An adaptive high-order unfitted finite element method for elliptic and Maxwell interface problems

陈志明（中国科学院数学与系统科学研究院）

We design an adaptive unfitted finite element method on the Cartesian mesh with hanging nodes for elliptic interface problems. We derive an hp-reliable and efficient residual type a posteriori error estimate on K-meshes. A key ingredient is a novel hp-domain inverse estimate which allows us to prove the stability of the finite element method under practical interface resolving mesh conditions and also prove the lower bound of the hp a posteriori error estimate. Numerical examples are included. The unfitted finite element method for time-harmonic Maxwell interface problems will be briefly discussed. This talk is based on joint works with Ke Li and Xueshuang Xiang.

酉算法

周爱辉（中国科学院数学与系统科学研究院）

带正交约束的极小问题求解、特征值族计算和正交基构造中，通常都需要反复地进行正交化操作。因此减少正交化操作很有意义。对非线性问题求解来说，迭代法的收敛性是重要的课题。我们将在本报告中扼要地介绍一类收敛的保正交性迭代算法—酉算法，并以电子结构计算为例展示该保酉结构迭代法之潜力。

Domain parameterization for iso-geometric analysis

陈发来（中国科学技术大学）

Iso-geometric analysis is a few framework for solving numerical PDEs which integrates two related discipline Computer Aided Design (CAD) and Computer Aided Engineering (CAE). One essential step in iso-geometric analysis is to compute a map from a parametric domain to a physical domain, which is called domain parametrization. In this talk, I will present methods to compute domain parametrizations using optimization technique.

Triangle configuration B-splines and their applications

曹娟（厦门大学）

Triangle configuration B-splines (TCB-splines) and their rational extensions are attractive alternatives of classical NURBS, as they share many desired properties with NURBS and can be defined over general polygonal domains. In this talk, we introduce the TCB-splines and their applications in surface reconstruction, image vectorization, etc. In particular, we propose to use TCB-splines in IGA to overcome the limits posed by the tensor-product structure of NURBS. We present the methodology for IGA to use rational TCB-splines over general polygonal domains. Then we propose a method to generate the computational domain according to given physical domain boundaries. This allows us to easily obtain a high-quality parameterization without resorting to the optimization method. Several numerical

examples with complex physical domains are provided to demonstrate the flexibility of our TCB-spline-based IGA method, the high quality of the parameterization, and the accuracy of the numerical solutions.

Hamiltonian system with singular Hamiltonians

金石（上海交通大学）

We consider Hamiltonian mechanical systems with potential functions admitting jump discontinuities. We first introduce the notion of solutions, which is consistent to the physical laws of reflection and refraction. Then we construct numerical schemes for such problems. In particular we will study symplectic, time-reversible, and high order integrators for such problems.

Preasymptotic error analysis of the HDG method for Helmholtz equation with large wave number

武海军（南京大学）

This paper addresses several aspects of the linear hybridizable discontinuous Galerkin method (HDG) for the Helmholtz equation with impedance boundary condition at high frequency. First, error estimates with explicit dependence on the wave number k for the HDG approximations to the exact solution u and its negative gradient $\mathbf{q}=-\nabla u$ are derived. It is shown that $k\Vert u-u_h\Vert_{L^2(\Omega)}+\Vert\mathbf{q}-\mathbf{q}_h\Vert_{L^2(\Omega)}=O(k^2h^2+k^4h^3)$ under the conditions that k^3h^2 is sufficiently small and that the penalty parameter $\tau\eqsim k$, where h is the mesh size. Note that the convergence order in $\bq_h$ is full and the pollution error is $O(k^4h^3)$, which improve the existent results. Secondly, by using a standard postprocessing procedure from the HDG method for elliptic problems, a piecewise quadratic function u_h^* is obtained so that $k\Vert u-u_h^*\Vert_{L^2(\Omega)}=O(k^3h^3+k^4h^3)$. Note that the postprocessing procedure improves only the interpolation error (from $O(k^2h^2)$ to $O(k^3h^3)$) but leaves the pollution error $O(k^4h^3)$ unchanged. Thirdly, a dispersion analysis and extensive numerical tests show that the pollution effect can be reduced greatly in 2D case by selecting appropriate penalty parameters.

