Titles and Abstracts

1. Xiaochuan Cai, University of Colorado at Boulder, USA
   Title: Nonlinear preconditioned Newton's methods for nonlinear PDES
   Abstract: Inexact Newton is a popular technique for solving large sparse nonlinear system of equations. In this talk, we discuss some recently developed versions of preconditioned inexact Newton methods which are more robust than the classical version when the nonlinearities in the system are not balanced. The preconditioners are constructed using a combination of some domain decomposition methods and nonlinear elimination methods. We show numerically that the preconditioned inexact Newton methods perform well for solving some nonlinearly difficult problems and on machines with large number of processors.

2. Xiaobing Feng, University of Tennessee, Knoxville, USA
   Title: Semi-Lagrangian methods for fully nonlinear Monge-Ampere type PDEs
   Abstract: In this talk I shall present a new approach for developing convergent semi-Lagrangian (and finite difference) methods for approximating viscosity solutions of second order fully nonlinear Monge-Ampere (MA) type equations on general triangular and rectangular grids. This is done by first establishing an equivalent (in the viscosity sense) Hamilton-Jacobi-Bellman (HJB) reformulation of the MA equation and then designing monotone semi-Lagrangian methods for the resulting HJB equation. The new approach opens a door to utilize the wealthy numerical techniques for HJB-type equations to solve MA-type equations, as a result, it bridges the gap between advances on numerical methods for the HJB-type and for the MA-type second order fully nonlinear PDEs. This talk is based on a joint work with Max Jensen of University of Sussex, UK.

3. Jan Hesthaven, EPFL, Switzerland
   Title: On the use of low rank approximations for the construction of efficient preconditioners for FEM matrices
   Abstract: During the last decade, substantial advances have enabled the efficient construction and application of low-rank approximations to large matrices. Among many examples, matrices arising as discretizations of compact operators such a boundary integral operators, have been shown to enable very efficient compression, thus allowing for both compression and solution in linear complexity. However, for matrices arising from unbounded operators, e.g., finite element discretizations of differential operators, progress has been slower and is often more challenging. In this talk, we shall discuss two different attempts to take advantage of low rank approximations to develop efficient preconditioners for a variety of problems arising as (hp-)finite element discretizations of linear problems, including highly anisotropic problems and the wave Helmholtz problem and, time permitting, for the use in the context of topology optimization.

4. Jun Hu, Peking University, China

Title: Mixed finite elements for linear elasticity problems and applications

Abstract: We developed a new framework to design and analyze the mixed FEM for elasticity problems by establishing the following three main results:
(1) A crucial structure of the discrete stress space: on simplicial grids, the discrete stress space can be selected as the symmetric matrix-valued Lagrange element space, enriched by a symmetric matrix-valued polynomial H(div) bubble function space on each simplex; a corresponding choice applies to product grids.
(2) Two basic algebraic results: (1) on each simplex, the symmetric matrices of rank one produced by the tensor products of the unit tangent vectors of the (n+1)n/2 edges of the simplex, form a basis of the space of the symmetric matrices; (2) on each simplex, the divergence space of the above H(div) bubble function space is equal to the orthogonal complement space of the rigid motion space with respect to the corresponding discrete displacement space (A similar result holds on a macroelement for the product grids).
These define a two-step stability analysis which is new and different from the classic one in literature. As a result, on both simplicial and product grids, we were able to define he first families of both symmetric and optimal mixed elements with polynomial shape functions in any space dimension. Furthermore, the discrete stress space has a simple basis which essentially consists of symmetric matrix-valued Lagrange element basis functions.
On the simplicial grids, in order to avoid enriching face-bubble functions of piecewise polynomials or nonconforming face-bubble spaces for each n-1 dimensional simplex for the cases, we also designed two classes of stabilized mixed finite element methods. In the first class of elements, we use and to approximate the stress and displacement spaces, respectively, for, and employ a stabilization technique in terms of the jump of the discrete displacement over the faces of the triangulation under consideration; in the second class of elements, we use to approximate the displacement space for, and adopt the stabilization technique suggested by Brezzi, Fortin and Marini.
As applications, we extended these schemes to the Reissner–Mindlin plate problem and constructed new robust finite element methods for it.

