MATHEMATISCHES FORSCHUNGSINSTITUT OBERWOLFACH

Tagungsbericht 21/1988

Approximation und Interpolation
mit Lösungen partieller Differentialgleichungen
8.5. bis 14.5.1988

Die Tagung wurde unter der Leitung von M. v. Golitschek (Würzburg) und W. Haußmann (Duisburg) durchgeführt. Fünfundzwanzig Teilnehmer aus den Ländern Bulgarien, Deutschland, Großbritannien, Israel, Kanada, Polen, Schweden, Spanien und den USA boten in dreiundzwanzig Vorträgen einen Überblick über aktuelle Resultate und Entwicklungen im Bereich der Approximation und Interpolation mit Lösungen partieller Differentialgleichungen dar.

Unter anderem wurden folgende Fragestellungen behandelt: Approximation mit Blendingfunktionen (einschließlich algorithmischer Methoden) und mit Lösungen elliptischer Differentialgleichungen (insbesondere mit Summen von Poisson–Kernen und von Räumen harmonischer Funktionen). Außerdem wurden Beiträge über Pseudodifferential–Operatoren und Holographie, Approximation singulärer Lösungen, Radontransformation auf Polynomräumen, über das inverse Potentialproblem sowie über Interpolation durch radialsymmetrische Funktionen präsentiert.

Besonders hervorzuheben sind die lebhaften und sehr fruchtbaren Diskussionen, in denen Methoden und Entwicklungen der partiellen Differentialgleichungen und der Approximationstheorie zusammengeführt wurden. Dadurch ergaben sich zahlreiche neue Gesichtspunkte und Anregungen für eine weitere Zusammenarbeit der verschiedenen Arbeitsrichtungen.

Ein besonderer Dank gebührt den Mitarbeitern des Forschungsinstituts für die ausgezeichnete Betreuung und dem Direktor des Mathematischen Forschungsinstituts Oberwolfach, Herrn Professor Barner, für sein verständnisvolles Entgegenkommen.

Vortragsauszüge:

G. BASZENSKI
Pseudohyperbolic Fourier Approximation

For $f : [0, 2\pi]^2 \to \mathbb{C}$ let (f, x_{kl}) denote its Fourier double series coefficients. The Korobov space for $\alpha > 0$ is defined as

$$E^\alpha = \left\{ f : |(f, x_{kl})| = O(\frac{1}{|kl|^\alpha}), \quad |k|, |l| \to \infty \right\}.$$

Examples of functions of a Korobov space are smooth functions with periodic continuous derivatives up to a certain order.

Hyperbolic Fourier partial sums $\sum_{|kl| \le n} (f, x_{kl}) x_{kl}$ approximate $f \in E^\alpha$ well both in L_2 and L_∞ norm, but the set of coefficients is difficult to organize as a data structure.

It is shown that pseudohyperbolic sums $\sum_{j=0}^{r} \sum_{|k| \le 2^j} \sum_{|l| \le 2^{r-j}}$ are simpler to handle and give the same asymptotic error estimates as the hyperbolic sums.

E. W. CHENEY
Interpolation by Radial Basis Functions

In a linear normed space, functions of the form $r_i = \|x - w_i\|$ have been termed "radial basis functions". They can be used for interpolating other functions at the nodes $w_1, w_2, \dots$. Particular instances of this occur in the two-dimensional space $\mathbb{R}^2$ with the l_1-norm or the l_∞-norm. In these cases, the interpolating elements $\sum_{i=1}^{n} a_i r_i(x)$ are piecewise linear functions of two variables on rectangular grids. The theory of these functions has been developed in a paper written jointly with W. A. Light.

