Workshop on

Special Functions and their Applications

August 28 – 30, 2013

Copenhagen, Denmark

Preface

The workshop is sponsored by The Danish Council for Independent Research | Natural Sciences, grant no. 10-083122.

The organizing committee consists of Professor Christian Berg and Professor Henrik Laurberg Pedersen from the Department of Mathematical Sciences, Faculty of Science, University of Copenhagen.

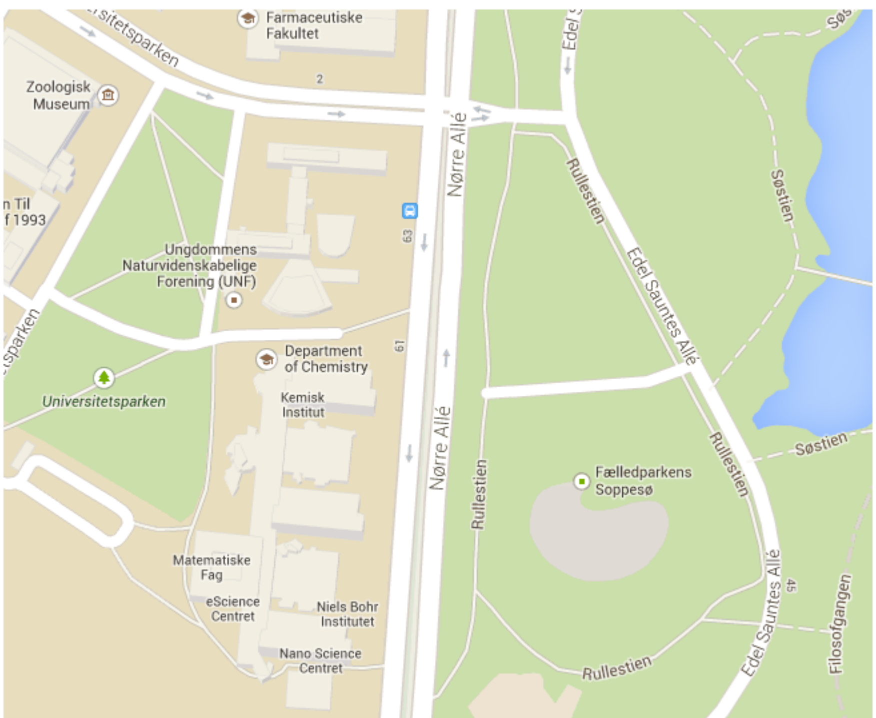
More information on the symposium can be found at
`www.math.ku.dk/~henrikp/wosfa/`

Practical information

The symposium takes place at the Department of Mathematical Sciences. The street address is:

> Department of Mathematical Sciences
> Universitetsparken 5
> DK-2100 København Ø

The department is located in the E-building in the building complex called the H.C. Ørsted Institute. The walking distance between CABINN Scandinavia Hotel and the department is approximately 30 minutes.



The Department of Mathematics and surroundings

The department can also be reached by bus from central Copenhagen, e.g. Bus no. 150S, 184 or 185 from Nørreport Station. You should get off at the bus stop "Universitetsparken" (the intersection near top of the map). The H.C. Ørsted Institute is north of Hotel CABINN Scandinavia and central Copenhagen.

Once you enter the H.C. Ørsted building, Aud. 9 is on the first floor in the south end of the building. Please follow the signs.

Registration

Registration takes place on Wednesday August 28 from 12.00 to 12.45 outside the lecture room Aud. 9.

At the registration desk you will receive the book of abstracts (this document), your badge and some additional information. Notice that doors in the building will be closed at 18.00, so after this hour it may be difficult to enter a room again once you have left it.

The opening of the workshop is at 12.55 in Aud. 9.

Wireless internet and facilities

To connect to the wireless internet in the building you can use `eduroam`. In case you are not registered on this net you can also use `Conference`. We will give you the password at the beginning of the workshop.

It is not possible to copy papers, notes and so on, and likewise there is no printer available.

Lecture room

All lectures take place in Aud. 9.

The room is equipped with computer, beamer and blackboards, so you need only bring your slides (in pdf format) on an usb-disk. In order to avoid last minutes problems please contact the organizers in order to upload the file of your talk preferably before the first talk of the day.

