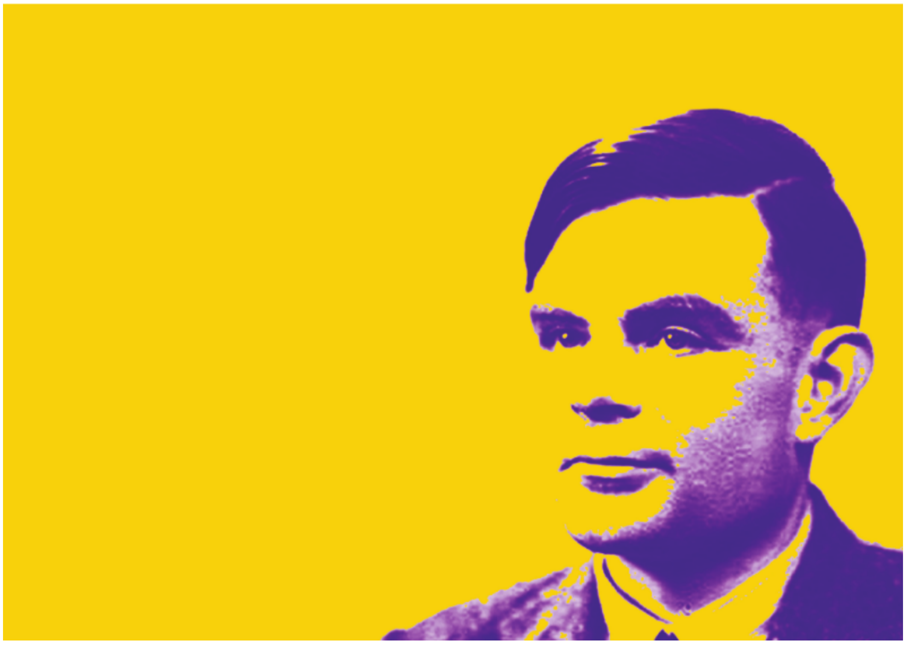
Programme and Abstracts

# Manchester SIAM Student Chapter Conference 2016



School of Mathematics
The University of Manchester

4 May 2016

http://www.maths.manchester.ac.uk/~siam/msscc16/

# Schedule

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|---|---|
| 09:00 - 09:30 | Registration and Coffee |
| 09:30 - 09:45 | Opening Remarks |
| 09:45 - 10:35 | Plenary Session I |
| 10:35 - 11:50 | Student Session I |
| 11:50 - 12:00 | Group Photo |
| 12:00 - 13:15 | Lunch |
| 13:15 - 14:05 | Plenary Session II |
| 14:05 - 15:20 | Student Session II |
| 15:20 - 16:00 | Poster Session and Coffee |
| 16:00 - 16:50 | Plenary Session III |
| 16:50 - 17:00 | Presentation of the Awards |
| 17:00 - | Informal outing |

# Plenary sessions

## Plants and Fat Pads: The Elasticity of Cellular Bodies in High Deformations

Plenary Session I
09:45 - 10:35

Angela Mihai*
*Cardiff University

Cellular bodies are strong, pliable structures, built from seemingly fragile materials. Among the best known mechanical qualities of these structures are their high strength-to-weight ratio and energy absorption capacity, which arise from the inextricable relation between the geometric architecture and the nonlinear elastic responses of their constituents. In many cellular structures, during functional performance, large strains and stresses also occur, and their mechanical analysis requires appropriate theoretical treatment. In this talk, I will show how, for hyperelastic cellular bodies, several main factors determine the magnitude of the enhancement of stress level in the cellular material, including the cell geometry, the cell wall thickness, and the presence of cell inclusions, and address the important question whether the same volume of material has the same effect when arranged as many cells or as fewer cells while the material volume remains fixed.

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## Implementing Algorithms

Plenary Session II
13:15 - 14:05

Edvin Hopkins*
*Numerical Algorithms Group, Ltd.

In the talk we will address some of the issues involved in taking a research algorithm and transforming it into commercial software. We will address aspects of modern computing that we should all be aware, even when writing the simplest MATLAB code.

