The Third Workshop on Recent Advances in Spectral Methods and Related Applications

July 15-16, 2011

Shanghai Normal University

Shanghai, China

Sponsored by:

E-Institute for Computational Science of Shanghai Universities

Scientific Computing Key Laboratory of Shanghai Universities

Contents

Background

Since the first application to three-dimensional turbulence simulation using the Fourier-spectral method at early 1970's, there is a phenomenal growth in the analysis and applications of the spectral and spectral-element methods. The main characteristic of spectral and spectral element methods is the use of high-order polynomials as basis functions, as compared to low-order piecewise polynomials in a finite element method. The main advantage of the spectral methods lies on the fact that the convergence of numerical solutions is exponential if the exact solution is smooth. While the classical spectral methods are limited to simple geometries, the development of the spectral element method allows to take advantages of the geometric flexibility of finite elements and the high accuracy of spectral methods. Undoubtedly the spectral and spectral element methods have become a major computational tool, especially when highly accurate solutions are needed.

The aim of this series of workshops is to bring together experts working on spectral and high order methods and their applications to exchange recent progress and to promote future research and collaborations. This is the third workshop in this series organized by Jie Shen (Purdue University) and Chuanju Xu (Xiamen University).

The first workshop in the series was held during June 14-16, 2007 at Xiamen University.

The second workshop in the series was held during May 29-31, 2008 in WuYi mountain.

The third workshop is sponsored by:

E-institute for Computational Science of Shanghai Universities

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Organizing Committee

Jiao Yujian, Shanghai Normal University, China

Shen Jie, Purdue University, USA

Wang Zhongqing, Shanghai Normal University, China

Xu Chuanju, Xiamen University, China

Accommodation

与会者将安排于上海师范大学徐汇校区的外宾楼入住。外宾楼周围绿树成荫，景色秀丽、幽雅静谧。主要为外籍专家，留学生提供舒适的生活、学习环境，营造闻馨家的氛围。除此还接待国内外团队与宾客，使您处处感到宾至如归的感觉。

