Information Institute®

Visiting Faculty Research Program

Summer Faculty Fellowship Program

2026

Research

Topics

Version 1.0

Visiting Faculty Research Program

2026 Research Topics
Version 1.0

This document provides information for faculty to help them connect with AFRL/RI scientists and engineers (S&Es) in Rome, NY. Additionally, it provides information about AFRL's research interests. It's an important document for recruiting faculty for both the AFOSR Summer Faculty Fellowship Program (SFFP) and the RI Visiting Faculty Research Program (VFRP).

SFFP is funded by the Air Force Office of Scientific Research (AFOSR). It offers hands-on exposure to Air Force research challenges through 8- to 12-week research residencies at participating Air Force research facilities and offers a sponsored student option. Open to US Citizens only. The typical application window is early August to early December; however, **in Summer of 2026, AFOSR will not fund SFFP**.

VFRP is funded by the Information Directorate (AFRL/RI) in Rome, NY. It is a complimentary program to SFFP. AFRL/RI's goal with the summer VFRP is to provide a rewarding experience to the highest qualified candidates from the academic research community. Offers sponsored student option. Open to US Citizens and Perm Residents. **For Summer 2026, the open application period for VFRP is 25 September 2025 to 2 January 2026**: https://www.afrl.af.mil/About-Us/Fact-Sheets/Fact-Sheet-Display/Article/2332471/afrlri-information-institute/

For both SFFP and VFRP, this document provides the research topics that the faculty applies against and helps to connect the faculty with the AFRL/RI Advisor. For each research topic, the advisor's contact information is listed. We encourage potential applicants to reach out to advisors to discuss his/her research ideas to ensure a good match

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Topic Advisor by Division

Robust Logistics and Cargo Transport

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The military requires the timely distribution of various movement of cargo, supplies and/or personnel often within strict time limits. This is hampered by a multitude factors ranging from weather disruptions to limited space at airports and depots. We seek new techniques for resilient logistics that can overcome these challenges. Potential topic areas include, but are not limited to:

- Optimization techniques for pickup and delivery of cargo.
- Vehicle routing to avoid congestion and reduce risk.
- Identification/mitigation of critical nodes and edges within the transport network.
- Multi-agent planning under limited communications.

Solutions may draw on a variety of approaches, for example using linear programming, multi-agent path finding, domain independent automated planners, or machine learning.

Dynamic Task Allocation for Distributed Workflow Execution

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The ability to coordinate distributed teams and weapon systems in a contested fight has become a major concern for the Air Force. Current Air Force operations rely on centralized command and control to conduct planning and orchestration for execution. Future operations will shift operations from centralized physical infrastructures to a network of smaller, dispersed locations. This will require a capability to execute distributed workflows across multiple locations while factoring in changing states, resources, and mission objectives.

We seek techniques to facilitate dynamic task allocation for distributed workflow execution among geographically distributed worker nodes. Techniques could draw from diverse discipline areas, including Internet of Things (IoT) task allocation on energy-constrained edge devices, or software defined network routing. Solutions may exploit a variety of approaches, for example using linear programming, constraint programming, domain independent automated planners, or machine learning. This topic may also cover techniques for sharing state information and reasoning over knowledge, in support of optimization and distributed decision-making.

Mathematical Theory for Advances in Machine Learning

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To alleviate the effects of the so-called ‘curse of dimensionality’, researchers have developed sparse, hierarchical and distributed computing techniques to allow timely and meaningful decisions based on large amounts of structured or unstructured data. As the amount of data available to analysts continues to grow, a strong mathematical foundation for new techniques is required. This research topic is focused on the development of theoretical mathematics with applications to machine learning and decision making with a special emphasis on techniques that admit sparse, low-rank, overcomplete, or hierarchical methods on multimodal data. Proposals with a strong mathematical foundation will receive special consideration.

Multi-Unit, Multi-Action Adversarial Planning

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Planning is a critical component for any command and control enterprise. While there have been impressive breakthroughs with domain independent heuristics and Monte Carlo tree search, in adversarial settings with multiple units, further work is still required to deal with the enormous state and action space to find quality actions that progress towards the goal and are robust to adversarial actions. We seek to develop new adversarial, domain-independent heuristics that exploit interactions between adversaries' components. In addition to developing new heuristics, we are also interested in more intelligent and efficient search techniques that will allow planning over multiple units. Areas of interest include Automated Planning, Heuristic Search, Planning over Simulators, and Game Theory.

