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Neurovascular coupling and its role in spreading of cortical depression and cardiovascular responses to the umbilical cord occlusion in fetal sheep

Dr. Bofu Wang

This study mainly focused on the bioconvection observed in a two dimensional chamber containing suspension aerotactic bacteria. The upper surface of the container is open to the atmosphere. The bioconvection is caused by swimming bacteria and the motion of fluid flow can be modeled with a coupled chemotaxis-fluid systems. The bacterial cells swim up along the direction of oxygen gradient, and they consume oxygen. This lead to a cell concentration near the water surface. When the vertical cell gradient becomes large enough, an overturning instability occurs which subsequently develops into a finger pattern. The motion of bacterial cells and the distribution of oxygen are governed by the conservation equations for the density and oxygen concentration, respectively. The driven fluid flow is governed by incompressible Navier-Stokes equations. In this talk, linear stability of stratified cells in quiescent flow is studied first in a finite 2D chamber. The finite length effect and dependence of the linear stability on physical parameters are evaluated. Specifically, the role of chemotaxis sensitivity and chemotaxis production are addressed. Furthermore, a high resolution numerical simulation was performed. The onset of flow instability to numerically stable flow is simulated.

For material related to this talk, click here.

Neurovascular coupling and its role in spreading of cortical depression and cardiovascular responses to the umbilical cord occlusion in fetal sheep

Prof. Huaxiong Huang

Neurovascular coupling is the interactive response between neural activities and changes in blood circulation. In this talk, we discuss two problems where neurovascular coupling plays an important role.

Cortical spread depression (CSD) is implicated as the underlying mechanism for migraine (with aura). It is also related to stroke and traumatic brain injury. In this talk, we present a model that couples ion transport with cerebral blood flow. We show that during CSD, metabolic demands of the cortex exceed the physiological limits placed on oxygen delivery, regardless of vascular constriction or dilation. On the other hand, vasoconstriction and vasodilation play important roles in determining the susceptibility of the cortical tissue to CSD and its recovery. This study incorporates relevant perfusion and metabolic factors into a model of CSD, and in doing so, helps to explain this phenomenon in vitro and in vivo.

One of the main issues during childbirth is the possibility of developing asphyxia in the fetus caused by umbilical cord occlusion (UCO). The occlusion increases the risk of hypoxicischemic brain injury due to oxygen deficiency and decreasing in pH (i.e. worsening acidity level). Therefore, it is important to understand the basic mechanisms involved under such conditions and find a non-invasive technique to detect asphyxia. In this talk we present a mathematical model for the cardiovascular responses to the umbilical cord occlusion in fetal sheep. The main objectives of our modeling exercise are to predict CO_2 accumulation in the fetus and its possible connection to fetal heart rate, a quantity easy to measure and is known to vary under such conditions.

For material related to this talk, click here.

Development of mathematical and computational models for the thermal ablation of liver tumor by high-intensity focused ultrasound

Dr. Maxim Solovchuk

High intensity focused ultrasound (HIFU) is a rapidly developing medical technology for a non-invasive tumor ablation therapy in various organs of the body. One of the major objectives of this study is to achieve a virtually complete necrosis of tumors close to major blood vessels and to avoid blood vessel damage. The present study is aimed at predicting liver tumor temperature during HIFU thermal ablation in a patient-specific liver geometry. The differential equation model comprises the nonlinear Westervelt equation and bioheat equations in liver and blood vessels. The nonlinear hemodynamic equations with the effects of convected cooling and acoustic streaming are also taken into account. Simulation of Westervelt equation in three-dimensional geometry in time domain requires a prohibitively large amount of computer resource. Hence, we developed a sixth-order accurate acoustic scheme for effectively solving the nonlinear wave equation.

For a large propagation distance the very important task is to retain the exact group velocity as much as possible. In the present work the discretization method is chosen to optimize the numerical dispersion relation equation for Westervelt equation. We develop a scheme with numerical group velocity that agrees well with the exact group velocity for the Westervelt equation. We found from this three-dimensional three-field coupling study that in large blood vessel both convective cooling and acoustic streaming may change the temperature considerably near blood vessel. More precisely, acoustic streaming velocity magnitude can be several times larger than the blood vessel velocity. The experience learned from the current work can be useful to construct a surgical planning platform under current development.

