TAGUNGSBERICHT 26/1998

Quantum and Classical Integrable Systems

28.06.1998 bis 04.07.1998

Introduction

By now, integrable systems have had an impact on many different areas of mathematics and physics. The purpose of this meeting was to bring together researchers from a wide variety of horizons.

Discrete versions of classic geometric objects turn out to be integrable, whereas certain matrix integrals are related to coloring problems of random triangulations and graphs. Kähler manifolds lead very naturally to a non-linear Schrödinger equation. Integrable systems are also related to $\bar{\partial}$-operators. Moreover, there is a mysterious link between integrable systems and hyperbolic equations satisfying the Huygens' principle. Along more geometric and physical lines, quantized supersymmetric gauge theories lead to new phenomena, not known in dimension two; it provides improved classifications of four manifolds. Approximate solutions to the $U(N)$- valued Skyrme model (in dimension 3) lead to a good classical descriptions of a nucleon.

The notion of symmetries of an integrable system has led to new equations, which are related to isomonodromic deformations. The study of random matrices relies very heavily on those symmetries, including vertex operators. The latter are disguised Bäcklund transformations, which have quantum mechanical versions, but also have higher dimensional generalisations, called the duality symmetries; they play a role in M-theory. Extensions of six-vertex models are related to the representation theory of $U_q(\hat{sl}_2)$.

Hypergeometric solutions to certain versions of the bispectral problem were discussed. Another related vein of research is concerned with the representations of kernels for the study of the spectrum of random matrices, already mentioned above, especially the orthogonal and symplectic ensembles.

Other topics lectured on in this meeting were the Calogero-Moser system for ADE- root systems. Along more algebraic-geometrical lines, algebraic desciptions of integrable systems were given, which are linearizable on Jacobians; they capture well-known integrable systems (Gaudin model, etc...).

Gefördert durch
DFG Deutsche Forschungsgemeinschaft

Vortragsauszüge

M. Adler, Waltham, USA

Symmetries in integrable mechanics (joint work with P. van Moerbeke)

The subject of my talk is the use of symmetries as a tool in mechanics. In the context of integrable mechanics, symmetries are an extension of the commuting algebra of integrable mechanics in such a way that the commuting vector fields play the role of a Cartan center and as a whole form a closed Lie algebra of vector fields. In many problems one is able to deform a situation so as to introduce an integrable system and the symmetries in effect enable one to compute the tangent space of the deformation in a very effective way. Random matrix theory is a wonderful example as the effect of the symmetry algebra is to effect the range of the integration variables in a Virasoro type way. This procedure is also effective in studying the role of the Bäcklund transformation on the tridiagonal operator associated with orthogonal polynomials. The so-called bispectral problem is yet another application of this technique.

H. Aratyn, Chicago, USA

Ghost symmetries

We propose a new infinite set of commuting additional abelian ("ghost") symmetries in the setting of the Kadomtsev-Petviashvili (KP) type integrable hierarchy. These ghost symmetries are generated by squared eigenfunction potentials and admit their own Lax representation in which they are realized as standard isospectral flows. This setup of the standard one-component KP hierarchy endowed with a special infinite set of abelian additional symmetries is shown to be equivalent to the two-component KP hierarchy.

Alexander I. Bobenko, Berlin

Discrete Affine Spheres (joint work with Wolfgang Schief)

Integrable discrete versions of affine spheres are constructed. Affine spheres with indefinite and definite Blaschke metric are discretized in a purely geometric manner. The technique is based on simple relations between affine spheres and their duals which possess natural discrete analogues. Cauchy problems are posed and shown to admit unique solutions. Particular discrete definite affine spheres are shown to include regular polyhedra and some of their generalizations. In the case of indefinite affine spheres it is shown that the underlying discrete Gauss-Codazzi equations reduce to an integrable discrete Tzitzeica system. The interpretation in terms of loop groups is presented.

E. Corrigan, Durham, GB

A new formulation of Calogero-Moser systems

This talk describes some very recent work in collaboration with Bordner and Sasaki, the full details of which can be found in [1]. There are two main themes. The first is a formulation of the Lax pair for Calogero-Moser models based on the ADE root systems within the class of 'minimal' representations. These Lax pairs capture the previous work of Calogero and Moser, Olshanetsky and Perelomov, and D'Hoker and Phong [2,3,4,5,6]. The minimal representations are a restricted set of fundamental representations comprising all the fundamental representations for members of the A series, the vector and two spinor representations for the D series, the two **27**s of E_6, and the **56** of E_7. However, there are no minimal representations for E_8. The matrices of the Lax pair are labelled by the weights of the representation but do not themselves form (part of) a representation for a Lie algebra (as, for example, they do for Toda sytems). The special properties of the minimal weights are used extensively, particularly the fact that they form a single orbit under the Weyl group, a happy circumstance they share with the roots themselves. These Lax pairs work for all three of the Calogero-Moser potentials $(1/(\alpha \cdot q)^2$, $1/\sinh^2(\alpha \cdot q)$, and $\wp(\alpha \cdot q))$.