5. Ronald H.W. Hoppe, Univ. of Houston, USA & Univ. of Augsburg, Germany
Title: C^0 interior penalty discontinuous Galerkin approximations of a sixth order Cahn-Hilliard equation modeling microemulsification processes

Abstract: Microemulsions can be modeled by an initial-boundary value problem for a sixth order Cahn-Hilliard equation. Introducing the chemical potential as a dual variable, a Ciarlet-Raviart type mixed formulation yields a system consisting of a linear second order evolutionary equation and a nonlinear fourth order equation. The spatial discretization is done by a C^0 Interior Penalty Discontinuous Galerkin (C^0IPDG) approximation with respect to a geometrically conforming simplicial triangulation of the computational domain. The DG trial spaces are constructed by C^0 conforming Lagrangian finite elements of polynomial degree . For the semidiscretized problem we derive quasi-optimal a priori error estimates

for the global discretization error both in the primal and the dual variable. The semidiscretized problem represents an index 1 Differential Algebraic Equation (DAE) which is further discretized in time by an s-stage Diagonally Implicit Runge-Kutta (DIRK) method of order. The resulting parameter dependent nonlinear algebraic system is numerically solved by a predictor-corrector continuation strategy with constant continuation as a predictor and Newton's method as a corrector featuring an adaptive choice of the continuation parameter. Numerical results show the formation of microemulsions in an oil/water system and illustrate the performance of the suggested approach.

6. Michal Krizek, Institute of Mathematics Academy of Sciences, Czech
   Title: On angle conditions in the finite element method
   Abstract: Angle conditions play an important role in the analysis of the finite element method. They enable us to derive the optimal interpolation order and prove convergence of this method, to derive various a posteriori error estimates, to perform regular mesh refinements, etc. In 1968, Milos Zlamal introduced the minimum angle condition for triangular elements. From that time onward many other useful geometric angle conditions on the shape of elements appeared. In this lecture, we give a survey of various generalizations of the minimum and also maximum angle condition in the finite element method and present some of their applications.

7. Buyang Li, Nanjing University, China
   Title: Time-discrete maximal parabolic regularity
   Abstract: We show that for a parabolic problem with maximal-regularity (for), the time discretization with a linear multistep method or Runge–Kutta method also has maximal -regularity uniformly in the stepsize if the method is A-stable. In particular, the implicit Euler method, the Crank–Nicolson method, the second-order backward difference formula (BDF), and the Radau IIA and Gauss Runge–Kutta methods of all orders preserve maximal regularity. The proof uses Weis' characterization of maximal-regularity in terms of the R-boundedness of the resolvent operator, a discrete operator-valued Fourier multiplier theorem by Blunck, and generating function techniques that have been familiar in the stability analysis of time discretization methods since the work of Dahlquist. The A(α)-stable higher-order BDF methods have maximal -regularity under an R-boundedness condition in a larger sector. As an illustration of the use of maximal regularity in the error analysis of discretized nonlinear parabolic equations, it is shown how error bounds are obtained without using any growth condition on the nonlinearity. Extension to elliptic operators with time-dependent coefficients and fully discrete finite element methods are also given.

8. Haiqing Lin, Beijing Computational Science Research Center
   Title: Simulation of optical properties of nanostructures
   Abstract: In this talk, I will report some of our recent studies on optical properties

of nanostructures by computer simulation combined with experiments. Results presented including (i) Universal scaling and Fano resonance in the plasmon coupled gold nanorods; (ii) Observation of two kinds Fano resonances in metal–dielectric core–shell nanoparticle clusters and directional light scattering; and (iii) Spectral tuning by nanoantenna-sandwiched graphene. Quantum size effects will also be discussed.

