demonstrate by simple examples that noise can give a natural selection principle for "the" solution. The first example gives an almost surely uniqueness result. The second example provides a unique probability measure on the space of solutions. Some open problems concerning the non-uniqueness phenomena and the Allen-Cahn equation are discussed.

Conservative Vortex Filament Dynamics

Robert Jerrard

We introduce a measure theoretic notion of a weak binormal curvature flow, and we establish some basic properties. We use this notion to show that: if $\{u^\varepsilon(t)\}$ is a sequence of solutions of the Gross-Pitaevsky equation with initial data satisfying

(1) $Ju^\varepsilon(0) \to$ suitable vector measure $\overline{J}$
(2) small energy assumption

then $Ju^\varepsilon(t)$ converges to a measure $\overline{J}_t$, and

(1) if one can verify a small energy condition at $t > 0$, then $\{\overline{J}_t\}_{t>0}$ is a weak binormal curvature flow; and
(2) this small energy condition can be verified if $\overline{J}_0 \sim$ round multiplicity 1 $m-2$-sphere.

Here $Ju^\varepsilon = \sum \det(u^\varepsilon_x, u^\varepsilon_y)\, e_i \wedge e_j$.

On the Rate of Convergence of Finite-Difference Approximations for Fully Nonlinear Equations

Nicolai V. Krylov

In the first part of the talk we consider the elliptic equation with constant coefficients

$$F(u_{x^ix^j}(x), u_{x=EE}(x), u(x), x) = 0 \quad x \in R^d,$$

where

$$F(u_{ij}, u_i, u, x) = \sup_{\alpha \in A}\{a^{ij}(\alpha)u_{ij} + b^i(\alpha)u_i + c(\alpha)u + f(\alpha, x)\}.$$

We prove that if h is the mesh size, then the rate of convergence of finite-difference approximations is not worse than $h^{1/3}$.

In the second part we consider the parabolic equation with variable coefficients

$$\sup_{\alpha \in A}[L^\alpha u + f^\alpha] = 0, \quad s \leq T, x \in R^d$$

where

$$L^\alpha z(s,x) := a^{ij}(\alpha, s, x) z_{x^i x^j}(s,x) + b^i(\alpha, s, x) z_{x^i}(s,x) - c^\alpha(s,x)\, z(s,x) + z_s(s,x).$$

We prove that in the case regular coefficients the rate is estimated from above by $h^{1/21}$.

Quadratic Tilt-Excess Decay and Strong Maximum Principle for Varifolds

Reiner Schätzle

We prove that integral $n-$varifolds μ in codimension 1 with $H_\mu \in L^p_{loc}(\mu)$, $p > n$, $p \geq 2$ have quadratic tilt-excess decay

$$tiltex_\mu(x, \varrho, T_x\mu) = O_x(\varrho^2)$$

for $\mu-$almost all x and a strong maximum principle which states that these varifolds cannot be touched by smooth manifolds whose mean curvature is given by the weak mean curvature H_μ, unless the smooth manifold is locally contained in the support of μ.

Regularity for the Hyperbolic Monge-Ampère Equation

Bernd Kirchheim

We study gradients $f = \nabla u$ of solutions

$$\mathrm{def}\,(D^2 u) = -1, \quad u \in W^{2,\infty}(\Omega, \mathbb{R}^2) \quad \Omega \subset \mathbb{R}^2.$$

If near some point $x \in \Omega$ the oscillation of ∇f is smaller that 1, then by a well-known interchange of one dependent and independent variable we arrive in the situation of the linear wave equation. We show that there might indeed be irregular points, where such a transformation is impossible, but that the set of all such singularities is discrete.

This allows us to prove rigidity for the crucial cases when we consider either gradients without rank-one connections or gradients building a flow interface.

