MATHEMATISCHES FORSCHUNGSINSTITUT OBERWOLFACH

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Geometry

27.09. - 03.10.1998

Organizers: Victor Bangert, Freiburg
Yurii D. Burago, St. Petersburg
Ulrich Pinkall, Berlin

The meeting has been attended by 48 geometers from England, France, Germany, Greece, Russia, Switzerland, USA. The talks covered a large variety of topics, with some emphasis on relations between surface theory and complex analysis. The style of the meeting differed in several respects from its predecessors:

- There were only a total of 20 talks leaving more time for informal collaboration.
- This interaction was facilitated by the posting of the research reports.
- There were two mini series of three and two one-hour talks, one on 'Quaternionic Line Bundles over Riemann Surfaces and Differential Geometry of Surfaces', the other on 'Characteristic Invariants of Hyperbolic Manifolds'.

Abstracts

FRANZ PEDIT

Quaternionic Line Bundles over Riemann Surfaces and Differential Geometry of Surfaces I, II, III

We present a new approach to the differential geometry of surfaces in $\mathbb{R}^3$ and $\mathbb{R}^4$ that treats this theory as a "quaternionified" version of the complex analysis and algebraic geometry of Riemann surfaces. (A reprint can be obtained from the documenta mathematica webpage www.mathematik.uni-bielefeld/documenta under the ICM volume.)

ISKANDER A. TAIMANOV

Non-formal simply connected symplectic manifolds

(Joint with I.K. Babenko)

We present the following result:

Theorem For any $N \geq 6$ there exists a non-formal simply connected symplectic manifold of dimension $2N$.

CHRISTIAN BÄR

The Dirac Operator on Hyperbolic Manifolds

We study the Dirac spectrum of hyperbolic manifolds. We show that if $M = H^n/\Gamma$ has finite volume, then the spectrum is either discrete or all of $\mathbb{R}$. It is a topological property of the spin structure which decides which of the two cases occurs. We see

- If $\dim M = 2$ or 3 and M has exactly one cusp, then the spectrum is discrete.
- $\dim M = 2$ and M has at least two cusps, then there is a spin structure such that spec $= \mathbb{R}$.
- If $M = S^3 - K$ is a link complement, then there exists a spin structure with spec $= \mathbb{R}$ iff K has two link components with odd linking number.
- If $\dim M = 2$ or 3 one can always choose the spin structure such that the spectrum is discrete.

In dimension 2 or 3 one can approximate open hyperbolic manifolds of finite volume by compact ones. In 2 dimensions the eigenvalues accumulate towards the continuous spectrum of the limit manifold. In 3 dimensions there is no accumulation because the spin structures with spec $= \mathbb{R}$ are not limits of spin structures on compact hyperbolic 3-manifolds.

TIM HOFFMANN

A Discrete Smoke Ring Flow

(joint work with U. Pinkall)

There is a strong link between integrable discretizations of surfaces described by integrable systems and their Bäcklund transformations. In particular, elementary quadrilaterals of the discrete surfaces arise in the Bianchi permutability for the continuous ones.

Out of a Bäcklund transformation for curves that is linked to the classical tractrix construction, we derive a discrete smoke ring flow for closed discrete curves. This leads to discrete Hashimoto surfaces. Moreover it is possible to view its spectral curve as the set of all closed Bäcklund transforms of it.

JÜRGEN BERNDT

Cohomogeneity One Actions on Riemannian Symmetric Spaces of Non-Compact Type

The cohomogeneity of an isometric Lie group action on a connected Riemannian manifold is the codimension of a principal orbit. We study the the classification problem up to orbit equivalence on Riemannian symmetric spaces of non-compact type. The only such space where a complete classification is known is the real hyperbolic space. We suggest the following approach.

Consider the Riemannian symmetric space $M = G/K$ of non-compact type as a solvable Lie group $S = AN$ equipped with some left-invariant Riemannian metric. Such a realization comes from the Iwasawa decomposition of the connected component G of the isometry group of M. Any cohomogeneity one action on M has either only principal orbits or exactly one singular orbit. Each Lie subalgebra with codimension one of the Lie algebra $\mathfrak{s} = \mathfrak{a}+\mathfrak{n}$ of S leads to a cohomogeneity one action on M without a singular orbit. Examples are provided by taking the orthogonal complement of any non-zero vector in $\mathfrak{a}$ or in the root space $\mathfrak{g}_\lambda$ of some simple root λ, or of a combination of two such vectors. Examples of such actions with a singular orbit arise from taking the orthogonal complement of a linear subspace V of $\mathfrak{g}_\lambda$, λ simple, dimension of $V \geq 2$, such that the centralizer of $\mathfrak{a}$ in K acts transitively on unit vectors in V. For instance, in the case of $SU(1,n)$ one may choose any linear subspace with constant Kaehler angle in $\mathfrak{g}_\lambda = \mathbb{C}^{n-1}$. This provides many examples of cohomogeneity one actions on complex hyperbolic space for which the singular orbit F is not totally geodesic, for which the image under the exponential map of any normal space of F is not totally geodesic, and for which F has globally flat normal bundle.