H(curl curl)-conforming and H(grad curl)-conforming finite elements---beyond Nedelec

张智民（北京计算科学研究中心）

In his two ground breaking papers(1980 and 1986),Nedelec proposed H(curl)-conforming and H(div)-conforming fininte elements to solve second-order electromagnetic equations that contains the “curl” and “div” operators. It is more or less as the H^1-conforming elements (or C^0 elements) for second-order elliptic

equations that contain the $(grad)^2$ operator. As is well known in the finite element method literature, in order to solve 4th-order elliptic equations such as the bi-harmonic equation, H^2-conforming elements (or C^1-elements) were developed. Recent years, there have been some research in solving electromagnetic equations which involve $curl^4$ operator and $(curl grad)^2$ operators. Hence, construction of H(curl curl)-conforming and H(grad curl)-conforming elements becomes necessary. In this work, we report some recent development in this direction.

A primal Douglas-Rachford splitting method for inverse variational inequality problems

韩德仁（北京航空航天大学）

Inverse variational inequalities have broad applications in various disciplines, and some of them have very appealing structures. There are several algorithms (e.g., proximal point algorithms and projection-type algorithms) for solving the inverse variational inequalities in general settings, while few of them have fully exploited the special structures. In this talk, we present a class of inverse variational inequalities that has a separable structure and linear constraints, which has its root in spatial economic equilibrium problems. To design an efficient algorithm, we develop a primal Douglas-Rachform splitting method.

Riemannian Optimization: Proximal Gradient Methods

黄文（厦门大学）

In this presentation, we first introduce the Riemannian optimization problem and then briefly review the history and current state of Riemannian optimization algorithms. In particular, we focus on the proximal gradient method and generalize it to the Riemannian setting. It is shown that the global convergence is obtained under mild assumptions. The O(1/k) convergence rates are established for the method and its variant under more assumptions. Local convergence rate analysis is further given using Kurdyka-Lojasiewicz property. Moreover, we show that the restriction of a semialgebraic function onto the Stiefel manifold satisfies the Riemannian KL property, which covers for example the well-known sparse PCA problem.
Numerical experiments on random and synthetic data are conducted to test the performance of the proposed Riemannian proximal gradient methods.

Tailored finite point method for singular perturbation problems

黄忠亿（清华大学）

In this talk, we will first give a short review of our proposed method – tailored finite

point method (TFPM) for multiscale problems. Then we will show the applications of TFPM to singular perturbation problem (SPP). Especially, we will present the uniform error analysis on some kind of SPPs.

A Hybrid Phase Field Method for Fluid-Solid Structure Interactions in Viscous Fluids

王奇（南卡来罗娜大学）

We present a novel computational framework to numerically investigate fluid-solid structure interaction using phase field embedding, a hybrid, two-scale phase field modeling approach. Each solid structure immersed in the fluid matrix, grossly referred to as the particle in this paper, is represented by a volume preserving phase field. The motion of the particle is driven by the surrounding fluid velocity (passive particle) and its self-propelling velocity (active particle). A repulsive force exists between each pair of particles and between a particle and the boundary. The particle also exerts a drag force to the fluid proportional to its velocity. When the particle is a rigid body, its state is described by a zero velocity gradient tensor and a phase field that defines its profile. A thermodynamically consistent hydrodynamic model is then derived for the fluid-particle ensemble by the generalized Onsager principle. Structure-preserving numerical algorithms are developed for the thermodynamically consistent model. Numerical tests are carried out to verify the rate of convergence and some numerical examples are given to demonstrate the usefulness of the computational framework for simulating fluid-structure interactions for self-propelling active particles.

