Mathematisches Forschungsinstitut Oberwolfach

Report No. 11 / 2000

Automorphic Forms and Representation Theory

March 5th – 11th, 2000

The meeting was organized by S. Kudla (College Park, Maryland) and J. Schwermer (Düsseldorf/Wien).

The functoriality principle, formulated by R. P. Langlands in 1967, has stimulated a tremendous amount of research in representation theory, automorphic forms and number theory in the intervening years. The meeting focused on the interplay between local representation theory and its global applications in the theory of automorphic forms, especially functoriality and automorphic L–functions.
The program of 18 lectures emphasized to survey recent developments in both local and global theory with the hope of fostering new collaborative efforts, particularly among the younger generation of researchers in these areas. The topics included:

1. Local representation theory
   The local Langlands correspondence provides a conjectural parametrization of the [L–packets of] irreducible admissible representations of the group of F–points $G(F)$ of a reductive group G over a local field F:
   - the case of the general linear group
   - classical groups (e.g. construction of square–integrable representations of classical p–adic groups)

2. Global theory: automorphic representations
   The functoriality priniciple predicts many relations among the automorphic forms on different groups. In particular, one expects that every form on a group G has a functorial lift to $GL(n)$ for some n. Roughly speaking, the set of forms on G with a common image are said to form a L–packet. But the actual construction of functorial lifts and L–packets remains a fundamental open problem:
   - Arthur–Selberg and relative trace formulas (e.g. stabilization of the twisted trace formula, fundamental lemma)
   - "backwards"–functoriality and L–functions, converse theorems
   - Integrals of automorphic forms over certain subgroups

3. Interactions of the theory of automorphic forms with (arithmetic) (algebraic) geometry.

The variety of these topics indicates the rigorous activity and diversity of current research in automorphic forms, and stimulated much fruitful discussion.

Abstracts

Converse Theorems and Liftings

J. Cogdell & I. Piatetski–Shapiro.

Langlands functoriality tells us that whenever we have a map of L–groups there should be an associated lifting of automorphic forms. When the target group is GL_N, one method for establishing such a lift is the Converse Theorem.

In particular, associated to the embedding

$$ {}^{L}SO_{2n+1} = Sp_{2n}(\mathbb{C}) \to GL_{2n}(\mathbb{C}) = {}^{L}GL_{2n} $$

there should be a lift of automorphic forms from $SO_{2n+1}(\mathbb{A})$ to $GL_{2n}(\mathbb{A})$. We apply the converse theorem to show that a globally generic cuspidal representation π of $SO_{2n+1}(\mathbb{A})$ (over a number field) has a weak lift to an automorphic representation of $GL_{2n}(\mathbb{A})$.

The converse theorem we use to establish automorphicity of an irreducible admissible representation Π of $GL_N(\mathbb{A})$ requires we show that its twisted L–function $L(s, \tau \times \Pi)$ is "nice" for all cuspidal automorphic representations τ which are of the form $\tau = \tau' \otimes \eta$, with τ' unramified out a *fixed* finite set of places $\mathcal{S}$ and η a *fixed* idele class character, as τ runs over cuspidal representations of $GL_m(\mathbb{A})$ with $1 \leq m \leq N-1$.

For π our cuspidal representation of $SO_{2n+1}(\mathbb{A})$ we first control the twisted L–functions $L(s, \tau \times \pi)$ with τ as above. Then we describe local lifts $\pi_v \to \Pi_v$ from $SO_{2n+1}(k_v)$ to $GL_{2n}(k_v)$, and then finally apply the converse theorem to $\Pi = \otimes \Pi'_v$.
The use of the (highly ramified) twist by η lets us rule out some extraneous global poles of $L(s, \tau \times \pi)$ and to compensate for the fact that we do not know what the local lift should be for those finite places v where π_v is ramified.