Singular Yamabe Metrics, Explosion for Superprocesses and Thinness

Denis Labutin

The problem of description of domains on the unit sphere, admitting complete metrics with constant scalar curvature conformal to the standard metric, oroginates in the works of Loewner and Nirenberg, and Schoen and Yau. We characterize such domains in the case of negative constant scalar curvature. The condition is inspired by the notion of thinness from potential theory.

On a Class of Fully Nonlinear Equation Arising from Conformal Geometry

Guofang Wang
(joint work with Pengfei Guan)

Let (M^n, g) be a closed Riemannian manifold. Its schouten tensor is defined by

$$S_g = \frac{1}{n-2}(Rie_g - \frac{R_g}{2(n-1)}g).$$

Let $\sigma_k (k = 1, \dots, n)$ by the k-th elementary symmetric function and $\Gamma_k^+ = \{\lambda = (\lambda_1, \dots, \lambda_n) \in \mathbb{R}^n \,|\sigma_j(\lambda) > 0, j \geq k\}$. g is said to be in Γ_k^+ if at every point eigenvalues of its schouten tensor lie in Γ_k^+.

σ_k-Yamabe problem: given a metric $g_0 \in \Gamma_k^+$, is there a conformal metric $g = e^{-2u} g_0$ with

$$\sigma_k(g^{-1} \cdot S_g) = \text{const}? \tag{1}$$

Equation (1) is equivalent to

$$\sigma_k(\nabla^2 u + du \otimes du - \frac{1}{2}|Du|^2\, g_0 + S_{g_0}) = \text{const} \cdot e^{-2u} \tag{2}$$

Equation (2) is a fully nonlinear equation. Usually, such equations have no local estimates.

Our main results:

(1) Equation (2) does have C^2 local estimates in terms of $\inf u$. More precisely,
$$\|u\|_{C^2(B_{1/2})} \leq c,$$
where c depends only on $\inf_{x \in B_1} u$.

(2) If M is locally conformaly flat and $n > 2k$, then σ_k- Yamabe problem has an affirmative answer.

On the Geometric Approach to the Motion of Inertial Mechanical Systems

Adrian Constantin
(joint work with B. Kolev)

According to the action principle, the spatially periodic solution, of one-dimensional mechanical systems with no external forces are described in the Lagrangian formulation by geodesics on a manifold configuration space, the group D of smooth orientation - preserving diffeomorphisms of the circle. The periodic invariant Burgess equation

$$u_t + 3uu_x = 0$$

is the geodesic equation on D with the L^2 right-invariant metric. However, the exponential map for this right-invariant metric is not a local C^1 diffeomorphism and the geometric structure is therefore different. On the other hand, the geodesic equation on D for the H^1 right-invariant metric

$$u_t - u_{txx} + 3uu_x = 2u_x u_{xx} + uu_{xxx}$$

is a re-expression of the Camassa-Holmes model for shallow water waves. We show that the exponential map in this case is a C^1 local diffeomorphism and that if two diffeomorphisms are sufficiently close on D, they can be joined by a unique length-minimizing geodesic - a state of the system D transformed to another nearby state by a uniquely determined flow that minimizes the energy.

Recent Results on Wave Maps

Michael Struwe

For any complete Riemannian target manifold N of bounded curvature and without boundary, in joint work with Jala Shatah we show the existence of unique global solutions $u : \mathbb{R}^{1+m} \to N$ to the Cauchy problem for wave maps with initial data $(u, u_t)|_{t=0} = (u_0, u_1) \in H^3 \times H^{s-1}(\mathbb{R}^m_j TN)$ having small energy in the critical norm $s = \frac{m}{2}$, provided $m \geq 4$. Our proof proceeds by very direct estimates in physical (rather than frequency) space, using the refined Stricharts estimate of Keel-Tao for the linear wave equation.