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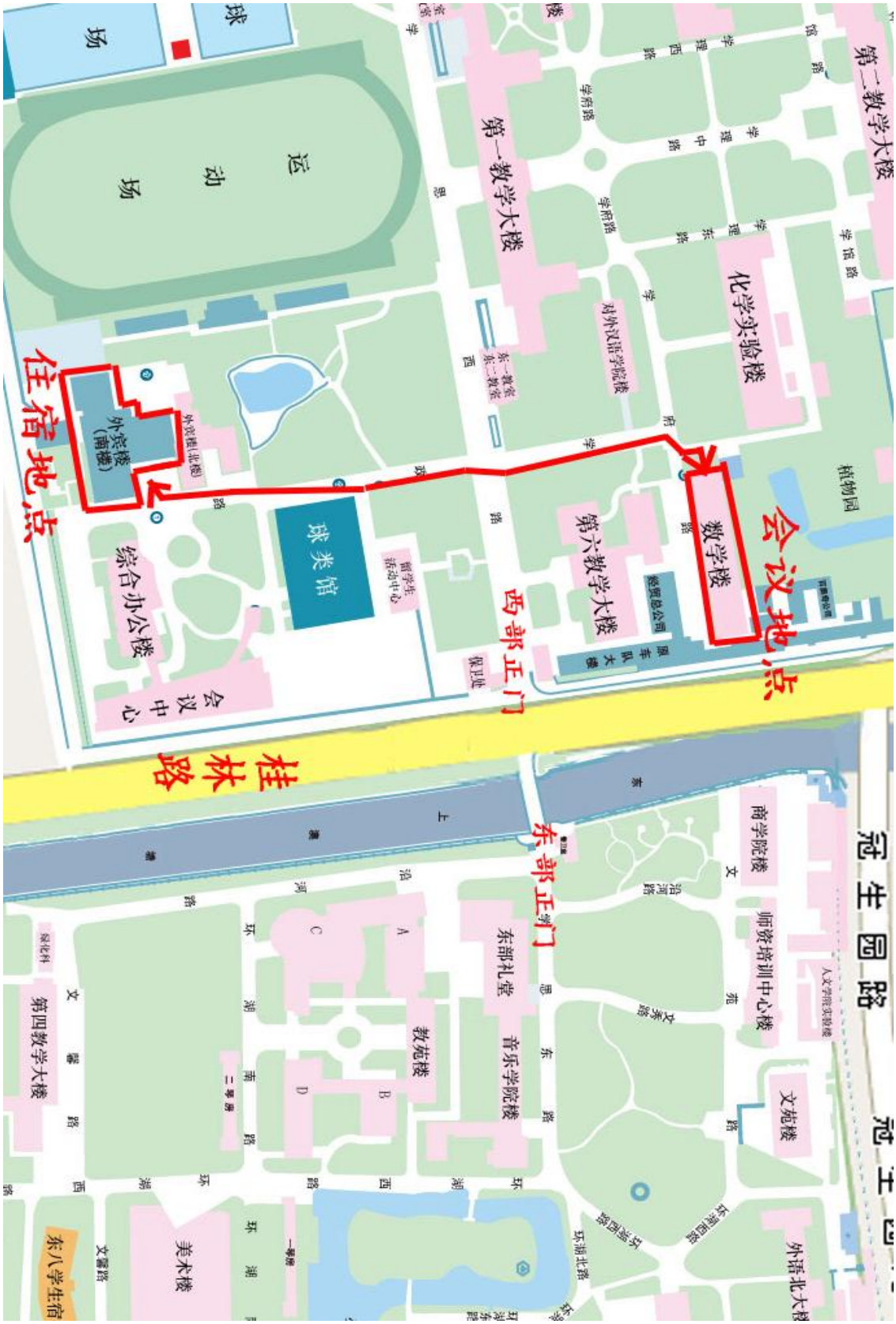
University Map

会议地点：徐汇校区三号楼三楼报告厅



Program

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Chen Yanping
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Daily Program

July 14, 2011 Thursday
Registration (8:00-18:00)
Reception (18:00)

July 15, 2011 Friday			
8:00 - 8:40	Opening remarks, Group photo		
8:40 - 9:10	Zhang Zhimin	Spectral Collocation Methods for Hamiltonian Dynamical Systems	Chair: Ma heping
9:10 - 9:40	Li Huiyuan	A New Spectral Method on Triangles by Using the Square-to-Triangle Mapping	
9:40 - 10:10	Teng Chunhao	Pseudospectral simulations of nano-optics induced by Ag nano-particles	
10:10 - 10:30	Tea Break		
10:30 - 11:00	Chen Min	Boussinesq systems for water waves	Chair: Xie Ziqing
11:00 - 11:30	Chen Yanping	Spectral collocation methods for Volterra integro-differential equations	
11:30 - 12:00	Li Xianjuan	A parallel in time/spectral collocation method for the Volterra integral equations of the second kind	
12:00	Lunch		
13:30 - 14:00	Shen Jie	Efficient and Stable Spectral Methods for Scoustic and Electromagnetic scattering	Chair: Xu Chuanju
14:00 - 14:30	Xie Ziqing	Convergence analysis of spectral Galerkin methods for Volterra type integral equations	
14:30 - 15:00	Yi Lijun	The h-p version of the FEM for elliptic problems with nonhomogeneous Dirichlet boundary conditions	
15:00 - 15:30	Yu Haijun	Efficient Numerical Methods for the Kinetic Equation of FENE Dumbbell Fluids	
15:30 - 15:50	Tea Break		