It is also possible to connect your own laptop.

If you need an overhead projector please contact the organizers well in advance.

Lunch and coffee breaks

Lunch can be bought in the cafeteria. Coffee is served close to the lecture room.

Workshop dinner

We plan a workshop dinner on Thursday, August 29 at 19.00. The address is:

Restaurant Allégade 10
Allégade 10
2000 Frederiksberg
http://www.allegade10.dk/

More information will be given on Wednesday. The dinner is free of charge for registered particiants. The price for a accompanying person is 50 Euros, to be paid at the registation desk on Wednesday.

Activities in Copenhagen

There are many sites to visit and things to do, e.g. visit the Tivoli Garden or the Glyptotek, experience the harbour of Copenhagen by boat, or take a walk in central Copenhagen along "Strøget" ending at the beautiful square "Kongens Nytorv" and the old harbour "Nyhavn" (which by the way means "new harbour" in Danish).

Other sites of interest are Amalienborg Slot (the Queen's castle), Rosenborg (where you can see the Crown jewells), or you can relax in one of the city parks.

There are also guided tours by bus.

Kronborg castle is situated in Helsingør, approximately 50 kilometers north of Copenhagen. It is easy to go there by train but travelling time is approximately one hour each way.

The official tourist site of Copenhagen is www.visitcopenhagen.com/.

There are many restaurants in central Copenhagen offering a wide selection of Nordic and international cuisine. In Vesterbro (close to the central station) you can find many restaurants near "Halmtorvet".

Workshop program

Wednesday, August 28

Time		
12.00 – 12.45	Registration	
12.55 – 13.00	Opening of workshop	Henrik Pedersen

Time	Activity	Chairman
13.00 – 13.50	Ruscheweyh	Henrik Pedersen
14.00 – 14.50	Zhang	
15.00 – 15.30	Coffee break	
15.30 – 16.20	Srinivasan	
16.30 – 16.55	Costas-Santos	
17.00 – 17.25	Berg	

All participants are welcome to attend the event “An evening with Words of Mathematics” that takes place in Frederiksberg Campus. Talks begin at 18.30. Further information can be found in the workshop material.

Thursday, August 29

Time			Activity	Chairman
09.00	–	09.50	Baricz	Ruscheweyh
10.00	–	10.50	Lopez	
11.00	–	11.30	Coffee break	
11.30	–	11.55	Temme	
12.00	–	12.25	Shermenev	
12.30	–	14.00	Lunch	
14.00	–	14.50	Koumandos	Christiansen
15.00	–	15.30	Coffee break	
15.30	–	15.55	Karp	
16.00	–	16.25	Derevyagin	
16.30	–	16.55	Szabłowski	

Friday, August 30

Time			Activity	Chairman
09.00	–	09.50	Andersen	Srinivasan
10.00	–	10.50	Fitouhi	
11.00	–	11.30	Coffee break	
11.30	–	11.55	Mesquita	
12.00	–	12.25	Neuschel	
12.30	–	14.00	Lunch	
14.00	–	14.25	Pedersen	Berg
14.30	–	15.20	Vuorinen	

Abstracts: Invited Talks

Real Paley–Wiener theorems

NILS BYRIAL ANDERSEN

AARHUS UNIVERSITY, DENMARK

Entire functions f of exponential type, whose restriction to the real line are in L^p, are usually characterized by the classical Paley–Wiener growth estimates in the complex plane or by support properties of the Fourier transform $\mathcal{F}f$ of f.

However, we may also consider Real Paley–Wiener theorems, which gives a description of the support of $\mathcal{F}f$ by L^p-growth properties of the derivatives $f^{(m)}$ of f, such as

$$\lim_{m\to\infty} \|f^{(m)}\|_{L^p}^{1/m} = \sup\{|\lambda| \,:\, \lambda \in \operatorname{supp} \mathcal{F}f\}.$$

Similarly, we could consider Bernstein inequalities for $\|f^{(m)}\|_{L^p}$.