The second theme is motivated by a desire to examine the E_8 case for which the previous formulation cannot work because there are no minimal representations. It is suggested that a Lax pair can be set up in which the matrices are labelled by roots but, as before, do not form part of a representation. (Indeed they cannot, because the adjoint representation would have to include a rank's worth of zero weights). The technicalities of checking the claim are given in [1] but there is a surprise. This time, there is an additional functional relation which must be satisfied by the potential and it is satisfied only by the quadratic choice, $1/(\alpha \cdot q)^2$. It remains to be seen if there is a further modification waiting to be found which will permit the other potentials. However, at least foı the quadratic potential there is now a Lax pair for E_8, and that is a strong indication of its integrability.

It is possible to recover Lax pairs for root systems based on the other Lie algebras whose root systems are not simply-laced. The principal tool is the concept of 'folding' — which can be used to obtain the roots of non-simply-laced systems from those of the ADE series by capitalising on symmetries of the Dynkin diagram.

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L. Dickey, Oklahoma, USA

Zakharov-Shabat Hierarchy and Isomonodromic Deformations

The Zakharov-Shabat (ZS) hierarchy incorporates all the integrable systems of the ZS type: the zero curvature equations with connection matrices rationally depending on some spectral parameter. Additional symmetries of the ZS hierarchy are constructed; along with the main symmetries they form an extended ZS. It is shown that some restrictions of the extended ZS coincides with the isomonodromic deformations found by Jimbo, Miwa and Ueno. Also a very simple proof of their isomonodromic property is given which does not require the study of asymptotic behavior of solutions of ODE's with rational coefficients near poles of coefficients, i.e., the study of Stokes lines, Stokes matrices etc. which makes the known proofs so awkward and hard to comprehend. Meanwhile, it is clear that if one needs, he can prove the preservation of Stokes matrices and connection matrices as well with the same easiness.

Ph. Di Francesco, Chapell Hill, USA and Paris, France

Folding and coloring problems in mathematics and physics

I formulate various (planar) lattice folding problems arising in the context of statistical physics of surfaces. A folding is a map from the lattice to the d-dimensional space preserving its faces. I'll show how one can define thermodynamical quantities such as the folding entropy, as suitable limits involving the number of distinct folded configurations of the surface, and present the case of the two-dimensional folding of the triangular lattice, and many more. Most of these problems may be mapped onto an equivalent vertex/face or edge coloring problem for the lattice.

In a second step, I address the folding problem of random surfaces, in the form of graphs with arbitrary connectivity. In particular, I'll show how the vertex tricoloring problem of random triangulations is solved by a simple matrix integral.

Finally, I'll address the folding of one-dimensional (polymer) chains. I'll describe the underlying algebraic structure of the problem, and suggest a general scheme to investigate the case of arbitrary dimensional objects.

A. Grünbaum, Berkeley, USA

The bispectral problem and some applications

I discuss several aspects of the bispectral problem mainly in its discrete-continuous version. This part of the talk is joint work with Luc Haine. The main result is that the "lowest order instances", when both the differential and the difference operator are of order two are completely classified by 3 complex numbers a,b,c and the entire contruction can be made explicit in terms of solutions corresponding Gauss hypergeometric equation. This shows that this version is richer than the continuous-continuous one, when the corresponding examples are only Bessel and Airy.

I also see how the classical ideas of Stieltjes giving an electrostatic interpretation for the zeros of the classical orthogonal polynomials can be modified when one applies the

Darboux process to these "basic" solutions of the bispectral problem and obtains new solutions.

J. Hurtubise, Montreal, Canada

Integrable systems and algebraic surfaces

Locally, an algebraically integrable Hamiltonian system is a Lagrangian fibration of Abelian varieties over a base, which we can take to be a ball U in C^g. The information describing such a system is then a map from U into the Siegel upper half plane, which must satisfy some constraints for the symplectic form to exist; in suitable coordinates, this constraint just say that the period matrices $Z_{ij}(u), u \in U$ are a matrix of second derivatives.

When one restricts to the case when the Abelian varieties are Jacobians, one has rather more. Indeed, one can consider the Abel map A from the family of curves S over U into the family of Jacobians, and consider the rank of the pull-back of the symplectic form. If the rank is two, then one can quotient the null foliation on S to obtain a symplectic surface Q; one can then show that the original integrable system is birational to the Hilbert scheme of Q. Most frequently studied integrable systems (Gaudin model, Hitchin systems, Sklyanin system, and others) fall into this rank two category.