Emergent Behaviors in Complex Systems: A Category Theory Approach.

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Military systems comprise multiple layers of system-of-systems (SoS) that are defined by mission objectives and multiple trade-offs at various abstraction levels and scales that need to be considered. In this context, the choice of a single system component needs to be studied jointly. For example, knowledge about the intended service of a new communication system would impact its design and deployment, while insights about its technological development could significantly affect communication management policies. In addition, the complex interactions among the component systems in a SoS may produce unexpected performance in individual systems or in the whole SoS, which are called Emergent Behaviors (EB). EBs are considered positive if they contribute to the system's performance and negative in the opposite case.

Category theory provides a powerful framework for modeling, analyzing, and designing SoS by offering a structured way to represent and compose different system components and their interactions, which enables better management of complexity, verification of system behaviors, and integration of diverse models. This research topic will explore category theory approaches devoted to:

- Developing optimal architectures for SoS to accomplish missions.
- Quantifying and classifying EB in SoS.
- Developing techniques to minimize negative EB.
- Quantifying cascading effects in SoS.

Resilient Distributed Optimization and Learning

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In many military applications, large volumes of heterogeneous streaming data are needed to be collected by a team of autonomous agents which then collaboratively explore a complex and cluttered environment to accomplish various types of missions, including decision making, optimization and learning. In order to successfully and reliably perform these operations in uncertain and unfriendly environments, novel concepts and methodologies are needed to 1) analyze the resiliency of algorithms, and 2) maintain the capability to reliably deliver information and perform desired operations. This research topic will develop resilient distributed optimization and learning algorithms in the presence of

- Abrupt changes in the inter-agent communication network,
- Asynchronous communications and computations,
- Adversarial cyber-attacks capable of introducing untrustworthy information into the communication network.

Some distributed methods of interest in this topic include, but are not limited to weighted-averaging, push-sum, push-pull, stochastic gradient descent, and multi-armed bandits.

Optimal Routing for Dynamic Demand in Networks with Limited Capacity

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Mission planning across operational and tactical echelons requires development of complex logistics plans in support of all AF missions. The size of the force, distances to be traveled, fragility of our supply networks, and the ability of the adversary to hold our forces at risk all confound the DoD’s ability to project and sustain the force. The objective is to facilitate the construction of a dynamic multigraph that represents the spatio-temporal logistics information and connections to mission objectives, defines the characteristics of those resultant multigraph properties that contribute to a contested state, and apply multivariate, critical node analysis techniques to provide a valuation of robustness of the logistics plan, and predict how an adversary may target critical logistics nodes so the Air Force may develop strategies to be resilient and robust to these attacks in order to optimize mission success. Ultimately, what is sought is how this newfound intuition into logistics plans can be leveraged to design them to be robust in the first place (not just to measure their fragility), and then how to address their resiliency on the fly when events happen dynamically in the middle of execution.

Enhanced Explainable Reinforcement Learning (XRL) Integrated with Topological Data Analysis (TDA)

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The need for Reinforcement Learning (RL) has surged because of its potential to address complex problems effectively. However, RL faces significant challenges such as balancing execution complexity with transparency, sequential decision-making, starving for data. As RL models become more intricate, understanding the rationale behind their decisions becomes more difficult. Since RL models learn autonomously, understanding the reasons behind their decisions is crucial for establishing trust between the user and the agent, which is influenced by the model's success or failure. On the other hand, Topological Data Analysis (TDA) has been a powerful tool to understand valuable insights into the structures and patterns within complex datasets. Therefore, when incorporated into XRL, TDA can enhance explainability of the learned policies and the decision-making process of the RL agents significantly. However, TDA has problems with scalability and computational efficiency. Therefore, this topic seeks proposal to utilize TDA integrated into XRL (but not only limited to) as follows:

