MATHEMATISCHES FORSCHUNGSINSTITUT OBERWOLFACH

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Four-Dimensional Manifolds

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The meeting was organized by
Simon Donaldson (Oxford)
M.Kreck (Bonn/Mainz)
Ron Stern (Irvine)

The conference was attended by about 50 participants from Europe, East Asia, and USA. The program focussed on the most active area in the theory of 4-manifolds. This was clearly gauge theory, where a very lively development is still going on. It was good luck for the conference that some of the talks presented particularly interesting and very new results. The atmosphere was very stimulating and the program left enough time for discussions which was extensively used by the participants.

Vortragsauszüge

D.Austin (joint work with P.Braam)
Equivariant Floer Theory And Gluing Donaldson Invariants

We are interested in extending the interpretation of Donaldson-Floer theory as a topological quantum field theory to allow one to split open 4-manifolds along rational homology 3-spheres. This means three things: to rational homolgogy 3-spheres, we must assign some groups (our extension of Floer homology) with a natural pairing which is formally Poincaré duality. Furthermore, there must be relative Donaldson invariants for 4-manifolds with boundary which take values in the Floer groups of the boundary.

We are motivated by two observations: first when splitting a moduli space along a reducible connection, it is most natural to work with the framed moduli space which may be written as a fibered product. Also, the μ map doesn't extend across the reducibles as a map into cohomology. Instead, it is best considered as a map into the equivariant cohomology of the space of framed connections on the 4-manifold. This leads us to consider the equivariant cohomology of the space of framed connections on the 3-manifold. Using Morse-Bott theory, one builds equivariant cohomology and homology groups which pair together naturally. One defines relative Donaldson invariants by integrating over the fibration which restricts an instanton on the 4-manifold with boundary to its value on the boundary. This theory extends the ordinary Floer theory for homology 3-spheres. Furthermore, the module structure on equivariant cohomolgy leads to a natural description for evaluating the 4-dimensional class in the Donaldson invariant. One also sees how the moduli spaces can interact cohomologically when there are reducible instantons on one side.

S.Bauer
Diffeomorphism Types Of Elliptic Surfaces Of Geometric Genus 1

From the work of Friedman and Morgan it is known that Donaldson's polynomial invariants in the case of elliptic surfaces with geometric genus $p_g \geq 1$ are polynomials in the intersection form Q of the surface and in a primitive class $\kappa \in H^2(S; Z)$, which is a rational multiple of the canonical divisor of the surface S. The leading coefficient also had been determined.

The talk now is on a computation of the second but leading term in this polynomial. This computation uses the algebro-geometric moduli space of Gieseker semistable torsion free sheaves on the elliptic surface and a universal sheaf on it. The result leads to a complete diffeomorphism classification of the elliptic surfaces of geometric genus one. The same result was also obtained by Morgan and O'Grady.

R. Fintushel

Surgery In Cusp Neighborhoods

In this lecture I spoke about joint work with Ron Stern. Its goal is the explanation of how the Donaldson polynomial invariant changes under log transform. It turns out that under reasonable hypotheses, this change is simple and predictable — furthermore it is independent of the existence of an elliptic fibration. It is rather a topological phenomenon measuring the change in the order of the fundamental group of a neighborhood of a PL embedded non-locally flat 2-sphere called a *cusp*. More precisely, we define a cusp in a 4-manifold to be a PL embedded 2-sphere of self-intersection 0 with a single nonlocally flat point whose neighborhood is the cone on the right-hand trefoil knot. (This agrees with the notion of a cusp fiber in an elliptic surface.) The regular neighborhood of a cusp in a 4-manifold is the manifold N obtained by performing 0-framed surgery on trefoil knot in the boundary of the 4-ball. This is a *cusp neighborhood*. Since the trefoil knot is a fibered knot with a genus 1 fiber, N is fibered by tori with one singular fiber, the cusp. One can perform the topological equivalent of a p-log transform on a regular torus fiber in N. This is called this a *p-surgery in the cusp neighborhood* N. I described the proof of:

Theorem. Let X be a simply connected 4-manifold containing a cusp F. Suppose $\pi_1(\partial N) \to \pi_1(X \setminus F) \cong \mathbf{Z}_q$ is surjective, and that q and $p \neq 0$ are relatively prime. Then the result X_p of a p-surgery in a cusp neighborhood of F is simply connected. If X has an $SU(2)$ Donaldson invariant q_X of degree d and if each of $z_1, \dots, z_d \in H_2(X;\mathbf{Z})$ has trivial intersection with F then

$$q_{X_p}(z_1, \dots, z_d) = p \cdot q_X(z_1, \dots, z_d).$$

With some added minor technical assumptions, this also holds for $SO(3)$ polynomial invariants if we assume that w_2 of the corresponding bundle evaluates trivially on $[F]$.

The key observation is that if N is a cusp neighborhood and N_p is the result of p-surgery in N, then $\pi_1(N) = 1$, but $\pi_1(N_p) = \mathbf{Z}_p$. The Donaldson invariant detects this change in the fundamental group near the cusp. This is seen by using a Mayer-Vietoris argument to compute the Donaldson invariant. For this, the thesis of T. Mrowka and the recent work of Morgan, Mrowka, and Ruberman on L^2 moduli spaces is instrumental.

This result can be applied to the following problems:

1. Which simply connected algebraic surfaces are homotopy equivalent to noncomplex irreducible 4-manifolds? In particular, are minimal surfaces of general type homeomorphic to noncomplex irreducible 4-manifolds?
2. Is each irreducible simply connected 4-manifold with $H_2 \neq 0$ homotopy equivalent to an algebraic surface?

