南京大學
NANJING UNIVERSITY

Conference Handbook

The Fourth International Workshop on the Development and Application of High-order Numerical Methods

第四届高精度数值方法发展与应用国际研讨会

2018.5.31-2018.6.4

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Organization

The purpose of this workshop series is to bring together researchers in computational and applied mathematics to discuss recent advances on the theoretical, computational and applied aspects of high-order methods for the solution of partial differential equations.

Scientific Committee

Gang Bao	Zhejiang University
Zhiming Chen	Chinese Academy of Sciences
Qiang Du	Columbia University
Weinan E	Princeton University and Peking University
Song Jiang	Institute of Applied Physics and Computational Mathematics
Shi Jin	University of Wisconsin
Chiwang Shu	Co-chair, Brown University
Tao Tang	Co-chair, Southern University of Science and Technology
Lexing Ying	Stanford University
Yaxiang Yuan	Chinese Academy of Sciences
Pingwen Zhang	Peking University

Organizing Committee

Juan Cheng	Institute of Applied Physics and Computational Mathematics
Weibing Deng	Nanjing University
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Haijin Wang	Nanjing University of Posts and Telecommunications
Chunwu Wang	Nanjing University of Aeronautics and Astronautics
Haijun Wu	Nanjing University
Xinyuan Wu	Nanjing University
Yuanming Xiao	Nanjing University
Qinwu Xu	Nanjing University
Yan Xu	University of Sciences and Technology of China
Qiang Zhang	Co-chair, Nanjing University
Hongqiang Zhu	Nanjing University of Posts and Telecommunications
Jun Zhu	Nanjing University of Aeronautics and Astronautics

Schedule

Registration

Time: PM 14:00-24:00 on May 30, 2018
Place: Lobby of New Era (Xinjiyuan) Hotel, Nanjing

Times and Venues

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10:40-11:15 *Y.-L. Xing*	10:20-10:55 *Y.-H. Xia*	10:50-11:25 *J. Yan*	10:35-11:10 *G. Li*	10:20-10:55 *D.-M. Luo*
11:15-11:50 *Y. Xu*	10:55-11:30 *D. Ling*	11:25-12:00 *C. Wang*	11:10-11:45 *X.-H. Zhong*	10:55-11:30 *W.-X. Cao*
	11:30-12:05 *W.-S. Don*			*11:30-12:05* *H.-J. Wang*
12:10-14:00 Lunch, Nanfang Yuan				
14:00-14:35 *S.-H. Zhang*	14:00-14:35 *J. Du*	14:00-14:35 *J. Cheng*	14:00-14:35 *H.-Q. Zhu*	Free Discussion
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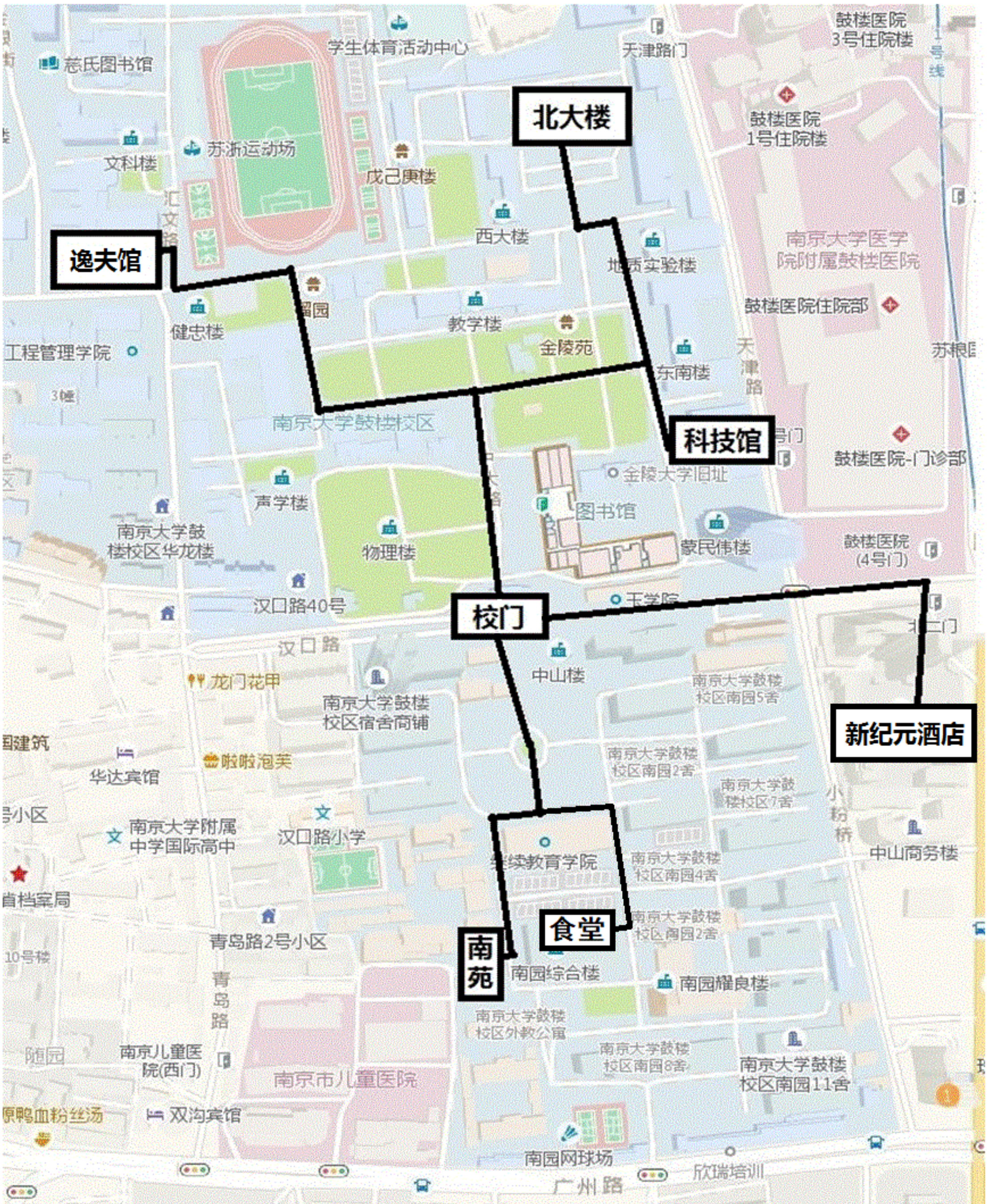
A: First Lecture Room, Science Hall.
B: First Lecture Room, Shaw Hall.