On the first eigenvalue of Laplacian for locally symmetric manifolds

Jian – Shu Li

Consider a simple Lie group G with accociated symmetric space $X = G/K$. For any lattice $\Gamma \subseteq G$ let $\lambda_1(\Gamma)$ be the first positive eigenvalue of the Laplace operator on $L^2(\Gamma \backslash X)$. Let $\gamma(G)$ be the infimum of all $\lambda_1(\Gamma)$ as Γ runs through all lattices in G. In this talk we outline a computation of $\gamma(G)$ for groups with Kazhdan's property T. We relate $\gamma(G)$ with another invariant $\lambda_1(G)$ which is defined in terms of the unitary representation of G. For most classical groups and some exceptional groups, we compute $\lambda_1(G)$ explicitly, and prove that $\gamma(G) = \lambda_1(G)$.

Automorphic Green functions associated with the secondary spherical functions

Takayuki Oda

This is a joint work with Masao Tsuzuki of Sophia University at Tokyo. To explain the moral of our investigation, we discuss here the typical case $G = SU(n,1)$ and $H = S(U(1) \times U(n-1,1))$. The associated symmetric domain $X = G/K$ is a complex hyperball of dimension n, and the orbit X_o of a point $o = eK$ of X under H is also a complex hyperball, but of codimension one. Let $\triangle$ be the G–invariant Laplacian on X. Then there is a unique H–invariant solution for the eigenvalue problem

$$\triangle\phi = (n^2 - s^2)\phi, \quad s \in \mathbb{C},$$

which is a $H \times K$–invariant spherical function on G. If we admit the singularity along the orbit X_0, then the same equation has another solution which has the logarithmic singularity along X_0. Among such solutions, we consider the unique one which has the fastest decay at ∞. We call this the secondary spherical function $\phi_s^{(2)}$.

Let E be an imaginary quadratic field and ϕ a non-degenerate Hermitian form of Witt index 1 on an E–vector space with signature $(n+, 1-)$. Then ϕ defines a commensurable class of arithmetic lattices in G. For such a lattice Γ, starting with the function $\phi_s^{(2)}$, we can construct Poincaré series

$$G_s(z) = \sum_{\gamma\in\Gamma\cap H\backslash\Gamma} \phi_s^{(2)}(\gamma_z), \quad z \in \Gamma\backslash X.$$

Our main purpose here is to establish some fundamental properties of $G_s(z)$.

(Pre–)Stabilization of elliptic singular terms in the twisted trace formula

J.–P. Labesse

Let G be a connected reductive group over a number field F. Let Θ be a finite order automorphism of G/F. Let $L = G \times \Theta$ be the coset of Θ in the semidirect product $G \times \langle\Theta\rangle$. An element $\delta \in L(F)$ is said to be elliptic if its centralizer G^δ is reductive and if the volume of the quotient $A_L Z_\delta(F)\backslash I_\delta(\mathbb{A}_F)$ is finite. Here $I_\delta = (G^\delta)^0 Z^\Theta$, with Z the center of G, and $A_L = A_G^\Theta$. The elliptic part of the trace formula is the distribution

$$T_e(\phi) = \int_{A_G G(F)\backslash G(\mathbb{A})} \sum_{\delta\in L(F)_e} \phi'(x^{-1}\delta x)\ dx$$

with $L(F)_e$ the subset of elliptic elements in $L(F)$. In the talk we described the notion of stable conjugacy, introduced various non abelian cohomological objects that describe stable conjugacy classes and allow an Fourier inversion formula. This formula is the first step towards the stabilization of all elliptic terms. The next step is the transfer to endoscopic groups.

Periods of Automorphic Forms and Applications

Dihua Jiang

Let G be a reductive algebraic group defined over a number field F, and $Q = L \cdot N$ be a closed subgroup of G (L reductive, N is unipotent). Let ψ be a character of $N(F)\backslash N(\mathbb{A}) \to \mathbb{C}^*$ ($\mathbb{A}$ is the adelic ring of F), $S = Stab_L(\psi)$. Set $R = S \cdot N$.
For $\phi \in L^2_{disc}(G) = L^2_{disc}(Z_G(\mathbb{A})G(F)\backslash G(\mathbb{A}))$ define

$$\mathcal{P}_{R,\psi}(\phi) = \int_{Z'R(F)\backslash R(\mathbb{A})} \phi\ (\gamma)\ \overline{\psi}\ (r)\ dr$$

which is called the period (integral) of ϕ associated to (R, ψ).