Pointing toward the answer to (1) we prove:

Theorem. Each of the following classes of surfaces of general type have in their homotopy types infinite families of simply connected 4-manifolds which admit no complex structure with either orientation:

double branched covers of $\mathbf{CP}^2$

complete intersections

Moishezon surfaces and Salvetti surfaces

In answer to (2) we have

Theorem. There exist simply connected irreducible 4-manifolds which are not homotopy equivalent to any complex surface.

Examples of this type are formed by taking 'fiber sums' of spin surfaces of general type with spin elliptic surfaces. "Irreducibility" results by proving the existence of a nonzero Donaldson invariant.

K.Fukaya

Floer Homology For 3-Manifold With Boundary

§ 0 Introduction

G.Segal proposed to consider the following program to define a new 2-3 dimensional topological field theory, where the associated invariant for 3-manifold is a Floer homology.

Associate a Category $C(\Sigma)$ to each surface Σ. If M is a 3-manifold which bound Σ, then find a relative invariant $I(M)$ which is a object of $C(\Sigma)$. Suppose that $\partial M_1 = \partial M_2 = \Sigma$, then $Hom(I(M_1), I(M_2))$ will be the Floer homology of $M_1 \cup_\Sigma -M_2$.

In this talk we will realize his program in some case, modulo one conjecture.

§ 1 Chain Category

Definition

A *Chain Category* is a collection of $\mathcal{Ob}$, $C(a,b)$, η_i, $i = 1,2,3,\cdots$, where $\mathcal{Ob}$ is a set, (set of Objects) : for $a,b \in \mathcal{Ob}$, $C(a,b)$ is a chain complex (set of morphisms) : $\eta_k : C(a_0,a_1) \otimes \cdots \otimes C(a_{k-1},a_k) \to C(a_0,a_k)$, is a homomorphism ($k$-th composition) : such that

η_2 is a chain map.

$(\partial\eta_3)(a,b,c) = \eta_2(a,\eta_2(b,c)) + \eta_2(\eta_2(a,b),c)$

etc.

That is the associativity of the composition of the maps hold modulo chain homotopy equivalence.

When $\mathcal{Ob}$ is a set of single element, Chain category is an A_∞-algebra.

Let $\mathcal{Ch}$ be the Category of Chain complexes. (The morphism is a homomorphism, which is not necessary to be a chain map.) $\mathcal{Ch}$ can be regarded as a chain category.

The set $\mathcal{F}(C,\mathcal{Ch})$ of all (chain) functors from a Chain category C to $\mathcal{Ch}$ is again has a structure of Chain Category.

There is a functor $F : C^\circ \to \mathcal{F}(C,\mathcal{Ch})$. Where C° is the Category C with opposite direction of morphisms. Under reasonable assumptions $F : C(a,b) \to C(\mathcal{F}(a),\mathcal{F}(b))$ is a chain homotopy equivalence. (Analogy of Morita equivalence.)

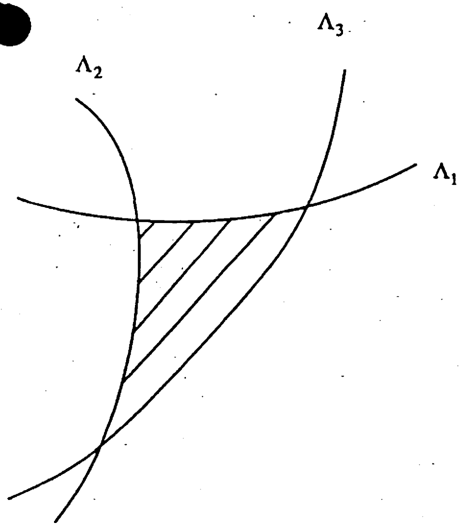
§ 2 Symplectic manifold

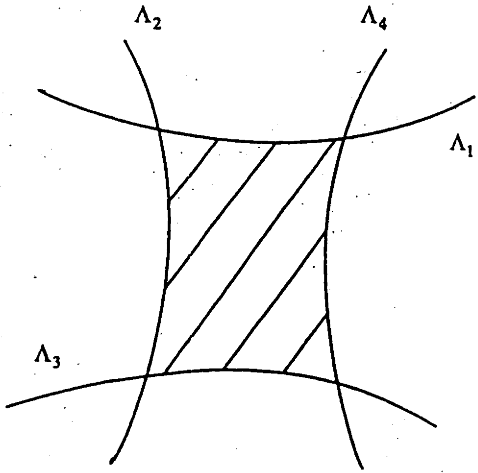
Let X be a monotone symplectic manifold. We can define a chain category $C(X)$ such that

the object is the set of all Laglangean of X,

$C(\Lambda_1, \Lambda_2)$ is the Floer's Chain complex,

2 and 3 compositions are defined by counting the pseudo holomorphic curves below. (Let us remark that the definition of 2 composition is mentioned by Donaldson in his talk at Warwick.)





§ 3 Floer homology for 3-manifolds with boundary

Let M be a 3-manifold with boudary Σ and E be an $SO(3)$ bundle over M such that its restriction to every connected component of Σ is nontrivial. (Σ is necessary to be disconnected by this assumption.)

Let $R(\Sigma)$ be the symplectic manifold consisting all the flat connections of the restriction of E to Σ.

Let $\Lambda(M)$ be the set of all flat connections of E on M. By perturbation, one can assume that $\Lambda(M)$ is immersed as Lagrangian in $R(\Sigma)$.

Let Λ be a Lagrangian of $R(\Sigma)$ which is transversal to $\Lambda(M)$. For $a,b \in \Lambda(M) \cap \Lambda$, we can define a finite dimensional moduli space of self dual connections A on $M \times R$ such that A converges to a,b as $t \to \pm\infty$, and that the restriction of A to $\Sigma \times R$ is roughly speaking a path in Λ. We can use them in a way similar to the definition of Floer homology and obtain a chain complex $C(M,\Lambda)$.