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Plenary Session III
16:00 - 16:50

# From Cancer Treatment to Cloud Modelling: Theory and Applications of Boundary Integral Equations

Timo Betcke*
*University College London

Boundary integral equations are a wonderful tool to solve partial differential equations in homogeneous, possibly unbounded, media. The idea is to represent the solution as an integral over the boundary, and then using boundary conditions to solve for the missing data. While theoretically appealing, the numerical solution of boundary integral equations using for example Galerkin methods, is significantly more involved than the solution of partial differential equations using finite element methods. For two-dimensional surfaces it turns out that four-dimensional singular integrals need to be evaluated. Moreover, the arising operators are non-local, leading to large dense matrices if discretized in a naive way.

In recent years we have developed an open-source library BEM++, whose goal it is to make boundary integral equation methods as easily accessible as standard finite element solvers. BEM++ supports a range of operators in electrostatics, acoustics and computational electromagnetics and provides fast hierarchical compression techniques to solve very large problems on a standard workstation.

In this talk we we will give an overview of the theory of boundary integral equations, and demonstrate how various interesting application problems can be easily formulated using the BEM++ library. We demonstrate some interesting applications involving highly oscillatory problems, in particular from cancer treatment planning in high-intensity focused ultrasound and the simulation of light-scattering from ice crystals in cirrus clouds.

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# Student talks & posters

## Reduced Basis Methods for Partial Differential Equations with Random Coefficients

Student Session I
10:35 - 11:00

Craig Newsum*

*The University of Manchester

In many applications the inputs to a model are not known exactly and so it is useful to understand how uncertainties in these inputs will affect the output, either the solution to a PDE or some quantity of interest. This is a typical problem in uncertainty quantification. More specifically, we are interested in approximating statistical properties of solutions to PDEs with random coefficients using sampling techniques, such as Monte-Carlo or sparse grid collocation. This gives rise to a parameter dependent problem which, for each parameter, is a deterministic PDE that can be solved using standard finite element methods. However when the number of parameters is large and the cost of solving each PDE is expensive this will be a costly undertaking. Reduced basis methods can be used to decrease the cost of solving each deterministic system. The idea of the method is to construct a so-called reduced basis during an expensive offline stage, which can then be used 'online' to rapidly evaluate the desired quantity of interest. In this talk we shall present several algorithms for the construction of a reduced basis, and demonstrate the efficiency of these methods in the case of a simple elliptic PDE.

Student Session I
11:00 - 11:25

## Elastic Wave Scattering in a Lattice Material and the Efficient Evaluation of the Periodic Green's Function

Georgia Lynott*
*The University of Manchester

Underwater sonar arrays are often protected by multi-layered cladding designed to shield them from nearby noise and vibration. We wish to understand how waves propagate through the different layers of such cladding, each of which may have its own complicated micro structure. One such example is a lattice material, which consists of a medium with macroscopic voids arranged on a 2D lattice. Previous work by Andrew [1] considered the acoustic scattering problem and successfully calculated the transmission and reflection coefficients for such lattices. We seek to extend this same approach to the fully elastic problem of a wave scattering from a periodic array, taking advantage of the periodicity of the problem and BEM to efficiently evaluate the wave scattering. I will discuss some of the current challenges involved with the convergence of the periodic Greens function required by this approach, and plans for future work.

[1] V. Andrew, *Efficient numerical evaluation of the scattering of acoustic waves by arrays of cylinders and bodies of revolution of arbitrary cross section.* PhD Thesis, University of Manchester, 2014.

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Student Session I
11:25 - 11:50

## Hard Particles as Building Blocks for Materials: Packing and Assembly

John McBride*, Carlos Avendaño*
*The University of Manchester

Designing new materials is a highly complex challenge. While they drive technological change, new materials were historically discovered through trial and error. With computer simulations we now have the tools to explore the vast domain of design space in a short period of time, thus enabling us to design materials based on the properties we want from them. In my work we explore how changing the shape of a particle can result in vastly different behaviour. Through studying the thermodynamics and kinetics of these systems we can suggest rules for the design of new particles.