L. COLLATZ
Approximation singulärer Lösungen partieller Differentialgleichungen in einfachen Fällen

Vorgelegt sei die Randwertaufgabe für eine Funktion $u(x) = u(x_1, x_2, \dots, x_n)$ in einem gegebenen Bereich B des $\mathbb{R}^n$ mit stückweise glattem Rand ∂B:

$$Nu = r(x) \text{ in } B,$$

$$Mu = s(x) \text{ auf } \partial B,$$

mit gegebenen (nichtlinearen) Operatoren N, M und gegebenen Funktionen $r(x)$, $s(x)$. Der Operator $T = (N, M)$ sei von "monotoner Art", d. h. $Tv \leq Tw$ habe $v \leq w$ in B zur Folge (Ordnung punktweise auf $B \cup \partial B$ im Sinne der klassischen Ordnung reeller Zahlen und für jede Komponente von T).
Dann kann man u in Schranken $v \leq u \leq w$ einschließen, sofern

$$Tv \leq \begin{pmatrix} r(x) \\ s(x) \end{pmatrix} \leq Tw$$

gilt. Dies wird an verschiedenen Typen von Singularitäten vorgeführt: An Ecken im $\mathbb{R}^2$ mit Eckenwinkel α (wobei $2\pi/\alpha$ ganzzahlig ist oder auch nicht ganzzahlig), an singulären Linien im $\mathbb{R}^3$ und an "versteckten" Singularitäten; numerische (meist im letzten Jahr gerechnete) Beispiele und noch offene Probleme werden genannt.

C. COTTIN

Mixed K–Functionals: A New Modulus of Smoothness for Blending–Type Approximation

The K–functionals of J. Peetre play an important rôle in the derivation of quantitave estimates for the degree of approximation of certain approximants for univariate functions. One reason for this is the fact that they are equivalent to the standard moduli of smoothness.

In the case of "blending–type" approximation of functions of two variables (e. g. approximation by Boolean sums of parametric extensions of univariate approximation operators or by pseudopolynomials) the so–called mixed moduli of smoothness have turned out to be appropriate devices for measuring smoothness.

We introduce "mixed K–functionals" as an analogue to the Peetre K–functionals in the context of blending–type approximation and state an equivalence relation between mixed K–functionals and mixed moduli of smoothness. As applications we show how mixed K–functionals can be used in the method of smoothing known e. g. from the univariate case, and give an optimal estimate for the degree of approximation by trigonometric pseudopoynomials.

F. DEUTSCH

Duality and Shape Preserving Interpolation

A general duality theorem characterizing best approximations from certain convex subsets of a normed linear space is proved. As a particular corollary, we get the following result.

Let $L_2 = L_2(T,\mu)$, $\{x_1, x_2, \ldots, x_n\} \subset L_2$, $(d_1, d_2, \ldots, d_n) \in \mathbb{R}^n$, and

$$K = \{y \in L_2 \mid y \geq 0,\ \langle y, x_i\rangle = d_i \ \ (i = 1, 2, \ldots, n)\}.$$

Then the best approximation to any $x \in L_2$ from K is

$$P_K(x) = (x + \sum_{i=1}^{n} \alpha_i x_i) + \chi_\Omega,$$

where

$$\Omega = \{t \in T \mid \exists k \in K \text{ with } k(\varepsilon) > 0\}$$

and the scalars α_i are chosen so that the element $k_0 := (x + \sum_{i=1}^{n} \alpha_i x_i) + \chi_\Omega$ satisfies $\langle k_0, x_j\rangle = d_j$ for $(j = 1, 2, \ldots, n)$.

W. FREEDEN

Splines for Solving Boundary Value Problems of Elasticity

A spline interpolation method is proposed for solving the classical displacement boundary value problem of elastostatics from discretely defined boundary displacement vectors or stress vectors. A stability theorem is developed, which is dependent on the spacing of the data on the boundary, and convergence is established for the case in which the data points become dense. A basic tool is a vectorial generalization of the addition theorem for spherical harmonics.

P. GAUTHIER

Approximation by solutions of elliptic equations

I wish to report on joint work with A. Dufresnoy and W. H. Ow published in Complex Variables, 1986, Vol. 6, pp. 235-247. Given a function on a closed set, we wish to approximate it uniformly by solutions of a given elliptic partial differiential equation.