$\Lambda \to C(M,\Lambda)$ defines a Chain functor from $C(R(\Sigma))$ to $\mathcal{C}h$. Let us call this element $I(M) \in \mathcal{F}(C(R(\Sigma)),\mathcal{C}h)$ Floer homology of M.

Suppose $\partial M_1 = \partial M_2 = \Sigma$. We can define a chain map

(*) $$C(M_1 \cup_\Sigma -M_2) \to C(I(M_1),I(M_2)).$$

Here we recall the right hand side is the set of all natural transformations between two functors, and the left hand side is the chain complex which gives the Floer homology of the closed manifold $M_1 \cup_\Sigma -M_2$.

Conjecture

(*) is a chain homotopy equivalence.

K.G. O'Grady
Relations Amongst Donaldson Polynomials Of Algebraic Surfaces

Let S be a smooth projective surface. We assume that $p_g(S) > 0$ and $\pi_1(S) = 1$. We let $C \subset S$ be a smooth connected algebraic curve of genus g. For $a \in \mathbf{Z}$, let $\gamma_{a,k}(S)$ be the Donaldson polynomial associated to the rank-two vector bundle on S with $c_1 = [aC]$ and $c_2 = k$. (So $\gamma_{0,k}(S) = \gamma_k(S)$.)

Theorem *Let $\alpha_1, \ldots, \alpha_i, \ldots \in H_2(S)$ be classes orthogonal to C. Assume that $C \cdot C = 0$. Then:*

(1) - If $g = 0$, $\gamma_k(C, \alpha_1, \ldots, \alpha_{d(k)-1}) = 0$. (Where $d(k)$ is the degree of $\gamma_k(S)$.)

(2) - If $g = 1$, $\gamma_k(C, C, \alpha_1, \ldots, \alpha_{d(k)-2}) = 0$.

(3) - If $g = 2$,

$$\gamma_k(C, C, C, C, \alpha_1, \ldots, \alpha_{d(k)-4}) = 8\gamma_{k-1}(\alpha_1, \ldots, \alpha_{d(k)-4}) + 8\gamma_{1,k-1}(\alpha_1, \ldots, \alpha_{d(k)-4}).$$

(4) - If $g = 3$,

$$\gamma_k(\underbrace{C, \ldots, C}_{7}, \alpha_1, \ldots, \alpha_{d(k)-7}) = \frac{632}{3}\gamma_{k-1}(C, C, C, \alpha_1, \ldots, \alpha_{d(k)-7}) - \frac{448}{3}\gamma_{k-1}(p, C, \alpha_1, \ldots, \alpha_{d(k)-}$$

$$\frac{472}{3}\gamma_{1,k-1}(C, C, C, \alpha_1, \ldots, \alpha_{d(k)-7}) + \frac{640}{3}\gamma_{1,k-1}(p, C, \alpha_1, \ldots, \alpha_{d(k)-7}).$$

It is reasonable to expect that there is a similar universal formula for any given self-intersection number (i.e. $C \cdot C$), genus and number, s, of copies of C, provided $s > 3g - 3$ ($s > 0$, $s > 1$ if $g = 0$ or $g = 1$, respectively).

R.E.Gompf
Some New Symplectic Manifolds

Topological constructions of closed, symplectic manifolds are rather scarce. We present a new construction which solves several problems. Specially, if M_1 and M_2 are closed, symplectic manifolds which have a common codimension 2 symplectic submanifold N, then we may form a symplectic "connected sum along N", provided that the embeddings have opposite normal Euler class. To do this symplectically, one uses the Tubular-Neighborhood Theorem of Weinstein. The case of trivial normal bundles is particularly simple: One immediately obtains symplectic embeddings $N \times D_\epsilon \hookrightarrow M_i$, $i = 1, 2$, and performs the sum using $id_N \times \chi$, where $\chi : D_\epsilon - 0 \to$

$D_\epsilon - 0$ is a symplectomorphism which reverses ends.
This construction (with trivial normal bundles) has various applications. First, we see that fiber sum of Kähler elliptic surfaces is a symplectic operation. Applying this to Dolgacher surfaces using a twisted normal framing, we obtain nonelliptic manifolds diffeomorphic to examples of the Author and Mrowka, which were shown to be honotopy $K3$ surfaces admitting no complex structure. This answers a question posed by Donaldson at Oberwolfach in 1988, realizing simply connected 4-manifolds which are symplectic but non-Kähler. A second application is to realize any finitely presented group as the fundamental group of a closed, symplectic 4-manifold (answering a question of Kotschick). Previously, no examples were known in any dimension of closed symplectic manifolds with $b_1 = 1$. These latter examples are produced by a surgery-like technique, killing π_1 in $F \times T$, F a surface of sufficiently high genus.

I.Hambleton (joint work with R.Lee)
Group Actions On 4-Manifolds And Moduli Spaces

Algebraic surfaces and algebraic group actions give an interesting class of group actions on smooth 4-manifolds. This class can be enlarged by considering equivariant connected sum along fixed points, and we wish to compare the actions constructed in this way to actions on smooth 4-manifolds in general.

Consider for example the complex projective plane $\mathbb{C}P^2$ together with a linear action of some finite group $G \subset PGL_3(\mathbb{C})$, the full group of collineations. Is every smooth action of a finite group on a connected sum $X = \mathbb{C}P^2 \# \ldots \# \mathbb{C}P^2$ equivariantly diffeomorphic to a connected sum of (linear) actions on $\mathbb{C}P^2$? The following result restricts the possible finite groups that can act smoothly on X, under certain assumptions.

