# Research topics 2025

# Topic 01
# Novel S&T solutions for unexpected loss of Positioning, Navigation and Timing (PNT) capabilities

**Key words:** PNT (Positioning, Navigation and Timing), CNI (Critical National Infrastructure), resilience, risks, mitigation, technology.

## Research topic description, including problem statement:

Positioning, Navigation and Timing (PNT) services are vital for the UK economy, as well as for critical sectors including emergency services, transport, defence, space, and energy. However, in some sectors, the vulnerabilities of PNT to both natural and ground-based interference, including through malicious attacks, are less understood. Meanwhile, over the last 15 years, the threats posed by accidental and deliberate interference and cyber-attacks have steadily evolved and increased. Examples of intentional interference range from teenagers subverting computer games e.g., Pokémon GO, to criminals attempting to flout financial trading regulations, and to numerous vessels in the Black Sea reporting GPS interference (Government Office for Science (2018, January 30). Satellite-derived Time and Position – A Study of Critical Dependencies. GOV.UK. Satellite-derived Time and Position (publishing.service.gov.uk).

We know that certain sectors are reliant on PNT to operate quickly and effectively including for critical aspects such as communications.

For this reason, the focus of this research is multifaceted. Our ideal deliverable would be to develop a better understanding of the resilience of CNI and how they would prepare for, respond to and mitigate against the risks associated with PNT. The UK already has extensive processes in place to deal with such threats, so we would like this research to focus on novel S&T solutions. Surrounding questions to this topic centre around, what steps could be taken to minimise the effect of a loss of PNT and how to effectively and efficiently operate in a PNT-denied environment.

This research will be fundamental in supporting the development of a policy response as well as shaping considerations for future technology.

## Example approaches:

Current research is neither comprehensive nor prescriptive. Therefore, this project provides the researcher with an opportunity to explore, in detail, these subject matters.

We will not be overly prescriptive on the scope of this research – this research area provides you with the opportunity to shape this project in the direction that your findings take you. However, it would be beneficial to have an individual from the engineering sector to lead on this research, with a systems-engineering approach and an ability to explore and analyse deep technical aspects.

We can facilitate access to end users for this research project, if required, as well as those organisations who are responsible for our PNT-related systems.

We appreciate that this is a broad topic covering many aspects of PNT research, therefore, we would welcome any expressions of interest in all or part of the above.

## Glossary:

Positioning, Navigation and Timing (PNT): PNT is a service that enables: Positioning, the ability to determine location and orientation. Navigation, the ability to determine current and desired position. Timing, the ability to acquire and maintain accurate and precise time from a standard anywhere in the world.

Critical National Infrastructure (CNI): Infrastructure that is essential for the functioning of a society and economy and deserving of special protection for national security.

## Topic 02
## Preparation, quantification and characterisation of trace explosive samples

**Key words:** trace, quantification, explosive.

### Research topic description, including problem statement:

To understand the capability of explosive trace detection solutions, specific amounts of explosive material are pipetted on to swabs or surfaces for detection systems to interrogate. This allows the limit of detection (LOD) of a system to be determined but isn't very realistic when it comes to finding real traces. The thumb print test takes a known amount of explosive deposited on a surface and then stamps a standardised thumb on to it. It is then imprinted onto different surfaces or swabs multiple times, to create more realistic residues, decreasing the residual amount with each print. The current challenge of this technique is whilst the print is more realistic, the quantity of explosive within the print is unknown. So, whilst both tests combined provide a qualitative measure for how well a trace detection system performs, ideally, we require a method that combines the quantitative nature of the LOD technique with the more realistic thumb print test.

As such, although we have methods for quantifying the amount of explosive on surfaces this method is destructive (solvent extraction followed by GC/LC-MS analysis) and resource intensive. We are not able to quantify mass loading before testing a surface. We therefore require a quick, non-destructive, technique that could be used to determine mass loading on a range of different surfaces. It would also be useful to understand the surface coverage, crystal form, particle size and other characteristics.

Separately, but as part of the same topic, we would also be interested in investigating innovative techniques to enable more representative, realistic and reproducible trace contamination to be deposited onto surfaces for T&E purposes.

We could provide some examples of surfaces of interest and range of mass loadings we would need capability for.

### Example approaches:

The focus of this project is to leverage emerging technology to develop a low cost, low burden solution to quantify the amount of explosive residue on various substrates.

Approaches should include the development of a prototype system.

## Topic 03
## The psychology of intuition - the implications associated with creativity and cognitive bias for the security community

**Key words:** game theory, search bias, improving decision making, human factors and security, augmented reality.

### Research topic description, including problem statement:

Creative and innovative thinkers provide huge benefit to the security sector and these characteristics are highly beneficial to analysts, engineers and scientists. These individuals can identify alternative solutions to reoccurring problems and adapt to new or novel situations, giving an organization huge advantage. Furthermore, these individuals have a heightened sense of intuition compared to others even in close peer groups. However, over a period of time their creative, novel thinking can be affected by organizational cultures, group or task behaviour. This manifests as a degradation of novel thinking or indeed cognitive bias from conducting repetitive tasks. This is of particular risk to those who conduct searches and inspections and the critical element to certify an environment as secure and safe.

Currently technology is used to assist to certify an inspection environment is safe, but do end users become biased over time in the manner in which they use/ do not use the technology provided correctly? To some degree an element of intuition can lead highly skilled individuals' experimentation, whereas others do not demonstrate the heightened flare of creativity. In the latter example, this can lead to both false positives and false negatives in results. In other words: decision making can become biased over time, leading to heightened risks from the repetitive nature of the tasks.

Do individuals lose their edge due to task fatigue or is it more peripheral bias that can paralyze application of novel thinking? Are some individuals more prone to search bias than others? If so, why?

Could the application of game theory provide any insight into this? Is it possible to develop a psychometric tool that could assist with the nurturing of creativity in individual officers?

Can differences between trained individuals be measured and what technologies could be used to prompt, focus, or even train for heightened intuition/ creativity to solve a problem? The relationship between eye movements and eye tracking can demonstrate bias in an independent way.

The use of augmented reality may be beneficial both during training and on task to provide prompts for the end user. How could this technology improve the decision-making during searches and prevent or direct biased thinking?

The topic will require a proposal that is a combination of applied psychology, together with some form of engineering innovation. It will also need to present new innovative approaches that have not already been explored through research for the benefit of those who conduct routine searches and inspections.

## Example approaches:

- Eye movement research is a field of psychology that has shown how eye movements and tracking eye movements, directly influenced our attention and understanding of the world around us.
- Various psychological theories have shown how task fatigue can lead to a degradation in performance.
- Technologies such as augmented reality and immersive reality have been shown to be beneficial for commercial pilots to learn in a simulated environment, how to make critical decisions when faced with a real-world event.