Models and numerical methods for geophysical flows. Application to sustainable energies

Prof. Jacques Sainte-Marie

The modeling, the analysis and the simulation of geophysical flows are complex and challenging topics. The difficulties arising in gravity driven flow studies are threefold.

The models and equations encountered in fluid mechanics (typically the free surface Navier-Stokes equations) are complex to analyze and solve.

The considered phenomena often take place over large domains with very heterogeneous length scales (size of the domain, mean depth, wave length. . .)and different time periods e.g. coastal erosion, propagation of a tsunami,. . .

Last but not least, these problems are multi-physics with strong couplings and nonlinearities.

During this presentation, we propose models approximating the free surface incompressible Euler equations and relaxing the classical shallow water assumptions. The smallness of dissipative effects in geophysical models which therefore generate singular solutions and instabilities reinforces the need of robust numerical methods. Even if the considered models do not strictly belong to the family of hyperbolic systems, they exhibit hyperbolic features and the analysis and discretization techniques we propose have connections with those used for hyperbolic conservation laws (e.g. kinetic description).

Several applications concerning hazardous flows and sustainable energies are given.

For material related to this talk, click here.

Long time asymptotics for some integrable nonlinear waves

Dr. Chueh-Hsin Chang

In the theory of integrable systems, long time asymptotics is an important topics and relates to many mathematical theories. Many nonlinear wave equations already enlighen their asymptotics by the Riemann-Hilbert problems. In this talk, we focus on some particular wave models subject to specified initial data. Under these data the asymptotics profiles and their Painlev'e transcendents can be revisited numerically in a more realized way.

For material related to this talk, click here.

Modified Poisson-Nerest-Planck systems

Prof. Tai-Chia Lin

In order to describe the dynamics of crowded ions (charged particles), we use an energetic variational approach to derive a modified Poisson-Nerest-Planck (PNP) system which includes an extra dissipation due to the effective velocity differences between ion species. Such a system has more complicated nonlinearities than the original PNP system but with the same equilibrium states. Using Galerkin's method and Schauder's fixed-point theorem, we develop a local existence theorem of classical solutions for the modified PNP system. Different dynamics (but same equilibrium states) between the original and modified PNP systems can be represented by numerical simulations using finite element method techniques. This is a joint work with Chia-Yu Hsieh, YunKyong Hyon, Hijin Lee and Chun Liu.

Two-phase numerical simulation of sediment suspension problems and its implications to environmental flow modeling

Prof. Yi-Ju Chou

This talk presents two-way coupled two-phase models to simulate suspensions of fine particles of environmental and geophysical relevance. Progress and challenges to model two-phase solid-liquid systems are discussed. A series of numerical experiments on the particle-induced Rayleigh-Taylor instability is carried out to investigate a bulk mixing attributable to the initial concentrations. This study identified deviations in the current two-phase simulation from the conventional single-phase approximations. The results indicate that the deviations are caused by non-equilibrium particle inertia and mixture incompressibility. In the dilute suspension, it is found that the non-equilibrium particle inertia enhances vertical motion resulting from the convective instability. As initial concentration increases, the influence of mixture incompressibility becomes more pronounced and is able to induce a significant suppression of vertical motions, which in turn decreases the efficiency of bulk mixing. Implications of the present study to the models of geophysical and environmental flows are also discussed.

For material related to this talk, click here.

High-order conservative asymptotic-preserving finite difference schemes for solving Boltzmann-BGK model equation

Prof. Jaw-Yen Yang

A direct solver of Botlzmann-BGK (BBGK) model equation in phase space for problems in rarefied gas dynamics requires the simultaneous discretization of the problem in both physical space and velocity space. However, traditional direct solver for BBGK are computationally demanding when the relaxation time is small, even for one or two-dimensional cases. Based on the framework of Yang and Huang [1] and adopting the asymptotic-preserving strategy of Jin [3], we introduce a class of Asymptotic-Preserving (AP) formulation to the reduced distribution function strategy that enforces the conservation properties of Boltzmann collision operator, as proposed by [2]. The resulting scheme can be viewed as an implicit-explicit (IMEX) discretization, similar to [4]. The velocity space is discretized by the discrete ordinate method and both Gauss-Hermite and equally spaced Newton-Cotes quadrature rules are employed. The physical space is evolved explicitly by using traditional high order finite diff

erence schemes such as weighted essentially non-oscillatory schemes (WENO)[5], and for the time integration we take advantage of the semi-implicit nature of the IMEX Runge-Kutta strategy or the new Additive Runge-Kutta (ARK) schemes [6].