Gulou Campus of Nanjing University

New Era Hotel (新纪元酒店)
Science Hall (科技馆)
Shaw Hall (逸夫馆)
The gate of Hankou Road (汉口路校门)
North Building (北大楼)
Nanyuan Restaurant (南苑)
Canteen (食堂)



Programme

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12:10-14:00	Lunch Break

Plenary Talks

Solving PDEs in Very High Dimensions

Weinan E (鄂维南)

Princeton University, Peking University

Traditional numerical algorithms for solving high dimensional PDEs suffer from the curse of dimensionality. In this talk, I will discuss two kinds of ideas which give rise to new classes of algorithms with polynomial computational complexity. The first class of algorithms is based on the so-called multi-level Monte Carlo methods. The second class of algorithms is based on deep neural networks. Both numerical results and theoretical analysis will be presented.

Hypocoercivity Based Regularity, Sensitivity and Numerical Analyses for Kinetic Equations with Random Uncertainties

Shi Jin (金石)
Shanghai Jiao Tong University, University of Wisocnsin-Madison

Kinetic equations describe dynamics of probability density distributions of large number of particles, and have classical applications in rarified gas, plasma, nuclear engineering and emerging ones in biological and social sciences. Since they are not first principle equations, rather are usually derived from mean field approximations of Newton's second law, thus contain inevitably uncertainties in collision kernel, scattering coefficients, initial and boundary data, forcing and source terms. In this talk we will review a few recent results for kinetic equations with random uncertainties. We will extend hypocoercivity theory, developed for deterministic kinetic equations, to study local sensitivity, regularity, local time behavior of the solutions in the random space, and also establish corresponding theory for their numerical approximation.

Entropy Stable High Order Discontinuous Galerkin Methods for Hyperbolic Conservation Laws

Chi-Wang Shu (舒其望)
Brown University

It is well known that semi-discrete high order discontinuous Galerkin (DG) methods satisfy cell entropy inequalities for the square entropy for both scalar conservation laws and symmetric hyperbolic systems, in any space dimension and for any triangulations. However, this property holds only for the square entropy and the integration in the DG methods must be exact. It is significantly more difficult to design DG methods to satisfy entropy inequalities for a non-square convex entropy, and / or when the integration is approximated by a numerical quadrature. In this talk, we report on our recent development of a unified framework for designing high order DG methods which will satisfy entropy inequalities for any given single convex entropy, through suitable numerical quadrature which is specific to this given entropy. Our framework applies from one-dimensional scalar cases all the way to multi-dimensional systems of conservation laws. For the one-dimensional case, our numerical quadrature is based on the methodology established in the literature, with the main ingredients being summation-by-parts (SBP) operators derived from Legendre Gauss-Lobatto quadrature, the entropy stable flux within elements, and the entropy stable flux at element interfaces. We then generalize the scheme to two-dimensional triangular meshes by constructing SBP operators on triangles based on a special quadrature rule. A local discontinuous Galerkin (LDG) type treatment is also incorporated to achieve the generalization to convection-diffusion equations. Numerical experiments will be reported to validate the accuracy and shock capturing efficacy of these entropy stable DG methods. This is a joint work with Tianheng Chen. We will also report the generalization to MHD in the symmetrizable Godunov form as a joint work with Yong Liu and Mengping Zhang.

Numerical Approximation and Uncertainty Quantification for Phase-Field Problems

Tao Tang (汤涛)
Southern University of Science and Technology

We study the numerical approximation of Allen-Cahn and Cahn-Hillaird type equations modeling the motion of phase interfaces. The common feature of these models is an underlying gradient flow structure which gives rise to a decay of an associated energy functional along solution trajectories. In this work, by considering the classical double-well potential model, we provide an alternative framework for stability analysis for the determininstic problems. The present work is also devoted to the development and analysis of numerical methods for the stochastic version of the phase-field equations.

An Entropic Fourier Method for the Boltzmann Equation

Lexing Ying (应乐兴)
Stanford University

We propose an entropic Fourier method for the numerical discretization of the Boltzmann collision operator. The method, which is obtained by modifying a Fourier Galerkin method to match the form of the discrete velocity method, can be viewed both as a discrete velocity method and as a Fourier method. As a discrete velocity method, it preserves the positivity of the solution and satisfies a discrete version of the H-theorem. As a Fourier method, it allows one to readily apply the FFT-based fast algorithms.

