UK 2019 Topic #1

Research Topic Title:

- Optimisation of the scalable partitioning of complex network graphs for processing

Key Words:

- Large complex networks; Scalable; Optimisation; Partition; Graph theory

Research Topic Description, including Problem Statement:

- Complex networks are widely used to represent a variety of scenarios: from social networks and terrorist cell structures to airline routing, as well as being used in image processing and biology. They can be used to represent any system and harness methods to identify control points, communities and key players. The structure of the network is key to its function. Often, the analysis of these networks is undertaken manually however the scale and breadth of these networks in all scenarios are vastly increasing and becoming more complex. This leads to very large networks which are too large for manual analysis and increasingly reaching limits on computational processing. The size of these networks is expected to continue to increase exponentially.

- For several months, limited research has been undertaken to identify ways of overcoming this problem. There are a limited number of algorithms available to process such large datasets, and most require setting a pre-determined number of partitions. Some algorithms found include:
    - Overview of algorithms: https://pdfs.semanticscholar.org/7a84/d1bf4f4b24f178fec8b7c685fa1459d5829a.pdf
    - Graph partitioning based on spreading the load across a pre-defined number of computers: https://link.springer.com/article/10.1007/s41019-017-0034-4
    - Partitioning based on structure of graph: https://arxiv.org/pdf/1806.00907.pdf
    - Open source datasets of complex networks are available for use including: https://github.com/gephi/gephi/wiki/Datasets http://www.ee.cityu.edu.hk/~gchen/ComplexNetworks/SoftwareDatabases.htm

Example Approaches:

- A scalable method for partitioning complex network graphs into an optimal number of parts is required. This could be approached by:
    - Research into available algorithms and assessment of suitability for implementation and/or adaption. Any methods should be considered against:
        - Scalability
        - Consideration of preserving key network structure
        - Optimisation of number of partitions.
    - Consideration of data flow techniques as emerging methods for understanding the underlying structure of networks.
    - Implementation of one or more methods for assessing against open source data
    - Updating of method dependent on test results.
    - Technical partnering will be provided.

UK 2019 Topic #2

Research Topic Title:

- Effective markers for the detection of synthesised hazardous materials in waste products

Key Words:

- Chemical synthesis; trace detection; marker reactions; environmental chemistry.

Research Topic Description, including Problem Statement:

- Detection of an illicit laboratory through waste generated during the synthesis procedure:
    - There are a range of illicit chemicals, including homemade explosives, that may be manufactured by chemistry synthesis using readily available domestic precursors. These reactions typically involve bringing together two or more chemicals that would not typically be combined during their legitimate use.
    - The purpose of this research topic is to identify and characterise materials that can be added to precursor chemicals and will, when exposed to conditions typical in illicit synthesis, undergo a reaction to produce a readily detectable material. A response to this topic would seek to provide molecular markers and potential reactions to generate marker materials, which, alongside appropriate currently available detection technologies, will enable detection of illicit material due to markers in the waste stream. Careful consideration will need to be given to common reactions in legitimate household waste streams which may interfere and/or cause false-positives.

Example Approaches:

- Marker chemicals are used to detect chemical reaction progress, improve the resolution on Magnetic Resonance Imaging (MRI) scans or monitor the pH in biological cells. These chemicals may be detected through detection technology, looking for physical properties. Additionally, commercially available equipment is available that detects the vapours from illicit materials.
- There are two potential approaches:
    - Conduct a broad review of synthesis protocols for marker chemicals and identify synthesis routes that are appropriate to illicit synthesis routes.
    - Conduct a broad-spectrum review and analysis of the potential (low cost) detection technologies and the chemical or physical signatures that the detection technologies are most sensitive to.
- Based on the review, target molecules and reaction routes that can be formed as a side product of an illicit synthesis.
- For successful materials / technology combinations the research would also consider the real-world implications of its implementation including; limits of detection, interferents, false positives and operating protocols. An impact assessment on the impact of the inclusion of additional chemicals within a formulation on the legitimate use of the original chemical should also be completed.
- This research, whilst aimed at detection of illicit synthesis, could be conducted using inert substitutes to demonstrate a proof of concept reaction schemes.

UK 2019 Topic #3

Research Topic Title:

- Use of artificial intelligence to validate data and to automate correction of poor-quality data

Key Words:

- Data; Artificial Intelligence; Automation; Validation; Machine Learning; Analytics; Error Correction; Knowledge; Semi-Supervised; Supervised; Big Data; Search; Prediction; Data Cleansing; Data Enrichment; Deep Learning; Data Formatting; Data Processing; Natural Language Processing; Neural Network.

Research Topic Description, including Problem Statement:

- Presently there are a number of law enforcement systems that are used for logging and to make enquiries pertaining to a potential suspect. The data held by systems may contain inaccuracies, duplication, redundant information and become outdated. This can be the result of misspelt and non-validated entries, which is then stored and retrieved from systems. Due to erroneous data, users will attempt to insert new entries to rectify the inaccuracies, thus contributing to the disparate amount of information held on the one suspect. From an analytics' perspective erroneous data creates difficulties when comparing entries from multiple systems, as there may be multiple unique identifiers generated for the one suspect due to incorrect data. To deliver accurate and effective analytics, error correction and de-deduplication are generally carried out manually by an analyst who will need to validate the entries. This is often time consuming, laborious and is an inefficient use of the analyst's time, due to the volume of entries and resources needed to comb through the data.