15:50 - 16:20	Wang Tianjun	Composite Laguerre-Legendre Spectral Method for Fourth-oder Exterior Problems	Chair: Wang Lilian
16:20 - 16:50	Yi Yonggang	Generalized Jacobi Rational Spectral Method and Its Applications	
16:50 - 17:20	Zhang Chao	Generalized Laguerre Quasi-orthogonal Approximation And Applications To Petrov Galerkin Spectral Method With Essential Imposition Of Mixed Boundary Conditions For High Order Problems	
17:20 - 17:50	Ma Heping	Spectral element methods for elliptic equations on polygon or polyhedron domains	
18:00	Banquet		

July 16, 2011 Saturday

8:00 - 8:30	Bao Weizhu	Emerging applications of spectral methods in quantum and plasma physics	Chair: Shen Jie
8:30 - 9:00	Jia Hongli	Pseudospectral Method For Polygons	
9:00 - 9:30	Wu Hua	TBA	
9:30 - 10:00	Song Lunji	A Spectral IPDG Method for The Helmholtz Equation	
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10:20 -10:50	Wang Lilian	Some new perspectives on spectral approximations and time-domain wave scattering	Chair: Bao Weizhu
10:50 - 11:20	Dong Suchuan	A High-Order Macro-Element Method	
11:20 – 11:50	Zeng Fanhai	Alternating Direction Implicit Legendre Spectral Element Methods for Schrodinger Equations	
11:50 - 12:20	Guo Benqi	TBA	
12:20	Lunch		
13:20 - 18:00	Tour		
18:30	Dinner		

Abstract of Invited Lectures

Emerging applications of spectral methods in quantum and plasma physics

Bao Weizhu
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Abstract: In this talk, I will review different numerical approximations for the nonlinear Schrödinger equation (NLS) in the semiclassical regimes, where the scaled Planck constant is small. I also compare properties preserved in the discretized level of different numerical methods including time reversibility, time transverse invariant, mass conservation, energy conservation, stability, accuracy and resolution in the semiclassical regime. Finally, I show applications of spectral method to different problems in quantum and plasma physics including Zakharov system, Maxwell-Dirac equations and Klein-Gordon Schrödinger equations, etc.

Boussinesq systems for water waves

Chen Min
Dept of Math,Purdue University, West Lafayette, IN 47906
Email: chen@math.purdue.edu , URL: http://www.math.purdue.edu/∼chen

Abstract: In this talk, I will present joint works over the years on the existence and stabilities of special solutions, which include solitary wave solutions, cnoidal wave solutions, standing wave solutions and two-dimensional wave patterns, for a class of Boussinesq systems. The techniques used in the existence results include, but not limited to, perturbation theory and topological index theory. Numerical simulations designed to gain more understanding on tsunami and wave patterns will be carried out and compared with theoretically results and fields data.

Spectral collocation methods for Volterra integro-differential equations

Chen Yanping
Department of Mathematics, Huanan Normal University
Email: ypchen@xtu.edu.cn, URL: http://daoshi.xtu.edu.cn/index.php?id=631

Abstract: In this talk, we investigate the convergence of Legendre spectral collocation methods for the Volterra delay-integro-differential equations with proportional (vanishing) delays. A vigorous error analysis is provided which shows that both the errors of the approximated solutions and the approximated derivatives decay exponentially in L^2 norm and L^∞ norm. Furthermore, we study Jacobi spectral collocation methods for Volterra integro-differential equations with a weakly singular kernel, which possesses smooth solutions. The spectral rate of convergence for the proposed method is established in the L^∞-norm and weighted L^2-norm. In our theoretical analysis, the initial condition is restated as an equivalent integral equation and all the integral terms are approximated by using Gauss quadrature rules. Numerical results are presented to demonstrate the effectiveness of the proposed methods.

A High-Order Macro-Element Method

Dong Suchuan

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Email: sdong@math.purdue.edu, URL: http://www.math.purdue.edu/∼sdong/index.htm

Abstract: We discuss the construction of a set of eigen expansion bases for spectral elements, and an extension of this construction to the space of piece-wise polynomials with global continuity. An element employing the extended expansion basis conceptually corresponds to a collection of ordinary spectral elements. But this macro-element approach results in smaller and better conditioned Schur-complemented system matrix. We will compare the performance of this eigen-based macro-element method and existing spectral-element bases with numerical examples.