Invited Talks

Superconvergence of Discontinuous Galerkin Method for Scalar Nonlinear Hyperbolic Equations

Waixiang Cao (曹外香)
Beijing Normal University

In this paper, we study the superconvergence behavior of the semi-discrete discontinuous Galerkin (DG) method for scalar nonlinear hyperbolic equations in one spatial dimension. Superconvergence results for problems with fixed and alternating wind directions are established. On the one hand, we prove that, if the wind direction is fixed (i.e., the derivative of the flux function is bounded away from zero), both the cell average error and numerical flux error at cell interfaces converge at a rate of $2k+1$ when upwind fluxes and piecewise polynomials of degree k are used. Moreover, we also prove that the function value approximation of the DG solution is superconvergent at interior right Radau points, and the derivative value approximation is superconvergent at interior left Radau points, with an order of $k+2$ and $k+1$, respectively. As a byproduct, we show a $k+2$-th order superconvergence of the DG solution towards the Gauss-Radau projection of the exact solution. On the other hand, superconvergence results for problems with alternating wind directions (i.e., the derivative of the flux function either changes sign or otherwise achieves the value zero in the domain) are also established. To be more precise, we first prove that the DG flux function is superconvergent towards a particular flux function of the exact solution, with an order of $k+2$, when Godunov fluxes are used. We then prove that the highest superconvergence rate of the DG solution itself is $k+\frac{3}{2}$ when sonic points (i.e., the derivative of the flux function achieves zero) appear in the computational domain. As byproducts, we obtain superconvergence properties for the DG solution and the DG flux function at special points and for cell average. Numerical experiments demonstrate that most of our results are optimal, i.e., the superconvergence rates are sharp.

Positivity-Preserving and Symmetry-Preserving Conservative Lagrangian Schemes for Compressible Euler Equations in 2D Cylindrical Coordinates

Juan Cheng (成娟)
Institute of Applied Physics and Computational Mathematics

In applications such as astrophysics and inertial confinement fusion, there are many three-dimensional cylindrical-symmetric multi-material problems which are usually simulated by Lagrangian schemes in the two-dimensional cylindrical coordinates. For this type of simulation, the critical issues for the schemes include keeping positivity of physically positive variables such as density and internal energy and keeping spherical symmetry in the cylindrical coordinate system if the original physical problem has this symmetry. In this talk, we will introduce our recent work on high order positivity-preserving and symmetry-preserving Lagrangian schemes solving compressible Euler equations. The properties of positivity-preserving and symmetry-preserving are proven rigorously. One- and two-dimensional numerical results are provided to verify the designed characteristics of these schemes. This is a joint work with Dan Ling and Chi-Wang Shu.

Radial Basis Function Based Shock Detector for Hybrid Compact-WENO Finite Difference Scheme in Solving Hyperbolic Conservation Laws

Waisun Don (曾维新)
Ocean University of China

Ever since the development of the high order WENO finite difference scheme by

Jiang and Shu, it has been widely adopted for solving hyperbolic conservation laws that captures shocks essentially non-oscillatory while resolving fine scale structures efficiently. Numerous advances have been proposed to reduce the dissipation and dispersion errors by improving/modifying certain critical components of the WENO reconstruction procedure, such as, the definitions of nonlinear weights and the smoothness indicators and the tuning of existing parameters. In this talk, I will present some recent works on the hybridization of high resolution linear compact scheme and shock capturing nonlinear WENO finite difference scheme with high order shock detector methods that based on the polynomial (multi-resolution analysis), trigonometric (conjugate Fourier method) and radial basis function (RBF) approximations. I will give a general discussion that addresses various numerical and theoretical aspects of each approach, some critical implementation issues (such as ill-conditioning, fast algorithm for finding the inverse of a perturbed Toeplitz matrix and domain decomposition in the RBF based shock detection method) and their respective performance in terms of accuracy, efficiency and robustness. Numerical examples in several one- and two-dimensional shocked flows will be presented to demonstrate the efficacy and sharp capturing of discontinuities of the hybrid scheme in solving hyperbolic conservation laws in comparison with the classical WENO-Z scheme.

Maximum-Principle-Preserving Third-Order Local Discontinuous Galerkin Method for Convection-Diffusion Equations on Overlapped Meshes

Jie Du (杜洁)
Tsinghua University

Local discontinuous Galerkin (LDG) methods are popular for convection-diffusion equations. In LDG methods, we introduce an auxiliary variable p to represent the derivative of the primary variable u, and solve them on the same mesh. It is well known that the maximum-principle-preserving (MPP) LDG method is only available up to second-order accurate. Recently, we introduced a new algorithm, and solve u and p on different meshes, and obtained stability and optimal accuracy. In this talk, we will continue this approach and construct MPP third-order LDG methods for convection-diffusion equations on overlapped meshes. The new algorithm is more flexible and does not increase any computational cost. Numerical evidence will be given to demonstrate the accuracy and good performance of the third-order MPP LDG method.

High Order Semi-Implicit Time Discretization and Local Discontinuous Galerkin Methods for Phase Field Models

Ruihan Guo (郭瑞晗)
Zhengzhou University

In this talk, we present the local discontinuous Galerkin (LDG) methods for a series of phase field models. The phase field models are PDEs containing high order spatial derivatives, which leads to the severe time step restriction of explicit time discretization methods to maintain stability. Due to this, we introduce semi-implicit first order time discretization methods which are based on the convex splitting principle of a discrete energy and prove the corresponding unconditional energy stabilities. To improve the temporal accuracy, a novel high order semi-implicit Runge-Kutta method and a novel semi-implicit spectral deferred correction (SDC) method combining with the first-order convex splitting method are adopted for the phase field models. The equations at the implicit time level are nonlinear and we employ an efficient nonlinear multigrid solver to solve the equations. Numerical results are also given to illustrate that the combination of the LDG method for spatial approximation, high order semi-implicit time marching methods with the multigrid solver provides an efficient and practical approach when solving the phase field models.