From our numerical experience the resulting formulations are stable, as bigger time step can be used and the discretization is not restrained by the relaxation time, and correct convergence of the solution can be achieved even when using minimum number of discrete velocity points. In this work, both initial and boundary value problems, mainly on shocks interactions with Maxwellian type (di
ffusive and/or reflective) boundaries, are investigated. Up to seventh order accurate WENO4 (r = 4) results are illustrated.

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Singular value decompositions for single-curl operators in three-dimensional Maxwell's equations for complex media

Prof. Tsung-Ming Huang

This article focuses on solving the generalized eigenvalue problems(GEP) arising in the source-free Maxwell equation with magnetoelectric coupling effects that models three-dimensional complex media. The goal is to compute the smallest positive eigenvalues, and the main challenge is that the coefficient matrix in the discrete Maxwell equation is indefinite and degenerate. To overcome this difficulty, we derive a singular value decomposition(SVD) of the discrete single-curl operator and then explicitly express the basis of the invariant subspace corresponding to the nonzero eigenvalues of the GEP. Consequently, we reduce the GEP to a null space free standard eigenvalue problem (NFSEP) that contains only the nonzero (complex) eigenvalues of the GEP and can be solved by the shift-and-invert Arnoldi method without being disturbed by the null space. Furthermore, the basis of the eigendecomposition is chosen carefully so that we can apply fast Fourier transformation (FFT)-based matrix vector multiplication to solve the embedded linear systems efficiently by an iterative method. For chiral and pseudochiral complex media, which are of great interest in magnetoelectric applications, the NFSEP can be further transformed to a null space free generalized eigenvalue problem whose coefficient matrices are Hermitian and Hermitian positive definite (HHPD-NFGEP).This HHPD-NFGEP can be solved by using the invert Lanczos method without shifting. Furthermore, the embedded linear system can be solved efficiently by using the conjugate gradient method without preconditioning and the FFT-based matrix vector multiplications. Numerical results are presented to demonstrate the efficiency of the proposed methods.

For material related to this talk, click here.

Scalable domain decomposition preconditioners in FreeFem++

Prof. Frédéric Hecht

Domain decomposition methods are, alongside multigrid methods, one of the dominant paradigms in contemporary large-scale partial differential equation simulation. In this presentation,a lightweight implementation of a theoretically and numerically scalable preconditioner is presented in the context of overlapping methods. The performance of this work is assessed by numerical simulations executed on thousands of core, for solving various highly heterogeneous elliptic problems in both 2D and 3D with billions of degrees of freedom. Such problems arise in computational science and engineering, in solid and fluid mechanics. While focusing on overlapping domain decomposition methods might seem too restrictive, it will be shown how this work can be applied to a variety of other methods, such as non-overlapping methods and abstract deflation based preconditioners. It is also presented how multilevel precondi- tioners can be used to avoid communication during an iterative process such as Krylov methods.

For material related to this talk, click here.

Assessment of redistribution and turbulent diffusion in low-Reynolds number Wall-Normal-Free Reynolds Stress Models

Dr. Celine Lo

Contrary to other Reynolds-Averaged Navier-Stokes (RANS) models, particularly eddy-viscosity models (EVM, two-equation models), Reynolds stress models (RSMs, seven-equation models) are inherently capable of capturing the majority of the time-averaged flow features and associated turbulence phenomenon. However, Reynolds stress models have been shown to not necessarily perform better than other RANS closures in detached flows where they usually overpredict the extent of the recirculation zone and predict reduced turbulent stresses in the shear layer bordering the recirculation zone. Deficiencies in RSM are known to be rooted in the redistribution, dissipation and turbulent diffusion term models in the Reynolds stress transport equations, especially near the wall. Research on how to model these terms has been pursued for more than fifty years. This work is concerned with Near-Wall Reynolds stress closures which are independent of any wall and geometry related parameters. Our aim is to clarify the influence of models used for the rapid homogeneous redistribution and the turbulent diffusion term in the Reynolds stress transport equations on the prediction of separating and reattaching flows.

Four low-Reynolds number Wall-Normal-Free Reynolds stress models developed by Gerolymos et al (2004) were implemented in the open source software OpenFOAM. They were compared with the low-Reynolds number two-equation model of Launder and Sharma (1989). The flow in the backward-facing step, where the separation point is fixed by the geometry, is considered. Comparison was done by reference to the experimental data obtained by Kasagi and Matsunaga (1995).