M. GOLDSTEIN
Quadrature and Harmonic L_1–Approximation in Annuli

Open sets D in $\mathbb{R}^N$ ($N \geq 3$) with the property that $\overline{D}$ is a closed annulus $\{x : r_1 \leq \|x\| \leq r_2\}$ are characterized by quadrature fomulae involving mean values of certain harmonic functions. One such characterization is used to give a criterion for the existence of a best harmonic L_1 approximant to a function which is subharmonic (and satisfies some other conditions) in an annulus.

M. v. GOLITSCHEK
Proximinality in Tensor Product Subspaces

Let S, T and $D \subseteq S \times T$ be compact Hausdorff spaces. Let $G \subset C(S)$ and $H \subset C(T)$ be finite–dimensional subspaces of real–valued continuous functions. The question is discussed which of the spaces

$$W = G \otimes C(T) + C(S) \otimes H$$

are proximinal in $C(D)$. It turns out that, in general, "bad functions" $f \in C(D)$ do not possess a best approximation in W.

H. H. GONSKA
Zur Güte der Silmultanapproximation durch Gordon–Operatoren

Boolesche Summen parametrischer Erweiterungen univariater Interpolations– und Approximationsverfahren haben seit Erscheinen der grundlegenden Arbeiten von W. J. Gordon weitreichende Verwendung im Computer Aided Geometric Design gefunden. Etwa gleichzeitig ist die Methode in der osteuropäischen Literatur untersucht und damit Gegenstand approximationstheoretischer Fragestellungen geworden.

In unserem Vortrag werden wir

(i) die sogenannte 'Blending–Methode' in einem historischen Zusammenhang darstellen,

(ii) mittels geeigneter Permanenzprinzipien einige Ergebnise allgemeiner Natur herleiten, und

(iii) unter Verwendung neuer Ergebnisse zur Approximation durch univariate interpolierende Spline-Operatoren darlegen, wie sich die allgemeinen Resultate zur Gewinnung von quantitativen Aussagen zur Simultanapproximation durch sog. Gordon–Operatoren heranziehen lassen.

W. HAUSSMANN

H–Sets and Best Uniform Approximation by Solutions of Elliptic Equations

We consider second order elliptic partial differential operators $Lu := \sum_{i,j=1}^{n} a_{ij}(x)\frac{\partial^2 u}{\partial x_i \partial x_j} + \sum_{i=1}^{n} b_i(x)\frac{\partial u}{\partial x_i}$ for $a_{ij}, b_i \in C(\mathbb{R}^n)$, and for a Jordan domain $D \subset \mathbb{R}^n$ the space

$$FC(\overline{D}) := \{w \in C^2(D) \mid Lw = 0,\ w \text{ has a continuous extension to } \overline{D}\}.$$

Given an $f \in C(\overline{D})$ we ask for a best approximant $w^* \in FC(\overline{D})$ satisfying

$$\|f - w^*\|_{\infty,\overline{D}} \leq \|f - w\|_{\infty,\overline{D}} \text{ for all } w \in FC(\overline{D}).$$

We give a characterization of a best approximant in terms of H–sets H_1, H_2 (introduced by Collatz 1965).

To this end we first characterize H–sets with respect to $FC(\overline{D})$ in terms of the polynomially convex hulls $h(H_1)$ and $h(H_2)$. This leads to a result of de la Vallée Poussin type, from which the characterization of best approximants follows. Main tool is the Runge approximation property (Browder 1962, Lax 1956). The uniqueness of a best approximant follows from the validity of the uniqueness condition in the Cauchy problem in the small (cf. Browder 1962).

Our result includes previous investigations due to Burchard (1976), Hayman–Kershaw–Lyons (1984) and Kounchev (1985) on approximation by harmonic functions.

In the case of L–subharmonic functions we construct the unique best approximant, and we show the monotonicity of the degree of approximation.