Pseudospectral Method For Polygons

Guo Benyu * *Jia Hongli* **

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Abstract: In this talk, we investigate domain decomposition pseudospectral method for polygons. We introduce a new Legendre-Gauss type interpolation on quadrilaterals and establish the basic approximation results, which play important roles in pseudospectral method for partial differential equations defined on quadrilaterals. As examples of applications, we propose pseudospectral method for two model problems and prove their spectral accuracy. Numerical results demonstrate the efficiency of suggested algorithms. We also develop a domain decomposition pseudospectral method for polygons by using certain composite Legendre-Gauss type interpolations on the whole domains, and prove its global spectral accuracy. Numerical results indicate its high accuracy too. The approximation results and techniques developed in this paper are also applicable to other problems defined on non-rectangular domains.

A parallel in time/spectral collocation method for the Volterra integral equations of the second kind

Li Xianjuan

Hong Kong Baptist University

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Abstract: we consider the numerical solution for the Volterra integral equations (VIEs) of the second kind with regular kernels. We propose a parallel in time (called also time parareal) method, combined with a spectral collocation scheme for temporal discretizations of these equations. The parallel in time method follows the same sprit as the domain decomposition that consists in breaking the domain of computation into subdomains and solving iteratively the sub-problems over each sub-domain in a parallel way using different processors. This parallel in time method is combined with the spectral method for each sub-problem, leading to an algorithm of high accuracy. The convergence analysis of the method is carried out. Some numerical tests are performed to confirm the theoretical results.

A New Spectral Method on Triangles by Using the Square-to-Triangle Mapping

Li Huiyuan (joint work with LiLian Wang & Michael Daniel Samson)
Lab. of Parallel Computing Institute of Software Chinese Academy of Sciences,
Beijing, 100190, China

Abstract: In this talk, a new square-to-triangle mapping

$$x = (1+\xi)(3-\eta)/8, \quad y = (3-\xi)(1+\eta)/8, \quad \forall\, (\xi,\eta) \in [-1,1]^2,$$

is introduced, which pulls one edge of the triangle to two adjacent edges of the reference rectangle. This square-to-triangle mapping is essentially the symmetry mapping

$$\hat{x} = \hat{\xi} + \hat{\eta}, \quad \hat{y} = \hat{\xi}\hat{\eta},$$

which reveals the mystery of the first example for multivariate Gaussian quadratures. Besides, this mapping possesses the same properties as the following Gordon-Hall square-to-disk mapping for spectral methods in a disk.

$$x = \xi\sqrt{1-\eta^2/2}, \quad y = \eta\sqrt{1-\xi^2/2}, \quad \forall\, (\xi,\eta) \in [-1,1]^2$$

In contrast with the collapsed mapping, such a mapping is one-to-one, and leads to a more reasonable distribution of quadrature points on the triangle. Most importantly, it allows an efficient design of spectral schemes on the triangle by direct using of the fully tensorial nodal Lagrange polynomial basis on the reference rectangle with a slight modification. We present the effective implementation of the new spectral method in detail and then study its discuss its error analysis.

Spectral element methods for elliptic equations on polygon or polyhedron domains

Ma Heping
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Abstract: Spectral element methods are applied to linear elliptic equations on polygon or polyhedron domains. The methods are based, respectively, on the recently presented triangle-to-rectangle or tetrahedron-to-cube mappings, which lead to more reasonable grid distributions than the collapsed transform. Some properties of the corresponding approximation spaces are studied. Numerical examples confirm the efficiency of the proposed methods.