9. Huiyuan Li, Institute of Software Chinese Academy of Sciences, China
   Title: Efficient spectral and spectral element methods for eigenvalue problems of Schrődinger Equations with an Inverse Square Potential
   Abstract: In this talk, we study numerical approximation of eigenvalue problems of the Schrődinger operator . There are three stages in our investigation: We start from a ball of any dimension, in which case the exact solution in the radial direction can be expressed by the Bessel functions of fractional degrees. This knowledge helps us to design two novel spectral methods by modifying polynomial basis to fit singularities of eigen-functions. At the stage two, we move to circular sectors in the two dimensional setting. Again the radial direction can be expressed by the Bessel functions of fractional degrees. Only in the tangential direction some modifications are needed from the stage one. At the final stage, we extend the idea to arbitrary polygonal domains. We propose a mortar spectral element approach: a polygonal domain is decomposed into several sub-domains with each corner including the origin covered by a circular sector, in which origin and corner singularities are handled similarly as in the stage two, and rest domains are either a standard quadrilateral/triangle or a quadrilateral/triangle with a circular edge, in which traditional polynomial based spectral method is applied. All sub-domains are linked by mortar elements (note that we may have hanging nodes). In all three stages, exponential accuracy are achieved. Numerical experience indicate that our new method is superior to standard polynomial based spectral (or spectral element) method and h-p adaptive method. Our study offers a new and effective way to handle eigenvalue problems of the Schrődinger operator including the Laplacian operator on polygonal domains with re-entrant corners.
   This is joint work with Zhimin Zhang, Beijing Computational Science Research Center and Wayne State University.

10. Jichun Li, University of Nevada Las Vegas, USA
    Title: Finite element analysis and application for a nonlinear diffusion model in image denoising
    Abstract: The stability analysis and error estimates are presented for a nonlinear diffusion model, which appears in image denoising and solved by a fully discrete time Galerkin method with k-th order conforming finite element spaces. Numerical experiments are provided with denoising several grayscale noisy images by our Galerkin method on bilinear finite elements.

11. Tzon-Tzer Lu, National Sun Yat-sen University, China
Title: A modified Adomian decomposition method with integrating factor
Abstract: We propose a new Adomian decomposition method by using integrating factor. It can solve nonlinear ordinary differential equations of first and second orders where the traditional one fails. A typical example is the Emden–Fowler equation. Nonlinear models are solved by this method to get more reliable and efficient numerical results. Computing experiments obtained from testing our linear and nonlinear problems are far more accurate than those from existing methods. We will also present a complete error analysis with a convergence criterion for this method.

12. Zhonghua Qiao, The Hong Kong Polytechnic University, Hong Kong
Title: Large time-stepping methods for a molecular beam epitaxy growth model
Abstract: Recent results in the literature provide computational evidence that stabilized semi-implicit time-stepping method can efficiently simulate phase field problems. In this work, we will present several semi-implicit time-stepping schemes to solve a molecular beam epitaxy model without slope selection. Energy stability will be proved. Numerical simulations for coarsening dynamics will be carried out with small diffusion parameters. The $t^{1/2}$ growth law for surface roughness, the $t^{1/4}$ growth law for mound width and the $-\ln(t)$ decay law for the energy will be recovered.

13. Hans-Grg Roos, TU Dresden, Germany
Title: Balanced error estimates for finite element methods solving singularly perturbed problems
Abstract: Error estimates for finite element methods applied to singularly perturbed problems are in general proved in norms related to the energy norm, i.e., in norms containing semi-norms weighted with some powers of the singular perturbation parameter. If these powers correctly reflect the layer behavior, we call the norm balanced. For second order convection-diffusion problems the energy norm is balanced if only exponential boundary layers exist. For reaction-diffusion problems, however, the energy norm is not balanced.
The first balanced error estimate for a second order reaction-diffusion problem was presented by Lin and Stynes [4] using a first order system least squares (FOSLS) mixed method. Later it was proved [7] that the standard Galerkin finite element method on a Shishkin mesh also allows an error estimate in a balanced norm, moreover, Roos and Schopf analysed a C^0 interior penalty method with better stability properties than standard Galerkin. See also [6]. Recently, Melenk and Xenophontos analyzed the hp-FEM on spectral boundary layer meshes in a balanced norm [5].
We shall prove that a direct mixed method (instead the more complicated least-squares approach from [4]), equivalent to some nonconforming method, also

allows balanced error estimates. Remark that Li and Wheeler [3] analyzed the method in the energy norm on so called A-meshes, simpler to analyze than S-meshes. Moreover, we discuss extensions of the result to some nonlinear and some fourth-order problems [2].

For convection-diffusion problems with two different layers it is more complicated to prove balanced error estimates, see [1], and it is open to prove such a result for the Galerkin finite element method. Other open problems include problems with two small parameters, systems of reaction-diffusion problems with several small parameters and the discontinuous Galerkin method for fourth-order problems.