The computational results show that the turbulent diffusion model in the Reynolds stress transport equation plays an important role in the prediction of the turbulent Reynolds stress anisotropy levels in the recirculation region. Around reattachment, the rapid homogeneous redistribution term is responsible for the overprediction or underestimation of the separation bubble length. All the Reynolds stress models predicted too slow a recovery after reattachment. Closures using the Daly-Harlow (1970) model for the turbulent diffusion tend to model the turbulence anisotropy before reattachment more satisfactorily than those using the Hanjalić-Launder (1972) closure. As it had already been pointed out, the rapid homogeneous coefficient of Gerolymos and Vallet (2001) overestimates the separation zone while the Launder and Shima (1989) coefficient underestimates it. Both remarks indicate that further efforts are needed to improve the modeling of the turbulent diffusion together with the pressure-strain correlation in order to capture separation more accurately. This study also reaffirmed that testing a turbulence model on different configuration is essential.

Sparse polynomial approximation of parametric PDE's - theory and algorithms

Prof. Albert Cohen

Various mathematical problems are challenged by the fact they involve functions of a very large number of variables. Such problems arise naturally in learning theory, partial differential equations or numerical models depending on parametric or stochastic variables. They typically result in numerical difficulties due to the so-called "curse of dimensionality". We shall discuss how these difficulties may be handled in the context of stochastic-parametric PDE's based on the concept of sparse approximation.

For material related to this talk, click here.

An efficient solver for the coupled Darcy-Stokes system

Prof. Wei-Cheng Wang

We propose an efficient solver for the coupled Darcy-Stokes system modeling the composition of porous media region (Darcy) and free flow region (Stokes). An additional set of interface condition, known as the Beavers-Joseph-Saffman condition, is supplemented on the Darcy-Stokes interface. The coupled system is discretized based on a new weak formulation which incorporates the BJS condition naturally without additional regularity requirement. The proposed solver is based on a new preconditioning operator which has a nontrivial component on the interface. The preconditioned system is observed to be uniformly well conditioned independent of mesh size, viscosity or permeability.

A mixture-energy-consistent numerical method for compressible two-phase flow with interfaces, cavitation, and evaporation waves

Prof. Keh-Ming Shyue

We will present a variant of the six-equation single-velocity model with sti
mechanical relaxation of Saurel, Petitpas, and Berry [3] for compressible two-phase tow with interfaces and cavitation. In our approach, we employ phasic total energy equations instead of the phasic internal energy equations of the classical six-equation system. This alternative formulation allows us to easily design a simple numerical method that ensures consistency with mixture total energy conservation at the discrete level and agreement of the relaxed pressure at equilibrium with the correct mixture equation of state. As in the work done of Saurel et al. [2] and Zein et al. [4],temperature and Gibbs free energy exchange terms are included in the equations as relaxation terms to model heat and mass transfer and hence liquid-vapor transition.

The algorithm uses a high-resolution wave propagation method for the numerical approximation of the homogeneous hyperbolic portion of the model. In two dimensions a fully-discretized scheme based on a hybrid HLLC/Roe Riemann solver is employed. In the algorithm, all the relaxation terms (mechanical, thermal, and chemical ones) are handled by numerical means that are devised to ensure the retain of the unique admissible equilibrium state under suitable thermodynamic conditions; we will discuss two di
fferent approaches on this. Sample numerical tests in one and two space dimensions will be given that show the ability of the proposed model to describe cavitation mechanisms and evaporation wave dynamics, see [1] for more details. Preliminary results obtained using a pressure-correction based all speed solver will be presented also for some benchmark tests of weakly compressible two-phase flow.

References [1] M. Pelanti and K.-M. Shyue. A mixture-energy-consistent 6-equation two-phase numerical model for fluids with interfaces, cavitation and evaporation waves. J. Comput. Phys.,259:331{357, 2014. [2] R. Saurel, F. Petitpas, and R. Abgrall. Modelling phase transition in metastable liquids: application to cavitating and flashing flows. J. Fluid. Mech., 607:313{350, 2008.

