ICMS and MAC-MIGS Modelling Camp 2024

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Improving techniques for the capture of environmental contaminants
Challenge holder and facilitator: Tim Myers (Centre de Recerca Matemàtica, Spain)

Efficient economic scenario generation
Challenge holder: Hymans Robertson
Facilitators: Aretha Teckentrup and Heather Yorston (University of Edinburgh)

Melting scrap copper in an electric arc furnace
Challenge holder and facilitator: William Lee (University of Huddersfield)

Machine learning applications for soundscape source separation and marine mammal detection
Challenge holder: Ocean Science Consulting
Facilitators: Xander O'Neill and Sandhya Patidar (Heriot-Watt University)

Energy efficiency in controlled environment agriculture
Challenge holder and facilitator: Ann Smith (University of Huddersfield)

Expanding lung health initiatives across Scotland
Challenge holder: The Cheyne Gang
Facilitator: Cathal Cummins (Heriot-Watt University)

Improving techniques for the capture of environmental contaminants

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CENTRE DE RECERCA MATEMÀTICA

Tackling environmental challenges is this generation's defining task (EC Green Deal 2020). A significant part of this involves reducing the release of environmental contaminants or actively removing them from the environment.

One of the most common methods for removing contaminants from a fluid is via column adsorption. Adsorption columns are employed in greenhouse gas capture, water treatment and groundwater remediation, biogas cleansing, chromatography and the purification of biopharmaceutical products. Industrial uses include: water providers (removing pollutants, odours, softening hard water and reducing evaporation); the cleansing of flue gases (from power stations, concrete and steel plants, pulp mills, etc); biofuel purification; biotechnology companies; the paint/coating industry (to remove volatile fumes) and many more. Research in these fields is focussed on optimising the process, through the use of new adsorbents, configurations and operating regimes.

During the week we will first develop a mathematical model for this process. We will then look to reduce the problem to a more tractable form and seek approximate solutions. A key practical issue is fitting experimental data to the model predictions and the determination of unknown parameters. These parameters characterise the system and may be used to analyse different configurations. Consequently the final stage of the study will involve finding a robust method to fit to experimental data.

Efficient economic scenario generation

Challenge holder:
Hymans Robertson

Facilitators:
Aretha Teckentrup and Heather Yorston (University of Edinburgh)

Typically, time series models are used for Economic Scenario Generation (ESG). These models are usually defined by algorithms which iteratively sample key economic variables to generate plausible future paths for variables such as interest rates, inflation, equity returns, and credit spreads.

Modern AI algorithms are based on the use of tensors, mathematical objects that define a multilinear mapping over vector spaces, to efficiently generate outputs such as text, images, and video using Graphical Processing Units. These operations are performed in using software packages such as torch and tensorflow. In principle, it is possible to encode ESG models as tensors. Doing so may allow us to generate scenarios more efficiently.

In this initial project we will look to define a tensor which generates data consistent with that generated by simple ESG models for interest rates and inflation. This will provide a "proof-of-concept" example for assessing the merits of tensor-based approach to ESG. Our primary objective is to assess the computational cost of generating trials from iterative sampling schemes vs. tensor representations of our models.

Melting scrap copper in an electric arc furnace

Challenge holder and facilitator:
William Lee (University of Huddersfield)

University of Huddersfield

Copper is an essential material in the global economy, used extensively in electrical applications, construction, and various industrial machinery due to its excellent conductivity and corrosion resistance. Recycling copper from scrap is a critical process, contributing to environmental sustainability and reducing the demand for ore. This project is aimed at investigating using an electric arc furnace for recycling copper by melting scrap copper for reuse.

In this system roughly 50 tonnes of copper scrap are placed in a large insulating vessel. The scrap consists of irregularly shaped items with sizes ranging from 10-50cm, which may be considered to be pure copper without significant impurities. The vessel may be taken to be a cylinder with a diameter of 2m and a height of 4m The process is initiated by pouring in a small amount of molten copper: enough to fill the vessel to a depth of 10cm. Three graphite electrodes are used to deliver 0.5MW of three phase power at the solid-liquid interface. The copper melts and the graphite electrodes are gradually raised to remain in contact with the interface. Once all the copper is melted it is poured out into ingots, except for a small amount used to initiate the next batch.

The aim is to create a digital twin of the process using a combination of computer vision and physical mechanistic modelling to understand the current state of the system. This model will then be augmented with a control system which will be optimised to minimise power requirements. Your task is to create the physical model component of the system.