- The advances of Artificial Intelligence (AI) and automation have the potential to greatly enhance our information sharing, processing and analytics capabilities. We believe that research and exploration into these technologies is essential for improving confidence in our own data, which could be used in future to explore options such as analytics for predictive policing, where the outcomes are dependent on the quality of data.

Example Approaches:

- Stage 1: Improve textual, Global Positioning System (GPS) and multimedia data submission, validation and verification of existing law enforcement systems.
    - Outputs include a comparison when a tasking is assigned on how will we know if:
        - The system has implemented the error corrections in comparison to the human analyst
        - There is a difference in productivity, that is has the quality of tasking improved due to the error corrections and suggestions made by the system?

- Stage 2: Data washing/cleansing/enrichment: Exploring and suggestion of an "intelligent" way to automate the process of erroneous data which an analyst would be expected to clean up and ensure data is fit for purpose.
    - Examine the use of automated and supervised/semi supervised learning approaches to learn corrections that should be applied to the data.

  - Confidence and error rate of the algorithm in comparison to a human analyst, for example trials to see whether a machine would be more accurate in their corrections and suggestions.
  - Data provenance such as the origins of the data. How has the algorithm/automated technique/method arrived at that decision?

- Stage 3: Repetition of the process but with multiple data feeds from a variety of law enforcement systems.
  - Outputs would be the same as above.
  - Inference of the data. Outputs could include deriving one "joined up" unique identifier purporting to that individual and seeking out any redundancies to be corrected and potentially merged.

- Stage 4: Early proof of concept demonstrator to determine the feasibility of outputs and any demonstrable benefits of implementing intelligent error correction. This will also be used to feedback and inform stage 5 work (below) as appropriate.

- Stage 5: Repetition of the process with other shared law enforcement databases.
  - Outputs would be the same as above.

- Stage 6: Introduction of modules to include open source data that is available in the public domain, for example: weather, company, land registration and census.

- It is envisaged that this topic could be approached by:
  - A review of current academic/research literature;
  - Testing of the technology capability;
  - Proof-of-concept demonstrator.

UK 2019 Topic #4

Research Topic Title:

- Application of sensing networks for situational awareness and early detection of threats

Key Words:

- Autonomous platforms; power conservation; power sources; live data; intelligent sensors.

Research Topic Description, including Problem Statement:

- Depending upon the situation or circumstances to be monitored, sensors will require to be deployed and remain in situ for periods of time, providing data to a central point. These sensors will enable decisions to be made that can mitigate threats. These sensing networks could be a simply as an intrusion detection system around a perimeter or inside a building, but these often require installation and routine maintenance. Furthermore, the location is often known well in advance and the logistics are carefully planned.

- There may be incidents where there could be threats to buildings or open spaces due to changing local dynamics. To effectively monitor the situation, it would be advantageous to deploy sensors to monitor the environment, such as Unmanned Aerial Vehicles (UAVs). However, UAVs have their challenges: size, payload, power, visibility. Therefore, what types of tools and techniques could we employ in the future that would enable us to: rapidly deploy sensors, that navigate to a location, remain in that location, source power in that location, transmit information to a control centre and remain discreet? The potential application and benefit for this is extensive: for example, monitoring construction sites overseas, monitor complex buildings, detect environmental conditions or detect the presence of CBRN (Chemical, Biological, Radiological and Nuclear) material or improve security in a wide range of scenarios such as following a major incident, without disrupting people going about their day to day business or creating more distress in circumstances where there has been a major incident.

Example Approaches:

- The use of unmanned aerial vehicle technology to enhance situational awareness is well known and widely employed in a range of scenarios and is merely a platform for other sensors to gather information. There is evidence of sensors placed *in situ* to monitor oil and gas pipelines over large distance to enable disruption of supply detection, sabotage or indicate a maintenance issue. These sensors can similarly self-repair as they operate in challenging environments in extreme temperatures. However, the challenge remains that these networks of sensors are often pre-planned installations. There is still a gap, to rapidly deploy small sensing networks which can monitor the environment, and then be removed without causing any disruption. This capability gap, could help many different sectors.

UK 2019 Topic #5

Research Topic Title:

- Research into improved methods for trapped-ion magnetometer sensors, detection and reporting

Key Words:

- Trapped-ion magnetometer, magnetic fields, DC-RF (Direct Current Radio Frequency), magnetic field gradients, NMR (Nuclear Magnetic Resonance), SNR (Signal to Noise Ratio), NQR (Nuclear Quadrupole Resonance), microwave fields.