Recent progress in minimizing communication for dense and sparse linear algebra operations

Prof. Laura Grigori

The cost of moving data in an algorithm can surpass by several orders of magnitude the cost of performing arithmetics, and this gap has been steadily and exponentially growing over time. This talk will review work performed in the recent years on a new class of algorithms for numerical linear algebra that provably minimize communication. The novel numerical schemes employed, the speedups obtained with respect to conventional algorithms, as well as their impact on applications in computational science will be also discussed.

A predictive mathematical model of acupuncture based on an explanation biological model

Prof. Marc Thiriet

Acupuncture requires a long-term training to handle acupoints. Four techniques exist: (1)~development of a local mechanical stress field by needle motions (lifting--thrusting cycle or rotation) at acupoints; (2)~development of a local temperature field by directly applying a heating moxa (mugwort herb) stick on the skin or indirectly by applying this stick on the acupuncture needle (moxibustion) at acupoints; (3)~development of a local electrical field by applying a small electric current between a pair of acupuncture needles (electroacupuncture, or percutaneous electrical nerve stimulation [PENS]) at acupoints; and (4)~laser light excitation independently of heating and other physical means probably via proper G-protein-coupled receptors on the surface of mastocytes.

Acupoints are enriched of mastocytes, among other biological structures and cells. Mastocytes are activation by a mechanical stress field (mechanotransduction), heating (thermotransduction), or an electrical field (electrotransduction). Whatever the operation mode, calcium entry in the mastocyte triggers degranulation and release of chemoattractants, neural stimulants, and endocrine substances. The process is sustained by recruitment of mastocytes (chemotaxis).

Acupuncture effects result from a set of signals sent from activated mastocytes at given acupoints to local nerve endings and capillaries that are transmitted to the brain and heart for processing and augmenting the flow rate, especially in the vasodilated acupoint. Released substances targets their cognate receptors on nerves and lymph and blood vessels. These two types of conduits deliver fast cues (electrochemical waves) and delayed information (blood transport) to the central nervous system, where they are processed for a desired output.

The mathematical model is a system of 5 partial differential equations. Its simplest form describes the evolution of the density of mastocytes and the chemoattractant concentration. A mathematical analysis of a simplified version of the equation set leads to a theorem for blow-up condition (the expected solution) as well as an analytical solution useful for validation. Numerical simulations are also carried out using a finite element method with mesh adaptivity. The computational model based on the home-made FreeFEM$++$ software demonstrated the occurrence of a stress field that excite mastocytes. It also shows that only adequate pools of mastocyte, that is, acupoints, must be targeted to have marked effects.

For material related to this talk, click here.

Prediction of local stress field on a mastocyte in acupuncture treatment

Dr. Yannick Deleuze

Acupuncture is used in the treatment of various physical and mental conditions in the Traditional Chinese Medicine. During acupuncture treatment, needles are inserted into specific points on the body, namely acupoints. The needle inserted in the skin interacts with the subcutaneous connective tissue. This talk focuses on the mathematical modeling and simulation of the generated local stress field yelling to the cellular response to acupuncture treatment.

We present the physiological basis of the acupuncture near acupoints. The physiological reactions of acupuncture treatment lead to therapeutic effects and could be explained by a series of interactions among the nervous system, endocrine system and immune system.

There is evidence that acupuncture treatment could cause degranulation of mastocytes to occur directly through a physical stress. In the case of a needle implantation, the generation of the local mechanical stress field is divided into two phases: (i) a transient phase in the interstitial flow caused by the motion of the needle ; (ii) a permanent phase where the interstitial medium has polymerized, thus forming a gel, and where the needle is at rest. This stimulation activates a set of sensitive proteins embedded in the membrane of mastocytes that rapidly release granules containing chemical mediators. The process is then sustained by complex recruitment of mastocytes through a chemotactic phenomenon.

We model the water flow in the connective tissue using the incompressible Brinkman's law in a porous medium. The motion of the needle is prescribed and we solve the Brinkman equations subject to a moving boundary with the finite element method in the ALE framework. In the transient phase, water flow is observed and an acute stretch is predicted on the mastocyte membrane. In the permanent phase, the interstitial fluid has become a gel and a low amplitude shear is predicted on the mastocyte membrane. The acute stretch would be responsible for the release of peripheral granules and the low shear would be responsible for the core granule displacement.

Finally, we present numerical results of the biomathematical model of the mastocyte response to acupuncture treatment motivated by chemotaxis. In the differential system, the mechanical stress generated by the needle is modeled by a compact supported function. We show that the recruitment of mastocytes occurs only at acupoints.