Our results have been established jointly with K. Zeller.

W. K. HAYMAN
Summen von Poisson Kernen

Es sei $f(\theta)$ eine beliebige positive nach unten halbstetige Funktion auf dem Einheitskreise $0 \leq \theta \leq 2\pi$ und

$$P(\theta, z) = \frac{1}{2\pi} \cdot \frac{1 - |z|^2}{|e^{i\theta} - z|^2}$$

der Poisson Kern. Wir suchen eine Repräsentation von f

$$(*) \qquad f(\theta) = \sum_{n=1}^{\infty} c_n \, P(z_n, \theta),$$

wo z_n eine im voraus gegebene Folge ist und die c_n positive Konstanten. Eine hinreichende Bedingung für (*) ist, daß jeder Punkt $e^{i\theta}$ Grenzwert einer Unterfolge von z_n in einem Stolzschen Winkel ist. Eine etwas schwächere Bedingung ist notwendig. Dies beantwortet zum Teil eine Frage von Walter Rudin.

L. I. HEDBERG
Approximation by Harmonic Functions in Dirichlet and Uniform Norm

In 1941, in his fundamental study of the Dirichlet problem, M. V. Keldysh characterized the compact sets K in $\mathbb{R}^n$ with the property that the continuous functions on K which are harmonic on int(K) can be uniformly approximated on K by functions harmonic on neighbourhoods of K. His proof was constructive and quite complicated. A proof by duality was given in 1950 by J. Deny.

In 1968 V. P. Havin studied the analogous problem for L_2–approximation by analytic functions on compact sets in the complex plane. He gave a necessary and sufficient condition which is easily seen to be equivalent to the condition given by Keldysh. Havin's problem can be reformulated as an approximation problem for harmonic functions in the Dirchlet norm, and then it makes sense also in n dimensions.

It is by no means obvious from the proofs why uniform approximation is possible if and only if approximation in the Dirichlet norm is possible. The talk is devoted to an effort at explaining this equivalence, by tracing its roots to H. Cartan's definition of balayage by means of projections in Hilbert spaces.

W. HENGARTNER

Univalent Harmonic Mappings and Approximate Solutions

We shall consider univalent, orientation-preserving, harmonic functions $f = u + iv$ defined on the unit disk U. Then f can be viewed as a solution of the elliptic partial differential equation $\bar{f_{\bar{z}}} = a \cdot f_z$, where the dilatation function a belongs to $H(U)$ and $|a(z)| < 1$ for all $z \in U$. Because a composition $f(\phi)$ with a conformal mapping ϕ remains harmonic we may suppose without loss of generality that f satisfies the normalisation $f(0) = 0$ and $f_z(0) > 0$. We shall discuss existence and uniqueness of such mappings onto a given simply connected domain Ω of $\mathbb{C}$, $\Omega \neq \mathbb{C}$, having a prescribed dilatation $a(z)$. Univalent harmonic mappings play an important part in the theory of minimal surfaces. Indeed, let S be an nonparametric surface over Ω given by $S = \{(u, v, F(u, v)) : u + iv \in \Omega\}$. Then S is a minimal surface if and only if S admits a reparametrization of the form $S = \{(u(z), v(z), G(z)) : z = u + iv \in D\}$, such that $f = u + iv$ is a univalent harmonic mapping from the unit disk D onto Ω and G is a real–valued harmonic function satisfying $G_z^2 = -a \cdot f_z^2$, where a is the dilatation of f. Let Ω be a strictly starlike domain of $\mathbb{C}$. Then for each $a \in H(U)$ such that $|a(z)| \leq k < 1$, $z \in U$, there is exactly one univalent solution of the above differential equation which is harmonic, maps U onto Ω and has the described normalization. This fact (which may fail if $|a(z)|$ tends to 1 as z tends to ∂U) allows to construct such mappings numerically. The method can also be modified for exterior mappings.