ANDREAS KOLLROSS

The Classification of Hyperpolar and Cohomogeneity One Actions on Compact Symmetric Spaces

An isometric action of a compact Lie group on a Riemannian manifold is called hyperpolar if there exists a flat section, i.e. a closed connected flat submanifold that meets all orbits orthogonally.

Examples for such actions are the isotropy actions of Riemannian symmetric spaces, which are a special case of the following construction. Let H and K be two symmetric subgroups of G. Then H acts hyperpolarly on the symmetric space G/K. Another type of example are cohomogeneity one actions on spheres and projective spaces which can be constructed from isotropy representations of rank two symmetric spaces.

We present a classification of the hyperpolar actions on the irreducible symmetric spaces of the compact type. The result is that, apart from the two types of examples mentioned above, there are seven exceptional hyperpolar actions of cohomogeneity one. The proof uses mainly the representation theory of compact Lie groups.

WILDERICH TUSCHMANN

Diffeomorphism Finiteness, Positive Pinching and Second Homotopy

We prove the following finiteness theorem: For any given numbers m, C and D, the class of simply connected m-dimensional closed smooth manifolds with finite second homotopy groups which admit a Riemannian metric with sectional curvature bounded in absolute value by $|K| \leq C$ and diameter uniformly bounded from above by D contains only finitely many diffeomorphism types. This implies that for given m, C and D, there exists a finite number of closed smooth manifolds E_i such that any simply connected closed m-dimensional manifold M admitting a Riemannian metric with sectional curvature $|K(M)| \leq C$ and diameter $\mathrm{diam}(M) \leq D$ is diffeomorphic to a factor space $M = E_i/T^{k_i}$, where $0 \leq k_i = \dim E_i - m$ and T^{k_i} acts freely on E_i. We show that for each natural number m and any $0 < \delta \leq 1$ there exists a positive constant $i_0 = i_0(m, \delta) > 0$ such that the injectivity radius of any simply connected δ-pinched compact m-dimensional Riemannian manifold with finite second homotopy group is uniformly bounded from below by $i_0(m, \delta)$. We sketch a proof of the fact that this last result is also true under the more general curvature assumptions of uniform Ricci instead of sectional curvature pinching, i.e., under the condition $0 < \delta \leq Ric$ and $K \leq 1$, and show by example that this result is optimal. Finally, by constructing sequences of uniformly pinched 7-dimensional Eschenburg spaces which collapse to a 4-dimensional Alexandrov space, we disprove a conjecture of Fukaya saying that any Hausdorff limit of a sequence of uniformly positively pinched simply connected manifolds with fixed dimension has codimension at most one.

ULRICH BREHM

A Universality Theorem for Realization Spaces of Maps

A *map* is a polyhedral complex on a closed orientable 2-manifold. A *polyhedral embedding* of a map M with vertex set V is a mapping $f : V \rightarrow \mathbb{R}^3$ such that each (abstract) polygon on M corresponds to a strictly convex polygon in $\mathbb{R}^3$ and no selfintersections occur.
Let $W = \{v_1, \ldots, v_5, w_1, \ldots, w_n\}$. A mapping $f : W \rightarrow \mathbb{R}^3$ is called *standard* if $v_1, \ldots, v_5$ are mapped onto a given fixed projective basis.
A *semialgebraic set* in $\mathbb{R}^n$ is a finite boolean combination of sets of the form $\{x \in \mathbb{R}^n | f(x) = 0, g(x) < 0\}$, where $f, g \in \mathbb{Q}[x_1, \ldots, x_n]$, $x = (x_1, \ldots, x_n)$.
Theorem For each semialgebraic set $P \subseteq \mathbb{R}^{3n}$ there exists a map M which contains only triangles and quadrangles with vertex set $V \supseteq W$ such that for each subfield $K \subseteq \mathbb{R}$ holds: An injective standard mapping $f : W \rightarrow K^3$ can be extended to a polyhedral embedding of M with $f(V) \subseteq K^3$ if and only if $(f(W_1), \ldots, f(W_n)) \in P$.

Corollaries

1. For each proper subfield K of the field of real algebraic numbers there is a map which can be polyhedrally embedded in $\mathbb{R}^3$ but not in K^3.
2. The realizability problem for maps in $\mathbb{R}^3$ is polynomial-time equivalent to the 'existential theory of the reals' and thus NP-hard.