1) Develop a novel method to better understand of the state space (simplification) for explainability
2) Develop a novel algorithm to apply TDA into the policy representation to identify key regions where policy changes drastically (policy and value function analysis)
3) Develop robust explainability algorithms/methods by identifying topological features in the state space that correlate to certain actions/decisions made by the agents

Autonomous UAV Swarm Communication in Denied, Disrupted, Intermittent and Limited (DDIL) Environments for Scalability, Heterogeneity, and Reconstitution

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The objective of this research is to conduct a feasibility study of scalable Federated Multi-Task Learning (FMTL) in Denied, Disrupted, Limited, and Intermittent (DDIL) networks on more than 1k low-cost, heterogeneous Unmanned Aerial Vehicles (UAVs) via modeling or simulation. The UAVs are to be reconstituted—reconnect, reassemble, restructure, or reform back together—until the system meets its point of scalability or it breaks. Existing swarm control techniques do not address scalability to large scales, multi-mission heterogeneity, or resilience in DDIL environments adequately [1]. Centralized approaches are hampered by latency, bandwidth, and single-point-of-failure limitations [2]. Current implementations of swarm autonomy in DARPA's OFFSET program are capped at approximately 250 nodes, illustrating the inherent scalability bottleneck [3]. Consequently, multi-agent reinforcement learning exhibits poor convergence for large-scale scaling with more than 100 agents [4]. Existing swarm intelligence techniques are not equipped dealing with multiple tasks, in that they frequently do not support simultaneous, and expedient reconstitution [5–8]. FMTL seems to demonstrate the capability to enable large-scale, heterogeneous swarms to learn collectively with reduced communication overhead, enable mission heterogeneity, and facilitate self-healing [6,7,10]. Performance of FMTL will be assessed in this feasibility study with simulated DDIL degradation from limited to intermittent, disrupted, and denied and compared relative to well-established swarm baselines for performance. The scenario will be large-scale sub-swarm performing various tasks (e.g., ISR, EW) in contested airspace. The activity will be non-prescriptive, promoting innovative, adaptive solutions to architecture, algorithms, and simulation environments.

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Compositional Optimization

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Automating Air Force planning often involves formulating an optimization problem, choosing/developing an appropriate solver, and feeding data of the initial conditions for a specific problem instance to the resulting system. In this project we will explore how to define mathematically and implement in software the composition of such systems. The goal of this work is to create a library for the creation of highly complicated and sophisticated planners using smaller atomic components. We will leverage techniques from applied category theory and mathematical programming to do so. In addition to extensions to existing work [1,2,3] that could include the study of properties of composite optimization problems, or the incorporation of more sophisticated solution algorithms, applicants can propose to study novel applications well suited to compositional approaches.

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Computing & Communications (AFRL/RIT)

Dynamic Resource Allocation in Airborne Networks

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From the Air Force perspective, a new research and development paradigm supporting dynamic airborne networking parameter selection is of paramount importance to the next-generation warfighter. Constraints related to platform velocity, rapidly-changing topologies, mission priorities, power, bandwidth, latency, security, and covertness must be considered. By developing a dynamically reconfigurable network communications fabric that allocates and manages communications system resources, airborne networks can better satisfy and assure multiple, often conflicting, mission-dependent design constraints. Special consideration will be given to topics that address cross-layer optimization methods that focus on improving the performance at the application layer (i.e. video or audio), spectral-aware and/or priority-aware routing and scheduling, and spectral utilization problems in cognitive networks.

Discovering Structure in Nonconvex Optimization

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Optimization problems arising from applications are often inherently nonconvex and non-smooth. However, the tools used to study and solve these problems are typically adopted from the classical domain, not adequately addressing the challenges posed by nonconvex problems. The purpose of this research is to develop accurate models and efficient algorithms which take advantage of useful structure or knowledge derived from the application in question. Examples of this structure include sparsity, generalizations of convexity, and metric regularity. Some areas of interest are sparse optimization, image and signal processing, variational analysis, and mathematical foundations of machine learning.