Now let f be a function on the torus $\mathbb{T}$, with Fourier coefficients $\widehat{f}(n)$. Considering derivatives of f as above yields a characterization of trigonometric polynomials of finite order. On the other hand, using difference operators Δ on sequences (in particular on $\widehat{f}$), we get a description of the support of f (in a neighbourhood of the identity) by the l^p-growth properties of $\Delta^n \widehat{f}$.

Using the Sampling Theorem, we also get generalized Bernstein inequalities and real Paley–Wiener type theorems for difference operators acting on Bernstein functions.

Finally, some of the results on the torus can be generalized to compact Lie groups, using invariant differential operators and a certain Weyl group invariant difference operator.

Turán type inequalities, Stieltjes transforms and infinite divisibility

ÁRPÁD BARICZ

BABEŞ-BOLYAI UNIVERSITY, ROMANIA

In this talk I would like to present some sharp Turán type inequalities for modified Bessel functions of the second kind, for parabolic cylinder functions and for Tricomi confluent hypergeometric functions. The key tools in the proofs are some Stieltjes transform representations of quotients of modified Bessel functions of the second kind, parabolic cylinder functions and Tricomi confluent hypergeometric functions. These results are important in the study of the infinite divisibility of the Student and Fisher-Snedecore distributions.

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q-Bessel-Hahn-Exton transform and applications

AHMED FITOUHI

FACULTY OF SCIENCES TUNIS, TUNISIA

Using a new formulation of the Graf's addition formula related to the third Bessel Hahn Exton function we prove the positivity of the q-generalized translation and give some applications such as the q-positive definite functions and the q-Levy-Kintchine theorem.

Positive trigonometric integrals and zeros of certain Lommel functions

STAMATIS KOUMANDOS

THE UNIVERSITY OF CYPRUS, CYPRUS

The study of the mapping behavior of the partial sums of certain analytic functions leads to investigations about the zeros of the function

$$F_\mu(z) := \int_0^z t^{\mu-1} \sin(z-t)\, dt, \quad \mu \in (0,1), \; z > 0.$$

Notice that for $\mu > 0$ we have $F_\mu(z) = z^{1/2} s_{\mu-1/2,1/2}(z)$, where $s_{\mu,\nu}(z)$ is the Lommel function of the first kind. We present estimates and monotonicity properties of the positive zeros of the functions $F_\mu(z)$ and $F'_\mu(z)$. The positivity of certain trigonometric integrals plays a key role in the proofs of these results. In particular, we show that the functions $F_\mu(z)$ and $F'_\mu(z)$ have only real and simple zeros and their zeros interlace.

We further describe various properties of the zeros of entire functions associated with Lommel functions of the first kind. We show, among other things, that some of these entire functions belong to the Laguerre-Pólya class. Moreover, we obtain Turán type inequalities for Lommel functions of the form $s_{a,\frac{1}{2}}(z),\ z > 0$.

The talk is based on joint papers written over the last few years with my collaborators Stephan Ruscheweyh, Martin Lamprecht and Árpád Baricz.

Some new techniques in the approximation of special functions

JOSÉ LOPEZ

STATE UNIVERSITY OF NAVARRA, SPAIN

In this talk we resume two recently introduced methods designed to approximate solutions of differential equations and parametric integrals respectively. Eventually, they may be used to get new approximations of special functions in terms of, some times, elementary functions.

The method for differential equations is a modification of the celebrated Olver's asymptotic method for linear second order differential equations containing a large (asymptotic) parameter Λ [Olver, 1974]. His method gives the Poincaré-type asymptotic expansion of two independent solutions of the equation in inverse powers of Λ. We add two initial conditions to the differential equation and consider the corresponding initial value problem. By using the Green's function of an auxiliary problem and a fixed point theorem, we construct a sequence of functions that converges to the unique solution of the problem. This sequence has also the property of being an asymptotic expansion for large Λ (not of Poincaré-type) of the solution of the problem. Moreover, we show that the idea may be applied to nonlinear differential equations with a large parameter.

The method for parametric integrals consists of an appropriate use of different multi-point Taylor expansions [Lopez and Temme, 2002 and 2004] of an appropriate factor of the integrand. We describe the method for the particular case of the Gauss hypergeometric function and indicate how it can be used in other integral representations of special functions. The key point is the election of the number and location of the base points used in the multi-point Taylor expansion. Typically, the method gives a convergent expansion of the parametric integral in terms of elementary functions or, at least, simpler functions than the one being approximated.