Theorem

(1) Let G be a finite group acting smoothly on a connected sum $X = \mathbb{C}P^2 \# \ldots \# \mathbb{C}P^2$ of n copies of $\mathbb{C}P^2$, $n \geqslant 1$. If G induces the identity on integral homology, then G is isomorphic to a subgroup of $PGL_3(\mathbb{C})$.

(2) If $n > 1$, then G is abelian of rank ≤ 2.

The method of proof involves gauge theory and a suitable equivariant moduli space constructed in our previous paper (Math. Ann. 1992).

L.Jeffrey (joint with J.Weitsman)
Symplectic Geometry And Flat Connections On Riemann Surfaces

Let G be $SU(2)$, and Σ^g a compact Rieman surface of genus g. We consider the stratified symplectic space

$$\overline{S}^g = \mathrm{Hom}\,(\pi_1(\Sigma^g), G)/G$$

which is identified with the space of flat G connections on Σ^g modulo gauge equivalence; this has dimension $6g-6$. We prove

Theorem 1 A pants decompositon of Σ^g determines an open dense set $\mathcal{U} \subseteq \overline{\mathcal{S}}^g$ equipped with a symplectic action of $\mathcal{U}(1)^{3g-3}$. The closure $\overline{\mu(\mathcal{U})}$ of the image of $\mathcal{U}$ under the moment map μ for this torus action is a convex polyhedron determined by inequalities which correspond to the $SU(2)$ quantum Clebsch-Gordan conditions.

As an application we obtain the formula for the symplectic volume of $\overline{\mathcal{S}}^g$:

Theorem 2

$$\mathrm{vol}(\overline{\mathcal{S}}^g) = \lim_{k\to\infty} \frac{1}{k^{3g-3}} D(g,k).$$

Here, for $k \in \mathbb{Z}$, $D(g,k)$ is the number of labellings of the boundary circles in a pants decomposition by integers in $[0,k]$ satisfying the **quantum Clebsch-Gordan conditions**

$$\begin{array}{lll} (Q(G1) & l_1+l_2+l_3 & \in 2\mathbb{Z} \\ (Q(G2) & |l_1-l_2| \le l_3 & \le l_1+l_2 \\ (Q(G3) & l_1+l_2+l_3 & \le 2k. \end{array}$$

We obtain these conditions by considering Hom $(\pi_1(P),G)/G$, where P is the 3-punctured sphere or "pair of pants".
The torus action is obtained as follows. Given a simple closed curve $C \subseteq \Sigma^g$, we define $h^C : \overline{\mathcal{S}}^g \to [0,1]$ by

$$h^C([A]) = \lambda \text{ iff } \mathrm{Hol}_C A \text{ is conjugate to } \mathrm{diag}(e^{2\pi i\lambda}, e^{-2\pi i\lambda})$$

. These functions have periodic Hamiltonian flows with period 1 (on an open dense set). If $C_j (j = I,\dots,3g-3)$ are the boundary circles of the pants decomposition, the Hamiltonian vector field corresponding to h^{C_j} commute; each Hamiltonian flow gerates a $\mathcal{U}(1)$ action and these fit together to form an action of $\mathcal{U}(I)^{3g-3}$. Theorem 2 is then obtained by identifying

$$D(g,k) = \#(k\overline{\mu(\mathcal{U})} \cap \Lambda),$$

where Λ is the integer lattice for the torus action and $\mu = (h^{C_1},\dots,\ h^{C_{3g-3}})$ is the moment map; $\overline{\mu(\mathcal{U})}$ is the closure of the image of $\mathcal{U}$ under the moment map.
These results generalize to groups $G \neq SU(2)$. The formulas for volumes were proved originally by Witten: we have obtained new proofs by considering symplectic group actions and moment maps.
A more detailed treatment may be found in:
L.Jeffrey, J.Weitsman, "Bohr-Sommerfeld Orbits in the Moduli Space of Flat Connections and the Verline Dimension Formula", **Commun. Math. Phys.**, to appear.
"Toric Structures in the Moduli Space of Flat Con nections on a Riemann Surface: Volumes and the Moment Map", preprint.

D.Joyce
Constant scalar curvature metrics on connected sums

In this talk we describe a result in analysis that gives an explicit description of metrics of constant scalar curvature in the conformal class of the connected sum of two compact Riemannian manifolds of the same dimension n and constant scalar curvature. The solution of the Yamabe problem tells us that such metrics must exist, but gives very little idea of what they are like. We are able to give a picture of what happens to the metrics of constant scalar curvature as the underlying conformal manifold decays into a connected sum, i.e. develops a 'long neck' looking like a cylinder of cross-section S^{n-1}.
The method has two parts. Firstly a result is proved using Sobolev spaces, embedding theorems and other tools of analysis, to the effect that given a manifold with scalar curvature close to a constant value in a certain sense, then there is a small conformal change to a metric of constant scalar curvature. Secondly, given for example two Riemannian manifolds of scalar curvature -1, we define a metric on the connected sum equal to the original metrics except on a small region of joining, and estimating the scalar curvature on this region we show it can be made close enough to -1 for the analytic result above to apply, provided the 'neck' region is small enough. We may also apply the result for every combination of positive, negative and zero scalar curvature on the two sum manifolds by defining a metric on the connected sum in different ways. In the case of the connected sum of two (generic) manifolds of scalar curvature $+1$, the results give three different metrics of constant scalar curvature in the same conformal class.