Optical Communications

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Quantum communications research involves theoretical and experimental work from diverse fields such as physics, electrical engineering and computer science, and from pure and applied mathematics. Objectives include investigations into integrating quantum data encryption with a QKD protocol, such as BB84, and characterizing its performance over a free space stationary link. The analysis of the secrecy of the data is extremely important. Quantum-based encryption systems that use the phase of the signal as the information carrier impose aggressive requirements on the accuracy of the measurements when an unauthorized party attempts intercepting the data stream.

Free Space Optical Communication Links: Laser beams propagating through the atmosphere are affected by turbulence. The resulting wave front distortions lead to performance degradation in the form of reduced signal power and increased bit-error-rates (BER), even in short links. Objectives include the development of the relationship between expected system performance and specific factors responsible for wave front distortions, which are typically linked to some weather variables, such as the air temperature, pressure, wind speed, etc. Additional goals are an assessment of potential vulnerability of the quantum data encryption.

Associated with the foregoing interests are the design and analysis of simple to complex quantum optical circuitry for quantum operations. Characterization of entanglement in states propagating through such circuits in terms of measures such as PPT, CSHS inequalities, and entropic techniques are of interest. Supporting innovative free-space optical (FSO) communication architectures—compatible with both classical high-throughput links and quantum-secure communication—that overcome turbulence, fading, and SWaP (size, weight, and power) constraints, and demonstrate a clear pathway to transition via photonic integrated circuits (PICs) are of interest for this application.

Software Assurance

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Ensuring software functions as intended – reliably, securely, and robustly – is paramount. Software Assurance (SwA) aims to provide justified confidence in these properties, yet current practices are often manual, error-prone, and demand specialized expertise. We believe SwA must be integrated throughout the software lifecycle to significantly enhance security and resilience. We are seeking innovative research that addresses these challenges in the following areas:

1. Foundations of trustworthy and resilient software systems: Research includes technology, components and methods supporting a wide range of requirements for improving the resiliency and trustworthiness of computing systems via multiple resilience and trust anchors throughout the system life cycle including design, specification and verification of cyber-physical systems. Research opportunities are available for model-based design, development and demonstration of foundations of resilient and trustworthy computing. Research supports security, resiliency, reliability, and usability leading to high levels of availability, dependability, confidentiality and manageability.
2. Formal methods software and systems development: The focus is on developing and applying formal methods-based tools to rigorously reason about software systems, with a specific emphasis on overcoming the limitations of scaling and usability of current formal methods.
3. Advanced Software Testing and Analysis: The focus is on advancing the state-of-the-art in software vulnerability/flaw detection. We are looking for research that provides practical and effective techniques that can be transitioned into real-world applications. The research can apply to source code, executables only or a hybrid. Particular attention should be given to minimizing false positives.

Secure Processing Systems

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The objective of the Secure Processing Systems topic is to develop hardware that supports maintaining control of our computing systems. Currently most commercial computing systems are built with the requirement to quickly and easily pick up new functionality. This also leaves the systems very vulnerable to picking up unwanted functionality. By adding specific features to microprocessors and limiting the software initially installed on the system we can obtain the needed functionality yet not be vulnerable to attacks which push new code to our system. The focus of this topic is selecting techniques and demonstrating them through the fabrication of a secure processor. Areas of interest include: 1) design, layout, timing and noise analysis of digital integrated circuits, 2) Implementing a trusted processor design and verifying that design, 3) Selection of security features for a microprocessor design, 4) verifying manufactured parts, and 5) demonstrations of the resulting hardware.

Nanocomputing

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Advances in nanoscience and technology show great promise in the bottom-up development of smaller, faster, and reduced power computing systems. Nanotechnology research in this group is focused on leveraging novel emerging nanoelectroic devices and circuits for neruromorphic spike processing on temporal data. Of particular interest is biologically inspired approaches to neuromorphic computing which utilize existing nanotechnologies including nanowires, memristors, coated nanoshells, and carbon nanotubes. We have a particular interest in the modeling and simulation of architectures that exploit the unique properties of these new and novel nanotechnologies. This includes development of analog/nonlinear sub-circuit models that accurately represent sub-circuit performance with subsequent CMOS integration. Also of interest are the use of nanoelectronics as a neural biological interface for enhanced warfighter functionality.