For arithmetic applications, we refer to M. Harris' paper in "Motives", Proc. Symp. Pure Math 55 (2) (1991). We gave a report on our results on relations between periods and automorphic L–functions and the lifting of automorphic representations.

Spherical unitary dual for split classical groups

Dan Barbasch

Let G be a split group. In this talk I explored the relation between the spherical dual of real and p–adic groups. The main result is that the parametrizations for split real and split p–adic groups coincide. A spherical irreducible representation is "classified" by exhibiting it as a canonical subquotient of a principal series. The theory of intertwining operators determines its unitarity (in principle). Formally this is independent of the field. We then exhibit a correspondence between certain K–types (we call spherical K–types) for real and p–adic groups where these intertwining operators coincide.

Matrix argument Kloosterman sums and the fundamental lemma

Masaaki Furusawa

This is a joint work with Joseph A. Shalika. We conjecture that both of Jacquet's relative trace formulas for $GL(2)$, where he has given another proof for Waldspurger's result on the central critical value for $L(s, \pi)$, generalize to $GSp(4)$. In fact we have proved the fundamental lemma for the unit elements in the Hecke algebras for the two relative trace formulas. We have computed the orbital integrals and expressed them explicitly in terms of the classical $GL(2)$ Kloosterman sums.
As an illustration, let us describe one of the results we obtained. Along the way we discovered that our orbital integrals may be expressed by the matrix argument Kloosterman sums.

Theorem. *Let F be a non–archimedean local field whose residual characteristic is not equal to two. Let ϖ be a prime element in F and $\mathcal{O}_F$ be the ring of integers in F. Let $q = \#(\mathcal{O}_F/\varpi\mathcal{O}_F)$. Let ψ be a character of F whose conductor is $\mathcal{O}_F$. Then for $A = \left(\begin{smallmatrix}\alpha & \beta \\ \gamma & \delta\end{smallmatrix}\right) \in \varpi M_2(\mathcal{O}_F) \cap GL_2(F)$ and $\epsilon \in \mathcal{O}_F^\times$, let*

$$K_{spl.}(A, \epsilon) = \int\limits_{\mathcal{X}_A} \psi[tr(X \left(\begin{smallmatrix}0 & 1 \\ 1 & 0\end{smallmatrix}\right) + \epsilon \cdot \left(\begin{smallmatrix}0 & 1 \\ 1 & 0\end{smallmatrix}\right) A^{-1} X^{-1}\, {}^tA^{-1}]dX$$

where $\mathcal{X}_A = \{X \in Sym^2(F) \mid XA \in GL_2(\mathcal{O}_F)\}$.
Then,

$$K_{spl.}(A, \epsilon) = |\triangle|^{-1} \cdot \{Kl(\frac{2\alpha}{\triangle}, \frac{2\epsilon\delta}{\triangle}) + Kl(\frac{2\beta}{\triangle}, \frac{2\epsilon\gamma}{\triangle})\}$$

where $\triangle = \det A$, $\quad Kl(r, s) = \int\limits_{\mathcal{O}_F^\times} \psi(r\epsilon + s\epsilon^{-1}) d\epsilon.$

We have also proved a similar formula for the anisotropic Kloosterman sum and generalized the Davenport–Hasse relation to our case.

On the cohomology with compact support of locally symmetric spaces

Birgit Speh

This is joint work with J. Rohlfs. Let $G/\mathbb{Q}$ be a reductive linear connected algebraic group and S the corresponding adelic locally symmetric space. Let $e[P]$ be a face of its Borel Serre compactification $\bar{S}, V$ a rational representation of $G(\mathbb{R})$. We construct a map cor: $H^*_C(e[P], \tilde{V}) \longrightarrow H^*_C(S, \tilde{V})$ explicitly using differential forms. This map is dual to the restriction res: $H^*(S, V) \cong H^*(\bar{S}, V) \to H^*(e[P], V)$. This allows us to construct forms ("pseudo Eisenstein forms") which represent cohomology classes in $H^*_C(S, V)$ which are dual to those classes constructed using Eisenstein forms following Harder/Schwermer.