P.Kirk and E.Klassen
Spectral Flow And Cup Products

Let X be a compact 3-manifold and let a_t be a path of flat connections on X. We show that the derivatives at $t = 0$ of the eigenvalues of the path of self-adjoint operators $D_t = *d_{a_t} - d_{a_t}{}^*$ acting on $0+2$ forms are given by the eigenvalues of a bilinear form $B : W \times W -> R$. Here W is the cohomology of X with local coefficients in the adjoint representation ρa_o. We use this to verify a conjecture of L.Jeffrey about the value of the stationary phase approximation of Witten's invariant for torus bundles.

D.Kotschick
Gauge theory on 4-manifolds with $b_2^+ = 1$

This talk was a continuation of my talk with the same title at the Oberwolfach meeting on 4-manifolds in 1988. The 1988 talk gave some applications of gauge theoretic invariants for manifolds with $b_2^+ = 1$ to the differential topology of complex algebraic surfaces with $p_g = 0$. The theory of the invariants was only discussed briefly.
The present talk focused on the invariants, rather than on specific applications. The

construction of invariants is complicated in this case by the appearance of reducible connections in generic 1-parameter families of metrics. This leads to invariants depending on a choice of chamber in the positive cone of the intersection form on $H^2(X, R)$. The fact that the period map from metrics to self-dual 2-forms is not well understood makes this discussion difficult.
First, results from [Ko] were discussed. Then, generalizations of those results obtained in joint work in progress with J.W. Morgan were explained. These go some way toward understanding the general formulae describing the change in the invariants as one crosses a wall between chambers.

[Ko] D. Kotschick, $SO(3)$-invariants for 4-manifolds with $b_2^+ = 1$, Proc. London Math. Soc. 63, (1991), 426–448.

M.Kontsevich
Graphs And Manifolds

We start from a formula arising from the perturbative Chern-Simons theory, developed as a mathematical theory by S.Axelrod and I.Singer.

Denote by $\omega(x)$ the closed 2-form $\frac{1}{8\pi}\epsilon_{ijk}\frac{x^i dx^j \wedge dx^k}{|x|^3}$ on $\mathbf{R}^3\setminus\{0\}$ (=standard volume element on S^2 written in homogeneous coordinates). For the knot $K(S^1)$ where $S^1 = [0,1]\setminus\{0,1\}$ the following sum

$$\int_{0<l_1<l_2<l_3<l_4<1} \omega(K(l_1)-K(l_3))\wedge\omega(K(l_2)-K(l_4))+$$

$$+\int_{0<l_1<l_2<l_3<1,\, x\in\mathbf{R}^3\setminus K(S^1)} \omega(K(l_1)-x)\omega(K(l_2)-x)\omega(K(l_3)-x)-\frac{1}{24}$$

is an invariant, i.e. does not change when we vary continuously K in the class of embeddings. This number is an integer, moreover, it is the second coefficient of the Conway polynomial.

One can associate two pictures with integrals in the formula above — the Mercedes logo and a circle with two intersecting chords.

There is another formula giving an invariant of rational homology 3-spheres. Roughly speaking, we remove one point from the manifold and choose a closed 2-form satisfying some mild growth conditions on the configuration space of 2 points on the rest. The invarint is the integral of cube of this form. Corresponding graph has two vertices and 3 edges connecting both vertices. C.Taubes proved that this is an invariant under homology trivial cobordisms.

We define a graph complex as the vector space over $\mathbf{Q}$ generated by equivalence classes of finite connected graphs with a kind of orientation. The differential in the graph complex is given by the sum over all edges of new graphs obtained by the contraction of an edge. We define (modulo some technicalities) a homomorphism from the graph complex to the de Rham complex of the classifying space of the diffeomorphism group of any rational homology sphere in dimensions ≥ 3. Comparision with the well-known combinatorial description of the moduli space of complex algebraice curves gives a nontrivial map from cohomology of mapping class groups to the graph complex.

Some modification of graph complex gives differential forms on the space of embeddings of S^1 into $\mathbf{R}^n$ for $n \geq 3$. In the case $n \geq 4$ we obtain a complete "computation" of the rational homology of the space of embeddings, in the case $n = 3$ we obtain at zero degree all so called Vassiliev knot invariants.

P.B. Kronheimer
Embedded Surfaces

If X is a smooth 4-manifold and ξ is a 2-dimensional homology class in X, one can always represent ξ geometrically by an oriented 2-dimensional surface Σ, smoothly embedded in the 4-manifold. Depending on X and ξ however, the genus of Σ may have to be quite large: it is not always possible to represent ξ by an embedded sphere. It is natural to ask for a representative whose genus is as small as possible, or at least to enquire what the genus of such a minimal representative would be. There is an attractive conjecture concerning the case that X is the manifold underlying a smooth complex-algebraic surface. The conjecture is best known in the case that X is the complex projective plane $\mathbb{CP}^2$, in which case it is often attributed to Thom, but the statement seems still to be viable more generally [1].

Conjecture 1 *Let X be a smooth algebraic surface, and ξ a homology class carried by a smooth algebraic curve C in X. Then C realizes the smallest possible genus amongst all smoothly embedded 2-manifolds representing ξ.*

The conjecture was proved for the case of a $K3$ surface X, by the author and Mrowka [4]. The talk at Oberwolfach concerned a plan of attack on this problem for more general surfaces, based on developing further properties of the moduli spaces of 'singular' instantons. This plan has since been completed, at least to the extent anticipated in the talk, and leads to:

Theorem 2 *The above conjecture holds at least under the following assumptions concerning X and C:*
(a) the surface X is simply-connected;
(b) the self-intersection number $C \cdot C$ is positive;
(c) there is a class $\omega \in H_2(X,\mathbb{C})$ dual to a holomorphic 2-form on X, such that $q_k(\omega + \bar{\omega}) > 0$ for sufficiently large k, where q_k denotes Donaldson's polynomial invariant. According to [6] and [5], the hypotheses on X are satisfied by many surfaces with p_g odd (complete intersections, for example). It seems likely now that, with a little extra effort, the result will be extended to complete intersections with p_g even and non-zero. Note that the case of $\mathbb{CP}^2$ is still outside our scope. Details of the proof will appear in [3]; a short sketch is given in the announcement [2].