Higher order energy stable ETD based methods for gradient flows

王晓明（南方科技大学）

Many natural and engineering problems follow gradient flow structures in the sense that systems evolve to decrease certain energy. The dynamics of most of these gradient systems are complicated, and hence numerical methods are called for. There are several desirable features for numerical algorithms for gradient flows with long evolution process: 1. efficiency; 2. higher-order accuracy; and 3. long-time stability. We present a class of efficient higher-order energy stable variable step methods for a class of gradient flows based on the exponential time differencing (ETD) method combined with multi-step methods and interpolation. As a specific example, we present a third order ETD based scheme for thin film epitaxial growth model together

with numerical results establishing the convergence and stability of the scheme, and the ability of the scheme to capture long-time scaling properties of the system.

Solving fluid models using spectral methods and deep learning-based methods

毛志平（厦门大学）

In the first part of this talk I will introduce my research work on fractional phase-field/phase-field crystal modeling: analysis, properties, approximation, and pattern formation. In this part, I will first introduce a fractional Cahn-Hilliard model, which preserves mass and indeed reduces the energy. The well-posedness is established, and we show that the solution is uniformly bounded in the sense and other properties. Then I will introduce a fractional phase-field crystal (PFC) model which gives a markedly superior fit to experimental measurements of the structure factor than the classical PFC for a number of crystalline materials. The fractional PFC model retains the salient feature of the PFC model, and, in addition, provides better predictions for the grain boundary energy at larger values of the mismatch angles.

Recently, neural network-based deep learning methods, which are different from the classical numerical methods, have attracted lots of attention not only in the traditional artificial intelligence community but also the scientific computing community. In the second part of this talk, I will introduce my work on physics-informed neural networks (PINNs) and deep multi-scale multi-physics net (DeepMMnet) for high-speed flows. In particular, I shall solve the inverse problems of the shock wave problems in supersonic flow by using PINNs based on the information of density gradient and limited data of pressure and inflow conditions instead of using boundary conditions. Then I will infer the high-speed flow past a normal shock by using the DeepMMnet.

动理学方程的自然模型约化

李若（北京大学）

处理高维问题是来自于现实的需求，动理学方程是典型而传统的高维问题之一。我们以动理学方程为案例，以新的提法使得问题虽具有高维表象，但因其解流形的低维结构而获得低维的本质。以此为出发点，我们可以在流形上对动理学方程进行自然的模型约化，获得低维的逼近模型，并可以给出保持原方程特质需遵循的准则。我们试图将此抽象理论应用于惯性约束聚变中的辐射输运问题的模型约化，虽然其中仍有很大差距有待持续改进，但部分关键的因素已经可以有所借鉴。

Recent Progress in Numerical Homogenization: Theory and Numerics

明平兵（中国科学院数学与系统科学研究院）

In this talk we shall discuss two aspects of numerical homogenization: one is

developing fast algorithm for retrieving the effective matrix, the other is how to compute the local macroscale information. In particular, we shall propose a bybrid method that aims for both quantities simultaneously. Error estimates have been obtained without regularity assumptions, and a hierarchical of numerical examples with different complexity will be reported to demonstrate the accuracy and efficiency of the method. This is a joint work with Siqi Song.

Inference of RNA velocity in scRNA-seq data analysis

李铁军（北京大学）

The RNA velocity provides a new avenue to study the stemness and lineage of cells in development in scRNA-seq data analysis. Some promising extensions of it are proposed and the community is experiencing a fast developing period. It is of prime importance to revisit the whole process of RNA velocity analysis from the mathematical point of view, which will help to understand the rationale and drawbacks of different proposals. The current talk is devoted to this purpose. The overall analysis aims at providing a mathematical basis and new inference methods for the development of RNA velocity type methods in the future.

A robust multilevel preconditioner for the Helmholtz equation

许学军（同济大学/中国科学院数学与系统科学研究院）

In this talk, we shall present a robust multilevel preconditioner for the algebraic system resulting from the continuous interior penalty finite element method for the approximation of the Helmholtz equation. The key idea in this work is the replacement of traditional smoothers by the one level overlapping domain decomposition method on coarse grids. The proposed multilevel method then serves as a preconditioner in the outer GMRES iteration. Numerical results show that for fixed wave numbers, the convergence of our multilevel method is independent of the mesh size. Furthermore, the performance of the algorithm depends relatively mildly on the wave number. This is a joint work with Peipei Lu.