Quantum Networking with Atom-based Quantum Repeaters

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A key step towards realizing a quantum network is the demonstration of long distance quantum communication. Thus far, using photons for long distance communication has proven challenging due to the absorption and other losses encountered when transmitting photons through optical fibers over long distances. An alternative, promising approach is to use atom-based quantum repeaters combined with purification/distillation techniques to transmit information over longer distances. This in-house research program will focus on trapped-ion based quantum repeaters featuring small arrays of trapped-ion qubits connected through photonic qubits. These techniques can be used to either transmit information between a single beginning and end point, or extended to create small networks with many users.

Trapped Ion Quantum Networking and Heterogeneous Quantum Networks

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Quantum networking may offer disruptive new capabilities for quantum communication, such as being able to teleport information over a quantum channel. This project focuses on the memory nodes and interconnects within a quantum network. Trapped ions offer a near-ideal platform for quantum memory within a quantum network due to the ability to hold information within the long-lived ground states and the exquisite control possible over both the internal and external degrees of freedom. This in-house research program focuses on building quantum memory nodes based on trapped ions, operating a multi-node network with both photon-based connections to communicate between the network nodes and phonon-based operations for quantum information processing within individual network nodes. In addition, the work focuses on interfaces to other qubit technologies (superconducting qubits, integrated photonic circuits, etc.) for heterogeneous network operation, quantum frequency transduction, and software-layer control. This work will be performed both in the in-house research laboratories at AFRL and the nearby Innovare Advancement Center.

Superconducting and Hybrid Quantum Systems

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The Superconducting and Hybrid Quantum Systems group focuses on the development of heterogeneous quantum information platforms and the exploration of related fundamental physics in support of the quantum networking and computing missions of AFRL's Quantum Information Science and Technology Branch. A central theme of the group's work is to develop quantum interfaces between leading qubit modalities to utilize the respective advantages of each of these modalities for versatility and efficiency in the operation of quantum network nodes. Towards this end, the group's research is composed of several main thrusts: the development of novel superconducting systems for generating and distributing multi-partite entanglement; the development of interconnects for encoding and decoding multiplexed quantum information on a superconducting quantum bus; the investigation of hybrid superconducting and photonic platforms for transduction of quantum information between microwave and telecom domains; and exploration of quantum interface hardware for bridging trapped-ion and superconducting qubit modalities.

Optical Interconnects

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Our main area of interest is the design, modeling, and building of interconnect devices for advance high performance computing architectures with an emphasis on interconnects for quantum computing. Current research focuses on interconnects for quantum computing including switching of entangled photons for time-bin entanglement.

Quantum computing is currently searching for a way to make meaningful progress without requiring a single computer with a very large number of qubits. The idea of quantum cluster computing, which consists of interconnected modules each consisting of a more manageable smaller number of qubits is attractive for this reason. The qubits and quantum memory may be fashioned using dissimilar technologies and interconnecting such clusters will require pioneering work in the area of quantum interconnects. The communication abilities of optics as well as the ability of optics to determine the current state of many material systems makes optics a prime candidate for these quantum interconnects.

Integrated Photonic Element Design

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The maturation of quantum technologies from table-top experiments to the field will require the miniaturization and implementation of functional elements which may or may not currently have free-space optical equipment analogs. With the growth of CMOS fabrication technologies that are specialized in optical circuit design, there will be a push from proof-of-concept components to ones which implement the operational requirements needed for scaling quantum computing and networking efforts with high fidelity, yield, and density while reducing the loss and overhead of operation.

The focus of this effort is the development of integrated optical components for tasks relevant in a quantum platform. Examples include high extinction-ratio filtering of closely placed optical frequencies; reduction of loss in integrated optical components; and the design and characterization of components which are compatible with quantum memory technologies (e.g. visible wavelengths or for cryogenic environments).

This is both a theoretical (e.g. simulation or analytic approximations) or experimental (device fabrication and/or measurement) effort.