K. JETTER

Bernoulli Distributions and Approximation by Trigonometric Blending Functions

Jackson-Favard estimates for trigonometric approximation are related to the convolution formula $f = c_0 + B_r \star f^{(r)}$ for periodic functions $f \in W_r^\star$ (with $c_0(f)$ the mean value of f and B_r the r-th Bernoulli spline). We develop a similar theory for multivariate approximation using the notion of periodic distributions and the (d-dimensional) Bernoulli distribution (introduced by J. Stöckler).

A typical result is the following: If $\alpha\xi = 1$ (with $0 \neq \xi \in \mathbb{Z}^d$) has a solution $\alpha = \alpha_\xi$ with integer components, and if $T_{n,\xi}$ denotes the space of periodic test functions of type

$$t(x) = g_0(x) + \sum_{k=1}^{n} (\cos(k\alpha_\xi x) \cdot g_k(x) + \sin(k\alpha_\xi x) \cdot h_k(x))$$

with g_k and h_k independent of ξ, then the approximation constant $\inf\{\|f - t\|_p; t \in T_{n,\xi}\}$ admits the Favard estimate $\|D_\xi^r f\|_p \cdot \frac{K_r}{(n+1)^r}$ with K_r the r-th Favard constant.

Applications of this result yield some of the estimates in the literature.

O. I. KOUNCHEV

Inverse Potential Problem and Approximation by Solutions of Partial Differential Equations

In the 1960s D. Zidarov invented the partial balayage method for constructing bodies graviequivalent to a given one. He was stimulated by the applications to the inverse problems of gravimetry.

For such bodies it is possible to prove a characterisation of the element of best L_1–approximation by harmonic functions, generalizing a result by M. Goldstein, W. Haußmann and K. Jetter.

This result may be generalized for other equations by appropriate generalization of Zidarov's construction.

D. LEVIATAN

The Rate of Approximation by Recipocals of Polynomials in L_p

Extending some recent results of Levin and Saff we prove in a joint work with them that a nonconstant and non-negative $f \in C[-1,1]$ can be approximated in the uniform norm on $[-1,1]$ by reciprocals of polynomials p_n (of degree not exceeding n) at the rate $\omega_\varphi(f, \frac{1}{n})$ where $\varphi(x) = (1-x^2)^{\frac{1}{2}}$ and $\omega_\varphi(f,\cdot)$ is the Ditzian-Totik modulus of continuity of f. For $1 \le p < \infty$ we prove:

Theorem: Let $f \in L^{(p+1)}[-1,1]$, $1 \le p < \infty$ be non-negative. Then there exist polynomials p_n such that

$$\|f - \frac{1}{p_n}\|_p \le C\,\omega_\varphi(f, \frac{1}{n})_{p+1}, \quad n = 1, 2, \ldots$$

W. A. LIGHT

Approximation of Vector–Valued Functions

The situation to be considered is as follows. The mapping f associates each element in a set S with some element in a Banach space X. The set S will be assumed to have some structure (measure–theoretical or topological) so that a Banach space of such mappings (denoted by $A(S,X)$), may be constructed. Under suitable conditions, a closed subspace G of X gives rise to a subspace $A(S,G)$ of $A(S,X)$. A natural question is "When does the proximinality of $A(S,G)$ in $A(S,X)$ follow from that of G in X?". Such problems are related to "blending functions" where one half of the approximating subspace contains elements of the form

$$a_0(s) + a_1(s)t + a_2(s)t^2 + \ldots + a_n(s)t^n,$$

when G is the subspace of polynomials of degree n. Then one approximates sections of bivariate functions $f_s(t)$ by polynomials. If $f, a_0, a_1, \ldots, a_n$ are continuous then the proximinality sought is that of $C(S, \Pi_n)$ in $C(S, C(T))$.