Universally Prestarlike Functions and Polylogarithms

STEPHAN RUSCHEWEYH

WÜRZBURG UNIVERSITY, GERMANY

It is well-known that the Hadamard convolution of two convex univalent functions in the unit disc of the complex plane is also convex univalent (Pólya-Schoenberg conjecture [1958], Ruscheweyh & Sheil-Small [1973]). We study the same situation for other discs/half-planes, and it turns out that the results are substantially different. In the universal case, where convexity preservation under convolution with convex univalent functions in arbitrary disks and half-planes (containing the origin) is required we are led to a specific class of Pick functions, for which a general representation is derived. In this connection the following questions will be discussed:

- The extension of the Pólya-Schoenberg theorem for universally convex functions and, more generally, for universally prestarlike functions.
- Polylogarithms as universally convex functions (extension of John Lewis result for the unit disc), and other special cases.
- The multiplier problem for generalized prestarlike functions in disc-like domains.
- A continuous link between trigonometric and Hausdorff moments: an open problem. Joint work with A. Bakan, L. Salinas and T. Sugawa (2007-2013).

On the integrals of Mellin–Barnes–Hecke Type

GOPALA KRISHNA SRINIVASAN

INDIAN INSTITUTE OF TECHNOLOGY BOMBAY, INDIA

The talk focusses on an approach to the study of the Mellin–Barnes integral using some ideas of distribution theory. Distributions functorially push forward but Hörmander introduced the notion of pull-back of distributions via smooth submersions. Here we look at some of its applications to the integral representations of special functions. We shall revisit the classical formulas of Ramanujan, Hardy, Hecke, Mellin and also some well-known formulas in the theory of Bessel's functions. Some of these formulas have played a chief role in analytic number theory and the study of real quadratic number fields by Hecke, and generalized by Rademacher in the study of number fields of higher degree.

Topics in special functions

Matti Vuorinen

University of Turku, Finland

A review of some old and new results on special functions often used in geometric function theory is given. In particular, some properties of the Gaussian hypergeometric function are reviewed. We also discuss some recent results on the p-trigonometric functions introduced by P. Lindqvist.

The generating series of values of the inverse of Gamma function over vertical line has a natural boundary

Changgui Zhang

Université de Lille 1

The lacunary series are the most classical examples among all the power series whose circle of convergence constitutes a natural boundary. In this talk, we will discuss a family of non-lacunary power series whose coefficients are given by means of values of the Gamma function over vertical line. By transforming these series into lacunary Dirichlet series, one can conclude the existence of their natural boundary, which illustrates in what manner the Gamma function may have a unpredictable behaviour on any vertical line.

Abstracts: Contributed Talks

On an iteration leading to a q-analogue of the Digamma function

CHRISTIAN BERG

UNIVERSITY OF COPENHAGEN, DENMARK

We show that the q-Digamma function ψ_q for $0 < q < 1$ appears in an iteration studied by Berg and Durán. This is connected with the determination of the probability measure ν_q on the unit interval with moments $1/\sum_{k=1}^{n+1}(1-q)/(1-q^k)$, which are q-analogues of the reciprocals of the harmonic numbers. The Mellin transform of the measure ν_q can be expressed in terms of the q-Digamma function. It is shown that ν_q has a continuous density on $]0,1]$, which is piecewise C^∞ with kinks at the powers of q.

The work has appeared in a joint paper with Helle Bjerg Petersen: J. Fourier Anal. Appl. **19** (2013), 762–776.

A connection between the Legendre polynomials and the Riemann Zeta function

ROBERTO S. COSTAS-SANTOS

UNIVERSIDAD DE ALCALÁ, SPAIN

In this talk we present all the theory developed during the last years about the Riemann Zeta function, the connection between the the irrationality proof of $\zeta(2)$ and $\zeta(3)$ and the Legendre polynomials, we also discuss about the irrationality of $\zeta(2n+1)$ and its connection with the Legendre polynomials presenting infinitely many integral sequences converging to such values as fast as we want. We also present analogous results of the results mentioned above for a q-analog of the Zeta function and its connection with the q-Legendre polynomials.