14. Dongyang Shi, Zhengzhou University, China

Title: A new error estimate of Crank-Nicolson Galerkin FEM for Maxwell's equations with nonlinear conductivity

Abstract: In this paper, we study a linearized Crank-Nicolson Finite Element Method for Maxwell's equations with nonlinear conductivity, The optimal L2 norm error estimate is provided. The main advantages show that the error is split into two parts, the temporal error and the spatial error. Here we employ the result that the numerical solution can be bounded in L_\infinity norm by an inverse inequality unconditional duo to the time step independent. To verify our theoretical analysis, numerical examples in both thransverse electric(TE) case and the transverse magnetic (TM) case are presented.

15. Ian H. Sloan, The University of New South Wales, Australia

Title: PDE with random coefficients–a nonlinear high-dimensional problem

Abstract: This talk describes recent computational developments in partial differential equations with random coefficients treated as a nonlinear high-dimensional problem. The prototype of such problems is the underground flow of water or oil through a porous medium, with the permeability of the material treated as a random field. (The stochastic dimension of the problem is high if the random field needs a large number of random variables for its effective description.). There are many approaches to the problem, ranging from the polynomial chaos method initiated by Norbert Wiener to the Monte Carlo and (of particular interest to my group) Quasi-Monte Carlo methods. In recent years there have been significant progress in the development and analysis of algorithms in these areas.

16. Jie Shen, Xiamen University, China & Purdue University, USA

Title: Efficient spectral methods for a class of fractional PDEs

Abstract: We shall present some recent work on spectral approximations for a class of fractional PDEs (FPDEs), including FPDEs with two-sided fractional derivatives (particular Riesz derivatives) and FPDEs in multi-dimension.

17. Li-Yeng Sung, Louisiana State University, USA

Title: C^0 finite element methods for two nonlinear elliptic PDEs

Abstract: We will present a unified approach to the construction and analysis of C^0 finite element methods for the von Krmn equations and the Monge-Ampre equation.
This is based on joint work with S.C. Brenner, T. Gudi, M. Neilan and A. Reiser.

18. Martin Stynes, University College Cork, Ireland
Title: Stabilised approximation of interior-layer solutions of a singularly perturbed semilinear reaction-diffusion problem
Abstract: A semilinear reaction-diffusion two-point boundary value problem, whose second-order derivative is multiplied by a small positive parameter ε^2, is considered. It can have multiple solutions. The numerical computation of solutions having interior transition layers is analyzed. It is demonstrated that the accurate computation of such solutions is exceptionally difficult.
To address this difficulty, we propose an artificial-diffusion stabilization. For both standard and stabilised finite difference methods on suitable Shishkin meshes, we prove existence and investigate the accuracy of computed solutions by constructing discrete sub- and super-solutions. Convergence results are deduced that depend on the relative sizes of ε and N, where N is the number of mesh intervals. Numerical experiments are given in support of these theoretical results. Practical issues in using Newton's method to compute a discrete solution are discussed.
This is joint work with Natalia Kopteva, Department of Mathematics and Statistics, University of Limerick, Ireland.

19. Lutz Tobiska, Otto University at Magdeburg, Germany
Title: An ALE-FEM of higher order for flows with surfactants
Abstract: The convective transport of surfactants induced by the flow field generates a local accumulation resulting in a non-uniform concentration of surfactants at the liquid-fluid-interface. The appearing Marangoni forces may lead to a destabilization of the interface with essential consequences for the flow structure. This is a complex process whose tailored use in applications requires a fundamental understanding of the mutual interplay.
We propose a finite element method for the flow of two immiscible incompressible fluids in the presence of surfactants in a bounded domain $\Omega \subset \mathrm{R}^d, d = 2,3$. We assume that a liquid droplet filling $\Omega_1(t)$ is completely surrounded by another liquid filling the domain $\Omega_2(t) = \Omega \backslash \Omega 1(t)$, . The distribution of the surfactant on the interface Γ_F (t) = influences the surface tension and thus the dynamic of the flow. The mathematical model consists of the time-dependent incompressible Navier-Stokes equations in each phase completed by the initial condition

$$\Omega(0) = \Omega_0,$$

the kinematic and force balancing conditions

$$\mathbf{w} \cdot \mathbf{n} = \mathbf{u} \cdot \mathbf{n}, \quad [\mathbf{u}] = \mathbf{0}, \qquad [\mathrm{S}(\mathbf{u}, p)] \cdot \mathbf{n} = \sigma(c_\Gamma)\boldsymbol{K} + \nabla_\Gamma \sigma(c_\Gamma) \qquad \text{on } \Gamma_F \text{ (t)}.$$