## Topic 04
## Machine learning trained fingerprinting of the near field measurement

**Key words:** machine learning, fingerprint, near field, electromagnetic, EM, RF.

### Research topic description, including problem statement:

Electromagnetic (EM) shielding controls have widespread usage ensuring secure communication facilities do not emanate unintentional EM signals. Over the past few years near field measurement has been obtained with traditional multiprobe technique in combination with analytical functional evaluation to provide a measurement of the complex and dynamic EM field, however this approach introduces uncertainties in its measurement result due to dynamic field complexity within its surrounding. Recent advancement in Machine Learning (ML) with linear/non-linear mapping algorithms has exhibited novel techniques to solve complex analytical functions in real-time.

This topic looks for the development of fast and efficient ML integrated near field measurement within a dynamic and complex EM environment to provide fingerprinting of its surroundings for secure communication.

### Example approaches:

- Literature survey for the near field measurement of EM signals.
- Near field measurement of an EM surrounding.
- Development and application of the ML algorithms integrated into near field measurements.
- Real time measurement and response accuracy enhancement within a dynamic EM environment.

### References:

- Wen, J et al., doi: 10.1109/TEMC.2020.3004251.
- Alavi, RR et al., doi: 10.1109/APUSNCURSINRSM.2019.8888868.
- Deschriiver, D et al., doi: 10.1109/TEMC.2011.2163821.

## Topic 05
## Light weight metamaterial ultrawideband frequency absorber

**Key words:** metamaterial, absorber, ultrawideband, polarized, acoustic, RF, technical surveillance, novel materials, attenuation.

### Research topic description, including problem statement:

Metamaterials have been widely used in the past few years for RF as well as acoustic shielding applications. These are typically only applicable over a limited bandwidth, and there has been limited research in the metamaterial absorber design for combined acoustic and RF application, from a few Hz up to 30 GHz. There are additional research gaps that RF absorption effects suffer from the incidence polarization of its signal, meaning that shielding often does not fulfill the requirements as desired for its application.

In this topic we would like to explore the research and development of novel lightweight metamaterial absorbers to provide the frequency absorption over a wideband range from a few Hz to 30 GHz that is insensitive to the incident signal phase. The development would help in providing an absorption and attenuation of various sound and RF signals emanating from multiple consumer devices and sources and bring new vitality into traditional approaches.

### Example approaches:

- Computational modelling and calculation of the architectural design.
- Model and simulate the behavior of metamaterial absorber for its intended frequency range.
- Identifying candidate materials and novel composite structures with negative permittivity and permeability, potentially using conductor and dielectric sandwich materials.
- Optimise the design for the physical construction.
- Experimental verification of the physical design and its analysis for its application.
- Development of lightweight design for its integration within a physical space.

### References:

- Zhang et al., 2020, “Engineering Acoustic Metamaterials for Sound Absorption: From Uniform to Gradient Structures”, iScience.
- Yang and Sheng, 2023, “Acoustic metamaterial absorbers: The path to commercialization”, Applied Physics Letter.
- Begaud et al., 2018, “Ultra-Wideband and Wide-Angle Microwave Metamaterial Absorber”, MDPI.
- Tirkey and Gupta, 2019, “The quest for perfect electromagnetic absorber: A review”, International Journal of Microwave and Wireless Technologies.

## Topic 06
## Utilizing a modern mobile to provide a level of TSCM capability

Please note that applicants for this research topic will be required to undergo security vetting and must meet the necessary security clearance requirements. If the Research Fellow fails to meet these requirements or does not complete the vetting process in a timely manner, the award will be withdrawn.

**Key words:** TSCM, mobile phone, tablet, discrete, AI.

### Research topic description, including problem statement:

Current Technical Security Countermeasures (TSCM) tools are various, expensive and a range of physical sizes. All of them together make a useful tool set, but there are operational challenges such as logistics, ease of use, discretion that are presented in their application.

The modern mobile platforms – i.e. mobile phones and tablets – are a high specification computer processor with a variety of measurement and communications sensors and transducers. These can be exploited to measure the physical world and collect information and measurement data equivalent to the TSCM tools, in a single device.

We are looking to find out how the intrinsic sensors and features on a mobile phone (accelerometers, cameras, magnetometers, Bluetooth, GPS, near field charging loops, vibrometers) can be leveraged in conjunction with software applications and software defined radio to be useful as a tool in monitoring an environmental for technical threats, such as hidden electronic, audio or visual devices.

Key questions – can a phone be used as a TSCM tool to detect hostile threats at first fix level? Secondly, how effective is that tool when compared to the specific equivalent TSCM tool. Additionally, what are the benefits of collecting data simultaneously and aggregately at scale?

Could a suite of modules apps operating the phones capabilities draw additional benefit of accumulated of data being analysed and filtered utilizing an ML or AI module to highlight data of interest or relevance, with all data recovery made to removeable media for security transfer by approved means leaving transportation of the device without sensitive data.

### Example approaches:

- Downloading and comparing commercial applications for example wifi scanning and ranking for performance.
- Utilizing a bespoke overarching application to manipulate and leverage the commercial applications.
- Utilizing external peripheral devices to exploit sensing not native to the phone. Infrared camera, lenses, borescopes, microphones.
- Utilizing a bespoke overarching application to manipulate and leverage the commercial applications would this be achievable with ML or AI components.

## Topic 07
## Utility of synthetically generated data for training or testing AI/ML systems

**Key words:** synthetic, training, evaluation, testing, AI, ML.

**Research topic description, including problem statement:**
How feasible is the use of synthetic data, in place of rare domain specific data, to train or evaluate ML models? What are the associated risks, benefits and explainability considerations?

(Video/imagery systems are used as an example, but the topic under investigation could cover any physically or digitally collected data or data-sets.)

Scenario 1 problem statement:
It is currently difficult to train novel ML models on data that is sufficiently representative of their final use case, when not much domain specific data is readily available. Specifically:

- large public data sets tend not to exist for the specific scenarios that are of interest,
- operational data cannot be made available and/or is insufficient in quantity,
- production, curation and labelling of 'real' data to cover all variants of scenarios can be extremely costly, complex and time-consuming (eg. i-Lids).

Scenario 2 problem statement:
A model pre-trained on publicly or commercially available data has been submitted for evaluation against an operational requirement that represents a similar task.

Insufficient domain specific data exists with which to evaluate the capability thoroughly, as it has generated in an uncommon manner.

Questions to be answered:
With advancements in the ability to generate increasingly realistic synthetic data (e.g. by Game Engines in the video example), what is the possibility and utility of generating representative synthetic data to allow training of AI systems used to detect and/or identify specific content, or otherwise enrich live or large operational data feeds?