A High Order Non-Splitting Conservative Semi-Lagrangian Discontinuous Galerkin Method for the Two-Dimensional Transport Simulations

Wei Guo (郭唯)
Texas Tech University

In this talk, we will introduce a high order non-splitting conservative semi-Lagrangian (SL) discontinuous Galerkin (DG) method for the two-dimensional transport simulations. The proposed method relies on a characteristic Galerkin weak formulation and a high order characteristics tracing mechanism. Unlike many existing SL methods, the high order accuracy and mass conservation of the method are realized in a non-splitting manner. Thus, the detrimental splitting error, which could significantly contaminate long term transport simulations, will be not incurred. One key ingredient in the scheme formulation is the use of Green's theorem which allows us to convert volume integrals into a set of line integrals. The resulting line integrals are much easier to approximate with high order accuracy, hence facilitating the implementation. The desired positivity-preserving property is further attained by incorporating a high order bound-preserving filter. To assess the numerical performance, we benchmark the proposed SLDG schemes for simulating several transport problems, the nonlinear Vlasov-Poisson system and incompressible flow. The efficiency and efficacy of the proposed scheme are numerically verified when

compared with other prominent transport solvers such as the Eulerian DG methods combined with Runge-Kutta time integrators.

A Numerical Study on Detonation by Finite Volume Method

Guanghui Hu (胡广辉)
University of Macau

In this talk, we propose a numerical framework to study the detonation phenomenon. In the numerical framework, the reactive Euler equations are split into a standard convection process governed by nonreactive Euler equations, and a reaction process governed by a series of ODEs, by Strange splitting method. In solving Euler equations, the reconstruction is done with Non-oscillatory 1-exact reconstruction, while the HLLC flux is used for the Riemann solver. The ODE is solved with a second order RK method. OpenMP is used to accelerate the simulation in both processes. ZND theory is briefly introduced, and it is successfully shown that our result confirm the one from ZND theory. Finally, some numerical challenges will be introduced.

A Second-Order Asymptotic-Preserving and Positivity-Preserving Discontinuous Galerkin Scheme for the Kerr–Debye Model

Juntao Huang (黄俊涛)
Tsinghua University

In this talk, we present a second-order asymptotic-preserving and positivity-preserving discontinuous Galerkin (DG) scheme for the Kerr–Debye model. By using the approach first introduced by Zhang and Shu in [Q. Zhang and C.-W. Shu, Error estimates to smooth solutions of Runge–Kutta discontinuous Galerkin methods for scalar conservation laws, SIAM J. Numer. Anal. 42 (2004) 641–666.] with an energy estimate and Taylor expansion, the asymptotic-preserving property of the semi-discrete DG methods is proved rigorously. In addition, we propose a class of unconditional positivity-preserving implicit–explicit (IMEX) Runge–Kutta methods for the system of ordinary differential equations arising from the semi-discretization of the Kerr–Debye model. The new IMEX Runge–Kutta methods are based on the modification of the strong-stability-preserving (SSP) implicit Runge–Kutta method and have second-order accuracy. The numerical results validate our analysis. This is joint work with Chi-Wang Shu at Brown Univerisity.

A Kernel-Based High Order Numerical Scheme

Yan Jiang (蒋琰)
Michigan State University

In this talk, I will introduce a novel numerical scheme, in which the spatial derivatives are represented as a special kernel based formulation of the solutions. We use this method to solve the nonlinear parabolic equations and Hamilton-Jacobi equations. Moreover, theoretical investigations indicated that the proposed scheme is unconditionally stable up to third order accuracy when combining with the SSP-RK scheme.

Well-Balanced Finite Difference Schemes for the Euler Equations Under Gravitational Fields

Gang Li (李刚)
Qingdao University

Euler equations under gravitational field admit hydrostatic equilibrium state where the flux produced by the pressure is exactly balanced by the gravitational source term. In this talk, we present high order well-balanced finite difference WENO schemes, which can preserve the isentropic hydrostatic balance state exactly and maintain genuine high order accuracy for general solutions. To obtain the well-balanced property, we firstly rewrite the source into an equivalent form, and construct the numerical flux by means of a flux modification technique. Rigorous theoretical analysis as well as extensive numerical examples all suggest that the present schemes preserve the well-balanced property. Moreover, one- and two-dimensional simulations are performed to test the ability to capture small perturbation of such steady state, and the genuine high order accuracy in smooth regions.

Smoothness-Increasing Accuracy-Conserving: Challenging the Assumption of Uniformity

Xiaozhou Li (李小舟)
University of Electronic Science and Technology of China

Previous investigations into accuracy enhancement for a discontinuous Galerkin solution demonstrated that there are many ways to approach obtaining higher-order accuracy in the solution, for example, the Smoothness-Increasing Accuracy-

Conserving (SIAC) filtering. For the discontinuous Galerkin method, the order of accuracy without post-processing is k+1. For the post-processed solution, it is 2k+1. Additionally, the SIAC filtering introduces higher levels of smoothness into the new approximation. However, previous investigations were mainly limited to uniform meshes (or nearly uniform meshes) consideration, which is highly restrictive for practical application. In this talk, we discuss the challenges and difficulties for nonuniform meshes. Additionally, we present several common techniques of for nonuniform meshes will be introduced. Moreover, we purpose a new technique which considers the mesh structure as a parameter when dealing the nonuniform meshes. A comparison is made among these techniques through numerical examples.

Conservative High Order Positivity-Preserving Discontinuous Galerkin Methods for Linear Hyperbolic and Radiative Transfer Equations

Dan Ling (令丹)
China Academy of Engineering Physics

In this presentation, we develop and analyze a conservative high order positivity-preserving DG method for both linear hyperbolic equations and radiative transfer equations. In the one dimensional case, a key result is proved that the DG solver based on the traditional Pk space can maintain positivity of the cell average if the inow boundary value and the source term are both positive, therefore the scaling positivity-preserving limiter can be used to obtain a high order conservative positivity-preserving DG scheme. In two dimensions we show that the DG solver based either on Pk or Qk spaces could generate negative cell averages. We augment the DG space with additional functions so that the positivity of cell averages from the DG solver can be restored, thereby leading to high order conservative positivity-preserving DG scheme based on these augmented DG spaces. Computational results are provided to demonstrate the good performance of our DG schemes.

