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Niedrigdimensionale Topologie
07.09-13.09.1997

Mathematisches Forschungsinstitut Oberwolfach

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Tagungsbericht

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The conference was organized by M. Boileau (Toulouse), K. Johannson (Knoxville) and H. Zieschang (Bochum). Of the 47 participants, 19 gave a lecture.

This conference has shown once more to what extent Thurston's geometrization results have changed the field of 3-dimensional topology. Roughly speaking, his results say that large classes of 3-manifolds (the conjecture is that all) can be cut along incompressible tori such that every arising piece can be endowed with a geometric structure of one of the eight 3-dimensional geometries. (This decomposition is due to Jaco/Shalen and Johannson and often referred to as JSJ-decomposition.) This has shifted much focus to the study of hyperbolic 3-manifolds, the least understood class of geometric 3-manifolds, which was apparent from the majority of talks.

Another very interesting development, namely the use of ideas from 3-dimensinal topology in group theory, has been exemplified by a talk of M.J. Dunwoody. He showed how ideas from the theory of 3-manifolds have helped to understand codimension one f.g. virtually Abelian subgroups of f.g. groups.

Many other topics were touched in the remaining talks. Particularly noticable was the lecture by A. Zastrow who indicated how to prove the fundamental fact that subset of $\mathbb{R}^2$ are aspherical, a result that is easy to believe but in fact hard to prove.

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Vortragsauszüge

Title: Immersed surfaces in hyperbolic 3-manifolds
Speaker: M. Baker (joint work with D. Cooper)

Let M be a compact, orientable 3-manifold with hyperbolic interior and a torus boundary. A slope on ∂M is an isotopy class of loops, α, on ∂M. The slope α is said to be an embedded boundary slope (EBS) (resp. immersed boundary slope (IBS)) if M contains an embedded (resp. immersed) essential surface F such that ∂F consists of simple loops parallel to α.

A well-known theorem of A. Hatcher implies that are only finitely many EBS on ∂M. We show, however, that M can have infinitely many IBS. We prove:

Theorem *Suppose there exists a finite cover $\tilde{M} \to M$ such that*

(1) α lifts to a loop, $\tilde{\alpha}$, on one torus, T', of $\partial \tilde{M}$.

(2) There exists a surface $F \hookrightarrow \tilde{M}$ such that $\partial F \cap T'$ consists of loops parallel to $\tilde{\alpha}$.

(3) F is not the fiber of a fibration of $\tilde{M}$.

Then α is an IBS.

Using this result we show that in the case of the figure-eight knot complement, every slope of the form $2p/q$ is an IBS. Recently J. Maker used the above theorem and Thurston norm arguments to show that if M is a once-punctured torus bundle or a 2-bridge knot complement, then all slopes on ∂M are IBS. This leads us to conjecture that if M is a compact orientable 3-manifold with hyperbolic interior and torus boundary, then infinitely many slopes on ∂M are IBS. The hyperbolic structure on M is essential, since a compact Seifert fibered 3-manifold with boundary an incompressible torus has only two IBS.

Title: Boundaries of Hyperbolic Groups
Speaker: B. H. Bowditch

In this talk, we give a topological characterisation of hyperbolic groups as uniform convergence groups. More precisely:

Theorem *Suppose that M is a perfect metrisable compactum, and that Γ acts as a uniform convergence group on M. Then, Γ is hyperbolic. Moreover, there is a Γ-equivariant homeomorphism from M to the boundary, $\partial\Gamma$, of Γ.*

The notion of convergence group was introduced by Gehring and Martin, and has been much studied by Tukia and others. If Γ acts by homeomorphism on a compactum, M, we say that it is a "convergence group" if the induced action on the space of distinct triples of M is properly discontinuous. We say that it is "uniform" if the action on triples is also cocompact. Gromov observed, in his original article on hyperbolic groups, that a hyperbolic group acts a uniform

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convergence group on its boundary. The converse, given above, remained an open problem for some time.

The definition of a convergence is more commonly phrased in an equivalent dynamical form — in terms of convergence subsequences. It was shown independently by Tukia and myself that uniform convergence groups can be similarly characterised as those convergence groups for which every point of M is a conical limit point. The above results therefore make explicit a relationship between dynamical and geometric hyperbolicity.