If we only have access to small amounts of real data with which to test a pre-trained AI, is it possible to synthetically extend the data to a suitably sized test set?

Can the synthetic data be generated with suitable detail to embed the desired information for later extraction?

Are AI's that have been trained this way subject to any biases in response?

Can the efficacy, accuracy or other performance metrics of AI's trained on synthetic data be relied upon when the same systems are then given 'live' data? And if not, is there a predictable performance adjustment that can be applied?

How does 'explainability' work with AI's trained on synthetically generated data?

What are the ethical considerations around the use of AI/ML systems trained on, or tested against synthetic data?

### Example approaches:

Scenario 1:

- Create two 'real' datasets and one synthetic dataset, that mimic a true data type of interest.
- Train two instances of an AI, one on the synthetic and the other on the first real data set.
- Test both AI instances on the 2nd 'real' dataset and compare performance.

Scenario 2:

- Make a short 'real' dataset.
- Make a larger 'real' data set.
- Synthetically extend short 'real' dataset.
- Test pre-trained AI to ensure responses are similar to both.

NB: 'real' as used above, means a dataset that contains true data (non-synthetic) that has been mocked-up or manipulated to provide an accurate representation of operational data.

## Topic 08
## Bio-manufacture of quantum technology

**Key words:** quantum biology, magnetometry, spin-dependent biochemistry.

### Research topic description, including problem statement:
Quantum 2.0 technologies have great potential. However, extensive engineering is required to deploy these cold-atom technologies. This confounds exploitation. Biological systems are thought to employ quantum mechanisms (e.g. magnetosensing in bird migration). This must happen in a wet and warm biological environment. If we can understand biological quantum sensing, it will be possible to do two new things. Firstly, the construction of new quantum sensing technologies, such as bio-magnetometers. Secondly, the bio-mechanisms that sustain quantum superposition (in wet and warm environments) may be emulated in biomimetic manufacturing to simplify and accelerate exploitation of quantum 2.0 technologies.

### Example approaches:
There are a number of biochemical chassis known to be responsive to magnetic fields, e.g. fluorescent proteins (Hayward 2024 preprint) and cryptochrome flavoproteins (Hore 2024). These biochemical systems allow structure-function relationships to be explored to define the mechanisms exploited by biology to leverage quantum superposition as a biological resource.

Mechanistic insights can then be engineered in to novel biomaterials, such as new bio-parts (e.g. *de novo* designed proteins, Hsien-Wei Yeh 2023) or more complex bio-systems (e.g. persistent environmental surveillance, Tang 2021).

## Topic 09
## Novel approaches to space domain awareness Radio Frequency Satellite Characterisation

**Key words:** space, SDA, characterisation, RF.

### Research topic description, including problem statement:

With space becoming increasingly congested due to the decreasing costs of access and increasing technological maturity, the ability to detect, track and characterise this increasing number of satellites is becoming ever more challenging. In addition to this, with the barriers to entry lower, there is ever greater diversity of satellite size and type; and greater complexity in understanding how satellites are operating. For safety-of-flight and national security purposes, both defence and civilian agencies are required to understand the current functional status of satellites in order to understand appropriate approaches to collision avoidance and to ensure that satellite operators in their jurisdiction are complying with license conditions.

For satellites across all orbital regimes (Low Earth Orbit, Geostationary Orbit, etc.), the UK's published Space Domain Awareness (SDA) requirements outline a variety of satellite parameters which must be determined through space object characterisation. These include the following:

- Active/Inactive status
- Status change detection
- Rotation/tumble rate
- Unambiguous unique Identification of satellites
- Attitude determination
- Mass
- Physical dimensions
- Construction materials
- Conjunction avoidance capability assessment
- Identification of satellite type/class (e.g. bus type)
- Satellite Payload identification
- Capability assessment – the overall evaluation of a Resident Space Object's payloads, ability to maintain and/or change its orbit and the operational status of various subsystems.
- History of orbital changes and manoeuvres
- Fault / Anomaly Detection
- Payload activity
- Associated Electromagnetic activity
- Damage assessment (the evaluation of damage or loss caused by an event)
- Verification of passivation procedures
- Payload deployment
- Rotation axis.

Operationally, both electro-optical and radio frequency (RF) techniques can be used to determine a number of these parameters, but different orbital regimes and satellite behaviours present different challenges to successfully addressing all characterization tasks. In many cases, novel techniques are required to provide this information at a sufficient level of detail or over longer periods of time.

The focus of this topic is to conduct research on novel RF sensors and associated data processing techniques to enhance capabilities for space object characterisation; either in directly addressing the range of characterisation parameters relevant to the UK's SDA requirements, and/or via methods to increase the duration of collected data or reduce its latency. Novel RF sensors under consideration could be similar to those classically described as radar, as well as any other different uses of the RF spectrum for sensing. Non-exclusive examples of this could be passive or opportunistic RF sensing.

It is not currently possible to meet the SDA characterisation requirements in totality at the performance level required by defence and civilian agencies. This research will aim to address this, particularly through understanding novel ways in which RF sensors and processing of data from RF sensors can contribute. It is not expected that the research under the fellowship produces more than a proof of concept or demonstration, where appropriate, as opposed to an operational system.

### Example approaches:

- Novel RF sensor designs or configurations that are capable of providing characterisation information about satellites with increased performance or duration than current sensors.
- Novel approaches to RF sensor data reduction and/or processing, including the use of AI/ML techniques.
- Design of system of systems that specifically help to address the SDA requirements for duration or latency that utilise RF sensing techniques.

## Topic 10
## Improved spatial resolution for optical surveillance using distributed apertures

**Key words:** distributed apertures, synthetic apertures, sparse apertures, electro-optical surveillance, heterodyne imaging interferometry, Fourier ptychography, Fizeau interferometer, Michelson interferometer, photonic integrated circuits.

### Research topic description, including problem statement:

The larger the primary lens or mirror diameter of an optical system, the better its diffraction-limited spatial resolution and the more detail there can be in the image. However, increasing the diameter of the single primary lens or mirror beyond a certain point becomes impractical due to factors such as weight, portability, optical aberrations, robustness, system volume and expense. Using larger monolithic primary lenses or mirrors for covert, mobile, standoff, high-spatial-resolution surveillance becomes less viable.

This work will break this limitation by combining several smaller optical systems to achieve higher spatial resolution imaging. This disruptive approach using distributed apertures could not only create a system with smaller volume, weight and cost, but one that is conformally integrated into the surfaces of vehicles or other items for covert disguise.

There are many different distributed aperture techniques but most would not be practical for mobile platform operation of standoff high-spatial-resolution surveillance in the visible to long-wave infrared wavelength range. The challenges of making a practical mobile distributed aperture optical system include:

- Mechanical vibration and thermal effect resistance without requiring a rigid structure that is heavier than a conventional monolithic telescope.
- Having a low setup and alignment time.
- Fast acquisition time to capture fast-moving images.
- Having no nulls in its 2D MTF plot out to its maximum spatial frequency.
- Consideration of atmospheric turbulence compensation.