Research Topic Description, including Problem Statement:

- Understanding the origin and source of signals within an environment are at the heart of protecting organizations assets from external and internal electronic threats. Signals can come from a vast range of sources such as unwanted mobile phone signals, Wi-Fi, RF frequencies, Unmanned Aerial Vehicles (UAVs) and so on. The ability to monitor, measure and assess these signals gives insight and protection across a wide range of government departments.

- Current generation ion-trap magnetometers are limited to measuring magnetic field strength at a particular point in space and are usually constrained to small areas over modest KHz (Kilo Hertz) ranges.

- Research and the development of a new Sensor is sought to be capable of much greater sensitivity and increased Signal to Noise Ratio (SNR) over existing systems.

- Required capability includes collecting magnetic fields over a large area, detection of extremely weak RF and microwave signals, sensing of magnetic fields in the DC-RF and in the GHz range with sensitivities on the order of pT/Hz^(1/2) (pico Teslas per square root Hertz) and a bandwidth in the μHz (micro Hertz) range as well as the ability to detect magnetic field gradients and detection of extremely weak RF and microwave signals.

Example Approaches:

- Example approaches include:
    - Alternative Magnetometer Coil approaches rely on high gain amplifiers which can add noise and instability to the overall system.
    - A solution that is designed to be portable.
    - Sensing range with the ability of the sensor to reject noise of any frequency apart from the one of interest. In addition, the sensor is expected to be able to sense magnetic fields with a frequency resolution down to the μHz level, Direct Current (DC) to 100s of MHz as well as sensing microwave fields around 12.6 GHz.

UK 2019 Candidate Topic #6

Research Topic Title:

- Opportunities and risks in the application of machine and deep learning to security screening

Key Words:

- Deep learning; machine learning; security screening; artificial intelligence

Research Topic Description, including Problem Statement:

- Research into the use of machine learning and deep learning as a means of automating aspects of the security screening process is increasing, particularly as applied to automated detection algorithms applied to interpretation of imaging data produced by aviation security screening systems. This brings with it undoubted opportunities to reduce the level of human effort required in the screening process, alongside potential improvements in levels of security. However, there are also risks in the early adoption of a rapidly evolving area of technology without full consideration of potential vulnerabilities, including how the effectiveness of systems can be rigorously quality assured both prior to deployment and throughout their lifecycle.

- An understanding of both the opportunities associated with the operational deployment of automated detection algorithms based on machine learning and deep learning techniques, balanced against the potential drawbacks and costs will be crucial to ensure that the most benefit can be derived from this technology.

Example Approaches:

- A study into potential vulnerabilities from the use of machine learning or deep learning approaches as applied to security screening applications, such as automated threat detection in X-ray images or millimetre-wave people-screening data.

- An evaluation of the best way to integrate automated machine learning and deep learning decision making with human interpretation, and the implications on human performance.

- An exploration of the public perception of the increasing use of automated decision-making in security screening, particularly through machine learning and deep learning.

UK 2019 Topic #7

Research Topic Title:

- Controllable and quantifiable methods for real-time explosive vapor generation

Key Words:

- Trace detection, explosives; vapor generation.

Research Topic Description, including Problem Statement:

- Explosive vapor detection systems provide a capability for detecting the presence of concealed explosives. However, before they can be used in the operational environment, there is a requirement to test their detection capability. Current testing processes are time consuming owing to the nature of generating reliable explosive vapor concentrations for range of materials of interest (high to low vapor pressure materials). Reliable and quantifiable means of producing explosive vapor samples, within short time-frames, are required to accurately determine limits of detection, and to better understand fundamental detection performance of devices. An additional requirement is to develop concepts that are able to generate vapor outputs suitable to test detection systems that sample different volumes, for example low volume, low sampling rate (< 1 litre/min) to high volume, high sampling rate (1 to 100s of litres/min).

Example Approaches:

- There are expected to be many potential approaches to this challenge, including the vaporisation of liquid samples on heated surfaces and thermal desorption.

- Any means of generating low concentrations of explosive vapor (parts per million to parts per quadrillion) could be a valid approach to this problem, or fundamental work exploring the issues around reliable generation of vapor.

UK 2019 Topic #8

Research Topic Title:

- Modelling the effects of mechanical stress for batteries in wearable applications

Key Words:

- Battery; batteries; electrochemical cells; Li-ion; lithium polymer; modelling; mechanical stress; wearables; wearable applications; composite structures; failure modes; conductive textiles.

Research Topic Description, including Problem Statement:

- Wearable technologies are becoming an increasingly large industry. As of 2017 the global wearables market was worth ~$38 Billion US Dollars by revenue and is forecasted to reach ~$85 Billion by 2022 (IDTechEx Wearable Technology 2017-2027). As a breakdown of the markets, this industry is dominated by smartwatches, fitness trackers and medical devices. Some of the leading players and products are well-known, such as the Apple Watch, Fitbit and the various hearing aids available. There is also significant growth expected in the e-textile market, from an almost non-existent market in 2016 to ~$2 Billion by 2022 (IDTechEx E-Textiles 2017-2027). This has been driven by the miniaturization and reduction in power consumption of electronics, advances in the maturity of printed electronics and the developments in weaving conductive threads. To further battery technology in these sectors, it is anticipated that batteries will be embedded directly into garments.