Langlands–Shahidi method and functorial lift

Henry H. Kim

This is a joint work, partly with J. Cogdell & I. Piatetski–Shapiro and partly with F. Shahidi. I will show that the Langlands–Shahidi method can be used to obtain Langlands' functorial lift in the following 7 cases, using converse theorem of Cogdell-Piatetski-Shapiro:

(1) $GL_2 \longrightarrow GL_3$ (symmetric square: Gelbart–Jacquet lift)
(2) $GL_2 \times GL_2 \longrightarrow GL_4$ (Ramakrishnan's result)
(3) $GL_2 \times GL_3 \longrightarrow GL_6$
(4) $GL_4 \longrightarrow GL_6$ (exterior square)
(5) $SO_{2n+1} \longrightarrow GL_{2n}$
(6) $Sp_{2n} \longrightarrow GL_{2n+1}$
(7) $SO_{2n} \longrightarrow GL_{2n}$.

Let H be the above group in the left hand side over a number field F. Then there is an L–group homomorphism $l : H^* \longrightarrow GL_n(\mathbb{C})$. Langlands' functoriality predicts that there is a map from cuspidal representations of $H(\mathbb{A}_F)$ to automorphic representations of $GL_n(\mathbb{A}_F)$. We construct this map for generic cuspidal representations of $H(\mathbb{A}_F)$, using converse theorem.

In (1), we use $GL_1 \times SL_2 \subset Sp_4$. We get an L–function $L(S, \pi, Ad^2 \otimes \mathcal{X})$ for π cuspidal representations of $GL_2(\mathbb{A}_F), \mathcal{X}$ a Grössencharacter of F. For (3), we need to consider the triple L–functions $L(s, \sigma \times \pi_1 \times \pi_2)$ for π_1 cuspidal representation of $GL_2(\mathbb{A}_F)$, π_2 cuspidal representation of $GL_3(\mathbb{A}_F)$, σ cuspidal representation of $GL_m(\mathbb{A}_F)$, $m = 1, 2, 3, 4$.
For $m = 2$, we consider $D_5 - 2$ case in Shahidi (using Spin (10)). For $m = 3$, we consider $E_6 - 1$; for $m = 4$, consider $E_7 - 1$.

One application is that we get a new estimate on Fourier coefficients of cuspidal representations of GL_2.

Towards a more local proof of the Langlands conjecture for GL_n over p–adic fields

Guy Henniart

This is a report on joint work with C. Bushnell. Let F be a finite extension of $\mathbb{Q}_p$. The Langlands conjectures, recently proved by global means using the cohomology of Shimura varieties, give for each positive integer n a bijection $\sigma \to \pi(\sigma)$ between the set $G_F^0(n)$ of irreducible degree n representations of W_F, up to isomorphism, and the set $A_F^0(n)$ of smooth irreducible supercuspidal representations of $GL_n(F)$, up to isomorphism. The main property is the preservation of ϵ–factors: if ψ is a fixed non trivial character of F, then $\epsilon(\sigma \otimes \sigma', s, \psi) = \epsilon(\pi(\sigma) \times \pi(\sigma'), s, \psi)$, for $\sigma \in G_F^0(n)$, $\sigma' \in G_F^0(n')$.

However, the global proofs shed no light on the nature of ϵ–factors, nor do they yield anything explicit about the correspondence. C. Bushnell and I have a strategy for another proof, more explicit and local, which uses both the cyclic base change of Arthur and Clozel and our own (non galois) tame base change.

For that strategy, it remains to get a direct proof of some properties of ϵ–factors for pairs. The first one is now a theorem.

Let n, n' be powers of p $n \neq n'$. Assume $\pi \in A_F^0(n)$, $\pi' \in \mathbb{A}_F^0(n')$ are inequivalent to their twists by non–trivial unramified characters.

<u>Theorem</u> There exists $c = c(\pi, \pi', \psi) \in F^*$ such that, for all tame quasicharacters χ of $F^\times$, $\omega(\chi\pi \times \pi', s, \psi) = \chi(c)^{-1}\epsilon(\pi \times \pi', s, \psi)$.

<u>Conjecture 1</u> $\epsilon(\pi \times \pi', s, \psi)$ behaves well under tame base change, in particular $c(\pi, \pi', \psi)$ is invariant under tame base change.