### Example approaches:

Example approaches include distributed apertures techniques that seek to replace one large telescope with an array of smaller apertures (lenses, mirrors or cameras etc.) or to use multiple illumination angles. This includes:

- Heterodyne imaging interferometry with passive scene illumination.
- Fourier Ptychography aperture synthesis snapshot imaging with active coherent scene illumination.
- Michelson Fourier-domain interferometric imagery using photonic integrated circuit (PIC) boards to form a planar (flat) telescope with passive scene illumination.

## Topic 11
## Ocean acoustic modelling for superior environment intelligence

**Key words:** sonar, underwater acoustics, ocean, measurements, modelling, data, information, intelligence, surveillance, reconnaissance.

### Research topic description, including problem statement:

Next Generation and Generation After Next sonar superiority in the underwater battlespace will depend significantly on our understanding and exploitation of the ocean acoustic environment. Understanding acoustic behaviour in the ocean environment, and acoustically-relevant properties of the environment, is highly complex depending on a wide range of factors that change both spatially and temporally across multiple scales – even on the calmest days, the ocean is constantly changing, under the influence of a wide range of complex and dynamic ocean-acoustic factors. Presently, only the simplest acoustically-relevant properties of the environment are well described by measurements and only the simplest ocean-acoustic factors are considered in modelling.

This research topic aims to combine several research challenges to produce a plenary ocean-acoustic model that can digest complex ocean-acoustic data and generate superior intelligence about the ocean-acoustic environment, reflecting a greater understanding of acoustically-relevant properties of the environment, which can be exploited for the purposes of intelligence, surveillance, and reconnaissance, as well as commercial monitoring of the ocean. Research challenges include:

- Mathematical descriptions of acoustically-relevant ocean properties, such as internal waves, eddies, and spice, covering multiple spatial and temporal scales.
- Development of physics based, data driven, or hybrid acoustic models, including noise and propagation models, to describe acoustic behaviour in the presence of different acoustically-relevant ocean properties.
- Sensitivity and uncertainty analysis and quantification, based on the quantity and quality of input environment data to ocean-acoustic models.
- Investigate the computational efficiency and accuracy of different models, including different model configurations.
- Development of schemes to generate, visualise, and exploit the best available description of the ocean acoustic environment.
- Investigate ocean-acoustic models, and other methods, to monitor the health of, and changes to, the ocean environment.

### Example approaches:

The research challenges can be approached using a mix of applied mathematics, programming, statistics, data analysis, and machine learning. Examples approaches include:

- Develop an underwater acoustics foundation model to understand and process ocean-acoustic data and to generate ocean-acoustic information for different applications; this could include the design and conduct of large scale data collection and preparation activities and other data collection to enable fine tuning for specific applications.
- Develop new analytical and numerical models to understand and predict acoustic behaviour in a variety of different environment conditions; this could include the development of methods to synthesise a variety of acoustically-relevant properties of the environment and to represent these properties in the acoustic models.
- Develop an efficient framework or architecture for combining different ocean models and acoustic models; this could include the design and development of intelligent hybrid models that optimise the combinations of models based, for example, on uncertainty or computational efficiency.

## Topic 12
## Aging of fingermarks. Can fingermark deposition time be determined from crime scenes/objects?

**Key words:** forensics, fingerprint, fingermark, visualisation, detection, enhancement, fingerprint analysis, aging.

### Research topic description, including problem statement:
Deposited friction ridge detail (i.e. finger or palm marks) are often recovered from crime scenes/ and/or objects, in order to assist with forensic investigations. However, determining the age of a fingermark remains a challenge, as current methods lack accuracy and reliability in estimating the age of fingermarks. Being able to reliably age a fingermark would be extremely valuable to a broad range of investigations as it provides a timeframe of events. There is also an opportunity to evaluate transfer and persistence in combination with the aging of fingermarks.

### Example approaches:
The approaches to tackling this problem can be broad, but commonly include identifying a chemical change as a function of time and using a form of spectroscopic analysis to measure it i.e. mass spectrometry. This approach would leverage the precision of mass spectrometry to detect and analyse the chemical changes in fingermarks over time, in order to determine their age. This is only one example of an approach, with more in-depth studies being envisaged.

## Topic 13
## Exploiting biology for overmatch compute advantage

**Key words:** molecular compute, biological compute, organoid intelligence, chemical reaction networks, algorithms, computer science, biology, DNA, RNA.

**Research topic description, including problem statement:**
Whilst there is a continued push for faster, cheaper, lower power compute, much of this effort is placed into further developing proven technology, specifically silicon, either by continual scaling (Moore's Law), or by adapting architectures (SysMoore and Amdahl's Law). These developments, and other factors, mean silicon-based approaches will continue to provide the main core of computing resource for a considerable time. However, other computing approaches have the potential to provide extraordinary benefits, especially for particular applications.

There are currently three types of computer in widespread use: silicon-based; living brains, which have prompted significant research in artificial intelligence and neuromorphic computing; and Chemical Reaction Networks (CRNs), which (for example) control the behaviour of every cell in the human body. Despite their prevalence, in comparison with other approaches, CRNs and other types of bio-based computing are heavily under-investigated.

As evidenced by their ubiquity in nature, bio-based computing approaches offer potential advantages over other forms of computation. For example, they can solve NP-complete problems1 and they exhibit different scaling properties to conventional (and quantum) computing[2]. Bio-based approaches can also operate at low-power and in environments that are hostile for traditional electronics.

This research topic aims to understand, develop, and evaluate (algorithmically) bio-based computing technologies that may provide Intelligence (and wider Defence) benefit, as well as facilitating a shift toward an evolutionary-proven, low-power compute solution. Challenges include:

- Evaluating and comparing different bio-based computing technologies.
- Developing a range of practically-useful algorithms using bio-based computing methods (including, massively parallel approaches, using either concentration-based or string-based encodings).
- Identifying integration and deployment challenges, to establish feasible routes toward exploitation.
- Specifying verification, test, assurance, and robustness considerations, together with potential methodologies that would allow bio-based computing approaches to be used with confidence.