The Numerical Study on the Underwater Explosion Loads and its Damage to its Nearby Structures

Yunlong Liu (刘云龙) Shiping Wang (王诗平)
Harbin Engineering University

When a charge explodes underwater, a shockwave would be firstly generated and then a bubble produced by high pressure explosive products. The peak pressure of the shockwave is very high which is over 10GPa in the near field. The travelling speed of the near field water particles is over 1000m/s. The motion of the subsequently pulsating bubble is very complex which is very much related to its surrounding environment. The liquid jet would be generated during the bubble's collapsing stage. Both the shockwave and the bubble load would do damage to its nearby structures. In this talk, I will introduce the recent study of our group in dealing with the propagation of the nearfield shockwave, the pulsating bubble and the interaction with its nearby structures using different numerical techniques.

A Moving Mesh Discontinuous Galerkin Method for Hyperbolic Conservation Laws

Dongmi Luo (罗冬密)
Xiamen University

A moving mesh discontinuous Galerkin method is developed for the numerical solution of hyperbolic conservation laws. The method is a combination of the discontinuous Galerkin method and the mesh movement strategy which is based on the moving mesh partial differential equation approach and moves the mesh continuously in time and orderly in space using a system of mesh partial differential equations. It not only can achieve the high order in smooth regions, but also capture shocks well in nonsmooth regions. For the same number of grid points, the numerical solution with the moving mesh method is much better than ones with the uniform mesh method. Numerical examples are presented to show the accuracy and shock-capturing features of the method.

Discontinuous Galerkin Methods for Nonlinear Scalar Hyperbolic Conservation Laws: Divided Difference Estimates and Accuracy Enhancement

Xiong Meng (孟雄)
Harbin Institute of Technology

In this paper, an analysis of the accuracy-enhancement for the discontinuous Galerkin (DG) method applied to one-dimensional scalar nonlinear hyperbolic conservation laws is carried out. This requires analyzing the divided difference of the errors for the

DG solution. We therefore first prove that the α-th order $(1 < \alpha < k+1)$ divided difference of the DG error in the L^2 norm is of order $k+\frac{3}{2}-\frac{\alpha}{2}$ when upwind fluxes are used, under the condition that $|f'(u)|$ possesses a uniform positive lower bound. By the duality argument, we then derive super- convergence results of order $2k+\frac{3}{2}-\frac{\alpha}{2}$ in the negative-order norm, demonstrating that it is possible to extend the Smoothness-Increasing Accuracy-Conserving filter to nonlinear conservation laws to obtain at least $\left(\frac{3k}{2}+1\right)$th order superconvergence for post-processed solutions. As a by-product, for variable coefficient hyperbolic equations, we provide an explicit proof for optimal convergence results of order $k+1$ in the L^2 norm for the divided differences of DG errors and thus $(2k+1)$ th order superconvergence in negative-order norm holds. Numerical experiments are given that confirm the theoretical results.

Exponential Time Differencing Methods for Phase Field Equations

Zhonghua Qiao (乔中华)
The Hong Kong Polytechnic University

We develop a class of exponential time differencing (ETD) schemes for solving phase field equations. Energy stabilities and error estimates of the first and second order ETD schemes are rigorously established in the fully discrete sense. Numerical examples will be given to demonstrate the efficiency of proposed methods.

High Order Semi-Implicit IMEX WENO Scheme for the Euler System with All-Mach Number

Jingmei Qiu (邱竞梅)
University of Delaware

We propose a high order asymptotic preserving method for all-Mach number simulations. In particular, we focus on finite difference schemes with weighted essentially non-oscillatory (WENO) reconstructions coupled with proper implicit-explicit (IMEX) Runge-Kutta (RK) treatments for the system. The proposed method enjoys the following properties:

1. the schemes can robustly capture shock fronts in the compressible regime when the Mach number is of order 1;

2. the schemes automatically become high order, stable and consistent solvers for the incompressible Euler system when the Mach number approaches 0;

3. the schemes are high order accurate in both space and in time both when the acoustic waves are well-resolved and are under-resolved. 1D and 2D numerical results will be presented to showcase the method.

Large Scale High Resolution Numerical Simulation of Explosion and Impact Problems

Cheng Wang (王成)
Beijing Insititute of Technology

Explosion and impact are nonlinear problems where a variety of media, such as gas, solid and liquid, strongly interact under high speed, high temperature and high

pressure conditions, formidable challenge is imposed on the theoretical and experimental research. Due to such advantages as confidentiality, design flexibility, environment and process controllability and high cost-effective ratio, numerical simulation becomes the main approach to investigate such problems. This paper introduces in detail high resolution computations of explosion and impact problems, high order numerical boundary condition, positivity preserving and multi-medium interface treatment by the authors in recent years. Based on Level Set and Moment of Fluid method, the computational method that can address high density and high pressure ratio is proposed. High order finite difference weighted essentially non-oscillatory (WENO) method is generalized to solve the explosion problems with chemical reaction source terms. Based on this, a high resolution large scale parallel computation software was developed for explosion and impact problems. The code can simulate problems such as gas detonation, initiation of condensed-phase explosives, detonation diffraction, shock wave interaction with bubbles, underwater explosion. By constructing artificial solutions and comparison with experimental results, the accuracy and computation results of the computation method are validated and verified.

The Positivity-Preserving Numerical Method for Compressible Multi-Media Flow

Chunwu Wang (王春武)

Nanjing University of Aeronautics and Astronautics

In the numerical simulation of the multi-medium flow, the loss of positivity of the physically positive variables may lead to nonlinear instability or blow-ups of the algorithm. In this paper, we construct high order accurate scheme which preserve

positivity of density and pressure in the simulation of compressible multi-media flows. The method is based on the positivity-preserving Runge-Kutta discontinuous Galerkin (RKDG) scheme for single medium flow and the real Ghost Fluid method (RGFM) for the treating of the interface. The obtained schemes are extended to the simulation of multi-media flow and the positivity-preserving limiters for pressure are modified for simplicity. The obtained limiters can keep the property of the original limiters and are cost effective. Furthermore, we develop a positivity preserving Riemann solver in RGFM interface treating method. Several numerical examples are given to test the robustness and efficiency of the algorithm. Numerical results show that the obtained method can maintain the positivity of pressure or density and can capture the discontinuities accurately.