On the fixed (in time) boundary $\partial\Omega$ we impose homogeneous Dirichlet type boundary conditions. The stress tensor $S_k(\mathbf{u}, p)$ and the velocity deformation tensor $D(\mathbf{u})$ are given by

$$S_k(\mathbf{u}, p) = 2\mu_k D(\mathbf{u}) - pI, \qquad D(u) =(\nabla\mathbf{u} + \nabla\mathbf{u}^T) , k = 1, 2.$$

Here, $\mathbf{u}$ is the fluid velocity, p is the pressure, ρ_k and μ_k are the density and dynamic viscosity of the associated fluid phases, $\mathbf{w}$ on Γ_F (t) is the interface velocity and K is the sum of principal curvatures. Further, $\mathbf{n}$ denote the unit outward vector of $\Omega_1(t)$ on Γ_F (t), I the identity tensor, $[\cdot]$ denotes the jump across the interface Γ_F (t), c_Γ the surfactant concentration at the interface and $\sigma(c_\Gamma)$ the surface tension coefficient depending on c_Γ.

It remains to add equations describing the surfactant transport. Let us assume that the surfactant is insoluble in $\Omega_1(t)$ but soluble in $\Omega_2(t)$. For the transport in the bulk phase we have

$$C_t + \mathbf{u} \cdot C = \nabla \cdot D_C\nabla C \qquad \text{in } \Omega_2(t) \times (0, T],$$

completed by the initial and boundary conditions

$= C_0$ in $\Omega_2(0)$, $\mathbf{n} \cdot D_C\nabla C = -S(C, c_\Gamma)$ on Γ_F (t), $\mathbf{n} \cdot D_C\nabla C = 0$ on $\partial\Omega$.

Here, D_C is the diffusive coefficient of the outer phase surfactant concentration C.

The source term $S(C, C_\Gamma)$ and the surface tension coefficient $\sigma(C_\Gamma)$ are given by

$$S(C, c_\Gamma) = k_a C(- c_\Gamma) - k_d c_\Gamma, \qquad \sigma(c_\Gamma)= \sigma_0$$

where k_a and k_d are adsorption and desorption coefficients and E denotes the surface elasticity. The surfactant concentration c_Γ on Γ_F is described by the initial condition and the surface pde

$$(c_\Gamma)_t + \mathbf{u} \cdot \nabla_\Gamma c_\Gamma + (\nabla_\Gamma \cdot \mathbf{u})c_\Gamma = \nabla_\Gamma \cdot (D_s\nabla_\Gamma c_\Gamma) + S(C, c_\Gamma)$$

with the diffusive coefficient Ds.

The finite element method is based on the ALE (arbitrary Langrangian-Eulerian) method [1, 2] on a moving, interface aligned grid. This interface tracking method allows for an accurate incorporation of surface tension and Marangoni forces and and accurate handling of the surface equation of convection diffusion type. The coupled bulk-surface pde for the surfactant concentrations is solved following the approaches in [3, 4] but with higher order isoparametric elements. Numerical test examples show the potential of the proposed discretization technique.

20. Takuya Tsuchiya, Ehemi University, Japan

Title: A priori error estimates of the Lagrange interpolation on triangles and tetrahedrons.

Abstract: At first, we consider the error analysis of Lagrange interpolation on right triangles. Babuska-Aziz showed that even if a right triangle is squeezed perpendicularly, the interpolation error of first order Lagrange interpolation will not be deteriorated. We extend their result to higher order Lagrange interpolation. To this end, difference quotients of functions with two variables are introduced.

Secondly, using the obtained estimates, we consider the Lagrange interpolation on general triangles and obtain an error estimation in which the error is bounded in term of the diameter and circumradius of triangles.
Thirdly, we show that our first method is applied to the case of “right” tetrahedrons. That is, we show that squeezing the reference tetrahedrons perpendicularly does not deteriorate the approximation properties of the Lagrange interpolation.