Efficient and Stable Spectral Methods for Scoustic and Electromagnetic scattering

Shen Jie
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Abstract: FENE Dumbbell model is one of the most simple mathematical models that predict basic properties of Non-Newtonian Fluids. However the dynamics of FENE dumbbell fluids are described by a high-dimensional Fokker–Planck equation which needs very fast computer to simulate. Most of the existing numerical algorithms involve factorization of a non-sparse matrix thus are not

suitable for discretizations with large degree of freedom. In this talk, we will present a fast spectral Galerkin method using real Fourier series and Jacobi polynomials as bases. This new algorithm has several virtues: 1. The Galerkin approximation bases on a proper weighted weak formulation, in which the numerical moments have spectral accuracy; 2. The numerical approximation leads to linear sparse (banded indeed) system, thus can be solved with linear computational cost; 3. The numerical algorithm can be easily extended to solve the Fokker–Planck equation arising in non-homogeneous systems, or the Navier–Stokes Fokker–Planck coupled system.

A Spectral IPDG Method for The Helmholtz Equation

Song Lunji

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Abstract: In this paper, we propose an iterative approach to localize the global DtN boundary condition, and provide sufficient conditions for its convergence together with some numerical justifications. For the spatial discretization, a p-type interior penalty discontinuous Galerkin (p-IPDG) method is proposed. Stability and a priori error estimates of this method are analyzed. Numerical results are presented to show that the p-IPDG is efficient. we find that the penalty along the normal direction will be sufficient in our method, rather than additional penalty in the tangential direction.

Pseudospectral simulations of nano-optics induced by Ag nano-particles

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Abstract: In this talk we will present time-domain pseudospectral simulations of induced optical fields of Ag nano-particles excited by external light waves. The physics and applications of the particles systems are first discussed. We then present the mathematical formulation of the problem and the computational framework for simulating the dynamics of nano-optics induced by the Ag particles systems. Numerical validations of the method and the physical meaning of the simulation results will be illustrated and discussed.

Some new perspectives on spectral approximations and time-domain wave scattering

Wang Lilian

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Abstract: In this talk, we shall present some sharp estimate on Jacobi polynomial approximations of smooth functions, and new results on the spectral differentiations of analytic functions based on Gegenbauer-Gauss-type collocation points. Moreover, we shall introduce an efficient spectral solver for time-domain wave scattering with exact transparent boundary conditions.

Composite Laguerre-Legendre Spectral Method for Fourth-oder Exterior Problems

Wang Tianjun

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Abstract: In this talk, we propose the composite Laguerre-Legendre spectral method for fourth-order exterior problems. Some results on the composite Laguerre-Legendre approximation, which is a set of piecewise mixed approximations coupled with domain decomposition, are established. These results play important roles in designing and analyzing the related spectral methods for fourth-order exterior problems with polygon obstacles. As examples of important applications, the composite spectral schemes are provided for two model problems. The convergence of suggested schemes are proved. Efficient algorithms are implemented. Numerical results demonstrate the spectral accuracy in the space of this new approach, and confirm the theoretical analysis well. The approximation results and techniques developed in this paper are also applicable to many other problems defined on unbounded domains, especially for exterior problems.

Convergence analysis of spectral Galerkin methods for Volterra type integral equations

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Abstract: This work is to provide spectral and pseudo-spectral Jacobi-Galerkin approaches for the second kind Volterra integral equation. The Gauss-Legendre quad-rature formula is used to approximate the integral operator and the inner product based on the Jacobi weight is implemented in the weak formulation in the numerical implementation. For some spectral and pseudo-spectral Jacobi-Galerkin methods, a rigorous error analysis in both L^∞ and $L^2_{\omega^{\alpha,\beta}}$ norms is given provided that both the kernel function and the source function are sufficiently smooth. Under some further assumptions on the kernel function and the source function, a super-geometric convergence is justified theoretically. Numerical experiments validate the theoretical prediction.

The h-p version of the FEM for elliptic problems with nonhomogeneous Dirichlet boundary conditions

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Abstract: Based on the local Jacobi operators, we consider the h-p version of the finite element method for second order elliptic problems with nonhomogeneous Dirichlet boundary conditions on polygonal domains, the optimal rate of the convergence in h and p for both smooth solutions and singular solutions are proved.