### Example approaches include:

- Assessing the merits/demerits of bio-based computing for different classes of compute problem, through:
  - identifying key real-world problems that are well-suited to bio-based approaches and clarifying which problem characteristics are key to this suitability;
  - establishing sound development methodologies for bio-based computing (e.g. string-encoding approaches, which can be designed and simulated in available languages such as Thue[3], or differential-equation based approaches, which represent concentration-based implementations);
  - using these methodologies to implement appropriate algorithms that exploit (and demonstrate) bio-based computing's unique properties;
  - proving conceptual algorithms through experimentation, using new or existing bio-based computing technologies;
  - comparing the effectiveness of bio-based computing with other computational paradigms (including silicon-based approaches), considering repeatability, robustness, timeliness, monotonicity, security, and Size, Weight, Power and Cooling requirements.
- Developing integration methods for bio-based computing (e.g. interfaces with traditional computing, human-machine interfaces), including miniaturisation strategies of supportive interfaces, and identification of missing, or under-developed, components required for exploitation.
- Understanding the potential offered by DNA-based storage, especially in combination with "processing in memory" techniques.

### References:

[1] Winfree, E., 2019. *Chemical reaction networks and stochastic local search*. In DNA Computing and Molecular Programming: 25th International Conference, DNA 25, Seattle, WA, USA, August 5–9, 2019, Proceedings 25 (pp. 1-20). Springer International Publishing. https://link.springer.com/chapter/10.1007/978-3-030-26807-7_1.

[2] Currin, A., Korovin, K., Ababi, M., Roper, K., Kell, D.B., Day, P.J. and King, R.D., 2017. *Computing exponentially faster: implementing a non-deterministic universal Turing machine using DNA*. Journal of the Royal Society Interface, 14(128), p.20160990. https://royalsocietypublishing.org/doi/pdf/10.1098/rsif.2016.0990.

[3] https://esolangs.org/wiki/Thue.

## Topic 14
## Integrating multimodality and context to automatic language analysis

**Key words:** linguistics, forensic linguistics, applied linguistics, computational linguistics.

### Research topic description, including problem statement:

There are two main underlying problems with automatic approaches to language analysis: a lack of ability to account for context, and a lack of interpretability of language across different modalities (for example, audio, image, video, and text). Human communication is exceedingly context dependent. As a simplified example, if I state that the table needs to be moved a listener will automatically use context clues to indicate whether I mean an item of furniture, or an excel style table. These might be physical context clues, or indicators from the co-text. When people are talking about sensitive, taboo, or illegal topics, this reliance on context increases even more. Automatic language tools are improving at utilizing co-text to help improve the accuracy of work, but they are still limited in the range of context that can be considered.

Online communications are exceedingly important to the intelligence community, and increasingly multimodal. This might be a soundtrack which changes the intended meaning of a picture (for example a classic circus soundtrack over a social media video of me parking my car, indicating that I am not showcasing my excellent parking skills but encouraging ridicule), or an emoji pasted over the top of an image (for example a picture of snow, with a nose emoji, indicating that the post is about nasally inhaled drugs rather than snow). Cross-modal communication like this is now the norm in many groups and societies, and that is particularly the case when discussing taboo (or illegal) topics.

Dover (2022) highlights how significant the internet and electronic communications are to intelligence communities. Automated approaches to language analysis can enable the quick triage and handling of significant amounts of data, however where they struggle significantly is with bringing together meaning from across different modes. This means that a significant amount of the communicative content risks being lost before it reaches an analyst.

These changes in meaning provided by either the context or the different modalities might be instantly understandable to us as humans, but an automated approach that struggles to consider such aspects, will provide a severely limited output. The topic here is designed to seek ways to combat these two problems – to integrate a holistic understanding of language with automatic language approaches. The desire is that the outputs will therefore be grounded in applied and sociolinguistics and able to address language and communication in a more accurate and reliable way, considering how language actually functions.

### Example approaches:

The exact approach will depend on the form of automatic language analyses that are being considered, though researchers will need to source their own data set(s) to show a proof of concept. An overarching example approach would be starting from a sociolinguistic or corpus linguistic perspective and seeking to ensure that the understanding of how language works remains in the automated approaches. This is supported by the literature, most notably Grieve et al. (2024), who in their recent paper on the Sociolinguistic Foundations of Language Modeling conclude that "incorporating insights from sociolinguistics is crucial to the future of language modeling" (p17).

However, the benefits of such integration has a much longer trail of evidence. For example, in a 2013 Native Language Identification challenge (sometimes called Other or Native Language Influence Detection), where participants seek to identify an author's first language (when they are writing in English), Bykh et al. (2013) achieved a higher classification accuracy that other participants through using linguistically-informed features in their classifier. This included features such as parts of speech, lemma realisations and use of derivational and inflectional suffixes. Further work on Other Language Influence Detection for forensic linguistic purposes by Kredens, Perkins, and Grant (2019) highlights how vital an explanatory rich approach (such as one grounded in sociolinguistic explanations and features) is to analysis of language in evidential and investigative situations.

Focusing on the concurrent analysis of both the verbal and visual aspects of Instagram posts at the same time, Caple (2018) shows that taking a corpus-assisted multimodal discourse analysis can reduce partiality and enable triangulation. Polli and Sindoni (2024) look at the multimodality in hateful memes, and that the interplay between non-hateful text and non-hateful images can be used to produce hateful messages. They note that multimodality is conceptualized differently across the domains of computer science and sociosemiotics, however they also show that AI driven models can benefit from sociosemiotic insights and incorporating a multimodal critical discourse analysis approach.

More specific focused example approaches might include:

- Given a set of political speeches or news reports that happen over time in a changing context (e.g. during a conflict), how could an understanding of context improve topic modelling, document summarisation, an understanding of the evolution of events, or other forms of automated analysis? This could include (for example) the change salience of different places or people during the conflict, or a need to show strength to an audience in reaction to provocation.

- Given a set of social media posts with associated images (e.g. memes), how could an understanding of meaning and mood be better extracted from the multi-media content? For example, memes such as Wojak and Pepe the frog are often adapted quickly to express emotion reactions and humour at a given situation – how could that data be analysed alongside the text to give a more nuanced understanding of messages. Another example would be when images are used to convey instant emotional impact – for example in Daesh propaganda, CGI from video games was used to make it seem like the Eiffel tower had been attacked, or during the 2011 London riots images were shown of the London Eye on fire. Images like this may have more impact than just text messages.

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## Topic 15
## Barriers to adoption of a security-minded approach to information management

**Key words:** data sharing, open data, data aggregation, data quality, provenance.

### Research topic description, including problem statement:

Adoption of digital engineering practices, e.g. design collaboration using cloud-based computer aided design (CAD) software has led to a dramatic increase in the volume of information and technical data shared between organisations. Alongside this there has been adoption of a culture of greater openness and sharing of organisations' information, e.g., adoption of policies such as presumed open. These developments potentially undermine good security practices by increasing the quantity and quality of data available to those conducting hostile reconnaissance or espionage.