[1] S. K. Donaldson, Complex curves and surgery, Publ. Math. I.H.E.S., 68, 1988, 91–97
[2] P. B. Kronheimer The genus-minimizing property of algebraic curves Bull. Amer. Math. Soc., to appear
[3] P. B. Kronheimer info (papers in preparation)
[4] P. B. Kronheimer and T. S. Mrowka Gauge theory for embedded surfaces. I, II info (submitted to Topology)
[5] J. W. Morgan Comparison of the Donaldson invariants of algebraic surfaces with their algebro-geometric analogues Topology, to appear
[6] K. G. O'Grady Algebro-geometric analogues of Donaldson's polynomials Inventiones Math. 107 1992

T. Lawson

Nonsmoothable Group Actions On 4-Manifolds

Theorem. Let $r, p > 0$ be relatively prime odd integers, and $l \geq 1$. Then there are smooth. contractible 4-manifolds W_l with $\partial W_l = \Sigma_l = \Sigma(r, lrp+1, lrp+2)$ which have pseudofree locally linear Z_p actions extending the standard free action on the boundary, but there are no such smooth actions on W_l.

The existence of such actions utilizes criteria developed by Edmonds involving Reidemeister torsion and ρ invariants. Nonsmoothability is shown using gauge theoretic techniques. Calculations of the invariants using elementary number theory play a key role in obtaining results for these infinite families.

P. Lisca

On Simply Connected Non-Complex Four-Manifolds

Abstract We define a sequence $\{X_n\}_{n\geq 0}$ of homotopy equivalent smooth simply connected 4-manifolds, not diffeomorphic to a connected sum $M_1 \# M_2$ with $b_2^+(M_i) > 0, i = 1, 2$, for $n > 0$, and non-diffeomorphic for $n \neq m$. Each X_n has the homotopy type of $7CP^2 \# 37\overline{CP}^2$. We deduce that only finitely many X_n can be diffeomorphic to a connected sum of complex surfaces and complex surfaces with reversed orientations.

J.W. Morgan

Splitting 4-Manifolds Along Tori

Let M be a closed oriented simply connected 4-manifold and let $T \subset M$ be an embedded 3-torus. We suppose that T splits M into two submanifolds P and Q and that $b_2^+(P)$ and $b_2^+(Q)$ are both positive. Fixing an identification of T with the boundary of $T^2 \times D^2$ we can adjoint $T^2 \times D^2$ to P and Q to obtain closed manifolds manifolds $\hat{P}$ and $\hat{Q}$. There is a product formula which expresses the Donaldson polynopmial of M in terms of Donaldson polynomials of $\hat{P}$ and $\hat{Q}$. For example, suppose that we have classes

$$x_1, \ldots, x_s \in H_2(P)$$

$$y_1 \ldots, y_t \in H_2(Q)$$

and a closed surface Σ which crosses T, meeting T in m times ∂D^2.

We have the following.

Lemma. *With the assumptions as above if the degree of the Donaldson polynomials $\gamma_k(\hat{P})$ and $\gamma_\ell(\hat{Q})$ are respectively $2s$ and $2t+2$ then the degree of $\gamma_{k+\ell}(M)$ is $2s+2t+2$ and*

$$\gamma_{k+\ell}(M)(x_1, \ldots, y_t, [\Sigma]) = m\gamma_k(\hat{P})(x_1, \ldots, x_s) \cdot \gamma_\ell(\hat{Q})(y_1, \ldots, y_t, [T^2]).$$

There are more general product formula of this nature for the same set-up but with more than one surface cutting through the 3-torus, assuming that all the surfaces meet the torus in multiples of ∂D^2. These results allow one to deduce the Donaldson polynomials of simply connected surfaces of geometric genus greater than one from those of the elliptic surfaces of geometric genus one. In particular, the computations of Morgan-O'Grady and Bauer of the second coefficient of the Donaldson polynomial γ_3 for elliptic surfaces of geometric genus one yields similar formula for the second coefficient of γ_{2p_g+1} of elliptic surfaces of geometric genus $p_g > 1$. These lead immediately to the result that two such surfaces are diffeomorphic if and only if their multiplicities and are the same and their genera are the same.

T.S.Mrowka
L^2-Moduli-Spaces

The talk discussed joint work with John Morgan and Danny Ruberman concerning the structure of the moduli space of finite energy anti-self-dual connections on a four manifold with cylindrical end.
The setup is as follows. Let X denote an oriented connected Riemannian four manifold with cylindirical end. That is an end of X is identified metrically with the cylinder $[0,\infty) \times N$ for some closed oriented Riemannian three manifold N. One considers the space $\mathcal{M}(X)$ of anti-self-dual connections ω in a principal $SU(2)$ bundle $P \to X$ so that the energy $\int_X |F_\omega|^2$ is finite. For such a connection a strighforward arguement using Uhlenbecks compactness theorem implies that the Chern-Weil integral $\frac{-1}{8\pi^2}\int tr(F_\omega \wedge F_\omega)$ takes on discrete values and that these values agree with the Chern-Simons invariant of a flat connection on N. This decomposes the space $\mathcal{M}(X) = \cup_\ell(\mathcal{M}_\ell(X)$ where $\ell \in R$ ranges over the set of values of Chern Simons on flat connections.
It is a basic fact of life that the ASD equation on a cylinder $[0,\infty) \times N$ is gauge equivalent to the gradient flow equation for the Chern-Simons function. This observation premeates the analysis of the ASD equation on a manifold with cylindrical end for it allows one to use the rather well developed theory for such equations to study the asymptotic behavior of solution of the ASD equation.
There are two main results. The first is that for a gauge equivalence class of connection $[\omega] \in \mathcal{M}_\ell(X)$ the limit $\lim_{t\to\infty}[\omega|_{\{t\}\times N}]$ exists and is a flat connections in N with Chern-Simons invariant equal to ℓ. Furthermore the the assignment to a gauge equivalence class of the limiting value of a connection defines a continuous map $\partial\mathcal{M}_\ell(X) \to \chi(N)$. This is proved using a method due to Leon Simon regarding gradient flow eqautaions and limiting values. It is based on the following inequality due to Stanislaw Lojaszewicz. Let $f : bfR^n \to R$ be a real analytic function with $f(0) = 0$ and $\nabla_0 f = 0$ then there is a constant γ with $0 < \gamma \leq \frac{1}{2}$ and neighborhood U of 0 so that for all $x \in U$ we have the pointwise bound