For material related to this talk, click here.

Aggregation models for protein polymerization & application to amyloid diseases

Prof. Marie Doumic-Jauffret

Amyloid diseases are a group of diseases which involve the aggregation of misfolded proteins, called amyloid, which are specific for each disease (PrP for Prion, Abeta for Alzheimer's). Elucidating the intrinsic mechanisms of these chain reactions, most probably specific for each disease, is a major challenge of molecular biology. Up to now, only partial answers have been provided, due to the complexity of the considered processes, which may involve an infinite number of species and reactions (and thus, an infinite system of equations). Mathematical modelling, simulation and parameter estimation methods are thus required.

In this talk I will review existing results and explain our approach, which is based on combined ODE-PDE (and more recently stochastic) models. I will also develop some of our recent findings, both in a mathematical side and for specific applications.

For material related to this talk, click here.

The existence of traveling wave solutions for a three species competition system

Prof. Jong-Shenq Guo

We study the existence of traveling wave front solutions for a three species competition system with discrete space (lattice dynamical system) or continuous space(partial differential equations). First, we study the lattice dynamical system and show that there exists a positive constant (the minimal wave speed) such that a traveling front exists if and only if its speed is above this constant. Applying the results of the lattice dynamical system and the discrete Fourier transform, we then show the existence of traveling wave solutions for the continuous model. Also, the linear determinacy for the minimal speed is addressed.

This talk is based on a joint work with Y. Wang, C.-H. Wu and C.-C. Wu.

For material related to this talk, click here.

Modeling blood flow by taking explicitly red blood cells into account

Prof. Chaouqi Misbah

This talk will focus on modeling and simulation of blood flow by taking into account explicitly the major blood component, namely the red blood cells (RBC), their mutual interactions and their interaction with blood vessel walls. We briefly recall recent major recent progress on dynamics under flow for a single RBC. Then collective effects will be studied showing non-standard rheological properties in blood mirco-circulation as well as the formation of stable RBC rouleaux mediated by plasma proteins. It is found that even under high mean shear rates and within physiological ranges of fibrinogen concentrations, RBC clusters persist. Formation of stable large enough clusters should strongly affect RBCs entrance in capillaries and impede oxygen delivery. RBCs aggregation is generally known to increase microvascular flow resistance and consequently reduce blood perfusion to the organs. Finally, recent results on the effect of glycocalyx on hemodynamics will be discussed.

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Self-focusing and jet instability of a micro-swimmer suspension

Prof. Philippe Peyla

For the abstract of this talk, please click here.

A hybrid immersed boundary and immersed interface method for electrohydrodynamic simulations

Prof. Ming-Chih Lai

In this talk, we introduce a hybrid immersed boundary (IB) and immersed interface method (IIM) to simulate the dynamics of a leaky dielectric drop under the influence of an electric field in Navier-Stokes flows. The electric potential is solved numerically by an augmented immersed interface method which incorporates the jump conditions naturally along the normal direction. Instead of applying the volume electric force arising from the Maxwell stress tensor, we alternatively regard the electric effect as an interfacial force bearing the normal jump of Maxwell stress on the interface. Thus, the capillary and electric interfacial forces can be formulated in a unified immersed boundary framework. A series of numerical tests for the present scheme have been conducted to illustrate the accuracy and applicability of the method. We first compute the potential and its gradient (electric field) to perform the accuracy check for the present IIM. We then check the convergence of the interfacial electric force and the fluid variables. We further run a series of simulations with different permittivity and conductivity ratios and compare the results obtained by the small deformation theory. Our numerical results show a good agreement with the theory.

High performance computing for complex fluids simulation

Prof. Mourad Ismail

For the abstract of this talk, please click here.

For material related to this talk, click here.

A model for hemodynamics for optimal design

Prof. Olivier Pironneau

For the abstract of this talk, please click here.

For material related to this talk, click here.