Neckpinching in Mean Curvature Flow

Gerhard Huisken

(joint work with Carlo Sinestrari)

We consider closed, smooth hypersurfaces $M^n_t \subset \mathbb{R}^{n+1}$ moving by mean curvature, and study the structure of singularities under the assumption that the $(n-1)$st elementary symmetric function $\sigma_{n-1}(\lambda)$ of the principal curvatures is positive. It is shown that near a singularity in case one eigenvalue is near zero, the other eigenvalues of the 2nd fundamental form have to approach each other. This new a priori estimate is used to detect necks in the hypersurfaces just before the singularity occurs. It is shown that each such neck can be given a canonical parametrization with the help of constant mean curvature foliations along the neck and harmonic maps fixing the tangential parametrization. Finally it is shown that surgery can be performed on necks in such a way that the known a priori estimates for the flow remain valid after surgery.

Ginzburg-Landau Functional

H. Mete Soner

(joint work with R. Jerrard)

For $u \in H^1(\Omega; \mathbb{R}^2)$ we estimate the Jacobian $Ju = \det(Du)$ (vector of all 2×2 minors of Du) in terms of the GL functional:

$$| \int \Phi Ju| \leq \pi \left[\frac{\lambda}{\pi} \mu^\varepsilon_u(spt\, \Phi) \right] \|\Phi\|_\infty + \varepsilon^\alpha C(u) \|D\Phi\|_\infty, \forall \Phi \in C^\infty_c,$$

where α is a constant, $C(u)$ is a constant depending only on μ^ε_u and μ^ε_u is the scaled GL functional

$$\mu^\varepsilon_u(A) := \frac{1}{\ln(1/\varepsilon)} \int_A \frac{1}{2}|\nabla u|^2 + \frac{1}{4\varepsilon^2}(1 - |u|)^2)^2\, dx.$$

If for a sequence $\{u^\varepsilon\}_{\varepsilon > 0}$, $\sup_\varepsilon \mu^\varepsilon_{u^\varepsilon}(\Omega) < \infty$, then the above estimate together with an interpolation argument yields

$$Ju^\varepsilon \rightharpoonup J \quad \text{in } (C^{0,\beta})^* \quad \forall \beta > 0.$$

Moreover, J is a Radon measure which is rectifiable with integer multiplicity. We discuss applications of this estimate to evolution problems.

PDEs Involving Volume Preserving Maps

Yann Brenier

Euler equations of incompressible fluids are known to be the equations of geodesic curves along the group of volume preserving diffeomorphisms for the L^2 metrics. A good approximation class for volume preserving maps is made up of permutation matrices. From numerical experiments, the concept of generalized flow comes up in a natural fashion. Some results of a work published in CPAM, 1999, are reviewed.

2D Curvature Functionals as Γ-limits of 3D Nonlinear Elasticity

Gero Friesecke

Boundary Regularity for Nonlinear Elliptic Systems

Joseph Grotowski

We consider questions of boundary regularity for solutions of certain systems of second-order nonlinear elliptic equations. We obtain a general criterion for a weak solution to be regular in the neighbourhood of a given boundary point. The proof yields directly the optimal regularity for the solution in this neighbourhood. The result is new for the situation under consideration (general nonlinear second order systems in divergence form, with inhomogeneity obeying the natural growth conditions).

Deformation of C^0 Riemannian Metrics in the Direction of their Ricci Curvature

Miles Simon

We examine the evolution of non-smooth (C^0) Riemannian metrics by the dual Ricci harmonic map heat flow. Applications include evolution of 'metric spaces bounded from above and below' in the sense of Aleksandrov.

Vortices in the Ginzburg-Landau Model of Superconductivity

Etienne Sandier

(joint work with Sylvia Serfaty)

The Ginzburg-Landau functional writes, in the presence of a magnetic field

$$J(u,A) = \frac{1}{2}\int_\Omega |\nabla_A u|^2 + |h-h_e|^2 + \frac{K^2}{2}(1-|u|^2)^2$$

where $\Omega \subset \mathbb{R}^2$, $u:\Omega\to\mathbb{C}$, $A:\Omega\to\mathbb{R}^2$, $\nabla_A u = \nabla u - i\,u\,A$, $h = \text{culr}|A$ and $K, h_e \in \mathbb{R}_+$ are parameters.