- The impact of the natural movement of a human and their garment on the mechanical stresses that develop within a lithium polymer cell is not well understood. As such embedded batteries in a wearable device are typically limited to a coin cell or a lithium ion cell which is encased in a relatively rigid outer packaging. Utilizing lithium polymer cells which are not rigidly encased and are instead in mechanically conformable devices will increase consumer appeal and could enable advanced power systems for wearables and e-textiles products.

- The aim of this topic is to better understand the mechanical and electrical degradation of lithium polymer cells when under a variety of mechanical stresses typical to wearable applications.

- It is noted that there is some open source information on the biomechanical movements and the muscular and joint forces of the shoulder region (Ambrosio, J.; et al. 2011 Symposium on Human Body Dynamics 2011) and the lower body during exercise (Thompson, W., K.; et al. *NASA/TM-2015-218852* 2015). There are also several e-textile and wearable porotypes that have been evaluated in the literature (Stoppa, M. and Chiolerio, A. *Sensors* 2014), where serpentine printed structures or woven conductors are used to aid strain relief during natural garment movement.

- These studies suggest that the number of mechanical variables that wearable electronics, specifically lithium polymer cells in this scenario, may undergo is vast. For example, the bending radii, number of bending cycles, twisting angle, effect of 'scrunching', the dimensions and aspect ratio of the lithium polymer cell, and the effect of the substrate or material supporting the lithium polymer cell (for example fabric, polymer, rigid leather backing). Due to the numerous variables outlined, it is impractical to test all scenarios.

- Computer modelling could dramatically reduce the amount of testing required. There have been models that have identified mechanical degradation in lithium ion cells during cycling (Laresgoiti, I.; et al. *J. Power Sources* 2015) and have simulated lithium ion cells under abuse (Ali, M. Y.; et al. *J. Power Sources* 2015), but to our knowledge there are limited open source publications modelling the effects of mechanical degradation on lithium polymer cells during realistic flexing scenarios.

- A successful model may incorporate the following:
    - Experimental observations as a basis to understand and then model particle to particle mechanical interactions in typical lithium polymer components, such as metal foils, coated electrodes and separators.
    - Simulate the effect of the mechanical stresses that occur within a multiple layered lithium polymer cell during typical flexing in a wearable garment.
    - Altering certain flexing variables (such as bending radii) to understand the effect of a variety of mechanical stresses on a lithium polymer cell.
    - Considering the elastic properties of the substrate or material supporting the lithium polymer cell.
    - Identifying likely failure modes of a lithium polymer cell and when they may occur.
    - Increase understandings of how the mechanical degradation effects the electrical response of a lithium polymer cell.
    - Including the effect of stresses from flexing on interconnects and woven conductive fibres.
    - It is noted that modelling human biomechanical movements is out of scope of this project.

Example Approaches:

- The unmounted soldier has an ever-increasing need for man portable power, leading to an increasingly heavy burden. It is desirable that equipment is powered by light-weight lithium polymer batteries that are body-borne, garment embedded, conformal, not impacting movement, and distributed evenly across a soldier. However, a barrier to utilizing such a system is the unknown effect of the mechanical stress on the lithium polymer cells, and subsequent impact on safety and the electrical performance fatigue. For example, if a lithium polymer cell is embedded within the soldier's garment, what are the effects of the mechanical stresses that the lithium polymer cell may undergo when the soldier is running?

UK 2019 Topic #9

Research Topic Title:

- Pathogen roles in complex diseases and unattributable infections, diagnosis and mitigation

Key Words:

- Multifactorial disease; complex disease; pathology; pathogen; virus; exposure; infection attribution; detection; mitigation; virus; genetic engineering.

Research Topic Description, including Problem Statement:

- Attributing disease to infection:
    - A range of pathologies borne from infections by pathogenic organisms have complex aetiologies which render the identification of their pathogenic origins challenging and complex. These are often multifactorial diseases which occur as a result of gene-environment interactions. In such cases, at worst the infections leading to pathological symptoms may go undetected medically, particularly when these symptoms are non-specific or disease is associated with numerous additional risk factors; at best, the pathogen is identified and acknowledged as a corollary disease-causing factor that is present, but there is no ability to causatively and definitively identify it as the single source of disease initiation.

- Attributing infection from natural versus intended exposure, and wild-type versus synthetic causes:
    - Whilst it may be that a disease, whether with multifactorial or causal origins, is the result of a naturally occurring infection, this may not always be the case. Identifying the cause, however, is a challenge. In contrast to certain biological or chemical toxins that are rarely encountered in the surrounding environment and whose attribution following third-party introduction is more easily isolated, many pathogens are naturally occurring within populations or geographical regions. In such cases it is more difficult to characterize how the pathogen was encountered; the context of exposure, through either natural or intended routes. This is further clouded by an indistinguishable symptomatic phenotype following infection by the same agent through opposing routes of exposure. An additional layer of complication to be considered is genetic engineering of pathogens, and the effects of this on modulating onset and severity of symptoms.