This research seeks to explore the attitudes, awareness, and understanding of organisations and their managers regarding the risks inherent in data/information sharing. Aspects that could be investigated include:

- Understanding by organisations and individuals of risks arising from sharing data and information with third parties.
- Understanding by organisations and individuals of data aggregation and its potential to magnify data sharing risks.
- How organisations and individuals assess the sensitivity of data and information.
- The identification, understanding, adoption and use of methods or techniques to establish information needs.
- The assessment of the provenance of data and information.

### Example approaches:

- Surveys and interviews of personnel employed in CNI sectors, e.g. water, energy, transport.
- Workshops to explore attendees understanding and use of security triage processes.

## Topic 16
## Can obscured biometric markers be detected from crime scenes/ objects with skin barriers in place?

**Key words:** forensics, DNA profiling, fingerprint analysis, human identification, attribution.

### Research topic description, including problem statement:
Deposited friction ridge detail (i.e. finger or palm marks) and human DNA are often recovered from crime scenes/ and/or objects, in order to assist with forensic investigations. The use of gloves and/or other physical hand/skin barriers may impede the recovery of friction ridge detail and reduce the amount of DNA deposited on a surface. Despite the use of a barrier, modern fingermark visualization techniques may be able to capture glove prints or possible friction ridge detail that could be used for forensic intelligence or evidential purposes. An evaluation of different glove types, textures, materials, and use methodology (e.g. double gloving) will provide important information on whether intelligence or evidential friction ridge detail can be recovered despite hand/skin barriers. There is also an opportunity to evaluate these types of barriers on their effectiveness of reducing touch DNA deposition.

### Example approaches:
An artificial finger pad could be used to test deposition of glove marks onto a variety of surfaces such as polymers, metals, and porous materials. The finger pad allows for controlled pressure deposition and can be adapted to also be used with artificial and real human fingerprints to test deposition with gloves or other skin barriers. Similar mechanisms could also be used to test for deposition of DNA. This is only one example of an approach, with more in-depth studies using human volunteers being envisaged.

## Topic 17
## Autonomous AI-powered red teaming for enhanced cybersecurity

**Key words:** Artificial intelligence (AI), Machine learning (ML), Deep learning (DL), cybersecurity, red teaming, penetration testing, vulnerability assessment, zero-day exploits, autonomous systems, cyber threat intelligence, network security, endpoint security, advanced persistent threats (APTs), Security information and event management (SIEM), intrusion detection systems (IDS), intruder prevention systems (IPS), security orchestration automation and response (SOAR), threat hunting, cybersecurity analytics, generative adversarial networks (GANs).

### Research topic description, including problem statement:

In some government and national infrastructure facilities, isolated computer networks exist due to legacy systems or high sensitivity levels. These critical systems must be defended against from cyber-attacks from hostile actors, necessitating rigorous testing of blue cybersecurity teams' response to potential network breaches and identification of vulnerabilities introduced by the configuration changes or new equipment. While penetration testing can identify existing vulnerabilities and assess blue team response, this research focuses on developing autonomous AI-powered red agents that can comprehensively test entire cybersecurity systems and detect vulnerabilities. To accelerate testing, AI-driven automation of red agent testing is proposed, which may also involve competition with AI-powered autonomous blue agents.

The research question: How can autonomous AI-powered red agents be designed to effectively identify vulnerabilities in isolated computer networks, simulate real-world attack scenarios, and enhance the overall cybersecurity posture of critical facilities?

### Example approaches:

There are two approaches outlined that should be considered:

- Stealthy approach: The red agent operates covertly, using advanced techniques to evade detection while identifying and exploiting vulnerabilities.
- Rapid exploitation approach: The red agent takes a more overt approach, rapidly identifying zero-day vulnerabilities and exploiting them quickly, simulating a real-world attack scenario.

The proposed approach may involve the development of a hybrid AI framework that combines traditional cybersecurity techniques with generative AI and machine learning algorithms. This framework will be designed to simulate various attack scenarios, including network vulnerabilities, phishing attacks and unauthorized device identification.

This research will push the boundaries of current AI-powered red agent technology by developing a novel framework that can adapt to evolving attack scenarios and learn from experience. This will ultimately enable the development of more sophisticated and effective cybersecurity testing and evaluation methods for blue teams.

## Topic 18
## Novel methods for structural health monitoring and detection of faults

**Key words:** non-destructive testing, quantum, gravimetry, magnetometers, materials, concrete, steel, density differentials, Infrastructure, structural health monitoring.

### Research topic description, including problem statement:

The Reinforced Autoclaved Aerated Concrete (RAAC) scandal caused major concerns in public infrastructure in 2023, some of which are ongoing. This highlighted the industry of non-destructively building materials testing in both new and long-standing infrastructure. For concrete, reinforced steel and other building materials, there are well established methods to non-destructively test, including penetration testing, the rebound hammer method and ultrasonic testing.

However, the defence and security want to explore emerging technologies that may be able to detect defects and offer high levels of penetration to building materials such as concrete and steel, for rust, micro material density differentials and other subtle defect detection.

### Example approaches:

The approach to this could be split into multiple routes, through testing a variety of technologies to a variety of building materials focusing on hard to detect defects and material density differentials. Narrowing this down early on will be key to directing the research in the most appropriate manner based on what is available.

Examples of technologies which could be used range from classical to quantum.

- Gravimetry would be a very interesting technique to explore, particularly from the view of understanding the different gravitational properties of different building materials and whether you could also “classify” an unknown material based on its gravitational properties.
- A light array could be used to see how much light passes through the material. Understanding what wavelengths would be optimal for this, which could also be used outside of a laboratory environment whilst meeting safety regulations, would be critical to the exploration of this methodology.
- Concrete is known to have a low-level magnetic field. Exploring the changes in this magnetic field based on how complete the concrete pour is could enable the identification of faults with the concrete.

There may be other approaches than these which we would be very interested to hear about.

## Topic 19
## Identifying hazardous materials using spectroscopic or quantum sensing techniques

**Key words:** quantum, spectroscopy, chemistry, physics, imaging, organic materials, detection.

### Research topic description, including problem statement:

The defence and security community have a need to detect materials of concern at a stand-off distances, at low parts per million, and enable a method to locate the source. For example, law enforcement, Home Office, Border Force and military applications users have the need to detect illegal narcotics, organic materials, hazardous chemical and biological items of concern.

There exist many methods to detect explosive materials for example, this research question is focused on emerging technology that can detect very low quantities at stand-off distances, tuned to certain materials.

### Example approaches:

Classical and quantum technologies could be used to explore this work.