Peter Buser

Numerical Methods in the Theory of Riemann Surfaces and Algebraic Curves

For compact Riemann surfaces S of genus $g \geq 2$ the Koebe Poincaré Uniformization Theorem states that there always exists a conformally equivalent hyperbolic metric on S. It is also well known that S is conformally equivalent to an algebraic curve C. The lecture is about numerical methods allowing to go from C to S using the computation of the conformally equivalent constant curvature -1 metric by solving PDE. Inversely the conformal capacities of hyperbolic geodesic polygons are computed numerically to obtain the algebraic curve via the period matrices and theta characteristics. The numerical tests lead to the discovery of numerous new examples in genus 2 which can be uniformized in exact form.

Conrad Plaut

Geometry and Groups

(Joint with V.N. Berestovskii and C. Stallman)

We present the notion of a "geometry" on a topological group as a semigroup of open neighborhoods of the identity with certain natural properties. Examples include the word metric on finitely presented groups, Carnot-Caratheodory metrics on Lie groups and valuations on fields. As a way to find geometries with curvature bounded below, we introduce a notion of covering group for a topological group - the construction of a universal cover involves an inverse limit of Malcev groups G_U. For locally compact, connected, locally connected metric groups, the universal cover factors as $L \times G_1 \times \ldots \times \mathbb{R}^\omega$, where L is a Lie group, G_i is a compact simple, simply connected group and ω is finite or countably infinite. Using suitable metrics on the Lie groups and a Hilbert space metric on a suitable subspace of $\mathbb{R}^\omega$, we can take the product metric and pass to the quotient G to get an invariant metric of curvature bounded below. We also presented some of the geometry of a weakly flat infinite torus.

Ruth Kellerhals

Characteristic Invariants of Hyperbolic Manifolds I, II

In this miniseries a report on the state of the art concerning the computation of characteristic invariants and especially volumes of hyperbolic manifolds is given.

In part I, we survey known results about minimal volume, volume estimates, covolumes of Coxeter simplex groups etc. in arbitrary dimensions ≥ 2.

In part II, we present new developments initiated by A. Goncharov, Neumann-Zagier, Bloch, Dupont and others. In this context, the volume of an oriented hyperbolic manifold of odd dimension $2n-1$ can be interpreted through the top-dimensional Borel class b_{2n-1} restricted to $SO(2n-1,1)$. Using difficult techniques Goncharov could find a representative for the Borel class in dimension 5 in terms of certain modified trilogarithms which led to a new structural result about the spectrum Vol_5 of 5-dimensional hyperbolic manifolds.

IVAN STERLING

A Symplectic Inertial Principle for General Relativity

This is joint work with G. Martin and P. Hewitt. We generalize special relativity to general relativity. The new ideas needed to solve the longstanding problem include: use space-time-momentum-energy as fundamental object, focus on the torsion of connections on this space, use symplectic geometry, extend the notion of a coordinate system via non-Heisenberg transverse foliations. Martin's Inertial Principle is $R(x_1, x_2)y = \kappa[PT(x_1), PT(x_2)]y$ (i.e. Mathematical Holonomy = Physical Holonomy). The PT's are boosts and commutators of boosts yield Thomas Precession. The equations yield the no preferred observer condition. For Einstein-de Sitter space we obtain a Doppler formula with a connection function.

THOMAS PÜTTMANN

Optimal Pinching Constants of Odd Dimensional Homogeneous Spaces

We compute the pinching constants of all homogeneous Riemannian metrics on the Berger space $M^{13} = SU(5)/(Sp(2) \times_{Z_2} S^1)$ and of all $U(2)$-biinvariant homogeneous Riemannian metrics on the Aloff-Wallach space $W_{1,1} = SU(3)/S^1_{1,1}$. We prove that the optimal pinching constants are precisely $\frac{1}{37} \approx 0.0270$ in both cases. So far M^{13} and $W_{1,1}$ were only known to admit Riemannian metrics with pinching constants $\frac{16}{29\cdot 37} \approx 0.0149$.
We also investigate the optimal pinching constants for the homogeneous metrics on the other Aloff-Wallach spaces $W_{k,l} = SU(3)/S^1_{k,l}$. In fact, our computations cover the class of T^2-biinvariant homogeneous Riemannian metrics. This class contains all homogeneous Riemannian metrics unless $k/l = 1$, however, in the case of $W_{1,1}$ it does not represent the entire moduli of homogeneous metrics. It turns out that the optimal pinching constants are given by a strictly increasing function in $k/l \in [0, 1]$. In particular, all the optimal pinching constants are $\leq \frac{1}{37}$.
In order to determine the extremal values of the sectional curvature of a homogeneous Riemannian metric on $W_{k,l}$ we employ a systematic technique, which can be applied to other spaces as well. The computation of the pinching constants for M^{13} is reduced to the curvature computation for two proper totally geodesic submanifolds. One of them is diffeomorphic to $\mathbb{C}P^3/\mathbb{Z}_2$ and inherits an $Sp(2)$-invariant Riemannian metric, and the other is $W_{1,1}$ embedded as recently found by Taimanov. This approach explains in particular the coincidence of the optimal pinching constants for $W_{1,1}$ and M^{13}.