- The purpose of this research topic is to address and characterize the two related attribution topics above through literature, modelling and experimental methods where required. A response to this topic would seek to explore the field of disease origins by pathological organisms, exposure routes and infection likelihood, and applications of engineered variants and their implications.

Example Approaches:

- There is extensive and exhaustive literature describing the molecular mechanisms and pathways that pathological agent infection facilitates disease progression. However, there is more sporadic and limited understanding of (i) the contribution of pathogenic infection to complex diseases, and ii) the ability to provide attribution from naturally occurring vs. intentional exposure routes, and wild-type versus synthetic pathogens.

- An approach would be to conduct a broad-spectrum review and analysis of the potential pathogens, diseases and methods that fall into these two areas of interest. Following this, focus would be on prioritizing and assessing viability of these methods as targets to cause unattributable harm, identifying knowledge gaps, and where necessary conducting experiments to fill these.

- Another key aspect to be considered is diagnostic and protective mitigations. A wealth of medical and physical diagnostic and protective methods exist against pathogen infections and symptoms. There is space to characterize these methods in the context of known versus unknown and natural versus intended exposures, whilst exploring future strategic methods of mitigating unattributed infection risk.

UK 2019 Topic #10

Research Topic Title:

- Ultra-narrowband transceiver design for long range low power and low-profile communications

Key Words:

- Ultra-Narrowband; Low power wide area (LPWA); Long range communications; Low profile communications

Research Topic Description, including Problem Statement:

- With the advent of the Internet-of-Things (IoT) and machine-to-machine (M2M) applications, wireless network operators are diversifying their traditional human-centric, high rate, always-on access paradigm to suit a new age of connected objects with vastly different traffic patterns and usage demands. Such applications typically require cheap, low frequency radio interfaces with greater than 10km range and 10-year battery life for the transferal of infrequent short length frames. This has heralded new communication standards for so-called low power wide area (LPWA) networks designed to minimize power consumption and increase range. Ultra-Narrowband (UNB) is a promising technique in this field.

- UNB uses advanced signal processing techniques and exploits the low noise floor of low bandwidth communications (typically less than 100Hz) to enhance the signal to noise ratio (SNR) of an UNB receiver providing superior sensitivity over traditional wideband systems, hence improved range of operation. Low bandwidths (therefore low data rate) combined with short frame durations allow for extended battery durations at ranges of 30km or more in small form factor embedded devices. This type of technology is particularly suited for command and control applications, long range infrastructure-less text messaging or location tracking applications.

- An additional and infrequently considered aspect of UNB communication is the difficulty of observation and interception by unintended recipients. An observer must have narrowband equipment with a noise performance similar to the UNB system in order to firstly detect the signal and secondly must tune to the precise 100Hz channel at the correct time for a short burst. This is further complicated by the effects of clock jitter since traditional UNB devices typically utilize cheap hardware with poor frequency stability. These attributes if combined with additional encryption strategies make UNB favourable for low rate, low observable communications which may defeat an opportunistic hacker.

- There are still aspects of practical UNB implementation that require further research. The application of more advanced modulation and encoding schemes hold the potential to increase range further, however this will require additional signal processing which is only now becoming possible to perform within an acceptable power budget. Similarly, encryption methods such as transport layer security (TLS) become difficult when one is trying to preserve low power consumption and short data frames. The challenge is to devise methods that provide acceptable security without compromising the low power aspects of the communications device.

- Taking these issues into account, this project aims to facilitate long range, low data rate communications utilizing UNB technology to enhance battery life and reduce power consumption for low observable applications.

Example Approaches:

- In order to realise practical UNB communications, it is important to thoroughly understand the requirements of a potential system and expected performance of UNB technology. There is little literature surrounding this relatively novel technology so firstly a thorough analysis of UNB must take place. This will consist of three parts
    - Literature review – Survey the field for recent advances.
    - Simulation of typical UNB deployments to establish the performance bounds and realize potential issues.
    - A more thorough analysis of currently available UNB implementations.

- Quantify the possibilities of unintended reception by a third party with regard to:
    - The inherently undetectable nature of UNB communications.
    - The expected performance of a third party's reception equipment.
    - Enhancements in achievable range through advanced modulation and encoding schemes (these have been the subject of previously funded research).
    - The potential for enhanced integrity of transmitted data via encryption given the overarching requirements for low power and cost.

- This initial research will culminate in the primary goal of this study to design and prototype UNB communications equipment specifically for low rate, low probability of detection/interception communications. Key aspects of consideration will include:
    - Long range transceiver architecture whilst maintaining low power consumption.
    - Signalling and setup procedures for reliable/acknowledged data delivery
    - Frame formats for maximum utilization of available capacity
    - Battery design and provisioning

UK 2019 Topic #11

Research Topic Title:

- Characterization of physics and approximations in urban weather and atmospheric dispersion models

Key Words:

- Weather Research and Forecasting Model; Urban Weather; Atmospheric transport and Dispersion; Plume Modelling; Machine Learning; Parallel Processing; Atmospheric Physics; Large Eddy Simulations; Computational Fluid Dynamics; Climatology; Metrology; Chemical, Biological, Nuclear, Radiological, & Explosives (CBRNE); Computer Science; Atmospheric Transport and Dispersion (ATD)

Research Topic Description, including Problem Statement:

- Urban and microscale weather models have been developed and deployed by many sectors within the U.S. Government for purposes of energy production, consequence management, pollution monitoring, force protection, and first responder coordination. New advancements in computing architectures, such as highly parallel processing (Graphical Processing Units, GPUs), and novel algorithms provided by the Artificial Intelligence and Machine Learning (AI and ML) communities provides new approaches to explore the non-linear processes of *Urban Weather* and *Material Dispersion Modeling*.