- Classical spectroscopic techniques could be used for detection through creating fixed wavebands and utilising characterisation techniques such as those used with Raman spectroscopy systems. Methods such as producing stimuli responsive luminescent particles that respond by fluorescing when exposed to certain pre-defined compounds.
- One possible route to research this involves colloidal quantum dots tuned to different optical wavelengths. The wavelengths would be tuned depending on the organic material of interest, but also the number of optical wavelengths which can be characterised at one time. Considerations would include how an array of dots could be utilised and deployed, tuning the spectral range to gain the necessary spectral resolution, and choosing the illumination method will be needed to ensure the right level of excitation of organic matter for characterisation.

## Topic 20
## Wideband Electromagnetic field measurement with a low cost, size, weight and power Quantum sensing solution

**Key words:** quantum, electromagnetic, electric, magnetic, RF, wideband.

### Research topic description, including problem statement:

Quantum sensing development has provided novel methods to capture various electrical parameters with a wide array of sensing solutions including the Electrical/ Magnetic/Electromagnetic field measurement however for its limited research and design, the EM field measurement is still at the nascent stage. This is further exacerbated with the absence of low cost, size, weight and power developmental solution. However, with the progress in Quantum sensing for its various technological solutions based on entangling, interference mechanism, Rydberg atoms and Nitrogen Vacancy detector have provided a hope for the sensitive, precise and low-level signal strength EM measurement at single frequency or limited bandwidth. The additional research gaps arise due to the sensing mechanism protocols for continuous, pulsed or mixed dynamical coupling and the absence of non-classical mechanism of processing at quantum level. The quantum sensing development would provide a low cost, power and portable mechanism for the metallic/non-metallic detection within a high precise EM field and weak signal strength in a noisy environment while bringing new vitality in the EM field sensing approach.

### Example approaches:

- Computational modelling and architectural design.
- Optimize the design for the physical construction.
- Experimental demonstration of the wideband EM field measurement.
- Real time measurement and response accuracy enhancement within a dynamic EM environment.
- Development of lightweight, low power design for its integration within a physical space.

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## Topic 21
## Advanced processing for real-time RF mapping

**Key words:** RF mapping, signal processing, machine learning, artificial intelligence, real-time analysis.

### Research topic description, including problem statement:

Radio frequency (RF) mapping involves monitoring and analysing electromagnetic signals to identify, locate, and track a range of communication devices. It is an important tool used across various fields to understand the electromagnetic landscape in a given area. However, this process comes with challenges such as the complexity of signal propagation in different environments, interference from multiple sources, and the dynamic nature of signals over time. Optimising RF mapping to enhance its effectiveness, precision, and efficiency is becoming increasingly important as communication technologies continue to evolve.

The ability to analyse RF data in real time is crucial for a range of applications; however, this is associated with technical and operational challenges that must be addressed to achieve accurate and efficient outcomes. Urban environments have a high density and diversity of wireless signals, generating a large amount of data during RF mapping. This creates significant noise and interference that complicates efforts to isolate relevant signals and interpret useful information in real time. Traditional processing methods struggle to handle the volume and complexity of this data, making it difficult to provide the real-time analysis that is necessary for quick decision-making. Reducing the time delay between data collection and acquiring actionable insights would have significant implications in a number of fields. Therefore, innovative approaches are required to streamline RF data processing, enhance analytical capabilities, and generate rapid outputs.

### Example approaches:

To address these challenges, more efficient methods capable of filtering and analysing large volumes of RF data in real time are required. A key focus will likely be the application of machine learning and artificial intelligence tools, which can be trained to recognise patterns, filter out irrelevant signals, detect anomalies, and prioritise actionable data in congested spectrum environments.

Proposed methods should be able to dynamically adapt to changing signal environments and accurately recognise common sources of interference. Edge computing approaches could also be considered to help process data closer to source to enable faster decision making in critical situations. Potential solutions should also be designed with scalability in mind to accommodate the growing network of modern communication devices. Additionally, consideration should be given to the integration of RF mapping data with other data sources in order to enable improved accuracy, provide better context, and achieve a more comprehensive understanding of the signal environment.

## Topic 22
## Central bank digital currency technology: the impact on global finance and implications for national security

**Key words:** central bank digital currencies; cryptocurrency; global finance; money laundering; sanctions evasion; serious and organised crime; blockchain.

### Research topic description, including problem statement:

Members of the BRICS community of states are seeking to establish Central Bank Digital Currencies (CBDCs). Trials of national CBDCs are currently taking place in several BRICS member states with the aim of expanding these by 2025, with plans to include over 30 banking institutions. The CBDCs will be utilized for cross-border payments within the BRICS community.

It has been confirmed that mBridge, developed in collaboration with the Bank of International Settlements (BIS) and both BRICS and non-BRICS members, has now reached the minimum viable product (MVP) stage. mBridge is being developed to support peer-to-peer and cross-border payments, built on a blockchain platform known as the mBridge Ledger. This blockchain is expected to be compatible with the Ethereum Virtual Machine (EVM), the foundation of the Ethereum network and its decentralized finance system (DeFi). Such compatibility indicates a potential for CBDCs to integrate with the existing cryptocurrency ecosystem.

Reports from blockchain forensics entities confirm the illicit use of cryptocurrency by both state-linked and non-state actors, including serious and organized crime (SOC) groups, cyber criminals, terrorist financiers, and sanctions evaders. Tracing of crypto transactions is possible across most blockchains within the crypto ecosystem; however, it remains unclear whether ledger technology supporting CBDCs will be compatible with current tracing software. Similarly, privacy protocols for CBDCs, particularly regarding user anonymity and pseudonymity, have yet to be established.

There is currently limited academic research on the issues highlighted here. Some publications explore aspects of CBDC architecture such as the security risks in CBDC systems, emphasising challenges such as de-anonymisation through methods like multi-party computations and zero knowledge proofs [1], the privacy trade-offs in CBDC architecture design [2], and the geopolitical implications of a BRICS-led supranational CBDC [3]. However, as CBDCs are an emerging technology, their integration and use by both legitimate and hostile actors is poorly understood. Therefore, research is required to understand the underlying technologies that support CBDCs and to identify current or future methods for tracing these funds within the wider global financial system.

Research should aim to examine potential use cases, their impact on global finance, and how they may be integrated into financial systems. It should also explore the threats and opportunities for hostile actors, including sanctions evaders, SOC groups, cyber criminals, and state-linked actors, to move funds undetected.

To understand the evolving landscape of CBDCs, several critical questions must be addressed. With a focus on the BRICS community, what is the current state of CBDCs, including which are currently in use and by whom? What technology underpins them and how do they interact with existing fiat and digital currencies? Are the technologies underpinning the CBDCs compatible with the blockchain technology that currently supports cryptoassets? What opportunities exist for tracing transactions across existing and future CBDCs? Additionally, what technological and methodological barriers hinder tracing these transactions, and how do these challenges differ from those associated with established cryptocurrencies?