Defining $H_{c_1} = \frac{\log K}{2\max_\Omega |\xi_0|}$, where $\xi_0 = h_0 - 1$ and h_0 solves

$$\begin{cases} -\Delta h_0 + h_0 = 0 & \Omega, \\ h_0 = 1 & \partial\Omega \end{cases}$$

We prove that for $h_e < H_{c_1} + c\log\log K$, the number of vortices for a minimizer of J in bounded independently of K.

Nonuniqueness for the Yang-Mills Heat Flow

Andreas Gastel

For the Yang-Mills heat flow in dimensions $5 \leq m \leq 9$, we find smooth initial connections ∇_n on the trivial bundle $\mathbb{R}^m \times \mathrm{SO}(m)$ such that the follo wing holds:

For every $n \in \mathbb{N}$, ∇n, when evolved by the Yang-Mills heat flow, develops a point singularity in finite time. After the point singularity, there are at least n different smooth continuations of the flow. Moreover, different continuations of the same flow can develop on different bundles (after the singularity), which can be proven for $m \in \{6, 8\}$.

Scaling Laws for the Cross-tie Wall

Felix Otto

This is joint work with A. deSimone, S. Müller and R. V. Kohn. By a combination of heuristic and rigorous analysis, we derive a scaling law for the periodicity w of the cross-tie wall in the material parameters d(exchange length), Q(anisotropy) and film thickness t. Starting point in the micromagnetic model, which is a nonconvex, nonlocal variational problem. Key ingredient is the identification of the specific energy of the Néel wall including the next order term.

Stokes Equations for Mixtures

Jens Frehse

We consider a stationary case of a model for mixtures of fluids, where the vorticity term is neglected. It reads (c. f. Rajagopal's book)

$$\begin{aligned} -\sum_k \mu_{ik} \Delta u^k &= -\nabla \varrho_i p + f \varrho_i \\ \operatorname{div}(\varrho_i u^i) &= 0, \quad \int \varrho \, dx = 1, \varrho \geq 0 \end{aligned}$$

Hypothesis: (μ_{ik}) positive definite, $f \in L^1 \cap L^\infty$, pressure law $p(\varrho) \sim \varrho^\gamma$, $\varrho = \sum \varrho_i$.

Theorem (in $\mathbb{R}^3$): $\exists$ solution $\varrho \in L^\infty$ $u \in H_0^{1,q}$, $q < \infty$. The case with Dirichlet boundary is treated via penalization, the zero boundary condition is formulated in the limit by a trace operator.

A PDE Approach to Singularities of Minimal Submanifolds

Leon Simon

This talk introduced a method for constructing new examples of minimal (i.e. zero mean curvature) hypersurfaces, based on the observation that a positive solution of the equation on a domain $\Omega \subset \mathbb{R}^n$

$$(*) \qquad \sum_{i=0}^{n} D_i \left(\frac{D_i u}{\sqrt{1 + |Du|^2}} \right) = \frac{m}{u\sqrt{1 + |Du|^2}}$$

has a "symmetric graph" $G \equiv \{(x, u(x)\omega) : x \in \Omega, \omega \in S^m\}$ which is minimal. Here $m \in \{1, 2...\}$ is given and $n \geq 2$.

A singular solution of $(*)$ is a function $u : \Omega \to \mathbb{R}$ which vanishes at at least one point and which is expressible, locally near each point of Ω, as the uniform limit of a sequence of positive solutions of $(*)$. The symmetric graph G of such a singular solution has singularities precisely where u vanishes, i. e. $\operatorname{sing} G = \{(x, 0) : x \in \Omega, u(x) = 0\}$.

Various properties of $(*)$ were discussed, including examples of singular solutions and the fact that graph solutions are automatically Hölder continuous with exponent $\frac{1}{2}$.

Edited by Ernst Kuwert

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