- The dispersion of materials throughout the environment is driven by highly complex nonlinear atmospheric processes, which have proven incredibly difficult to accurately model, especially in urban/microscale environments. *Current urban dissemination models* are driven by high order approximations, which lowers computational demand at the cost of prediction accuracy and robustness. However, research has also shown that modeling attempts based solely on physics and first order calculations have also surprisingly fallen short of performance expectations. These two points suggest there is an optimal point of balance between approximations and physics as it pertains to urban dissemination modeling. The "point of balance" between approximations and physics will likely be completely unique to a particular scenario, and thus balance will need to be dynamically derived to be useful across the many potential use cases.

- The interest of the current solicitation is not to generate a dispersion prediction model, but is rather focused on the academic pursuit and characterization of optimal balance of ***Physics and Approximations*** in the context of the highly complex urban weather and dispersion scenarios.

- Urban environments provide an almost infinite dimensionality to dispersion modeling, through complex turbulence features and shifting boundary layers, which arise from tightly packed architectural volumes and pattern of life activities. Factors defining the "urban setting" further compound the already highly dynamic fluid dynamics of atmospheric systems that are the driving force behind dispersion processes.

- Dispersion modeling, especially in urban environments, requires the careful balance of first order calculations with environmental approximations. Each modeling scenario is uniquely dynamic, and the approximation/calculation balance would seem to require varying degrees of optimization between scenarios.

- The current research solicitation involves the characterization of the optimization between first order physics and dispersion approximations across modeling scenarios in urban settings.

- The key question this announcement is trying to answer is; how should one balance physics and approximations in ATD modeling in urban environments? Generating and running urban dispersion is not within scope of this announcement and those responses detailing such efforts will not be accepted. Scientific understanding yielded under this announcement will provide a foundational understanding of dynamic interplay in modelling between physics and approximations which currently does not exist*. Therefore, results of this work would likely be broadly impactful and applicable across the modelling communities using various Urban Weather and Dispersion Models.*

Example Approaches:

- Research could focus on deconstructing dispersion events to approximate the highest contributing physical factors driving the process of urban dispersion. This approach would enable the ranking of the feature space to determine which model features should be approximated. Open datasets, such as Joint Urban 2003 Tracer Field Tests, could be leveraged as ground truth experimental data.

- Machine learning (ML) alone is not expected to yield significant increases in dispersion prediction accuracy, but ML could be leveraged to sort out which contributing factors should be prioritized through physics and which features should be handled through approximations only. How should models handle features within a scenario to yield the highest performance?

- Approaches should be compared against the available experimental data to demonstrate a performance improvement. The key research question under the current announcement is solely focused on characterizing the optimization of approximation versus physics to enable higher accuracy predictions. Other considerations, such as speed and processing efficiency, are not the focus of the current solicitation. The solicitation is not seeking new dispersion models.

UK 2019 Topic #12

Research Topic Title:

- Mathematical intuition in neural discovery and understanding (MINDU)

Key Words:

- Machine Learning; Artificial Intelligence; Deep Neural Networks; Deep Learning; Explainable AI; Generative Adversarial Networks; Adversarial Attacks; Non-parametric Bayesian Networks; Probabilistic Programming; Neural Chunking; Probabilistic Graphical Models; Spectral Theory; Harmonic Analysis; Operator theory; Function Approximation; Dynamical Systems; Lie Algebras; Bratteli-Vershik Diagrams; Control Theory; N-gram modeling; Hidden Markov Models; Model Capacity; Statistical Learning Theory; PAC Learning; Vapnik-Chervonenkis Dimension; Stochastic/Stationary Processes; Entropy; Fisher Information; Information Bottleneck; Statistical Mechanics; Renormalization Group.

Research Topic Description, including Problem Statement:

- In recent years, there has been a tremendous growth in research in machine learning and artificial intelligence. This growth is spurred by trends toward large curated data sets, availability of General Purpose Graphical Processing Unit (GPGPU)-enabled cloud environments and free collaborative ecosystems for rapidly distributing and testing new software. While the growth in Machine Learning and Artificial Intelligence (ML/AI) continues to expand, there has not been matching progress in understanding the implications of new ML/AI applications. In particular, recent deep learning techniques have shown tremendous power in addressing computer vision and human language technology problems, but are shown to succumb to broadly engineered adversarial attacks.