For integrable systems of Prym-Tyurin varieties one has a similar invariant, and one obtains, when the rank is two, some quite restricted types of manifolds, instead of surfaces.

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B. Julia, Paris, France

Superdualities and twisted self-duality

I reviewed a systematic doubling procedure that allows a manifest implementation of duality symmetries of field theories of differential forms of various degrees. Invariant (twisted) seld-duality constraints reduce the number of degrees of freedom to the original one. Duality symmetries are higher dimensional generalisations of Bäcklund transformations, they are extremely important in modern theories of particles and extended objects including strings, in M-theory for instance. The subgroup of duality symmetries of a particular Lagrangian depends on the choice of one particular half of the doubled set of fields. This has been studied in great detail on supergravity theories, where a compact description of gauge symmetries is obtained by considering them (locally) inside finite dimensional supergroups of "superdualities". These ideas are of general applicability and are being extended to reexpress gravity as well as the other interactions as instanton models.

V.A. Kazakov, Paris, France

Two-Matrix model with ABAB interaction (in collaboration with P. Zinn-Justin)

Using recently developed methods of character expansions we solve exactly in the large N limit a new two-matrix model of hermitian matrices A and B with the action

$$S = \frac{1}{2}(\mathrm{Tr}\,A^2 + \mathrm{Tr}\,B^2) - \frac{\alpha}{4}(\mathrm{Tr}\,A^4 + \mathrm{Tr}\,B^4) - \frac{\beta}{2}\mathrm{Tr}\,(AB)^2.$$

This model can be mapped onto a special case of the 8-vertex model on dynamical planar graphs. The solution is parametrized in terms of elliptic functions. A phase transition is found: the critical point is a conformal field theory with central charge c=1 coupled to 2D quantum gravity.

B. Konopelchenko, Lecce, Italy

Integrable systems for D-bar operators of non-zero index (joint work with L.Martinez Alonso and E.Medina)

Integrable hierarchies associated with D-bar operators of non-zero index, or equivalently, with the singular sector of the KP hierarchy are discussed. They arise as the restriction of the standard KP hierarchy to submanifolds of finite codimension in the space of independent variables. For higher D-bar indices these hierarchies represent themselves families of multidimensional equations with multidimensional constraints. The D-bar dressing method is used to construct these hierarchies. Hidden KdV, Boussinesq and hidden Gelfand-Dikii hierarchies are considered too.

V. Kuznetsov, Leeds, GB

Quantum Bäcklund transformations

We construct several new Bäcklund transformations (BT's) for finite-dimensional integrable systems and find their quantum analogs. As application, some new integral equations for the associated multi-variable special functions are derived. A connection to the problem of quantum separation of variables is discussed.

Suppose that $L(u)$ and $M(u)$ are two representations of the Sklyanin algebra:

$$\{L_1(u), L_2(v)\} = [r(u-v), L_1(u)L_2(v)].$$

Making use of the co-multiplication property, we define an integrable system with two different Lax matrices, LM and ML. Let us now define a map B:

$$B : L \mapsto \tilde{L}, \qquad M \mapsto \tilde{M}$$

through the following matrix equation:

$$ML = \tilde{L}\tilde{M}.$$

On several examples we show that such map amounts to an automorphism of the Sklyanin algebra, thereby being a Poisson map.

The next step is to make the following reduction:

$$\tilde{M} = M,$$

so that we get the "discrete-time" Lax equation of Bäcklund transformation for an integrable system with the Lax matrix L:

$$ML = \tilde{L}M.$$

The corresponding map stays Poisson.

This approach was applied to get new BT's and their quantum analogs for several finite-dimensional integrable systems. Main examples are sl_2 Heisenberg and Gaudin magnets.

T. Miwa, Kyoto, Japan

Alternating vertex models (a joint work with J Hong, S-J Kang and R Weston)

We consider the Z invariant vertex models with alternating spins. In the six-vertex model, the spin is 1/2 everywhere. We consider the lattice consisting of lines with spins, e.g., 1/2 and 1. We show that the Z-invariance, which implies the independence of the one-point function on the spectral parameters, does not imply the equality of the one-point function of the alternating lattice with that of the pure lattice because a mixing of the ground states occurs. We also give the exact formula of the mixing by using the representation theory of $U_q(\widehat{sl}_2)$, in particular, the deformed version of the Goddard-Olive-Kent decomposition.

D. Olive, Swansea, GB

Introduction to Electromagnetic Duality

Progress in fundamental particle theory has been inexorably linked to an increased understanding of symmetry and its role. Quantum integrability is emerging as another example. Its mode of operation in space-time of four dimensions differs from that familiar in two dimensions yet involves quite old ideas concerning an interchange of electricity and magnetism. The feature that extends from two to four dimensions is of an integrable field theory being a certain deformation of a conformally invariant theory. Apparently the Lax pair/zero curvature concept does not extend.