Generalized Jacobi Rational Spectral Method and Its Applications

Yi Yonggang (Joint with Guo Benyu)
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Abstract: In this talk, We introduce an orthogonal system on the whole line, induced by the generalized Jacobi functions. Some results on the generalized Jacobi rational approximation are established, which play important roles in the related spectral methods. As examples of applications, the rational spectral schemes are proposed for sine-Gordon, Klein-Gordon and Fisher equations, with the convergence analysis. Numerical results demonstrate their efficiency.

Efficient Numerical Methods for the Kinetic Equation of FENE Dumbbell Fluids

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Email: hyu@lsec.cc.ac.cn, URL: http://lsec.cc.ac.cn/∼hyu

Abstract: FENE Dumbbell model is one of the most simple mathematical models that predict basic properties of Non-Newtonian Fluids. However the dynamics of FENE dumbbell fluids are described by a high-dimensional Fokker–Planck equation which needs very fast computer to simulate. Most of the existing numerical algorithms involve factorization of a non-sparse matrix thus are not suitable for discretizations with large degree of freedom. In this talk, we will present a fast spectral Galerkin method using real Fourier series and Jacobi polynomials as bases. This new algorithm has several virtues: 1. The Galerkin approximation bases on a proper weighted weak formulation, in which the numerical moments have spectral accuracy; 2. The numerical approximation leads to linear sparse (banded indeed) system, thus can be solved with linear computational cost; 3. The numerical algorithm can be easily extended to solve the Fokker–Planck equation arising in non-homogeneous systems, or the Navier–Stokes Fokker–Planck coupled system.

Alternating Direction Implicit Legendre Spectral Element Methods for Schrödinger Equations

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Abstract: An alternating direction implicit (ADI) Legendre spectral element method for the two dimensional linear(nonlinear) Schrodinger equation is developed, and the optimal H^1 error estimate for the linear case is derived. This method can convert the two dimensional computation to several one dimensional ones, and the domain decomposition method is applied to deal with one dimensional problems further to reduce the size of the one dimensional problems. The main advantage of this method rests with its highly parallel computing, and the storage is reduced. By choosing appropriate base functions, strip sparse matrices are derived. Various numerical experiments are conducted to confirm the validity of the method by comparison. Keywords: alternating direction implicit method(ADI), Shrodinger equation, spectral element method, domain decomposition method.

Generalized Laguerre Quasi-orthogonal Approximation And Applications To Petrov Galerkin Spectral Method With Essential Imposition Of Mixed Boundary Conditions For High Order Problems

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Abstract: we introduce the generalized Laguerre functions which are mutually orthogonal with the weight $x^\alpha e^{-\beta x}$ where α is any real number and $\beta > 0$. The corresponding orthogonal approximation, quasi-orthogonal approximation and Laguerre-Gauss-Radau interpolation are investigated. A series of approximation results are established, which play important roles in numerical solutions of high order differential equations. In particular, they serve as some basic tools in Petrov-Galerkin spectral and collocation methods with essential imposition of mixed boundary conditions. As examples of applications, we propose the Petrov-Galerkin spectral schemes for two model problems of fourth order, with error analysis. Numerical results demonstrate their high accuracy. The suggested methods also work well for solutions which oscillate seriously and grow up at infinity.

Spectral Collocation Methods for Hamiltonian Dynamical Systems

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Abstract: Numerical approximation of the Hamiltonian dynamical system has been research focus for a long time. Geometric integrators are popular among researchers in the field. One of the most successful methods is the symplectic method invented by Professor Feng, Kang. Recently, the spectral method and spectral collocation method have been used to solve Hamilton systems and demonstrated some promising features. In this talk, we will introduce several versions of the spectral type methods and make a sysmatic comparison with the symplectic method.