Local Discontinuous Galerkin Methods with Explicit-Implicit-Null Time Discretizations for Solving Nonlinear Diffusion Problems

Haijin Wang (王海金)
Nanjing University of Posts and Telecommunications

In this talk we introduce an explicit-implicit-null time discretization coupled with the LDG method for solving nonlinear diffusion problem $u_t = (a(u)u_x)_x$. The basic idea is to add and subtract two equal terms $a_0 u_{xx}$ on the right hand side of the partial differential equation, then to treat the term $a_0 u_{xx}$ implicitly and the other terms $(a(u)u_x)_x - a_0 u_{xx}$ explicitly. By studying the stability on a simplified model, we give a guidance for the choice of a_0. Several numerical experiments are given to demonstrate the stability, accuracy and performance of the proposed schemes.

A Multiscale Discontinuous Galerkin Method for Stationary Schrodinger Equations

Wei Wang (王为)
Florida International University

In this talk, we will introduce a multiscale discontinuous Galerkin method for one-dimensional stationary Schrodinger equations which have highly oscillating solutions. Because of the oscillatory behavior of the solutions, traditional numerical methods require extremely refined meshes to resolve the small scale structure of solutions, thus the computational cost is huge. The main ingredient of our method is to incorporate the small scales into finite element basis functions so that the method can capture the multiscale solution on coarse meshes. We prove that the DG approximation converges optimally with respect to the mesh size h in L^2 norm without the constraint that h has to be smaller than the wave length.

Finite Element Method and its Analysis for a Nonlinear Helmholtz Equation with High Wave Numbers

Haijun Wu (武海军)
Nanjing University

The well-posedness of a nonlinear Helmholtz equation with an impedance boundary condition is established for high frequencies in two and three dimensions. Stability estimates are derived with explicit dependence on the wave number. Linear finite elements are considered for the discretization of the nonlinear Helmholtz equation, and the well-posedness of the finite element systems is analyzed. Stability and

preasymptotic error estimates of the finite element solutions are achieved with explicit dependence on the wave number. Numerical examples are also presented to demonstrate the effectiveness and accuracies of the proposed finite element method for solving the nonlinear Helmholtz equation.

Maximum Principle of Arbitrary Lagrangian-Eulerian Discontinuous Galerkin Methods for Conservation Laws

Yinhua Xia (夏银华)

University of Science and Technology of China

In this talk, we present the arbitrary Lagrangian-Eulerian discontinuous Galerkin (ALE-DG) methods for conservation laws. The method will be designed for simplex meshes. This will ensure that the method satisfies the geometric conservation law for any time integration method with the accuracy order at least the same as patial dimension. For the semi-discrete method the L^2-stability and the suboptimal $(k+1/2)$ convergence with respect to the $L^1(0;T;L^2)$-norm will be proven, when an arbitrary monotone flux is used and for each cell the approximating functions are given by polynomials of degree k. The two dimensional fully-discrete explicit method will be combined with the bound preserving limiter. This limiter does not affect the high order accuracy of the numerical method. Then, for the ALE-DG method revised by the limiter the validity of a discrete maximum-principle will be proven. This approach can also be developed for the positivity preserving of ALE-DG methods for Euler equations. The numerical stability, robustness and accuracy of the method will be shown by a variety of computational experiments on moving meshes.

High-Order Compact Difference Methods for some Boussinesq Systems

Shusen Xie (谢树森)
Ocean University of China

Consider the compact difference methods for the numerical approximation of solutions of some Boussinesq systems (BBM-BBM, Bona-Smith, KdV-BBM, etc). Some IMEX multistep compact difference schemes are derived. The stability analysis and error estimates are given. Numerical experiments on model problems show that the proposed schemes are of high accuracy and our numerical simulations are compared with existing theoretical and numerical results.

High Order WENO and Discontinuous Galerkin Methods for the Shallow Water Flows in Open Channels

Yulong Xing (邢雨龙)
The Ohio State University

In this presentation, we construct and study high order finite volume weighted essentially non-oscillatory (WENO) methods and discontinuous Galerkin (DG) methods for the shallow water flows in open channels with irregular geometry and a non-flat bottom topography. The proposed methods are well-balanced for the still water steady state and can preserve the non-negativity of wet cross section numerically. Some numerical tests are provided to verify the well-balanced property, high-order accuracy, and good resolution for smooth and discontinuous solutions.

A Hybrid Discontinuous Galerkin Scheme for Multi-Scale Kinetic Equations

Tao Xiong (熊涛)
Xiamen University

We develop a multi-dimensional hybrid discontinuous Galerkin method for multi-scale kinetic equations. This method is based on moment realizability matrices, a concept introduced by D. Levermore, W. Morokoff and B. Nadiga. The main issue addressed in this work is to provide a simple indicator to select the most appropriate model and to apply a compact numerical scheme to reduce the interface region between different models. We also construct a numerical flux for the fluid model obtained as the asymptotic limit of the flux of the kinetic equation. We perform several numerical simulations for time evolution and stationary problems, to illustrate the effectiveness and efficiency of our proposed approach.