Title: Characteristic Submanifold Theory and Dehn Filling.
Speaker: S. Boyer (joint work with Marc Culler, Peter Shalen, and Xingru Zhang)

The characteristic submanifold theory of Jaco-Shalen and Johannson is applied to study the topology of Dehn fillings of a hyperbolic manifold. Consider an essential surface F properly embedded in a compact, connected, orientable 3-manifold M whose interior admits a complete hyperbolic metric of finite volume and whose boundary is a torus. Assume that $\partial F \neq \emptyset$. We call F a *generalized fibre* if either it is a fibre of some realization of M as a surface bundle over S^1 or it splits M into two twisted I-bundles.

Let P be a polyhedron. An *essential homotopy of length* $n > 0$ in (M, F) of a function $f : P \to F$ is a homotopy $H : P \times [0, n] \to M$ satisfying

- $H(x, 0) = f(x)$ for each $x \in P$;
- H is transverse to F and $H^{-1}(F) = P \times \{0, 1, \ldots, n\}$;
- For each $i = 1, 2, \ldots, n$, $H|(P \times [i-1, i], P \times \{i-1, i\})$ is not homotopic as a map of pairs into (F, F).

Theorem 1. *Suppose that F is not a generalized fibre and that $f : P \to F$ is such that $f_{\#}(\pi_1(P))$ is non-abelian. If f admits an essential homotopy of length $n > 0$, then $n \leq 2$ rank $(H_1(F)) - 1$.* □

This result is then applied to study Dehn filings of M. Assume that the curves of ∂F have slope r_0.

Theorem 2. *If $\Delta(r, r_0) \geq 10 + \frac{10}{m}(2g-1)$ then $\pi_1(F)$ includes into $\pi_1(M(r))$.* □

Theorem 2 is used to investigate exceptional fillings of M which yield small Seifert spaces (i.e. manifolds which admit a Seifert structure whose base orbifold is of the form $S^2(p, q, r)$ where $p, q, r \geq 1$). An example of what can be proved is contained in the following result.

Theorem 3. *Suppose that $M(r)$ is a small Seifert manifold. If $M(r_0)$ is reducible but neither $S^1 \times S^2$ nor $\mathbf{R}P^3 \# \mathbf{R}P^3$, then $\Delta(r, r_0) \leq 6$.* □

Title: The Algebraic Annulus and Torus Theorems
Speaker: M.J. Dunwoody (joint work with E. Swenson)

Let G be a finitely generated group and let J be a subgroup of G. Let X be a cell complex on which G acts freely and cocompactly, e.g. X could be the Cayley

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graph of X with respect to a particular finite generating set. We say that J has codimension one in G if the quotient $J\backslash X$ has more than one end. For example any rank $n-1$ subgroup of a rank n free abelian group has codimension one, and any infinite cyclic subgroup of an infinite triangle group has codimension one.

We classify the structure of finitely generated groups with codimension one finitely generated virtually abelian subgroups. In particular we have the following result.

The Algebraic Annulus Theorem. *Let G be a one-ended finitely generated group and let $J < G$ be a two-ended subgroup of G. If J has codimension one then one of the following is true.*

1. *G splits over a subgroup commensurable with J.*
2. *G is an extension of a finite group by a closed orbifold group. Thus G acts properly discontinuously by isometries on either the hyperbolic or Euclidean plane.*
3. *There is a finite graph of groups decomposition for G in which there is a vertex group H such that $J < H$ with H a finite-by-orbifold group and in which the edge groups are peripheral subgroups of H. In this case H acts properly discontinuously by isometries on the hyperbolic plane.*

The above results generalize well-known results for three manifolds.

Title: Branched covers, equations in free groups and coincidence theory
Speaker: D. Goncalves (joint work with H. Zieschang)

Given a pair of continuous maps $(f_1, f_1) : M \to N$ among two oriented compact manifolds of the same dimension we say that (f_1, f_2) has the Wecken property if $N(f_1, f_2) = \#coin(f_1', f_2')$ for some pair of maps (f_1', f_2') homotopic to (f_1, f_2) respectively where $N(f_1, f_2)$ is the Nielsen coincidence number and $\#coin$ is the number of coincidence points.

Let f_2 be the constant map denoted by c and M, N compact orientable surfaces. We consider the open question to classify which pairs (f, c) have the Wecken property and we also study the solution of certain quadratic equations in free groups which is related with the Wecken property.

We solve completely the Wecken property question. More precisely we proof the following

Theorem *Let $f : S_h \to S_g$ be a map such that $f_\#(\pi_1(S_h)) \subset \pi_1(S_g)$ is a subgroup of index l. Then*

a) (f, c) does not have the Wecken property if $|deg\ f| > \dfrac{2h-2+l}{2g-1}$.

b) (f, c) satisfies the Wecken condition if $|deg\ f| \leq \dfrac{2h-2+l}{2g-1}$.