Certain supersymmetric gauge theories possess soliton solutions carrying magnetic charge. When quantised, these states are symmetrically related to the electrically charged states whose fields enter the original equations of motion. This idea has no known counterpart in two dimensions. Important mathematical tools are provided by the Atiyah-Singer index theorem, hyper-Kähler geometry and the theory of modular functions. The ideas extend in many different ways: an explanation of quark confinement, the consistent unification of all the forces including gravity in superstring theory (requiring space-time of ten dimensions), and an improved classification theory of four manifolds.

C. Terng, Princeton, USA

Geometric integrable systems and their symmetries

In this talk, I explain some joint work with Karen Uhlenbeck. Many soliton equations arise in differential geometric problems. I'll use one example to explain the interplay between soliton theory, differential geometry and symmetries. Let (M, g, J) be a Kähler manifold with Kähler metric g and complex structure J, and $E : C_a(R, M) \to R$ the energy functional, where $C(R, M)$ is the space of all smooth curves $\gamma : R \to M$. The complex structure J on M induces a symplectic structure on $C_a(R, M)$. The geometric non-linear Schrödinger equation (GNLS) on M is the Hamiltonian flow defined by E: $\gamma_t = J_\gamma(K_{\gamma_x}\gamma_x)$. Using the embedding of $Gr(k, n)$ as an adjoint orbit of $u(n)$, we construct a development map ϕ from $C(R, M)$ to the linear space $C(R, gl(k, n-k))$ such that the GNLS equation corresponds to the Fordy-Kulish equation $q_t = i(q_{xx} + 2qq^*q)$, where $gl(k, n-k)$ is the space of all $k \times (n-k)$ matrices and $q^* = \bar{q}^t$. There is a sequence of Poisson structures for each equation, and we show that the map ϕ maps the order k structure to order $k+2$ structure. We also explain the relation among the loop group action, Bäcklund transformations and scattering theory of this equation.

A.P. Veselov

Multi-dimensional Baker-Akhiezer functions and Huygens' Principle (joint work with O.A.Chalykh and M.V.Feigin)

A notion of rational Baker-Akhiezer (BA) function related to a configuration of hyperplanes in $\mathbf{C}^n$ is introduced. It is proved that the BA function exists only for very special configurations (locus configurations), which satisfy a certain overdetermined algebraic system. The BA functions satisfy some algebraically integrable Schrödinger equations, so any locus configuration determines such an equation. Some results towards the classification of all locus configurations are presented. This theory is applied to the famous Hadamard's problem of description of all hyperbolic equations satisfying Huygens' Principle. We show that in a certain class all such equations are related to locus configurations and the corresponding fundamental solutions can be constructed explicitly from the BA functions.

H. Widom, Santa Cruz, USA

Random matrices

For the unitary ensembles of $N \times N$ Hermitian matrices associated with a weight function w there is a kernel, expressible in terms of the polynomials orthogonal with respect to the weight function, which plays an important role. In particular one has formulas for the correlation functions and spacing probabilities in terms of them. For the orthogonal and symplectic ensembles of Hermitian matrices there are 2×2 matrix kernels, usually constructed using skew-orthogonal polynomials, which play an analogous role. The derivations in the literature of the various formulas are somewhat involved. We present a direct approach, joint work with Craig A. Tracy, which leads immediately to the scalar kernels for the unitary ensembles and matrix kernels for the orthogonal and symplectic ensembles, and the representations of the correlation functions and spacing probabilities in terms of them. We indicate how the entries of the matrix kernel can be expressed in terms of the scalar kernel for the associated unitary ensemble. If w'/w is rational then one of the entries of the matrix kernel (from which the others are computable) is equal to the corresponding scalar kernel plus a sum of terms whose number equals the order of w'/w. Thus for the Gaussian ($w(x) = e^{-x^2}$) and Laguerre ($w(x) = x^\alpha e^{-x}$) ensembles there will be one "extra" term because of the poles of w'/w at ∞ and 0, respectively.

W. Zakrzewski, Durham, GB

Skyrmions and Harmonic Maps

In this talk I have discussed recent ideas of how to find approximate solutions of the U(N) valued Skyrme model in 3 spatial dimensions. The model itself provides a good classical and phenomenological description of a nucleon and other low lying nuclei; unfortunately its equations are too complicated to be solved analytically.

The recent idea, based on numerical observations, is to use polar coordinates and approximate the angular dependence of U(N) fields by harmonic maps of S^2 into U(N).

The talk described the results obtained in this approach and concentrated on spelling out the differences in the shapes of equipotential surfaces for different N (i.e., for SU(2) and SU(3)).

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