On some continued fractions related to Nevanlinna-Pick problems

Maxim Derevyagin

TU Berlin, Germany

It is well known that the classical Hamburger moment problem is the limiting case of the Nevanlinna-Pick problem in the upper half-plane. Recall that the Nevanlinna-Pick problem consists in finding a holomorphic function mapping the upper half-plane into itself and taking specific points to specific points. It turns out that orthogonal polynomials, Jacobi matrices and Padé approximants appear in the frame work of Nevanlinna-Pick problems as well as in the Hamburger moment problem case. The key point in getting those objects is a generalization of Jacobi fractions, which goes back at least to Wall and it coincides with the even part of Thiele interpolating continued fractions. These generalized interpolating fractions are also known as MP-fractions (considered by Hendriksen and Njastad) and R_{II}-fractions (studied by Ismail and Masson).

I am going to present the interpolating fractions from the classical spectral point of view. In other words, I will show how one can use Jacobi matrices and orthogonal polynomials to study Nevanlinna-Pick problems and how they appear in the context of Nevanlinna-Pick problems by means of the continued fractions. Also, an analog of Stieltjes continued fractions, which reminds both Stieltjes and Thiele continued fractions, will be introduced.

Zero-balanced G-function of Meijer and representations of generalized hypergeometric functions

Dmitrii Karp

Far Eastern Federal University, Russia

Meijer's G-function generalizes many elementary and special functions including hypergeometric functions and allows to give reasonable meaning to the symbol ${}_pF_q$ when $p > q+1$ and the series defining the generalized hypergeometric function ${}_pF_q$ diverges everywhere except the origin. Very recently, Meijer's G- function popped up naturally in the random matrix theory. It's various applications in statistics have been known for some decades.

In the talk we discuss Meijer's G-function of the type $G^{q,0}_{q,q}$ in the case when the difference of sums of upper and lower parameters is zero or negative integer. In this situation, its behavior in the neighborhood of the regular singular point 1 seem to remain understudied. We find a representation of this function in this neighborhood and give applications to formulas for generalized hypergeometric functions of Gauss and Kummer type. In particular, we demonstrate the generalized Stieltjes and Laplace transform representations with measures containing an atom at 1. A curious formula for a sum of sine functions which revealed itself during the derivation of the main results will also be presented.

Appell polynomial sequences with respect to some differential operators

TERESA MESQUITA

INSTITUTO POLITÉCNICO DE VIANA DO CASTELO & CMUP, PORTUGAL

We present a study of a specific kind of lowering operator, that we call Λ, which is defined as a finite sum of lowering operators. Firstly we exhibit different configurations for this operator, attending, for instance, to the fact that it can be altered by the use of Stirling numbers, and consequently we prove different (functional) identities that characterize the polynomial sequences fulfilling an Appell relation with respect to Λ.
Considering a concrete cubic decomposition of a simple Appell sequence, we prove that the correspondent polynomial component sequences are Λ-Appell, with Λ defined as previously, although by a three term sum.
Ultimately, we prove the non-existence of orthogonal polynomial sequences which are also Λ-Appell, when Λ is the lowering operator $\Lambda = a_0 D + a_1 DxD + a_2 (Dx)^2 D$, where a_0, a_1 and a_2 are constants with $a_2 \neq 0$ and D is the standard derivative. In this operational context, the case where $a_2 = 0$ and $a_1 \neq 0$ - studied in 2008 by Loureiro and Maroni [1] - is naturally recaptured, and we are able to see the so-called $\mathcal{G}_{\epsilon,\mu}$ operator, debated in [2], as a particular Λ operator with four terms. In this last reference, it was proved the absence of orthogonal $\mathcal{G}_{\epsilon,\mu}$-Appell sequences, indicating that our results may be generalized at a latter time for operators with other specific number of terms.

This is joint work with P. Maroni.

[1] A. Loureiro, P. Maroni, *Quadratic decomposition of Appell sequences*, Expo. Math. 26 (2008), 177-186.
[2] A. Loureiro, P. Maroni, *Quadratic decomposition of Laguerre polynomials via lowering operators*, J. Approx. Theory 163 (2011), 888-903.