Airborne Networking and Communications Links

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This research effort focuses on the examination of enabling techniques supporting potential and future highly mobile Airborne Networking and Communications Link capabilities and high-data-rate requirements as well as the exploration of research challenges therein. Special consideration will be given to topics that address the potential impact of cross-layer design and optimization among the physical, data link, and networking layers, to support heterogeneous information flows and differentiated quality of service over wireless networks including, but not limited to:

- Physical and MAC layer design considerations for efficient networking of airborne, terrestrial, and space platforms;
- Methods by which nodes will communicate across dynamic heterogeneous sub-networks with rapidly changing topologies and signaling environments, e.g., friendly/hostile links/nodes entering/leaving the grid;
- Techniques to optimize the use of limited physical resources under rigorous Quality of Service (QoS) and data prioritization constraints;
- Mechanisms to handle the security and information assurance problems associated with using new high-bandwidth, high-quality, communications links; and
- Antenna designs and advanced coding for improved performance on airborne platforms.

Wireless Innovations at Spectrum Edge: mm-Waves, THz Band and Beyond

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Today's increasing demand for higher data rates and congestion in conventional RF spectrum have motivated research and development in higher frequency bands such as millimeter-wave, terahertz band and beyond. In higher frequency bands such as millimeter wave and terahertz, where channel properties are affected by mobility and atmospheric conditions, an agile system with a flexible, resilient architecture and the ability to adapt to the changing environment is required. To that end, we are interested in both foundational and applications-focused research to meet the demands of next generation wireless systems.

For foundational research for wireless communications at spectrum edge, we would like to address the technical challenges in both accessing the spectrum and exploiting the spectrum. We are interested in advanced technologies in architecture, waveform and signal processing that enable access to the emerging spectrum bands that are not traditionally widely used for wireless communications. We are also interested in the radio architecture, system design, waveform, algorithm and protocols that will let us exploit the abundant bandwidth that the spectrum edge for future AF wireless applications. Examples include but are not limited to:

- Novel waveform designs that are robust to the high atmospheric absorption loss.
- Use of novel relay architectures such as reconfigurable intelligent surfaces to solve the blockage problem at higher frequency bands.

- Use of data science tools in machine learning to construct meaningful datasets from few RF data collected at these frequency bands.

We are also interested in applications-focused research that specifically calls for the use of frequency bands at spectrum edge in the proposed applications. Examples include but not limited to high bandwidth links for next-generation mobile communication systems, Air Force and commercial applications that consider converged sensing and communications systems, etc.

Quantum networking infrastructure: Techniques and hardware development

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While quantum computing (QC) and networking have matured rapidly over the last decade, there are threshold capabilities, tools, and technologies that still need development before a large-scale quantum internet can be fully realized and utilized for real-world applications. Accomplishing this requires expertise from diverse fields including quantum optics/photonics, AMO physics, solid-state physics, materials science/engineering, computer science/engineering, and pure/applied mathematics.

Toward that end, the objectives of AFRL's Quantum Information Science (QIS) group include emphases on: developing tools from quantum information theory to benchmark and verify the integrity of quantum networks and the resources employed therein; developing quantum computing algorithms achieving an advantage over conventional computing toward practical challenges; and in developing the physical hardware needed to carry out operations on these networks.

Among these emphases, topics of special interest include developing/characterizing quantum transducers between disparate species of qubits (e.g., microwave/optical transducers to connect distant superconducting-circuit qubits over fiber optics); developing quantum algorithms targeted to speed the solution of optimization and machine learning problems, and in developing efficient techniques to characterize quantum resources at a large scale.

Towards Data Communication using Neutrinos

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Existing beyond line of sight (BLOS) data communications relies on electromagnetic radiation for transmission and detection of information. This topic involves investigating a non-electromagnetic data communications approach using neutrinos.

Technical challenges to address include:

- *Transmission*: Particle accelerations are limited in transmit power and data modulation bandwidth. Perform analysis of the state-of-the-art particle accelerators and optimize particle accelerator designs primarily for digital communications.

- *Propagation*: Measuring the absorption coefficient and beam divergence of neutrino beams is key to distant neutrino communications. Propose techniques to measure and additionally perform data analysis of experimental data from ongoing experiments measuring both cosmic and accelerator neutrinos such as CERN.
- *Detection*: To achieve a practical bit error rate in data communications, increasing detector sensitivity or neutrinos detected per bit is crucial. Investigate neutrino detection methods to increase receiver sensitivity and optimize for digital communications.