- Much of the research on explainable ML/AI has focused on the security of ML/AI techniques, and on better understanding and characterizing failure modes. The work has generally looked at the problem from an experimental, or statistical learning theory point of view. There has been little research that taps into previous deep mathematical theory that is relevant in this domain.

- In particular, recurrent neural networks (RNNs) such as Long, Short-Term Memory (LSTM) models may be viewed as dynamical systems preserving an invariant measure, or stationary processes. Note that well-studied Markov Processes (or Hidden Markov Models, HMMs) are stationary. There is a long history of research on measurable dynamics, including that of von Neumann, Kolmogorov, Shannon, Ornstein, Furstenburg, and more recently field medalists: Lindenstrauss, Avila, Mirzakhani and Venkatesh. In 2015, field medalist Terence Tao posted a 77-page preprint on the Navier-Stokes Equations; while falling short of solving the Millennium Problem, did shed new light on the possibility of a counter-example. On page 15, Tao writes:

> *"It is worth pointing out, however, that even if this program is successful, it would only demonstrate blowup for a very specific type of initial data (and tiny perturbations thereof), and is not necessarily in contradiction with the belief that one has global regularity for most choices of initial data (for some carefully chosen definition of "most", e.g. with overwhelming (but not almost sure) probability with respect to various probability distributions of initial data). However, we do not have any new ideas to contribute on how to address this latter*

question, other than to state the obvious fact that deterministic methods alone are unlikely to be sufficient to resolve the problem, and that stochastic methods (e.g. those based on invariant measures) are probably needed."

- There are many questions that may be explored with respect to Deep Learning (DL) models from a mathematical perspective. DL models demonstrate a sensitivity to initial conditions, both in the training regimes, and during run-time classification. Local minima distribute throughout the parameter space. It would be interesting to understand how local minima spread throughout the parameter space? Which local minima track closely the output by an absolute minimum, and how do local minima distribute as models increase in size, and architectures change? How do regularizations effect convergence to local minima or potentially to an absolute minimum? Is there any advantage in introducing regularization (that is convexity constraints)? Potentially viewing DL models in a larger hyperspace will yield insights. Could there be ever evolving or constantly learning networks which stay ahead of potential adversarial attacks? Could a better mathematical understanding of Deep Neural Networks (DNNs) lead to better network design or more efficient models as well as improved convergence and generalizations of models?

Example Approaches:

- One approach is to apply the theory of function approximation or related principles from harmonic analysis. One example can be seen by the research of Mhaskar and Poggio, *Deep vs. Shallow Networks: An Approximation Theory Perspective*.

- Other recent research has pointed to the strengths and limitations of an important framework, Generative Adversarial Networks (GANs). GANs can be used to boost training and generalization of DNN, as well as create realistic synthetic data.

- When the data to be modeled has a temporal aspect, other areas come into play such as non-parametric statistics, time series modeling, statistical physics, topological and measurable dynamics, statistical learning theory, time series prediction and econometrics. There has been little research applying principles from pure and applied mathematics to better understand deep neural networks.

- There could be advantages to exploring a universal representation of stationary processes and how these representations might be used for prediction or learning features for distinguishing various temporal phenomenon. Examples include RNNs or possibly other mathematical models such as adic transformations defined on Bratelli-Vershik diagrams (that is a type of directed acyclic graph).

- Another approach might explore the renormalization group. For example, see the 2014 preprint *An Exact Mapping between the Variational Renormalization Group and Deep Learning* by P. Mehta and D.J. Schwab.

UK 2019 Topic #13

Research Topic Title:

- Construction and evaluation of a compressive imaging system from a single indium gallium arsenide photo sensor

Key Words:

- Compressive sensing; sensing; photosensing; single-pixel imaging; through-the-wall radar; antenna arrays

Research Topic Description, including Problem Statement:

- Compressive sensing is a signal processing technique that uses the expected sparsity of a signal in a certain basis to capture and reconstruct the information using fewer samples than that of the Nyquist rate. This method, however, can only be used when all of the data is available to be sampled and the basis functions projected in a given moment. Thus, compressive sensing lends itself to spatially or spectrally spread data, such as two-dimensional (2D) imaging applications, antenna arrays, or even multi-view through-the-wall radar reconstructions. Techniques have been proposed to use it for temporal signal data, using high-speed shifting cascaded digitizers, but the value of that approach is dubious. For imaging, the act of projecting the data on a basis function is done by simply applying a dynamic image mask in the system optics (using a micro-mirror array or filtering Liquid Crystal Display, LCD, matrix), and a single photosensor to integrate the resulting total light intensity. The use of a single photosensor can be a significant cost advantage, with or without compressive sensing, versus a matrix of high quality photosensors. Compressive sensing theory is currently being explored and evaluated as a means to enable various different measurement systems. The specific problem to be addressed here is the construction of a single pixel compressive imaging system using a single InGaAs photosensor designed to be as practical as possible, and the evaluation of the practicality for using the resulting system. The LCD image mask should be integrated into the photosensor such that the system only needs a single lens. Supporting the system, the optimal basis functions should be investigated such that real images are maximally sparse and compressibility is maximized. Also, compressive reconstruction of images should be improved to mitigate high frequency noise when solutions are not sparse. Also, reconstruction algorithms should be optimized for speed, and computer-identifiable indicators of image quality should be used to determine when a solution is acceptable. Beyond the imaging system, the practical value of using compressive sensing to improve the methods of other applications such as antenna arrays, through-the-wall radar, and quantum photon entanglement imaging should also be evaluated.