Unsteady aerodynamics of insect wings from the perspective of a force element theory

Prof. Chien-Cheng Chang

In this talk, we propose to investigate the unsteady aerodynamics of dragonfly using a simplified wing–wing model from the perspective of a force representation theory and the associated force elements. It is shown that there are important cases where the added-mass effect (potential force) is non-negligible. Insect flight usually operates at Reynolds numbers of the order of several hundreds, at which the surface vorticity is shown to play a substantial role although the major contribution to the forces comes from the vorticity within the flow. This study focused on the effects of mutual interactions due to phase differences between the fore- and hind-wings in the translational as well as rotational motions. It is well known that the dynamic stall vortex is an important mechanism for an unsteady wing to gain lift. In analyzing the life cycles of lift and thrust elements, we also associate some high lift and thrust with the mechanisms identified as ‘riding on lift elements’, ’driven by thrust elements’ and ‘sucked by thrust elements’, by which a wing makes use of a shed or fused vortex below, in front of, and behind it, respectively.

With these insights gained based on a simplified model, we extend the force-element theory to identify and quantify the forces exerted on a 3D insect wing in terms of all the fluid elements with nonzero vorticity, such as in the tip vortices (TiVs), leading- and trailing-edge vortices (LEV and TEV) as well on the wing surface. The interplay between the LEV and the TiVs by assessing the relative importance of the transverse as well as the longitudinal vorticity components at various time stages leads to insightful physical explanations of the force mechanisms.

On ground states of spin-1 Bose-Einstein condensates w/o external magnetic field

Prof. I-Liang Chern

In this talk, I will first give a brief introduction to the spinor Bose-Einstein condensates (BECs). Then I will present two recent results, one is numerical,the other is analytical for spinor BECs w/o uniform external magnetic field. In the numerical study of spinor BECs, a pseudo-arclength continuation method (PACM) was proposed for investigating the ground state patterns and phase diagrams of the spin-1 Bose-Einstein condensates under the influence of a homogeneous magnetic field. Two types of phase transitions are found. The first type is a transition from a two-component (2C) state to a three-component(3C) state. The second type is a symmetry breaking in 3C state. After that, a phase separation of the spin component occurs. In the semi-classical regime, these two phase transition curves are gradually merged. In the analytical study, the ground states of spin-1 BEC are characterized. First, we present the case when there is no external magnetic field. For ferromag-netic systems, we show the validity of the so-called single-mode approximation (SMA). For antiferromagnetic systems, there are two subcases.

When the total magnetization $M \neq 0$, the corresponding ground states have vanishing zeroth ($mF = 0$) components (so call 2C state), thus are reduced to two-component systems. When $M = 0$, the ground states are also reduced to the SMA, and there are one-parameter families of such ground states. Next, we study the case when an external magnetic field is applied. It is shown analytically that, for antiferromagnetic systems, there is a phase transition from 2C state to 3C state as the external magnetic field increases. The key idea in the proof is a redistribution of masses among diff
erent components, which reduces kinetic energy in all situations, and makes our proofs simple and unied. The numerical part is a joint work with Jen-Hao Chen and Weichung Wang, whereas the analytical part is jointly with Liren Lin.

For material related to this talk, click here.

Development of a wavenumber optimized model for steady incompressible Navier-Stokes equations and its implementation in GPU

Prof. Tony Wen-Hann Sheu

A 3D upwind finite element model is developed to solve the incompressible steady-state Navier-Stokes equations in tri-quadratic elements. This streamline upwind model yields optimized numerical wavenumber for the advection terms. While solving the unsymmetric and indefinite mixed finite element matrix equations iteratively, the finite element equation has been normalized to avoid a Lanczos or a pivoting breakdown. The conjugate gradient Krylov iterative solver can be therefore applied to get an unconditionally convergent solution from the resulting symmetric positive-definite matrix equation. The matrix condition number becomes, unfortunately, the square of the original unsymmetric indefinite matrix equation.

To fully exploit the conjugate gradient iterative solver, an element-by-element strategy is adopted at an element level. To alleviate the drawback of slower convergence due to the increased condition number in the matrix equation, the positive definite matrix has been preconditioned so that we can more effectively get the solution from the resulting preconditioned matrix equation in a matrix-free manner. The developed three-dimensional incompressible finite element Fortran code implemented in GPU is first verified by solving the problem amenable to analytical solution. The lid-driven cavity benchmark problem is also solved in a cube for the assessment of the three chosen iterative solvers.

For material related to this talk, click here.