ROB KUSNER

Parabolicity of Minimal Surfaces in $\mathbb{R}^3$

A finite topology Riemann surface is parabolic if its ends are conformal to punctures. This is equivalent to a Liouville property, and also to the fact that Brownian motion is recurrent. A classical theorem of Ossermann asserts that a complete, finite total curvature minimal surface in three space is parabolic. A more recent result of Collin shows that a properly embedded minimal surface in three space with finite topology and more than one end has finite total curvature; thus it is also parabolic.

For Riemann surfaces with infinite topology (infinite genus or an infinite number of ends) the various notions of parabolicity are no longer equivalent. Nevertheless, it turns out that properly embedded minimal surfaces with more than one end are again parabolic, in the sense that Brownian motion is recurrent. In a certain sense this result is sharp.

We shall discuss some of the geometric and topological consequences for minimal surfaces in our talk. (This is joint work with Bill Meeks, Pascal Collin and Harold Rosenberg.)

WILHELM KLINGENBERG

Real Hypersurfaces in Kähler manifolds

We investigate the geometry of the maximal complex subbundle HN of the real tangent bundle of a real hypersurface N. In particular we prove that strict pseudoconvexity and the condition that the sum L of those eigenvalues of the second fundamental form of N in $\mathbb{C}^n$ that correspond to HN is constant imply that N is the metric sphere. In joint work with G. Huisken, we consider an evolution of N in the direction of the real normal and with speed L. This gives rise to a weakly parabolic system of PDE for which we prove local existence and a result that is particular to $\mathbb{C}^2$: If N^3 is a hypersurface in $\mathbb{C}^2$, compact and weakly pseudoconvex, than the evolution immediately leads to strictly pseudoconvex hypersurfaces.

References:

W. Klingenberg: Real hypersurfaces in Kähler manifolds, 1997.

G. Huisken, W. Klingenberg: Flow of real hypersurfaces by the trace of the Levi form, 1998.

CHRISTOPH HUMMEL

Convex Hulls in Singular Spaces of Negative Curvature

(C. Hummel, U. Lang, V. Schroeder)

We give a simple example of a complete CAT(-1)-space containing a set S with the following property: The boundary at infinity $\partial_\infty CH(S)$ of the convex hull of S differs from $\partial_\infty S$ by an isolated point. However, if CH is replaced by some notion CH_a of 'almost convex hull', the we have that $\partial_\infty S = \partial_\infty CH_a(S)$ for any subset S of a complete CAT(-1)-space.

HANS-BERT RADEMACHER

Twistor Spinors

This is a report on joint work with *Wolfgang Kühnel (Stuttgart).* We consider Riemannian spin manifolds carrying twistor spinors with zeroes and we assume that the manifold is not conformally flat. These twistor spinors are conformal analogues of parallel spinors outside their set of zeroes. Based on the Berger–Simons holonomy classification we characterize these manifolds. In particular the dimension n of the manifold is even or $n = 7$. Outside the set of zeroes of the twistor spinor the metric is conformal to a Ricci flat and asymptotically Euclidean metric. We give examples in all even dimensions.

KARSTEN GROSSE-BRAUCKMANN

Constant mean curvature surfaces with three ends

(K. Grosse-Brauckmann, R. Kusner, J. Sullivan)

Almost embedded constant mean curvature (CMC) surfaces of finite topology are classical with less than three ends (the 2-sphere or the Delaunay unduloids of revolution), and known to exist for each number of ends larger than three with any genus by work of Kapouleas. The case of almost embedded CMC surfaces with three ends and genus 0 is particularly interesting in view of the trousers decomposition of surfaces. The generalized Alexandrov reflection method of Korevaar, Kusner, Solomon, shows these surfaces always have a plane of reflection. We exploit this property to classify their moduli space with an open 3-ball, using methods of Lawson and Karcher. Our classifying map is in terms of asymptotic data. As a further result we show no two surfaces can have the same asymptotic data. The maximum principle gives this uniqueness statement.

Our main theorem is that the moduli space of the CMC surfaces with three ends and genus 0 is homeomorphic to the open three-ball. Essentially, we use a continuity method to derive this result. While closedness follows from known a priori estimates, openness is a consequence of our uniqueness result and the structure of real analytic varieties. In fact, in general the moduli spaces of almost embedded CMC surfaces form real analytic variety, as was proven by Kusner, Mazzeo, Pollack.

Except for cases accessible to ODE methods, we are not aware of many other geometric variational problems which allow a similar complete analysis.

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