Asymptotics for Apéry Polynomials

THORSTEN NEUSCHEL

KU LEUVEN, BELGIUM

The Apéry polynomials and in particular their asymptotic behavior play an essential role in the understanding of the irrationality of $\zeta(3)$. We present a method to study the asymptotic behavior of the sequence of Apéry polynomials $(B_n)_{n=1}^{\infty}$ in the whole complex plane as $n \to \infty$. The proofs are based on a multivariate version of the complex saddle point method. Moreover, the asymptotic zero distributions for the polynomials $(B_n)_{n=1}^{\infty}$ and for some transformed Apéry polynomials are derived by means of the theory of logarithmic potentials with external fields, establishing a characterization as the unique solution of a weighted equilibrium problem.

Positivity and remainders in expansions of Gamma functions

HENRIK L. PEDERSEN

UNIVERSITY OF COPENHAGEN, DENMARK

The remainders in asymptotic expansions of the logarithm of Euler's gamma function can be studied through Binet's formulas and this study has lead to the notion of complete monotonicity of positive order.

Monotonicity properties of remainders in asymptotic expansions of the logarithm of Barnes' double and triple gamma function are investigated. The ideas behind these results can also be used in obtaining Turán type inequalities for the partial sums and remainders of the generating functions of the Bernoulli and Euler numbers.

The talk is based on joint work with Stamatis Koumandos from University of Cyprus. The research is supported by The Danish Council for Independent Research — Natural Sciences.

Separation of variables for nonlinear wave equation in cylinder coordinates

ALEXANDER SHERMENEV

RUSSIA

Some classical types of nonlinear wave motion in the cylinder coordinates are studied within quadratic approximation. When the cylinder coordinates are used, the usual perturbation techniques inevitably leads to overdetermined systems of linear algebraic equations for the unknown coefficients (in contrast with the Cartesian coordinates). However, we show that these overdetermined systems are compatible for the special case of the nonlinear acoustical wave equation and express explicitly the coefficients of the first two harmonics as polynomials of the Bessel functions of radius and of the trigonometric functions of angle. It gives a series of solutions to the nonlinear acoustical wave equation which are found with the same accuracy as the equation is derived.

[1] Shermenev, A. & Shermeneva, M. 2000 Long periodic waves on an even beach. *Physical Review* **E**, No. 5, 6000–6002
[2] Shermenev A. 2003 Nonlinear acoustical waves in tubes, Acta Acustica, vol. 89, 426–429
[3] Shermenev A. 2004 Separation of Variables for Nonlinear Wave Equation in Polar Coordinates. Journal of Physics, A, 37, 1-9
[4] Shermenev A. 2005 Separation of variables for the nonlinear wave equation in cylindrical coordinates. Physica D: Nonlinear Phenomena, 212:3-4 pp 205-215

Askey–Wilson Integral and its Generalizations

PAWEŁ SZABŁOWSKI

WARSAW UNIVERSITY OF TECHNOLOGY, POLAND

We consider sequence of nonnegative, integrable functions: $g_n : [-1,1] \longmapsto \mathbb{R}^+$ defined by the formula:

$$g_n\left(x|\mathbf{a}^{(n)},q\right) = f_h\left(x|q\right)\prod_{j=1}^{n}\varphi_h\left(x|a_j,q\right),$$

where $\mathbf{a}^{(n)} = (a_1,\ldots,a_n)$, functions f_h and φ_h denote respectively the density of measure that makes the so called continuous $q-$Hermite polynomials orthogonal and the characteristic function of these polynomials calculated at points a_j, $j = 1,\ldots,n$. Naturally functions

g_n are symmetric with respect to vectors $\mathbf{a}^{(n)}$. We expand these densities in a series of products of continuous $q-$Hermite polynomials times the density that makes these polynomials orthogonal.