This model must describe the energy consumption, temperature distribution and phase changes. In particular it must track the level of the liquid to enable correct placement of the electrodes. You may find it helpful to consider the mathematics of Stefan problems and porous media. A good starting point to build intuition about this problem might be to consider adapting the standard Stefan problem to have the heat input at the interface instead of the boundaries.

Some questions to consider: Dominant heat transfer mechanism? Does the scrap float on the liquid or sink into it? Wall boundary conditions? Upper surface boundary condition? Should the larger scrap be placed at the top or the bottom?

Machine learning applications for soundscape source separation and marine mammal detection

Challenge holder:
Ocean Science Consulting

Facilitators:
Xander O'Neill and Sandhya Patidar (Heriot-Watt University)

Soundscape ecology, also known as ecoacoustics, is a novel, promising area of research that studies landscape and bioscape patterns based on their acoustic composition. In marine environments, ecoacoustics focuses on the distribution of biotic, abiotic, and anthropogenic sounds to gather monitoring and management-relevant information, from species up to ecosystem level.

To conduct such studies, researchers analyse recordings from underwater acoustic dataloggers, which are becoming increasingly accessible and capable of storing long-term data series. The increase in availability of long-term acoustic datasets, joint with the industry need for quick assessments have created the requirement for automatic processing methods capable of reducing analytical time.

Consequently, traditional machine learning methods have been applied to process data on different soundscapes, characterising mainly presence–absence of species. In addition, it has been employed for source segmentation, species identification, and sound source clustering. However, these approaches present the bottleneck of requiring consistent training data, that are, in most cases, not available (e.g. labelled data). Some authors highlight the importance of the approaches that use unsupervised deep learning methods. Venturing in exploring this possibility, OSC could provide sample acoustic data to experiment on unsupervised machine learning to reach two goals 1) overall source separation (i.e. biophonical and anthrophonical sources) and 2) marine mammal detection and classification.

Energy efficiency in controlled environment agriculture

Challenge holder and facilitator:
Ann Smith (University of Huddersfield)

University of HUDDERSFIELD

Global food security is a priority for the UK and international research. Urgent action is required to create and maintain a system capable of providing sufficient quality food worldwide into the future.

"The challenge is to deliver nutritious, safe and affordable food to a global population of over 9 billion in the coming decades, using less land, fewer inputs, with less waste and a lower environmental impact. All this has to be done in ways that are socially and economically sustainable."
Prof. Sir John Beddington, Government Chief Scientific Adviser Forward to UK Global Food Security Strategic Plan 2011-2016

To achieve this goal alternative methods of distribution and production are necessary to ensure a fair allocation to all communities worldwide. One key area of research into alternative production methods is efficacy of controlled environment agriculture (CEA) and vertical farms.

This problem focuses on optimising the heating ventilation and air condition (hvac) system for a vertical farm. The aim is to devise a control system to maintain target temperature, relative humidity and vapour pressure deficit within the chamber while using the minimum amount of energy. All target factors affect each other so changing one changes the others. Also, methods of control affect multiple target factors in different ways. This leads to a complex multivariate system with multiple target parameters and multiple interlinked control methods.

References:
[Our Approach | Cambridge Global Food Security]
[Review of energy efficiency in controlled environment agriculture - ScienceDirect]

Expanding lung health initiatives across Scotland

Challenge holder:
The Cheyne Gang

Facilitator:
Cathal Cummins (Heriot-Watt University)

THE CHEYNE GANG
'Sing to Breathe'

The Cheyne Gang is a Scottish charity dedicated to supporting individuals with lung conditions, through fortnightly guided "singing for lung health" sessions.

Co-founded by 3 general practice nurses, with an interest in respiratory health and singing, our mission has shown significant promise in improving the health and wellbeing of individuals with respiratory conditions, e.g. Bronchiectasis, COPD (Chronic Obstructive Pulmonary Disease), Asthma.

However, we face two challenges that we currently need help in:

1. effectively measuring the impact of our therapeutic sessions, and
2. identifying the regions in Scotland where our services could deliver the greatest benefits.

These challenges require the identification and analysis of various data sets, including pulmonary rehabilitation referrals, social prescribing trends, and demographic indicators that affect lung health. Our objective is to map out the necessity for lung health initiatives across Scotland and to develop a framework that accurately quantifies the impact of our interventions within the communities we serve.

This is an opportunity to contribute to a cause that directly influences the well-being of individuals across Scotland. The outcome of this work will be crucial as we seek to broaden our reach and enhance our programs. This involves identifying areas with a high prevalence of lung conditions and understanding the accessibility and potential barriers to our services. The insights gained through this analysis will guide The Cheyne Gang in planning and resource allocation, ensuring that our efforts are targeted and impactful.