Example Approaches:

- Construct a single pixel monochromic imaging system with compressive sensing and a single high quality InGaAs photosensor, including all hardware, optimized software algorithms, and optimal basis functions. The system should be constructed as small as possible, and as self-contained as possible, integrating the LCD filter with the photosensor and using only a single focusing lens.

- Research optimal basis functions for different types of real data (images of different types, non-uniform baseline antenna array data, modern urban frequency spectra and so forth.).

- Evaluate, both experimentally and theoretically, all practical considerations of the use of the imaging system, such as sensor noise tolerance, system size for different dynamic mask types, optimal dynamic masks performance, temporal tolerance and sampling rate for imaging objects in motion, processing time and power and so on.

- Evaluate the use of compressive sensing in the practical implementation of other proposed applications, such as through-the-wall radar imaging, antenna arrays, and quantum photon entanglement measurements.

UK 2019 Topic #14

Research Topic Title:

- Quantum and optical sensors

Key Words:

- Atomic sensor; optical sensor; quantum; NV centers in diamond; trapped ion; magnetometer; atomic clock; atom interferometer; optical frequency comb; optical waveguide; optical fiber; chip scale; electromagnetic field sensing; optical sensing; acoustic sensing; inertial sensing; timing measurements; gravitational measurements; noise suppression; noise characterization

Research Topic Description, including Problem Statement:

- Quantum sensors, such as Nitrogen Vacancy (NV) centers in diamond, atomic magnetometers, atomic clocks and atom interferometers, offer extremely sensitive instruments that that may also be operated outside of a laboratory environment. High-performance optical devices can be a co-technology for these sensors (for example, stabilized lasers and optical frequency combs are used in some atomic clocks) but may also be used as key components in other sensor systems. This topic supports research that will improve the performance of small- from chip-scale to person-portable- quantum and optical sensors, through device improvements and/or suppression of noise affecting the device performance. This topic also supports the use of quantum or novel optical sensors in a proof-of-concept demonstration either in a laboratory or field environment.

Example Approaches:

- Projects for this topic can use a variety of approaches to improving the sensors and demonstrating their use. Some interesting techniques are to reduce decoherence or increase quantum sensor response using, for example, dynamic decoupling techniques, different atomic transitions, various laser modulation formats, quantum techniques such as squeezed laser light, or by multiplexing several sensors. New manufacturing techniques or materials and coatings may also improve both quantum and optical sensor performance and may reduce their size and make the sensors more manufacturable. Demonstrations should show the potential advantages of the sensor over traditional sensors—for example, improved imaging resolution using the output of a chip-scale frequency comb, increased sensitivity of an atom interferometer gravimeter to changes in nearby mass distributions, or longer (Global Positioning System) GPS-free operation times of acoustic beam-forming using miniature atomic clocks. These suggestions are not meant to limit proposed approaches or applications but only to give a broad sense of the scope of the topic.

UK 2019 Topic #15

Research Topic Title:

- Detecting needles in haystacks – how can quantum sensors help improve security screening

Key Words:

- Detection of explosives, weapons, contraband; security screening of vehicles, containers, cargo, deliveries, pallets; security screening of crowds

Research Topic Description, including Problem Statement:

- Whilst there is a wide variety of proven technologies for screening people and items for the presence of explosives and weapons threats and other contraband, deployment of these established technologies can become impractical from the perspective of efficiency as the requirement scales. For example, while baggage X-ray machines can screen hundreds of items an hour, larger, purpose-built machines can typically only screen a few tens of vehicles or containers per hour. Similarly, airport-style screening of people and their possessions cannot easily be scaled to work at major sports stadia and concert venues where peak flows of people are much greater.

- Globally, governments, industry and academia expend considerable effort identifying and commercializing innovative improvements to established technologies such as X-ray, metal detection, passive millimetre-wave, radar, explosives trace detection.

- How might innovations in quantum technologies – especially quantum sensors – be harnessed to offer alternative approaches? In particular, how might quantum techniques offer new, more efficient and / or effective ways of detecting threat items that are several to many orders of magnitude smaller than the volume being screened – the proverbial problem of "finding a needle in a haystack"?

Example Approaches:

- Potential applications / problems include:
    - Screening vehicles (cars, vans, lorries, buses, coaches and so on) for explosives and weapons threats and other contraband;
    - Screening shipping containers, pallets and other bulk cargo / freight / delivery items for explosives and weapons threats and other contraband;
    - Screening individuals and their possessions for very small contraband / threat items (for example, sim cards, Universal Serial Bus, USB, sticks, razor blades);
    - Screening groups – or even crowds – of people collectively (rather than individually) for the presence of explosives and weapons threats.