<u>Conjecture 2</u> $\epsilon(\pi \times \pi', 1/\alpha, \psi) \equiv \omega_\pi^{-Yn}\omega_{\pi'}^{-Yn'}(c)G(c, \psi)^{nn'}$ mod p^{th} power roots of unity, where $G(c, \psi)$ is some explicit Gauss sum depending on ψ and c modulo squares.

About the classification of discrete series for classical groups

Colette Moeglin

The goal of the talk was to explain what are the parameters which can give a classification of discrete series for classical groups (case of p–adic fields). One needs an analogon of the Jordan blocks (used in the classification of unipotent orbits) and an analogon of local systems on orbits. Such definitions can be given using some properties of reducibility of certain induced representations and some properties of Jacquet's modules. But to prove something, I need an assumption about the points of reducibility of induced of cuspidal representations. With this assumption (known in some case and which follows from Arthur's conjectures) the result says that the cuspidal support and the above parameters classify the discrete series. The surjectivity in the theorem is a joint work with Marko Tadic.

A Polya–Hilbert operator for automorphic L–functions

Anton Deitmar

In analogy to the case of zeta functions of hyperbolic dynamical systems one seeks to describe the zeros of an automorphic L–function as the eigenvalues of the generator of a flow.
We give the flow as central multiplication on $GL_n(\mathbb{A})$ and find a suitable space of functions on which the generator of the flow has as eigenvalues exactly the zeros of the L–function along the critical line.

As a by product we get a new proof of the meromorphicity of general automorphic L–functions which gives new insights to their analytic behavior.

Construction of square–integrable representations of classical p–adic groups

Marko Tadić

In the talk we reviewed some methods of construction of square–integrable representations of classical p–adic groups, and talked about joint work with C. Moeglin ("Construction of discrete series of classical p–adic groups"). C. Moeglin attached to each discrete series an admissible triple (which is a combinatorial object modulo cuspidals and cuspidal reducibilities), and showed injectivity. In the joint work surjectivity is shown. The proof of surjectivity reduces to the proof of square integrability of certain representations. We illustrated the arguments used in the paper in some examples. The proof is modulo a basic assumption, which is expected to hold in general (in the generic case it is known that it holds by F. Shahidi's work).

The above classification of discrete series (modulo cuspidals and cuspidal reducibilities) also gives a classification of the non–unitary duals modulo cuspidals and cuspidal reducibilities.

An endoscopic lift for $\mathbf{Spin}_7$

Nadya Gurevich

We consider the theta correspondence associated to the dual pair of type $(A_1 \times C_2, B_3)$ inside E_7 and obtain a new example of functorial lift (on the level of unramified representations).

We also consider another theta–correspondence associated to the dual pair of type $(A_1 \times C_2, A_1 \times A_1)$ in D_6 and show that these two pairs fit into a tower, and the standard property of a tower of theta–correspondences holds.

Howe correspondence for discrete series

Goran Muic

In this talk I explain Howe lifts of discrete series for symplectic orthogonal dual pairs. More precisely, I use the classification of discrete series for $Sp(n, F)$ in semisimple rank, due to Moeglin and Tadić in order to describe the first occurance in a fixed tower $V_r, r \leq 0$, the structure of each lift and the asymptotic properties of matrix coefficients of lifts of discrete series $Sp(n, F)$ to $O(V_r)$; $r \geq 0$. I need the same assumption about the points of reducibility of representations induced from supercuspidals in rank–one case that is described in Moeglin's talk. In fact, there is no assumption for discrete series of $Sp(n, F)$ that are subquotients of representations induced from supercuspidal representations having Whittaker models.