Part a) of this result is obtained using some formula similar to Kneser's formula, but for maps among compact surfaces with boundaries, which takes the

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boundary into the boundary. The proof of part b) is obtained by constructing branched covers $f : S_n \to S_g$ with a certain number of branched points together with the order of the pre-image of such points and the degree of the branched map. We first construct the case where f is primitive, that is that $f_\#$ is surjective, and then the other cases.

Finally we consider the question of the existence of solutions of certain quadratic equations in the free group on $2g$ generators F_{2g} and also the question of describing all solutions when they exist. More precisely consider the equation: $[z_1, z_2]...[z_{2h-1}, z_{2h}] = (B^{w_1})^{d_1}...(B^{w_l})^{d_l}$ where $B = [a_1, b_2]...[a_g, b_g]$ and a_i, b_i $i = 1, ..., g$ is a set of free generators. We use the fact that the Wecken property problem is equivalent to the existence of a solution of such a quadractic equation and derive some results about solutions of such equations. Further, we provide an inductive method to construct explicit solutions of some equations of the above type.

Title: An orientation for the SU(2)-representation spaces of knot groups – applications and examples
Speaker: M. Heusener

Let $k \subset S^3$ be a knot and let X be its exterior. The fundamental group $\pi_1(X)$ is denoted by G.

A representation of G in SU(2) is by definition a homomorphism $\rho : G \to \mathrm{SU}(2)$. The space of equivalence classes of non-abelian representations is denoted by $\widehat{R}(X)$ i.e

$$\widehat{R}(X) = \hom(\pi_1(X), \mathrm{SU}(2))^{\text{irred.}} / \sim .$$

Here two representations are called equivalent ($\sim$) iff they differ by an inner automorphism of SU(2).

The aim of the talk was to present a construction which makes it possible to orient the the space $\widehat{R}(X)$ (in a generic situation). This construction is motivated by Casson's invariant. The Heegaard splitting will be replaced by a plat decomposition of X.

Explicit examples and application have been discussed.

Title: Geometry of configuration spaces
Speaker: S. Kojima (joint work with H. Nishi and Y. Yamashita)

A purely combinatorial compactification of the configuration space of $n\,(\geq 5)$ distinct points in the real projective line was introduced by M. Yoshida. Converting each configuration to an equiangular polygon by Schwarz-Christoffel formula in complex analysis, and applying Thurston's method described by Kojima, we hyperbolize the configuration space so that it will be a real hyperbolic cone-manifold of finite volume with dimension $n - 3$. It is regarded as a totally real sub-cone-manifold of a completion of the configuration space over not real but the complex projective line in by Thurston.

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The case $n = 6$, in which we obtained a nonsingular hyperbolic 3-manifold with ten cusps, will be discussed in more details. In particular, we show that a conversion of each configuration to a hexagon with fixed but not necessarily equal angles creates a Dehn filled resultant of the original manifold, and that a 5 dimensional freedom of conversions injects to the space of hyperbolic Dehn fillings at least locally.

Title: On the geometry of 3-manifold groups
Speaker: B. Leeb (joint work with M. Kapovich)

Our main result states that the canonical decomposition (i.e. the Jaco-Shalen-Johannson splitting) of the fundamental group of a Haken 3-manifold with boundary of zero Euler characteristic is preserved by quasi-isometries. As a byproduct of our proof we describe all 2-quasiflats (i.e. quasi-isometric embeddings of $\mathbb{R}^2$) into these groups.

Our proof relies on the close relation between Haken manifolds and nonpositive curvature: A Haken manifold M with incompressible boundary admits a metric of nonpositive sectional curvature and totally geodesic boundary if (but not only if) the boundary of M is non-empty or an atoroidal component occurs in the JSJ-decomposition of M. Moreover, if M does not admit a geometric structure (in Thurston's sense) then the universal cover of M is bilipschitz homeomorphic (and therefore in particular quasi-isometric) to the universal cover of a nonpositively curved Haken manifold. The latter may be viewed as a (very) weak geometrisation statement on the level of fundamental groups, namely that Haken manifold fundamental groups are generically nonpositively curved in the following sense: They are quasi-isometric to Nil, Sol, or to a nonpositively curved space.

As an application we show that the large scale geometry of a finitely generated group G contains the information whether G is (a finite extension of) the fundamental group of a non-geometric Haken (orbifold).

Title: On the kernel of the Casson invariant
Speaker: C. Lescop

We prove: Any two homology 3-spheres with the same Casson invariant can be obtained from one another by surgery on a boundary link each component of which has trivial Alexander polynomial.