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# Depth-Averaged Free-Surface Granular Flows



Aaron Russel*, Andrew Edwards*, Christopher Johnson*, Nico Gray*
*The University of Manchester

Free-surface granular flows, such as debris flows and snow avalanches, can spontaneously develop large-amplitude surge waves that are interspersed by periods in which grains are completely stationary. These waves are important in natural hazard mitigation because each individual surge is much more destructive than a steady uniform flow with the same mass flux. A key feature of these flows is the interaction between static and flowing material, which occurs both when the travelling waves erode the static layer of particles in front of them, and when they deposit grains behind them. Although erosion and deposition problems are notoriously difficult, we find that a simple model that uses a depth-averaged version of the $\mu(I)$-rheology, and Pouliquen and Forterres extended friction law, captures the underlying physics and is in good agreement with experiments. Importantly, this depth-averaged rheology includes not only the leading-order effective basal friction, but also incorporates a depth-averaged viscous term, which is essential for predicting the onset of roll-wave instabilities. Numerical simulations, obtained with a shock-capturing scheme for viscous problems, show that the depth-averaged model quantitatively predicts the wave amplitude, wavespeed and coarsening dynamics of these erosion-deposition waves. This agreement suggests that depth-averaged $\mu(I)$-rheology may be more widely useful for prediction of other erosion and deposition phenomena.

[1] A. N. Edwards and J. M. N. T. Gray, *Erosion-deposition waves in shallow granular free-surface flows.* J. Fluid. Mech. 762,35-67. 2015.

[2] A. N. Edwards and J. M. N. T. Gray, *A depth-averaged $\mu(I)$-rheology for shallow granular free-surface flows.* J. Fluid. Mech. 755,503-534. 2014.

Student Session II
14:30 - 14:55

# Interpretation of Algebraic Preconditioning as Transformation of the Discretization Basis in Numerical Solution of PDEs

Tomàš Gergelits*, Jan Papež*, Zdeněk Strakoš*
*Charles University in Prague

In numerical solution of PDEs it is convenient to consider discretization and preconditioning closely linked together. As suggested by several techniques used throughout decades, preconditioning can always be linked with transformation of the discretization basis. It has been shown recently that effective algebraic preconditioners can be interpreted as the transformation of the discretization basis and, simultaneously, as the change of inner product on corresponding Hilbert space. This contribution will explain this interpretation and will present recent work in this direction.

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Student Session II
14:55 - 15:20
Poster Session
15:20 - 16:00

# Buckling in an Elastic Holey Column

Utkarsh Jain*
*The University of Manchester

Buckling of an Euler strut under uniaxial compression is a classic example of elastic instability and the canonical pitchfork bifurcation. We observe a number of new and surprising buckled states if a column has a periodically repeated structure. Here we report the results from studies on an elastic column with a regular array of holes. Two buckled states are preferred at the onset of instability. A computational model of the system has been developed to study bifurcations in columns of finite length and columns with periodic boundary conditions using in-house software OOMPH-LIB. We find new secondary bifurcations in holey columns with finite length. For holey-columns with periodic boundary conditions an asymptotic theory is developed and validated for the types of buckled states predicted. Behaviour predicted by numerics for finite columns is robust, scale independent and also observable in experiments.

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## Structured Condition Number of $f(X)$ when $f$ is a Smooth Map between Matrix Manifolds

Poster Session
15:20 - 16:00

Bahar Arslan[*], Vanni Noferini[†], Françoise Tisseur[*]
[*]The University of Manchester, [†]University of Essex

The sensitivity of problems to perturbations in the data is measured by condition numbers. We investigate the effect of structured perturbations in the sensitivity of matrix functions. Since the extra condition on the structure of the symplectic/orthogonal perturbation matrix restricts it to a smaller set we have the obvious fact that $cond_{struc}(f, X) \leq cond(f, X)$, where $cond_{struc}(f, X)$ and $cond(f, X)$ respectively, represent the structured and unstructured condition numbers of matrix function $f$ at $X$. Condition number of matrix functions is computed by the Fréchet derivative of the functions. We show that when a matrix function f is a smooth map between manifolds then the differential $df_X$ plays for the structured condition number the same role as the Fréchet derivative for the unstructured condition number. Since an automorphism group is not a linear subspace, we need to describe the tangent spaces of these manifolds. We can then obtain a structured condition number by restricting the perturbation matrix to such tangent space. In particular, we study the ratio of the structured condition number to the unstructured one for the matrix logarithm and square root, which arise in many scientific and engineering applications, and argue that structured algorithms should be employed whenever possible.

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## Skill Assessment for Catheter Ablation

Poster Session
15:20 - 16:00

Christopher E. Mower[*]
[*]Imperial College London

Abnormal electrical activity in the heart causes cardiac arrhythmias and this can cause symptoms from dizziness through to cardiac arrest. Of particular complexity are adult patients who have been previously treated for congenital heart defects. Treatment for arrhythmias can be through radiofrequency ablation, where an ablation catheter is used to create a line of lesions to block the trigger points of the arrhythmia and its propagation. Knowledge of the morphology and electrical activation is essential, otherwise collateral damage or incorrect ablation can occur. The introduction of 3D mapping platforms, such as the electromagnetic Biosense-Webster CARTO system, has greatly improved navigation and robotic catheter technologies (e.g. Stereotaxis Niobe) has provided improved stability and navigation through complex anatomy. However, when it comes to training and assessing novice electrophysiologists it can be difficult to explain the paths taken by expert operators. Here we propose a method for objective assessment of skill in catheterization procedures.