GPU parallelization of a three-dimensional Riemann Solver using unstructured tetrahedral grids

Prof. Matthew Smith

Many engineering and design problems require the use of Computational Fluid Dynamics (CFD) in order to understand the features of the flow present and the influence the design plays on these flows. Hence, it is critical that any flow solver used as part of an integral design process is both (i) computationally efficient and fast enough to use as part of a design cycle, and (ii) based on a meshing procedure which is both easily applied to arbitrary geometries and is easily automated, thus reducing the manual time spent on mesh generation. In recent times, the rise in popularity of the GPU (Graphics Processing Unit) for parallel computation of CFD methods has led to the development of numerous solvers and parallel paradigms. This performance increase is made possible through the use of thousands of (semi) independent streaming cores which excel at vector-based parallel computation.

Very high degrees of speedup have been obtained using vector split methods due to the high locality and embarrassingly parallel nature of the split flux and state computations. However, such approaches are not well suited to the requirements stated above – traditional approaches employ structured grids to increase the structured nature of memory access, and many vector split approaches have an associated numerical dissipation which makes them not ideal for industrial application. Presented here is the application of an inexact Riemann solver to an unstructured tetrahedral grid using Graphics Processing Units. The Riemann solver employed is Jacob's approximate solver which is suitable for situations where high temperature gradients are present in the absence of pressure gradients. The application employs an interface-based parallelization paradigm for surface flux computation and a cell based paradigm for state computations. The performance characteristics of the proposed implementation shall be presented, along with comparisons in performance across a various number of GPU devices and several industrial applications.

For material related to this talk, click here.

Parallel hybrid simulation of gas flow and gas discharge with a temporal multi-scale algorithm

Prof. Jong-Shinn Wu

Simulation considering direct coupling of discharge and gas flow has been considered a challenging task, mainly because of the wide disparity of time scales of light and heavy species, e.g., electron (~10^{-10} s) and neutral species (~10^{-3}-1 s). Development of hybrid plasma fluid modeling and gas flow of atmospheric-pressure plasmas is presented in this paper. The fluid model we employed in the current study is basically the same as that presented by Lin et al. [1]. The fluid model includes the continuity equations for charged and neutral species, the momentum equations for charged and neutral species, the energy equation for electron and the Poisson's equation for electrostatic potential. In the gas flow solver [2], the governing equations include the mass, momentum, energy and species conservation equations. Both solvers are coupled using a temporal multiscale algorithm (TMA). The basic idea of the TMA is to integrate those species temporally which respond fast and slow to the driving voltage with a small (electron limited) and large (diffusion limited) time step, respectively. Parallel computing using domain decomposition with message passing interface (MPI) is applied to speed up the computation. Several examples including low-pressure and atmospheric-pressure gas discharges are used to demonstrate the proposed method.

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References [1] K.-M. Lin, C.-T. Hung, F.-N. Hwang, M.R. Smith, Y.-W. Yang and J.-S. Wu, Comp. Phys. Comm., 183, pp. 1225–1236, (2012). [2] M.-H. Hu, J.-S. Wu and Y.-S. Chen, Computers & Fluids 45, p. 241 (2011).

How GPU can benefit matrix computations

Prof. Weichung Wang

High-performance matrix computations can be achieved on GPUs via well-designed algorithms. We illustrate how GPUs can benefit large sparse linear system and eigenvalue solvers. In linear system solvers, we show how we can fit multifrontal method to one-CPU-one-GPU systems and how this multifrontal solver can be extend to multi-CPU-multi-GPU systems via substructure method. In eigenvalue solvers, we focus on a sequence of challenging eigenvalue problems arising in the simulation of three dimensional photonic crystals. We address how the problems can be solved on CPU-GPU heterogeneous parallel system in a ultra fast manner. Furthermore, to balance the loads between CPU and GPU for dense block QR factorization, we demonstrate an adaptive auto-tuning scheme based on statistical performance models.

Regularity criteria in weak L3 for 3D incompressible Navier-Stokes equations

Prof. Tai-Peng Tsai

We study the regularity of a distributional solution (u,p) of the 3D incompressible evolution Navier-Stokes equations. Let B_r denote concentric balls in R^3 with radius r. We will show that if $pin L^{m} (0,1; L^1(B_2))$, $m>2$, and if u is sufficiently small in $L^{infty} (0,1; L^{3,infty}(B_2))$, without any assumption on its gradient, then u is bounded in $B_1times (frac{1}{10},1)$. It is a borderline case of the usual Serrin-type regularity criteria, and extends the steady-state result of Kim-Kozono to the time dependent setting. This is a joint with my student Yuwen Luo.

For material related to this talk, click here.