Our elementary but crucial observation for this paper is that examples of functions g_n are the densities of measures that make orthogonal respectively the so called continuous $q-$Hermite (q-Hermite, $n = 0$), big $q-$Hermite (bqH, $n = 1$), Al-Salam–Chihara (ASC, $n = 2$), continuous dual Hahn (C2H, $n = 3$), Askey–Wilson (AW, $n = 4$) polynomials. This observation makes functions g_n important and what is more exciting allows possible generalization of both AW integral as well as AW polynomials, i.e. go beyond $n = 4$. Besides developing this idea we obtain simple proof of the AW integral. Our approach uses nice, old formulae of Carlitz.

Similar observations were in fact made in the book of G.E. Andrews, R. Askey and R. Roy "Special functions" (Encyclopedia of Mathematics and its Applications, 71. Cambridge University Press, Cambridge, 1999) when commenting on formula 10.11.19. Hence one can say that we are developing certain idea of the this book.

Numerical Methods for Special Functions

NICO M. TEMME

CWI, AMSTERDAM, THE NETHERLANDS

For the numerical evaluation of special functions we mention the basic tools: series expansions, recursions, and quadrature. We give examples on how to use these tools in recently developed software in the Santander-Amsterdam project on numerical software for special functions, in particular how to handle highly oscillating integrals in the complex plane by selecting asymptotic methods and suitable quadrature rules. We explain why the simple trapezoidal rule may be very efficient for a certain class of integrals that represent special functions. We discuss recent activities in our project, in particular for certain cumulative distribution functions. We start with the incomplete gamma functions, and we give recent results for the non central chi-squared or the non central gamma distribution, also called Marcum $Q-$function in radar detection and communication problems.

This is joint work with Amparo Gil and Javier Segura (University of Cantabria, Santander, Spain).

List of Registered Participants

The participants are listed in alphabetical order together with email information.

1. **Andersen, Nils Byrial** University of Århus, Denmark
   `byrial@imf.au.dk`
2. **Baricz, Árpád** Babeş-Bolyai University, Romania
   `bariczocsi@yahoo.com`
3. **Berg, Christian** University of Copenhagen, Denmark
   `berg@math.ku.dk`
4. **Christiansen, Jacob** Lund University, Sweden
   `stordal@maths.lth.se`
5. **Costas-Santos, Roberto S.** Universidad de Alcala, Spain
   `rscosa@gmail.com`
6. **Derevyagin, Maxim** TU Berlin, Germany
   `derevyagin.m@gmail.com`
7. **Fitouhi, Ahmed** Faculty of Sciences Tunis, Tunisia
   `ahmed.fitouhi@fst.rnu.tn`
8. **Johansen, Troels** University of Kiel, Germany
   `johansen@math.uni-kiel.de`
9. **Kalmykov, Sergei** IAM FEB RAS, Russia
   `Sergeykalmykov@inbox.ru`
10. **Karp, Dmitrii** Far Eastern Federal University, Russian Federation
    `dimkrp@gmail.com`
11. **Koumandos, Stamatis** University of Cyprus, Cyprus
    `skoumand@ucy.ac.cy`
12. **Mesquita, Teresa** Instituto Politécnico de Viana do Castelo, Portugal
    `teresam@portugalmail.pt`
13. **Lopez, José** State University of Navarra, Spain
    `jl.lopez@unavarra.es`
14. **Neuschel, Thorsten** KU Leuven, Belgium
    `Thorsten.Neuschel@wis.kuleuven.be`
15. **Pedersen, Henrik Laurberg** University of Copenhagen, Denmark
    `henrikp@math.ku.dk`
16. **Ruscheweyh, Stephan** Würzburg University, Germany
    `ruscheweyh@mathematik.uni-wuerzburg.de`

17. **Shermenev, Alexander** , Russia
shermenev@mail.ru

18. **Srinivasan, Gopala Krishna** Indian Institute of Technology Bombay, India
gopal@math.iitb.ac.in

19. **Szabłowski, Paweł** Warsaw University of Technology, Poland
pawel.szablowski@gmail.com

20. **Temme, Nico M.** Centrum Wiskunde & Informatica, Amsterdam, The Netherlands
Nico.Temme@cwi.nl

21. **Vuorinen, Matti** University of Turku, Finland
vuorinen@utu.fi

22. **Zhang, Changgui** Université de Lille 1, France
Changgui.Zhang@math.univ-lille1.fr