$$|f(x)|^\gamma \leq |\nabla_x f|.$$

The second result is a establishing a refinement of the map ∂. First one shows there is for any flat connection Γ there is a center manifold $\mathcal{H}$ for the Chern-Simons gradient flow near Γ. This center manifold is diffeomorphic to a neighborhood of zero in the cohomolgy group $H^1(N; ad\Gamma)$. (A center manifold for a flow equation near a critcal point is an invariant submanifold tangent at the critical point to the kernel of the Hessian in particular there is a flow on the center manifold). Then one shows that every finite energy ASD connection with boundary value sufficiently close to Γ and with energy sufficcently small on the cylinder tracks a unique flow line in the center manifold upto an exponentially small error. It is then shown that the map which assigns to a connection the asymtotic flow line is continuous. Also the fibers of this map can be analysed using the wieghted Sobolev spaces in a way similar to Taubes' paper on periodic ends. One is then left with the problem of analysing the behavior of the flow on the center manifold. This can be done in many cases of interest for example circle bundles on Reimann surfaces.

V.Pidstrigatch
Spin$^{\mathbb{C}}$-Structures And Invariants Of Smooth Structures For 4-Manifolds

Consider 4-manifold X with Riemannian metric g and fix some $Spin^{\mathbb{C}}$-struture C on it. This means that we fix integral lift C of second Shtifel-Whitney class $w_2(X)$ and this lift define a pair of complex Hermitian vector bundles W^+, W^- of rank two with following condition satisfied:

$$c_1(\Lambda^2 W^{\pm}) = C$$

Choise of a connection ∇ on the line bundle $\Lambda^2 W^+$ gives rise to a Dirac operator

$$\mathcal{D}^{C,\nabla} : \Gamma(W^+) \to \Gamma(W^-)$$

and coupling to any connection a on a Hermitian rank 2 - bundle E gives a family of Fredholm operators over the space $\mathcal{A}$ of all hermitian connections on E :

$$\mathcal{D}_a^{C,\nabla} : \Gamma(W^+ \otimes E) \to \Gamma(W^- \otimes E)$$

Assume that

$$ind(\mathcal{D}_a^{C,\nabla}) = dimker(\mathcal{D}_a^{C,\nabla}) - dimcoker(\mathcal{D}_a^{C,\nabla}) < 0$$

Define a moduli space of 1-instantons $\mathcal{M}_1^{g,C,\nabla}$ as follows.

$$\mathcal{M}_1^{g,C,\nabla} = \{[a] \in \mathcal{M}_{asd} | dim(ker \mathcal{D}_a^{C,\nabla}) > 0\}$$

Assuming transversality one have codimension of moduli space of 1-instantons in the space of usual instantons:

$$codim \mathcal{M}_1^{g,C,\nabla} = 2(-ind(\mathcal{D}_a^{C,\nabla}) + 1)$$

$$ker \mathcal{D}_a^{-K_S,\nabla} = H^0(E) \oplus H^2(E)$$

and therefore

$$\mathcal{M}_1^{g,C,\nabla} = M_{1,0}^H \cup M_{0,1}^H$$

where

$$M_{1,0}^H = \{H - stable\ bundle\ with H^0(E) \neq 0\}$$

and symmetrically for $M_{0,1} = M_{1,0}(E^\vee \otimes K_S)$ by Serre duality. In order to define invariants of smooth structure one need following standart collection of statements.

Proposition 1: One can get the moduli space of 1-instantons as the preimage of zero for some nonlinear smooth Fredholm map and therefore one have local "Kuranishi" description of the moduli space.
Proposition 2: One have the moduli space being smooth manifold of the dimension

$$dim\mathcal{M}_1^{g,C,\nabla} = -\frac{3}{2}p_1(E) + \frac{(C + c_1(E))^2}{2} - \frac{sign(X)}{2} - 3b_2^+(X) - 5$$

with singularities in reducible connections for generic pair:metric and connection ∇. The same is true for generic path in space of pairs, etc. Proposition 3 The moduli space have natural orientation. If in the case of algebraic surface S and $C = -K_S$ one take standart complex orientation for $M_{1,0}^H$, then one need to twist standart complex orientation for $M_{0,1}^H$ by $(-1)^{-\chi(E)+1}$. Now one in standart way can construct invariants of smooth structures as polynomials

$$\gamma_1^C(rankE = 2, c_1(E), c_2(E))$$

on $H_2(X)$.
Remark 1: All construction depends in fact only on the sum $C + c_1(E) \in H^2(X)$, not on summands themselves. One have

$$\gamma_1^{C+2\delta}(2, c_1(E), c_2(E)) = \gamma_1^C(2, c_1(E) + 2\delta, c_2(E) + c_1(E) \cdot \delta + \delta^2)$$