Title: Chern-Simons invariants of hyperbolic manifolds via coverings
Speaker: M. T. Lozano (joint work with H. Hilden and J.M. Montesinos)

In this talk a method to compute the volume and the Chern-Simons invariant of any hyperbolic manifold M obtained as a covering of a hyperbolic orbifold N is explained. The result is achieved from a simple formula involving the volume

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and the Chern-Simons invariant of the orbifold N, and the monodromy of the covering map. The covering, in this case, is always a virtually regular covering. We give also examples of different hyperbolic manifolds with the same volume, whose Chern-Simons invariants (mod 1/2) differ by a rational number, as well as a pair of different hyperbolic manifolds with the same volume and the same Chern-Simons invariants (mod 1/2).

Title: Heegaard splittings of 3-manifolds
Speaker: M. Lustig (joint work with Y. Moriah)

Every Heegaard splitting of genus g of a 3-manifold M can be *stabilized* canonically to give a Heegaard splitting of genus $g+1$. Any two Heegaard splittings of M become isotopic after sufficiently many stabilizations. Thus the set of Heegaard splitting of M (up to isotopy) carries a natural structure as a 1-ended tree, with vertices stratified by the genus of the corresponding splitting.

In the talk we will discuss the structure of this tree for various classes of 3-manifolds. In particular we will consider irreducible Heegaard splittings, i.e. vertices of the tree with valence 1 (assuming M is irreducible). We will exhibit large numbers of 3-manifolds with such splittings of arbitrarily high genus. However, we can show that for all 3-manifolds where such irreducible splittings are known which are not of minimal genus, then these have distance 1 from the "trunk" of the tree. This brings us to the following open problem:

Question: Do there exist vertices of the Heegaard tree on the same stratum, which have distance bigger than 2 ?

It follows from our results that examples of this type should, if ever, occur only at the "roots" of the tree. We will give some necessary conditions for the occurrence of such examples, and present some likely candidates.

Title: Branched standard spines and contact structures on 3-manifolds
Speaker: C. Petronio (joint work with R. Benedetti)

We consider the problem of existence and uniqueness of contact structures on a closed oriented 3-manifold M inducing a given characteristic foliation on a branched standard spine P of $N = M \setminus B^3$, in particular when P is a flow-spine for M (see [Benedetti-Petronio, Lecture Notes in Math. 1653, Springer-Verlag, 1997] for the appropriate definitions). We first prove that there is no smooth intrinsic universal model of a neighbourhood of P in M, therefore no local uniqueness result can hold. Despite this, by restricting to an open dense subset of the set of all foliations, we prove the following result.

Theorem *Let P be an abstract branched standard spine of N, and let $\mathcal{F}$ be a foliation on P satisfying the following assumptions: there are finitely many singularities of $\mathcal{F}$, none of these singularities lies on the singular set $S(P)$ of P, all the singularities have non-zero divergence, and there are finitely many simple*

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tangency points between $\mathcal{F}$ and $S(P)$, all of which are away from the vertices of P. Let $i : P \hookrightarrow M$ be an embedding. Then the set:

$$\mathcal{C}(P,\mathcal{F}) := \Big\{[\xi] : \ \xi \text{ induces } i_*(\mathcal{F}) \text{ on } i(P)\Big\}$$

(where $[\xi]$ denotes the isotopy class of a contact structure ξ on M), is non-empty and independent of i, and it contains at most one **tight** *contact structure, also independent of i. If the divergence of $\mathcal{F}$ is positive at all singularities and P is a flow-spine of M, then $\mathcal{C}(P,\mathcal{F})$ contains contact structures which belong to the homotopy class carried by P; the tight structure, if any, lies in this class.*

Title: On Thurston's orbifold conjecture
Speaker: J. Porti (joint work with M. Boileau)

Theorem (Thurston). *Let M^3 be an orientable, irreducible, closed and geometrically atoroidal three-manifold. If there is a finite group G of orientation preserving diffeomorphisms such that*

$$\Sigma_G = \{x \in M^3 \mid \mathrm{Stab}_G(x) \neq \emptyset\}$$

is a nonempty submanifold, then M^3 admits a G-invariant geometric structure.

In 1982 Thurston announced this theorem and gave the main ideas of the proof (without the assumption that Σ_G is a submanifold, but just nonempty). Since then, several authors have given some details. With Boileau, we give a new approach to the last step, the collapsing of cone manifolds, that completes the proof of this theorem.