### Example approaches:

- Investigate how blockchain or similar distributed ledger technologies (DLT) can be integrated into the structure of the CBDCs for adoption by BRICS members.
- Assess the capacity of BRICS CBDCs to connect with the existing cryptoasset ecosystem, including an evaluation of the compatibility of the underpinning technologies.
- Explore opportunities for tracking and tracing transactions completed by users of BRICS CBDCs.

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## Topic 23
## Performance improvement from antenna diversity from space platforms

**Key words:** spatial antenna diversity.

### Research topic description, including problem statement:
With lower cost brought about by 'New Space', there is growing interest in clusters of satellites operating together to provide spatial diversity for antenna systems for the purpose of increasing performance at a lower cost than a large single aperture antenna.

This research topic is about exploring, through simulation and practical experimentation, the performance improvements e.g. sensitivity, bandwidth improvement together with features such as interference rejection and geolocation as a minimum. The research is likely to include methods for coherence across platforms and efficient communications to facilitate spatial diversity.

### Example approaches:
Spatial diversity, Pattern diversity, Polarization diversity, Transmit/Receive diversity, Adaptive arrays.

## Topic 24
## Development high-throughput informatic tools to support proteomic analysis in complex samples

**Key words:** AI, computational, methods, bioinformatics, biothreats, mass spectrometry, proteomics.

### Research topic description, including problem statement:
Analysis of protein samples collected for law enforcement or intelligence purposes are frequently of low quantity and poor quality. Proteomic analysis provides critical information to support the attribution process. The IC laboratories frequently utilize mass spectrometry to identify key peptides in a protein. This project seeks to develop informatic processes that can support the identification of novel proteins with confidence scores that would be linked to specific peptides or groups of peptides identified in public or private databases.

### Example approaches:
- Develop an algorithm that exploits the robust protein sequence databases available to compare partial sequence information.
- AI has been successfully applied to predicting the structure of proteins; use the same approach to provide possible protein “matches” based on partial sequence information from MS analysis.

## Topic 25
## Advanced Techniques for Antenna-Receiver Performance Enhancement and Miniaturization (ATARPEM)

**Key words:** SWaP, electrically small antenna, bandwidth, efficiency, amplification, RF, receiver.

### Research topic description, including problem statement:
The IC often requires communication systems working under severe size, weight, and power (SWaP) constraints (e.g., space, man-portable). This is particularly true when RF antennas are small in relation to the wavelength of operation which sets limits on the efficiency, bandwidth, sensitivity, or other properties of the communication system. Recent approaches to overcome the limitations of electrically small antenna systems include antenna-amplifier codesign, predistortion and feedback, direct antenna modulation, on-board parametric amplification, and fast antenna tuning.

### Example approaches:
- Predistortion of transmitted waveform to account for dispersive impedance with nonlinear, adaptive amplifier.
- Direct antenna modulation (DAM) where an antenna is driven directly without the waveform passing through an amplifier.
- On-board parametric amplification used to increase receive sensitivity or transmit bandwidth.
- Antenna tuning faster than the sample rate to increase bandwidth or enable broadband waveform transmission.

## Topic 26
## Enhancing the effectiveness of routine security scanning checks at border crossings

**Key words:** X-Ray, Computed Tomography (CT) scan, behavioral science, Artificial Intelligence (AI), crowd monitoring, machine vision, machine learning, distributed sensor network, pattern recognition, public transport ticket Information.

### Research topic description, including problem statement:

Security checks at border crossing points provide a crucial detection function for a wide range of items including weapons, explosives, liquids, sharp objects, pills, as well as many other objects that may be hidden on a person's body or in their luggage. A range of detection technologies are used at these security check points, including X-Ray and Computed Tomography (CT). Modern systems employ advanced technologies including Machine Learning (ML) and Artificial Intelligence (AI) to enhance performance of the tool and reduce the workload of the human operator.

These tools analyse the scene and highlight areas of potential concern for the operator to scrutinise, ranked in priority according to a defined, yet adaptive risk profile. Although these systems are highly effective, the reliable detection of evolving threats in a complex environment while avoiding excessive false positives, maintaining low latency and high throughput is a significant optimisation problem.

While the effectiveness of these tools is beyond the scope of this research proposal, we seek to investigate and build understanding of the potential for improving the effectiveness of these tools through augmentation with external data analysis to increase the likelihood of threat detection.

### Example approaches:

External data analysis could include processing of a range of data sources to identify anomalous characteristics, including but not limited to:

- Ticketing data (routes, purchase lead times, payment system used, visas, passport type).
- Pose, gait, body language, biological indicators on approach to scanning systems.
- Luggage and carried item object classification/combinations.

## Topic 27
## Using AI to power synthetic biology applications

**Key words:** multi-omics, synthetic biology, Artificial Intelligence.

### Research topic description, including problem statement:

The increasing availability and volume of multi-omics data, technical knowledge and tools, and the advance of Artificial Intelligence (AI) capabilities is revolutionising science. AI powered synthetic biology stands to alter the biological threat and opportunity paradigm and raises unique challenges that need to be better understood.

Synthetic biology is an evolving and diffusing technology, new developments in AI, and notably the improvement of generative AI, have opened the door to additional creativity in synthetic biology. For example, large language models (LLMs), have been adapted to the genetic code by replacing words with the nucleotide bases. This enables LLMs to optimise experiments to generate new DNA sequences (and thus new virtual organisms) precisely, quickly and cheaply. The resulting molecules organisms and knowledge promise to be useful in accelerating drug discovery, food engineering, conservation of biodiversity, climate remediation and the understanding of life. Generative AI could be used to predict the outcomes of gene editing experiments. This will reduce time spent investigating eventual dead ends, broadening the scope of testing and deliver savings in cost and time. Those applications are like software engineers' use of generative AI to test code.

What are the possible applications stemming from AI powered synthetic biology? What are the risks and vulnerabilities of employing or not employing AI powered or supported synthetic biology? What do international research trends suggest are the major development or investment directions? How might potential concerns be mitigated?

### Example approaches:

Research proposals could approach this issue from a variety of disciplines, or as a cross-disciplinary effort. The challenge touches on aspects of synthetic biology, AI, future applications, transnational issues, ethics and privacy. Proposals could consider (but are not limited to):

- The utility of AI platforms to; enhance current or develop novel synthetic biology tools/techniques and/or generate novel tools/techniques for the detection of modified organisms.
- Combining AI and multi-omics data, including proteomics, genomics, metabolomics, and transcriptomics to provide a more holistic view of biological systems.
- The use of generative AI to accelerate synthetic biology applications.
- With respect to AI development trends, evaluate the coordination among domestic and global stakeholders for monitoring, assessment and mitigation of risks associated with advances in synthetic biology research and applications.
- Evaluating the international societal effects and public policy implications, with respect to privacy and social license guardrails, of synthetic biology research and development.

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