Remark 2: Stability condition gives for algebraic surface

$$2K_S.H \leq c_1(E).H \leq 0 \Rightarrow \mathcal{M}_1 = \emptyset$$

and this provides vanishing of invariants . This is in contrast with Donaldson polynomials which are nonzero for algebraic surfaces for big enough c_2.
Remark 3: In the case of 1-instantons it is much easier to find the discrete parameters (bundle E and class C) in order to get zero-dimensional moduli space and to define the invariant as a algebraic number of points in it. For example it is possible to find theese for all homotopy types $CP^2\#k\overline{CP^2}$ for all $1 < k < 9$.
Remark 4: Assume $b_2^+(X) = 1$ and $p_1(E) \leq 7$. In this case one can get an explicite formula for a change of an invariant when metric is crossing the wall defined by the vector of negative length in the intersection lattice $H_2(X), q$.. For example it is

$$\binom{i_e}{d} \cdot (q(e, \cdot))^{d-i_e-1}$$

for $e^2 = p_1(E)$, $i_e = -\frac{sign(X)}{8} + \frac{(C+c_1(E)+e)^2}{8} \geq 0$ (the last inequality holds at most for one of $\pm e$ and we take this one as e).
Remark 5: It is very interesting to compare polynomials γ_1^C and Donaldson's polynomials γ. From one hand homology classes of the locus of degeneration of the family of Fredholm operators can be defined in terms of Chern classes of the index bundle of this family and theese are polynomials in μ-classes and four-dimensional

ν-class as Donaldson polynomials are. This gives direct relations in the case of compact moduli space of instantons but for other cases meaning of the evaluation of named cohomological classes on the "fundamental class" of moduli space are given by geometrical constructions which are different for γ and γ_1^C. From the other hand one can get following formula

$$\gamma(2,0,\frac{D^2-K_S^2}{4})(k\times \to D,\dots,D) = \gamma_1^{-K_S}(2,D+K_S,2p_g+g_D+1)(k-1\times \to D,\dots,D)$$

where D is a smooth effective algebraic curve of genus $g_D = \frac{D\cdot(D+K_S)}{2}+1$ on an algebraic surface S of geometric genus p_g with following numerical conditions satisfyed:

$$D = K_S \; mod2 \; D.H > K_S.H$$

for some polarisation H on S.
The rough scheme of the computation of "zero-dimensional" invariant for algebraic surface follows. Assigning of the stable bundle with a section to a zero-cycle of zeroes of the section gives a map to a Hilbert scheme $Hilb^d(S)$ of the surface S. One can get the description of the image of this map as a locus of degeneration of the morphism of certain bundles. Portheus formula gives the homology class of the locus in terms of Segre class of certain bundle over $Hilb^d(S)$ and this one can be computed explicitly for $d \leq 8$. Application of this technick to surface of general type and argument of remark 2 to rational one provides following statement. /vskip2ex
Theorem: Minimal algebraic surface of general type with geometric genus equal to zero can not be diffeomorphic to rational one.

D.Ruberman

2-Spheres And Tori In 4-Manifolds

In a complex surface, the adjunction formula tells what genus a smooth curve must have, given its self-intersection and its intersection with the canonical class. We give some theorems which show, at least for small genus, how the Donaldson polynomial invariants can play a similar role. Suppose that M is an oriented, simply connected, smooth 4-manifold with $b_2^+(M) > 1$ and odd. For k a sufficiently large integer, we have the Donaldson polynomial invariant $\gamma_k(M)$ associated to the SU(2) bundle with Chern class k. In joint work with T. Mrowka and J. Morgan, we showed that the existence of a certain 2-spheres and tori in M implies the vanishing of $\gamma_k(M)$. This derives from the following splitting theorem.
Theorem A. *Suppose that M (as above) can be decomposed as $P \cup_N Q$, where N is a circle bundle over a torus, whose Euler class is even and non-zero. If in addition $b_2^+(P) > 0$ and $b_2^+(Q) > 0$, then $\gamma_k(M) = 0$ when evaluated on homology classes disjoint from N.*

By considering P to be the tubular neighborhood of a torus, Theorem A immediately implies the following corollary.
Corollary. *Suppose that T is a smoothly embedded torus in M (as above) with self-intersection greater than or equal to 2. Then the Donaldson polynomial invariants of M vanish.*

By considering the behavior of the Donaldson polynomial under diffeomorphisms, and making use of the formula for the polynomial of $M\#-CP^2$, we can obtain a similar result to the corollary for 2-spheres:

Theorem B. *Suppose that S is a smoothly embedded sphere in M (as above) with self-intersection greater than or equal to 0, and that S is non-trivial in homology. Then the Donaldson polynomial invariants of M vanish.*

It is also interesting to consider what is the influence of tori (and spheres) of *negative* self-intersection on the polynomial invariants. Here I was motivated by recent work of K. O'Grady on the algebro-geometric version of the polynomial invariants. To state the result, let A be a homology class, and let $\gamma_{k,A}(M)$ denote the polynomial invariant derived from the SO(3) bundle over M with $p_1 = -4k$ and w_2 Poincaré dual to A.

Theorem C. *Suppose that T is a smoothly embedded torus in M which has self-intersection -2, and that $C_1, \ldots, C_{d-2}$ are homology classes in M orthogonal to T. Then the polynomial invariants of M satisfy the relation:*

$$\gamma_k(T, T, C_1, \ldots, C_{d-2}) = \pm 2\gamma_{k,T}(C_1, \ldots, C_{d-2}).$$

The ambiguity in the sign in the above formula is only due to the fact that I have not yet sorted out all the orientations.

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