Toric varieties and modular forms

Paul Gunnells

Let $\ell \geq 1$ be an integer, let $N \cong \mathbb{Z}^d$ be a lattice, and let $M = Hom_{\mathbb{Z}}(N, \mathbb{Z})$. Let $deg : N \longrightarrow (1/\ell)\mathbb{Z}$ be a piecewise–linear function that is linear on the cones of some N–rational complete fan $\Sigma < N \otimes \mathbb{R}$. Let $\tau \in \mathcal{H}$ and let $g = e^{2\pi i \tau}$. We define $f_{N,deg} : \mathcal{H} \to \mathbb{C}$ by

$$f_{N,deg}(c) = \sum_{m \in M} \sum_{C \in \Sigma} (-1)^{codim C} a.c.(\sum_{n \in C \wedge N} g^{<m,n>} e^{2\pi i deg(n)}).$$

Here the $a.c.$ denotes analytic continuation, and $<,>$ is the pairing between M and N. Then under certain mild conditions on deg, we show that $f_{N,deg}$ is a holomorphic modular form of weight d on the group $\Gamma_1(\ell)$.

By considering all possible pairs (N, deg) we obtain a subring $J_1(\ell)$ of the modular forms of level ℓ. We show that this subring is stable under the Hecke operators, Atkin–Lehner lifting, and the Fricke involution. Moreover, we show that,modulo Eisenstein series, $J_1(\ell)$ is isomorphic to the $\mathbb{C}$–span of those cuspidal eigenforms whose L–functions do not vanish at the center of the critical strip.

This is joint work with Lev Borisov.

On the singularities of residual Eisenstein series

Jens Franke

Let $f \in A_2(A_P(\mathbb{R})^+ P(\mathbb{Q}) N_P(\mathbb{A}) \backslash G(\mathbb{A}))$ be a square integrable automorphic form and

$$(E_P^G(f, \lambda))(g) = \sum_{\gamma \in P(\mathbb{Q}) \backslash G(\mathbb{Q})} exp((\lambda + \rho_P) \cdot H_P(\gamma g)) f(\gamma g) \qquad \lambda \in (\check{\mathfrak{a}}_P)_{\mathbb{C}}$$

its Langlands Eisenstein series. The conventions are made such that $i\check{\mathfrak{a}}_P$ is the unitary axis.

If H is a singular hyperplane of $E_P^G(f, \lambda)$ which meets $\overline{\check{\mathfrak{a}}_P^+} + i\check{\mathfrak{a}}_P$ (the tube domain over the closed positive Weyl chamber), then H is real and meets $\check{\mathfrak{a}}_P^+$ (the interior of the positive Weyl chamber).

This fact is well known for cuspidal f. In the general case, I prove it using a filtration on the space of automorphic forms.

Integrals of Borcherds forms

Stephen Kudla

A basic quantity in Arakelov theory is the real number, associated to a non–zero meromorphic function f:

$$K(f) = -\frac{1}{vol(X)} \int_X \log |f|^2 \mu$$

where $X \simeq \Gamma\backslash\mathcal{H}$ is a uniformized curve of genus $g \geq 2$ and μ is the hyperbolic volume term. When X is a Shimura curve associated to an indefinite division algebra over $\mathbb{Q}$, meromorphic functions $f = \Psi(F)$ can be constructed by the method of Borcherds, beginning with a meromorphic vector valued form F of weight $\frac{1}{2}$ with q–expansion of the form

$$F(\tau) = \sum_{\phi}\sum_{m} c_{\phi}(m)q^m \cdot \phi, \quad c_{\phi}(m) \in \mathbb{Z} \text{ for } m \leq 0.$$

Then $\Psi(F)$ has weight $k = c_0(0)$; and

$$\begin{aligned} K(\Psi(F)) &= -\frac{1}{vol(X)}\int_X \log|\Psi(Z,F)y^{k/2}|^2 \; d\mu(z) \\ &= \sum_{\phi}\sum_{m\geq 0} c_{\phi}(-m)K_{\phi}(m) \end{aligned}$$

where $K_{\phi}(m)$ is given by writing the Eisenstein series of weight $\frac{3}{2}$ attached to ϕ

$$E'(\tau, \frac{1}{2}, \phi^{\frac{3}{2}}) = \sum_{m} b_{\phi}(m,v)q^m.$$

Then

$$\begin{aligned} K_{\phi}(m) &= \lim_{v\to\infty} b_{\phi}(m,v) \quad \text{if } m \neq 0 \\ K_{\phi}(0) &= \frac{1}{2}(log(2\pi) + \Gamma'(1)). \end{aligned}$$

Berichterstatter: Joachim Schwermer (Wien)

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