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Poster Session
15:20 - 16:00

## How Can One Locate a Sound Source Using Microphones?

Adilet Otemissov*
*The University of Manchester

The sound source location problem attracted considerable recent interest due to its wide range of applications. Acoustic localisation technique has been used by submarines to detect other watercrafts and obstacles and it is being adapted to new applications such as 3D mapping of rooms. The poster aims at developing a method for finding an approximate location of the noisy object given certain assumptions. It also provides an error analysis and compares feasible regions obtained when different number of microphones are used. We conclude that at least five microphones are necessary to obtain a bounded feasible region.

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Poster Session
15:20 - 16:00

## An Optimal Solver for Linear Systems Arising from Stochastic FEM Approximation of Diffusion Equations with Random Coefficients

Pranjal*, David Silvester*
*The University of Manchester

This poster discusses the design and implementation of efficient solution algorithms for symmetric linear systems associated with stochastic Galerkin approximation of elliptic PDE problems with correlated random data. The novel feature of our preconditioned MINRES solver is the incorporation of error control in the natural 'energy' norm in combination with a reliable and efficient a posteriori estimator for the PDE approximation error. This leads to a robust and optimally efficient inbuilt stopping criterion: the iteration is terminated as soon as the algebraic error is insignificant compared to the approximation error.

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## PAIS: The Parallel Adaptive Importance Sampler

Poster Session
15:20 - 16:00

Paul Russel*, Colin Cotter*, Simon Cotter*
*The University of Manchester

It is frequently of interest to solve data assimilation problems of the form

$$D = \mathcal{G}(u) + \varepsilon, \qquad \varepsilon \sim \mathcal{N}(0, \Sigma),$$

where the data $D$ is a noisy observation of the system $\mathcal{G}(u)$. We assume knowledge of the observation operator $\mathcal{G}$, and the covariance operator for the noise, $\Sigma$, and try to recover the parameter $u$ which best satisfies the equation.

Viewing the problem from a Bayesian perspective and assuming prior knowledge of $u \sim \mathcal{N}(0, \mathcal{T})$ we can construct a posterior distribution, $\mu_Y$, and use Markov Chain Monte Carlo (MCMC) to produce a sample from this distribution. This poster demonstrates that commonly used serial MCMC methods do not take full advantage of modern computer architecture, and that designing parallel algorithms can lead to a large reduction in computational costs.

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## Proliferating Lévy Walkers and Front Propagation

Poster Session
15:20 - 16:00

Helena Stage*
*The University of Manchester

Many motility patterns of animals follow Lévy walks, a class of random walks characterised by a finite velocity of movement for a certain time, after which a new direction is chosen. These running times are sampled from heavy-tailed distributions making the walks non-Markovian (they have memory effects). We develop a model for walkers with birth and death processes, and study the resulting wave of movement from high to low-density areas. Hyperbolic scaling is applied to our equations, enabling us to find the front propagation velocity of the system. We find conditions on the birth, death and turning rates for which the rate of propagation equals the upper bound, i.e. the walkers speed. Conditions are found for which standard diffusion methods overestimate the velocity. The death rate of the walkers is shown to temper the anomalous behaviour of our system.

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Poster Session
15:20 - 16:00

# American Put Options for Power System Balancing

David Zoltan Szabo*
*The University of Manchester

We study the problem of offering American put options on electricity with immediate physical delivery for real-time balancing of a power system. The real-time price is assumed to be the composition of a price stack function with a stochastic process modelling physical imbalance in an electrical power system. Our paper is an extension of recent work of Moriarty and Palczewski who considered the corresponding problem for call options, and we also obtain explicit results for the stopping regions and value functions for both the single option and the infinitely repeated option. Further we obtain results for a wider range of price stack functions and perform an empirical analysis of the price stack in the UK electricity market. As empirical results suggest the price stack function depends both on the imbalance process and on the current time, which leads our further research to the numerical solution of the related free boundary problems.