W. H. OW

Uniform Harmonic Approximation with Continuous Extension to the Boundary

Let G be a domain in the complex plane $\mathbb{C}$ such that $\mathbb{C} \setminus G$ contains a closed disk; and let F be a closed subset of G such that F is the closure in G of its interior F°. We say $f \in C^1(F)$ if f is continuous on F and possesses continuous first partial derivatives in F° which extend continuously to F as finite-valued functions. Let $G^* \setminus F$ be connected and locally connected, $f \in C^1(F)$ be harmonic in F°, and E be a subset of $\partial F \cap \partial G$ (here G^* denotes the one-point compactification of G and the boundaries $\partial F, \partial G$ are taken in the extended plane). Suppose there is a sequence of functions $\langle h_n \rangle$ harmonic in G such that $|f - h_n| \to 0$, $|\frac{\partial f}{\partial x} - \frac{\partial h_n}{\partial x}| \to 0$, and $|\frac{\partial f}{\partial y} - \frac{\partial h_n}{\partial y}| \to 0$ uniformly on F as $n \to \infty$. We prove that if f extends continuously to $F \cup E$ then each h_n can also be chosen to have the same property.

M. REIMER

Radontransformierte auf Polynomräumen

Für die konstruktive Behandlung der Radontransformation und ihrer Inversen ist es von großer Bedeutung, daß man ihre Wirkung auf Polynome genau kennt. Wir entwickeln hierzu auf "elementarem" Wege eine Theorie, bei der gewisse Pseudoentwicklungen nach homogenen harmonischen Polynomen und eine zweiparametrige Familie univariater Polynome mit Orthogonalitätseigenschaften die zentrale Rolle spielen.

W. SCHEMPP

PDE Aspects of Holographic Grids

Starting with the cardinal interpolation series of the classical Whittaker–Shannon–Kotel'nikov sampling theorem, the elementary holograms with radial trace are calculated explicitly in terms of Laguerre and Poisson–Charlier polynomials. It is established that they give rise by a rescaling procedure to the eigenfunction expansion of the Schwartz kernel associated with the self–adjoint hypoelliptic sub–Laplacian on the Heisenberg nilpotent Lie group. Moreover, they generate the five Euclidean orientable 3–orbifolds of holographic grids on the complex plane. The existence of the planar holographic grids has been established experimentally by Professor Dr. Pál Greguss (Applied Biophysics Laboratory, Technical University Budapest) by using a Majoros–type toroidal lens. As a result, new identities for theta–null values are popping up. Finally, a series of applications to different fields (laser physics, opto–electronics, neural computers, ...) are indicated.

J. VERDERA

Planar BMO Harmonic Approximation and Spectral Synthesis for Hardy–Sobolev Spaces

We prove the following Theorem:

Let $X \subset \mathbb{C}$ be compact and let $f \in VMO(\mathbb{C})$ be harmonic on X°. Then there exists a sequence (f_n), each f_n being harmonic on some neighbourhood of X, with

$$f_n \longrightarrow f \text{ in } BMO(\mathbb{C}).$$

As an application we give a spectral synthesis theorem for Hardy–Sobolev spaces on $\mathbb{R}^2$.

K. ZIETAK

On the Approximation of Matrices Connected with the Discrete Approximation of Functions in Two Variables

An approximation of a matrix is very close to an approximation of a function in two variables. Let S be a discrete point set $S = \{(x_i, y_i) : i = 1, \ldots, m; \;\; j = 1, \ldots, n\}$ and let f be a function in two variables. We can approximate $f(x, y)$ over S by functions which can have one of the following forms:

$$\sum_{k=1}^{r} g_k(x) h_k(y) \quad , \quad \sum_{k=1}^{r} a_k f_k(x, y).$$

Then we have the following matrix problems:

$$\min_{G,H} \|F - GH\| \quad , \quad \min_{a_k} \left\| F - \sum_{k=1}^{r} a_k F_k \right\|$$

with an appropriate definition of the matrices F and F_k and any matrix norm. In this talk we discuss some properties of these matrix problems.

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