Tour Information

7 月 16 日下午旅游安排 —— 南翔古猗园半日游

古猗园初名猗园，建于明代嘉靖年间（公元 1522—1566 年），为时任河南通判闵士籍所建。取《诗卫风淇奥》“绿竹猗猗”为美盛貌，融嵇康《琴赋》“微风余音，靡靡猗猗，余音袅袅”为一炉而得“猗园”名。由明代嘉定竹刻名家朱三松精心设计，有“十亩之园，五亩之宅”的规模，后转让贡生李宜之，又先后为陆、李两姓所有。

清乾隆十一年冬（公元 1746 年），洞庭山人叶锦购得后，大兴土木，修葺装点，于 1748 年秋竣工，因隔了一个朝代，更名为“古猗园”。乾隆五十三年（公元 1789 年）由地方人士募捐购置古猗园，作为州城隍庙的灵苑；同治至光绪年间，园内又增建厅、堂、庵院，开设酒楼茶肆，作为祀神集议和游览休闲的场所。

新中国成立后，古猗园历经多次改扩建，2009 年经过园区改造和东扩建设，面积达到 150 余亩。全园按不同景观划分为猗园、花香仙苑、曲溪鹤影、幽篁烟月 4 个景区，各具独到精巧的艺术构思，散发着古猗园特有的古朴、素雅、清淡、洗练的气质。园内保存的唐代经幢、宋代普同塔、南厅、微音阁等文物、历史遗迹，弥足珍贵，引人探古问胜。

地点：上海市嘉定区沪宜公路 218 号

上海市其它旅游景点简介

➢ 豫园

豫园（Yu Garden）位于上海老城厢东北部,北靠福佑路,东临安仁街,西南与老城隍庙、豫园商城相连。它是老城厢仅存的明代园林。园内楼阁参差,山石峥嵘,湖光潋滟,素有“奇秀甲江南”之誉。豫园始建于明嘉靖年间（1559 年），距今已有四百余年历史。它原是明朝一座私人花园，占地三十余亩.园内有穗堂、大假假山、铁狮子、快楼、得月楼、玉玲珑、积玉水廊、听涛阁、涵碧楼、内园静观大厅、古戏台等亭台楼阁以及假山、池塘等四十余处古代建筑，设计精巧、布局细腻，以清幽秀丽、玲珑剔透见长，具有小中见大的特点，体现明清两代南方园林建筑艺术的风格，是江南古典园林中的一颗明珠。

值得一提的是，豫园与另一热门景点老城隍庙相邻。

➢ 杜莎夫人蜡像馆

杜莎夫人蜡像馆（Madame Tussaud's）在中国的上海分馆于 2006 年开幕。蜡像馆是由蜡制雕塑家杜莎夫人建立的。杜莎夫人蜡像馆是全世界水平最高的蜡像馆之一，有众多世界名人的蜡像。上海分馆入住名单如下

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七宝古镇位于上海西南近郊，始建于宋，自古以来商贾云集、人文荟萃。古镇上一条南北贯通的明清老街，仅容三人并行，两旁都是朱红排门的老商铺。小桥流水、明清街巷是江南古镇的共同特色，而在七宝却能感受到与众不同的海派韵味。蟋蟀馆、老行当再现的是昔日上海的民俗风情；老饭店、天香楼推出的是颇具代表性的上海菜；七宝戏园展演的是沪上一些主要地方戏曲；微雕馆、书翰馆表现的是中国民间艺术与海派文化的和谐结合；张充仁纪念馆的西洋雕塑艺术更是诠释了海派精神对于外来文化介入时的宽容和理智。 酒肆、茶馆内都是老式的八仙桌、长条凳、长嘴铜壶、方头竹筷。坐在酒旗飘飘的小酒馆里，品着七宝大曲，尝着七宝糟肉、拆蹄、云糕，悠闲地消磨几个小时的时光，是在快节奏的上海难得的享受。

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注：南京东路、南京西路、淮海路、四川北路为四大传统商业街。

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