Efficient numerical schemes for flow in porous media and applications

陈黄鑫（厦门大学）

In this talk I will firstly introduce my research field in finite element method and its application such as local multigrid, stable numerical methods for high wave problems, efficient simulators for flow and transport in porous media. Then I will further introduce a recent work about an efficient threshold dynamics method for topology optimization for fluids modeled with the Stokes equation. We aim to minimize an objective energy function that consists of the dissipation power in the fluid and the

perimeter approximated by nonlocal energy subject to a fluid volume constraint and an incompressibility condition. A one-domain approach is applied to solve the problem in the whole domain and the minimization problem can be solved with an iterative scheme in which the Stokes problem is approached with a Brinkman problem. The total energy decaying property of the iterative algorithm can be obtained. The extension of applying the iterative thresholding method for topology optimization for the Navier-Stokes flow will also be introduced.

用带噪声的部分短期观测数据进行非线性动力系统的参数辨识的理论和算法
——以 Lorenz63 模型为例

程晋（复旦大学）

复杂非线性动力系统的参数辨识问题是一个理论上非常重要的问题，具有重要的实际背景和潜在的应用价值，也是大气科学和海洋科学等重要研究领域学者所关心的问题之一。在最近的研究中，我们考虑非线性动力系统的一个重要例子 Lorenz63 系统，这个系统是一个著名的混沌系统，微小的初值改变，经过一段时间的演变，会产生很大的差别。因为用反问题的一般方法处理会遇到很大的困难。基于我们提出的处理带有大的随机噪声数据的方法，我们提出了一种利用部分低维短期观测数据反演动力系统参数的新方法，并给出的相应的理论分析和误差估计。数值结果表明我们的算法具有较好的稳定性、精确性和有效性。

Data assimilation from a viewpoint of regularization theory

陆帅（复旦大学）

Inverse problems are ubiquitous in real applications. Understanding of algorithms for their solution has been greatly enhanced by a deep understanding of the linear inverse problem. In the applied communities ensemble-based filtering methods have recently been used to solve inverse problems by introducing an artificial (continous) dynamical system. This opens up the possibility of using a range of other filtering methods, such as 3DVAR, Kalman-Bucy filter (online) and 4DVAR (offline), to solve inverse problems, again by introducing an artificial dynamical system. The aim of this talk is to undertand these methods in the context of the regularization theory under the framework of linear inverse problems.

双曲型守恒律方程的熵稳定格式

汤华中（北京大学）

双曲型守恒律方程（组）为20世纪50年代兴起的一个研究领域，它是数学与力学之间的一个重要枢纽，在流体力学、空气动力学、天体物理、航空航天、国防等领域有重要的应用。熵条件在双曲型守恒律的理论和数值方法的研究中扮演了重

要角色,例如它可保证标量方程的解的唯一性和关于初始数据的稳定性等。
本报告介绍我们近期关于双曲型守恒律方程的熵稳定格式的一些结果：对于给定的熵对，格式所满足的熵条件或其中的数值熵通量不是唯一的；Tadmor的充分条件可以唯一地确定标量方程的熵守恒通量，但不能唯一确定方程组的熵守恒通量；可以给出方程组的空间一阶精度的熵守恒格式；探讨在熵守恒通量上添加数值粘性得到的显式熵稳定格式需要满足的条件及常见的时间离散的影响。本报告还将介绍狭义相对论(磁)流体力学方程组的熵稳定格式的得到。

High-order finite element methods for time-moving interface problems

郑伟英（中国科学院数学与系统科学研究院）

We develop high-order numerical methods for solving advection-diffusion equation and the Oseen equation (linearized Navier-Stokes equations) with time-moving interfaces. The methods are based on unfitted finite element discretization on fixed Eulerian meshes of the domain. The locus of the moving interface is tracked by high-order cubic MARS algorithms. We present thorough error estimates for the methods (orders $2 \le k \le 4$) by taking full consideration of all errors from interface-tracking, spatial discretization, and temporal integration. Numerical experiments demonstrate the optimal convergence of the methods for $k = 3$ and 4.