Superconvergence of Arbitrary Lagrangian-Eulerian Discontinuous Galerkin Method for Linear Hyperbolic Conservation Laws

Yan Xu (徐岩)
University of Science and Technology of China

In this paper, we study the superconvergence properties of the Arbitrary Lagrangian-Eulerian discontinuous Galerkin (ALE-DG) approximations to scalar linear hyperbolic equations with smooth solutions. We build a special interpolation function by constructing a correct function, and prove the numerical solution is

superclose to the interpolation function in the L^2 norm. The order of superconvergence is $2k+1$, when the polynomials of degree at most k are used. In our analysis, the special correct functions and special initial conditions are required, which are the main differences from the usual discontinuous Galerkin method for the linear hyperbolic equations. We also rigorously prove a $(2k+1)$-th order superconvergence rate for the domain, cell averages, and the numerical fluxes at the nodes in the maximal and average norm. Furthermore, we prove the function value approximation is superconvergent with a rate of $(k+2)$-th order and a superconvergence rate of $(k+1)$-th order for the derivative approximation at the Radau points. All theoretical findings are confirmed by numerical experiments.

Symmetric direct DG (DDG) method for elliptic interface problems

Jue Yan (阎珏)
State University of Iowa

We first review recent development of DDG method and its variations, the DDGIC and symmetric DDG methods. Under the topic of maximum principle, we prove the DDG methods satisfy strict maximum principle with at least third order of accuracy. Recent application to Chemotaxis Keller-Segel equations shows that the DDGIC method have the hidden super convergence property on its approximation to the solution’s gradients. We then discuss our studies of symmetric DDG method on second order elliptic problems, especially on elliptic interface problems.

Discontinuous Galerkin Methods for the Variational Inequality Problems in Incompressible Flows

Wenjing Yan (晏文璟) Feifei Jing (荆菲菲)
Xi'an Jiaotong University

In this work, discontinuous Galerkin methods are introduced and analyzed to solve a variational inequality from the hydrodynamics equations with a nonlinear slip boundary condition of friction type. Existence, uniqueness and stability of numerical solutions are shown for the discontinuous Galerkin methods. Error estimates are derived for the velocity in a broken H^1-norm and for the pressure in an L^2-norm, with the optimal convergence order when linear elements for the velocity and piecewise constants for the pressure are used. Numerical results are reported to demonstrate the theoretically predicted convergence orders, as well as the capability in capturing the discontinuity, the ability in handling the shear layers, and the application to the general polygonal mesh of the discontinuous Galerkin methods.

The DG Methods for Ideal MHD Equations and Their Applications

Mengping Zhang (张梦萍)
University of Science and Technology of China

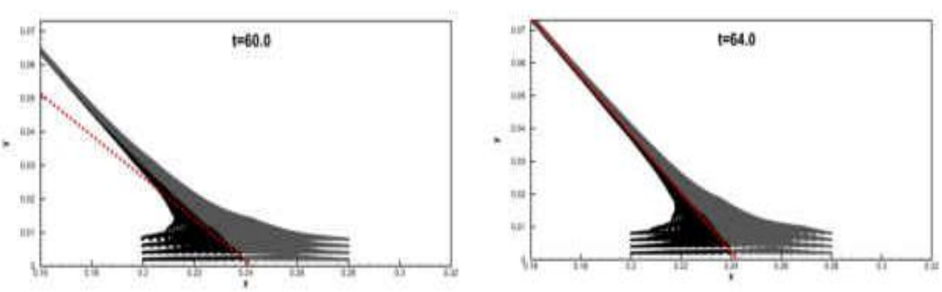
In the talk, we present a locally divergence-free discontinuous Galerkin methods for the ideal MHD equations on 3D Cartesian coordinate system and cylindrical coordinate system, respectively. Here we use the methods, with the positivity-preserving limiters, to simulate some problem of magnetic hydrodynamics and nuclear fusion.

Numerical Study of Cavity Flows

Shuhai Zhang (张树海)

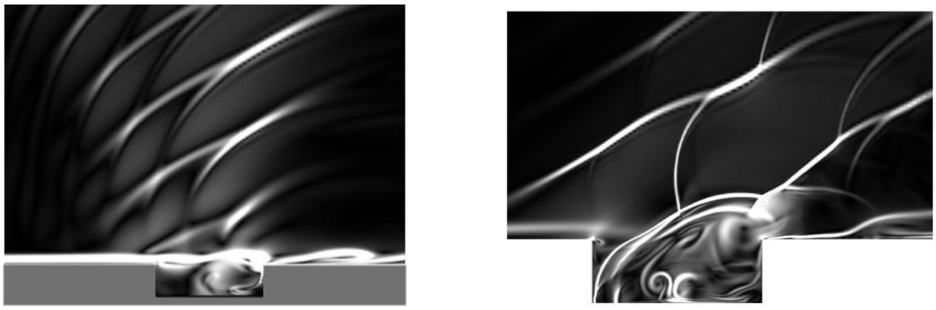
State Key Laboratory of Aerodynamics

Cavity flows have been of great interest in a lot of engineering applications, such as the landing gear well of airplane at landing and takeoff and window open conditions of cars. The cavity flows are very complex. They have the features of strong unsteady and multiscale. The strong unsteady flow can produce the strong fluctuation of pressure on the surface and result in the structural fatigue and damage the structure. It can also produce strong aerodynamic noise and pollute our environment. Using high order WENO schemes, we systematically study the cavity flow with direct numerical simulation and the flow structures are obtained with high accuracy. The mechanism of unsteady flow separation and sound generation are analysed. The numerical result verified our criteria for two dimensional periodic flow separation, it is the zero point of the finite time Lyapunov exponent (FTLE). It is found that there is essential difference in the mechanism of sound generation between the subsonic cavity flow and supersonic cavity flow. In the subsonic flow, the sound is mainly produced by the interaction of the shear layer and the rear wall. In the supersonic flow, the sound is generated by the shock waves. Figure 1 contains separating material spike in periodic lid-driven cavity flow and the leading-order separation profile. Figure 2 contains the numerical schlieren photographs of two dimensional cavity flow.