21. Haijun Wu, Nanjing University, China
Title: Finite element method for nonlinear Helmholtz equation with high wave number
Abstract: A nonlinear Helmholtz equation (NLH) with impedance boundary condition at high frequency is considered. Stability estimates with explicit dependence on the wave number for the NLH in 2 and 3 dimensions are proved. Preasymptotic error estimates are proved for the linear finite element discretizations.

22. Qi Wang, University of South Carolina, Columbia, USA
Title: Numerical methods for dissipative hydrodynamic systems
Abstract: Hydrodynamic systems derived using the generalized Onsager's principle possess not only the variational structure, but also the dissipative property known as the energy dissipation law. A systematic approach can be taken to design numerical schemes to mimic the system's property in numerical approximations. In this talk, I will discuss the strategy and show by a few examples how to construct numerical schemes that respect the energy dissipation law using finite difference methods. I will then give a few numerical examples using the numerical methods simulating multiphase complex fluid flows.

23. Chuanju Xu, Xiamen University, China
Title: Numerical investigation of complex flows with abnormal diffusion
Abstract: In this talk, we will present efficient methods for numerical simulations of complex flows with abnormal diffusion.
The main ingredients of the talk include:
1) Spectral methods for space fractional elliptic equations;
2) A stable direction splitting schema for the fractional diffusion equation in high dimension;
3) Applications of the above methods, including some two-phase flows governed by the fractional Allen-Cahn equation.

24. Aihui Zhou, Chinese Academy of Sciences, China
Title: A parallel orbital-updating approach for electronic structure calculations
Abstract: In this presentation, we will show a parallel orbital-updating approach for solving the single-particle nonlinear eigenvalue problems as well as the associated energy minimization problems, which model electronic structures. This

approach is based on our understanding for the single-particle equations of independent particles that move in an effective potential. With this new approach, the solution of the single-particle equation is reduced to some solutions of independent linear algebraic systems and a small scale algebraic problem, for instance. It is demonstrated by our numerical experiments that this approach is quite efficient for electronic structure calculations for a class of molecular systems.
This presentation is based on some joint work with Xiaoying Dai, Xingao Gong, Zhuang Liu, Xin Zhang, and Jinwei Zhu.

25. Chengjian Zhang, Huazhong University of Science and Technology, China
    Title: A compact multi-splitting scheme for nonlinear delay convection-reaction-diffusion equations
    Abstract: This talk deals with the effective computation for nonlinear delay convection-reaction-diffusion equations. A new linearized compact multi-splitting scheme is presented. Firstly, with an exponential transformation, we convert the equations into a class of delay reaction-diffusion equations. Then, the latter are discretized by compact difference method in space and multi-splitting scheme in time. The error estimation of the computational scheme is derived under the sense of -norm. To improve the accuracy in temporal direction, a Richardson extrapolation technique is utilized. Finally, some numerical examples are presented to illustrate the computational effectiveness of the scheme and the competitiveness with other numerical schemes.

26. Hongkai Zhao, University of California at Irvine, USA
    Title: Convergence analysis of the fast sweeping method for static convex Hamilton-Jacobi Equations
    Abstract: We study the convergence of an efficient iterative method, the fast sweeping method (FSM), for numerically solving static convex Hamilton-Jacobi equations. We illustrate that the combination of a contraction property of monotone upwind schemes with proper orderings can provide a fast convergence for iterative methods. We show that this mechanism produces different behavior from that for elliptic problems as the mesh is refined.
    This is a joint work with Songting Luo.

27. Jun Zou, The Chinese University of Hong Kong, Hong Kong
    Title: Adaptive finite element methods and their convergence for some ill-posed inverse problems
    Abstract: In this talk we shall present some a posteriori error estimates of finite element methods for solving several ill-posed inverse problems, including the electrical impedance tomography, inverse Robin problem and flux reconstruction problem. Based on these a posteriori error estimates, adaptive finite element algorithms are formulated and their convergence are established. Then numerical experiments are presented to demonstrate their effectiveness and efficiencies for

solving ill-posed inverse problems.

This is a joint work with Bangti Jin (University College London) and Yifeng Xu (Shanghai Normal University). The work was substantially supported by Hong Kong RGC grants (projects 14306814 and 405513).