Title: Cyclic coverings of hyperbolic knots and hidden isometries
Speaker: M. Reni

Let M be a hyperbolic 3-manifold which is a n-fold cyclic branched covering of a hyperbolic link L in the 3-sphere. We say that M has no hidden symmetries if the isometry group of M is the lift of (a subgroup of) the isometry group of the link. It follows from Thurston's hyperbolic surgery theorem that M has no hidden symmetries if n is sufficiently large. We give a constant, in terms of the volume of the complement of L, such that M has no hidden symmetries for all n larger than this constant. We give also some results on the possible orders and the structure of the isometry groups of M.

Title: Hakeness and b_2
Speaker: A. Reznikov

1.we use the technique of quasifuchsian surfaces to give a new proof of the recent theorem of Freedman-Cooper-Long.

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2. We define tight knots and show that ramified coverings over tight knots have π_1-injective surfaces.

Title: 4-manifolds which behave like 3-manifolds
Speaker: J.H. Rubinstein (joint work with I.R.Aitchison)

Aspherical 4-manifolds appear to share many properties in common with 3-manifolds. Many examples can be constructed of such 4-manifolds which admit immersed π_1 injective aspherical 3-manifolds. Other important properties are solvability of the word problem in the fundamental groups, having universal covering by Euclidean 4-space and having Cat(0) structures. It is well known (Davis) that aspherical 4-manifolds can have universal covers with many ends at infinity which are therefore not Euclidean 4-space. Also general 4-manifolds have unsolvable word problem (Markov). Basic constructions include polyhedral metrics of non-positive curvature, non-positively curved and combinatorial versions of Gromov-Thurston Dehn filling, Coxeter groups in hyperbolic 4-space and hierarchies and Haken 4-manifolds. The latter class of 4-manifolds have many properties of 3-manifolds, including a system of embedded π_1 injective 3-manifolds, solvable word problem, universal covering by Euclidean 4-space, tameness of ends and a characteristic variety theorem. The latter result is that there is a maximal compact submanifold V bounded by π_1 injective flat 3-manifolds, so that any immersed π_1 injective flat 3-manifold can be homotoped into V. A completely new proof of Dehn's lemma and the loop theorem for 3-manifolds was also given, using a principle called localisation of Dehn's lemma, related to properties of hierarchies. This is the key to the structure of Haken 4-manifolds. No covering space theory is needed in this approach.

Title: A survey of some invariants of knotted graph
Speaker: J. Sawollek

Let G be a topological graph (= 1-dimensional cell complex) embedded into 3-space $\mathbb{R}^3$. The following invariants of graph embeddings and their diagrams are introduced and discussed:

1. subgraphs of G
2. fundamental group of $\mathbb{R}^3 \backslash G$ and derived invariants, e.g. Alexander polynomials and p-colourings of graph diagrams
3. replacing vertices of G with tangles
4. polynomial invariants arising from knot polynomials, e.g. the Kauffman bracket
5. finite type (Vassiliev) invariants

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Some applications of these invariants are given, e.g. a "generalized Tait conjecture" can be proved: an alternating and reduced diagram of a 4-regular graph in $\mathbb{R}^3$ has minimal crossing number.

Title: $t(K_1 + ... + K_n) \geq n$
Speaker: M. Scharlemann (joint work with J. Schultens)

An important geometric knot invariant is the "tunnel number" $t(K)$, defined as the minimal number of arcs which need to be attached to the knot $K \subset S^3$ before a regular neighborhood has complement a handlebody (i. e. is unknotted). An equivalent definition is that $t(K)$ is one less than the Heegaard genus of the manifold $S^3 - K$. By posing the problem this way, it becomes accessible to new techniques appearing in the theory of Heegaard splittings. In particular, by comparing the decomposing annuli of the knot complement of a sum of knots with the "untelescoping" of the Heegaard splitting, in the sense of Scharlemann-Thompson, we deduce that $t(K_1 + ... + K_n) \geq n$. In particular, this solves problem 1.70B on the new Kirby problem list.

Title: All subsets of $\mathbb{R}^2$ are aspherical
Speaker: A. Zastrow

The talk was essentially about how to tackle possible very pathological subspaces of $\mathbb{R}^2$ in order to prove the result stated in the title. Amongst the techniques involved is the construction of "word sequences" which provide an infinite combinatorial system to describe all paths in our subspace of consideration. In addition, they allow us to choose a minimal representative even for those homotopy classes that cannot be represented by rectifiable paths. These minimal representatives of relative homotopy classes of non-closed paths then enable us to define a contraction of an arbitrary continuous image of a sphere which is the desired result.

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