(a) t=60 (b) t=64

Fig.1 Separating material spike in periodic lid-driven cavity flow and the leading-order separation profile.



(a) M=0.8 (b) M=1.2

Fig.2 The numerical schlieren photographs of two dimensional cavity flow.

Galerkin Method for Stationary Radiative Transfer Equations with Uncertain Coefficients

Xinghui Zhong (仲杏慧)
Zhejiang University

We study the stationary radiative transfer equation (RTE) with random coefficients. Galerkin type approximation is used, and in random space, orthogonal polynomials associated with the probability distribution of the random variable are utilized as basis functions. Such algorithms have been widely used for kinetic equations with random inputs, but the corresponding numerical analysis is rare. In this talk, we rigorously justify the validity, namely, we study the smoothness of the solution on the random space, and prove the convergence of N-term truncated polynomials under the spectral method framework. The associated numerical tests are conducted to demonstrate our analytical results.

High-Order Time-Stepping Schemes for Time-Fractional Diffusion Equations

Zhi Zhou (周知)
The Hong Kong Polytechnic University

The time-fractional diffusion, which has received much attention in recent years, describes a diffusion process in which the mean square displacement of a particle grows slower (sub-diffusion) than that in the normal diffusion process. The solution of the fractional diffusion often exhibits a singular layer, provided that the source data is not compatible with the initial data, which makes the numerical treatment and analysis challenging. We develop a systematic strategy to the starting k-1 steps in order to restore the desired kth-order convergence rate of the k-step BDF convolution quadrature for the time-fractional equations. The desired kth-order convergence rate can be achieved even if the solution is non-smooth.

h-Adaptive RKDG Methods for Several Model Problems

Hongqiang Zhu (朱洪强)
Nanjing University of Posts and Telecommunications

In this talk we present an h-adaptive Runge-Kutta discontinuous Galerkin method which is based on mesh refinement and coarsening. First, the framework of this method is presented, together with the implementation details. After that, we show its applications to different model problems, including hyperbolic conservation laws, detonation wave simulations, Vlasov-Possion system and 2D incompressible Euler equations in the vorticity-stream function formulation. Numerical results of classical test problems are given to illustrate the effectiveness and the capability of this method.

A New Type of Finite Volume WENO Schemes on Triangular Meshes

Jun Zhu (朱君)
Nanjing University of Aeronautics and Astronautics

In this presentation, we design a new type of high order finite volume weighted essentially non-oscillatory (WENO) schemes to solve hyperbolic conservation laws on triangular meshes. The main advantages of these schemes are their compactness, robustness and could maintain good convergence property for some steady state problems. Comparing with the classical finite volume WENO schemes, the optimal linear weights are independent of the topological structure of the triangular meshes and can be any positive numbers with one requirement that their summation is one. And it is the first time to obtain any high order accuracy with the usage of only five unequal sized stencils in spatial reconstruction methodology on triangular meshes. Extensive numerical results are provided to illustrate the good performance of such new finite volume WENO schemes.

Transport to Hotel

➢ **From Nanjing Lukou International Airport (南京禄口国际机场)**

- By taxi, it takes about 50 minutes and about ￥145.
- By metro, it takes about 1h 30min and about ￥7, and needs to walk for about 1.8km in total.
    - ◆ Take Line S1 to the final destination Nanjing South Railway Station (南京南站), and then take Line 1 to Zhujiang Road (珠江路) Station. The direction is to Maigaoqiao (迈皋桥) Station. The total number of stops is 9. Finally, leave from the entrance No.3 and walk to the hotel for 340m.

- By airport bus, it takes about 1h 50min and about ￥22.
    - ◆ Firstly take airport bus Line 1 to Longpanzhong Road Yixian Bridge (龙蟠中路・逸仙桥) Station. Then, take bus No.47 to Yushi Road (鱼市街) Station, at the 5th stop. Finally, walk for 560m to the hotel.

➢ **From Nanjing South Railway Station (南京南站)**

- By taxi, it takes about 30min and about ￥34.
- By metro, it takes about 45min and about ￥3.
  - ◆ Take Line 1 from Nanjing South Station (南京南站) to Zhujiang Road Station (珠江路站) (The direction to the final destination Maigaoqiao (迈皋桥) Station). The total number of stops is 9. Finally, leave from the entrance No.3 and walk to the hotel for 340m.

➢ **From Nanjing Railway Station (南京站)**

- By taxi, it takes about 20min and about ￥17.
- By metro, it takes about 10min and ￥2.
  - ◆ Take Line 1 from Nanjing Station to Zhujiang Road. The direction is to China Pharmaceutical University (中国药科大学方向) Station. The total number of stops is 3. Finally, leave from the entrance No.3 and walk to the hotel for 340m.

Useful Information

Tourist Attractions in Nanjing

1. Nanjing Presidential Palace（南京总统府）

Location: Xuanwu (玄武) District, Changjiang Road (长江路) No.292
Open time: 8:30 - 17:30
Ticket: ￥40 (Half for students and elder over 60, free for elder over 70)

2. Xuanwu Lake（玄武湖）

Location: Dongting Road (洞庭路)
Open time: all day.
No tickets.

3. The Sun Yat-sen Mausoleum (中山陵)

Open time: 8:30 - 17:00
No tickets.

4. Confucius Temple (夫子庙)

Location: Qinhuai (秦淮) District, Gongyyuanxi Road (贡院西街) No.152
Open time: all day.
No tickets.

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Appendix

Link

http://maths.nju.edu.cn/~qzh/shumeeting/highordermethod.html

Sponsors

Tianyuan exchange program of NSFC

Jiangsu Mathematical Society

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南京大学数学系以历史悠久、实力雄厚、治学严谨而著称。教学体系较为完备，学科构架独具特色，其学术影响蜚声国际，吸引大批的杰出学者到本系执教共勉。

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