Modular Machine Learning via Hyperdimensional Computing (HDC)

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Modular components can be independently optimized and arbitrarily arranged. Biological brains can compute across multiple data modalities because biological sensors convert diverse environmental stimuli to a consistent information representation, viz. high-dimensional spike time patterns. In contrast, traditional deep neural networks (DNN) can be independently trained but then not are not trivially cascadable: the output of one DNN as input to another DNN. Alternatively, DNNs may be assembled but must be trained monolithically, with exponentially increasing training resource costs. Consequently, there is growing interest in information representations to unify these algorithms, with the larger goal of designing ML modules that may be arbitrarily arranged to solve larger-scale ML problems, analogous to digital circuit design today. One promising information representation is that of a "symbol" expressed as a high-dimensional vector, thousands of elements long. Hyperdimensional computing (HDC), or vector symbolic architectures (VSA) is an algebra for the creation, manipulation, and measurement of correlations among "symbols" expressed as hypervectors. This research topic includes work towards implementing HDC in DNNs and spiking neural networks (SNN), sensor fusion via HDC symbolic reasoning, robotic perception and control, on-line/ continual/ life-long learning, and natively modular neural networks (e.g. external plexiform layer).

Neuromorphic Computing

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The current high-profile demonstrations of machine learning/Artificial Intelligence (ML/AI), while impressive, are a) not suitable for Size, Weight, and Power (SWaP) limited systems and b) not operational without access to "the cloud" via high bandwidth communications. Neuromorphic computing is one of the most promising approaches for low-power, non-cloud-tethered ML/AI, capable of implementing a complete, high level intelligence at the level of a sensor platform, by imitating aspects of biological brains, such as trainable networks of neurons and synapses, in non-traditional, highly parallelizable, reconfigurable hardware , in contrast to typical ML approaches today, which utilize commodity hardware and digital algorithms for ML/AI. This research aims for alignment of "the physics of the device" with ML algorithms to intrinsically and efficiently perform the computations in reconfigurable hardware the same way biological systems do so well. This research effort encompasses mathematical models, hardware emulation and characterization, computing architecture design, and algorithm development for neuromorphic computing. We are particularly interested in approaches that exploit the characteristic behavior of physical systems to perform computation, such as the complex behaviors provided from optics/photonics, memristors/ReRAM, superconductors, and metamaterials, among others. Again, special emphasis will be placed on imaginative technologies and solutions to satisfy future Air Force and Space Force needs for non-cloud-tethered ML on SWaP limited assets.

Enable AI for Next-Generation Edge Computing

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The growing adoption of edge computing is poised to revolutionize Artificial Intelligence (AI) by distributing intelligence to the points where data is generated and consumed. Powering this evolution are groundbreaking advances algorithms and specialized hardware, including lightweight AI models and neuromorphic accelerators, which promise to unlock new levels of efficiency and performance. However, current edge AI solutions are hampered by limitations, including: (1) inefficient processing of large-scale neural networks; (2) computationally intensive training methods struggling to keep pace with rapidly increasing data volumes; and (3) vulnerabilities to malicious agents that can compromise network behavior and accuracy. The scope of this research is to advance fundamental understanding in neuroscience, leading to the development of next-generation machine intelligence algorithms and highly efficient neuromorphic hardware. Specifically, the project focuses on: (1) constructing lightweight AI models using a modular framework to support edge inference; (2) enhancing learning algorithms to reliably detect unknown and potentially adversarial agents; and (3) developing a functional prototype of neuromorphic hardware using novel circuit and system architecture.

Phased Array Control, Characterization, and Sensing for Directional Communications

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There is an immediate need for enabling RF spectrum agility and resilient communications in contested environments. Modern analog active electronically steered arrays (AESAs) enable highly directional communication systems that are inherently resilient to interference. However, the current state-of-the-practice for AESA control results in firmware-based controllers that often integrate a specific, singular radio architecture with a single, specific AESA panel. This system design paradigm increases system development time, SWaP, and cost while greatly reducing the spectrum agility and flexibility that the inherent modularity of the AESA panel itself enables.

We are interested in expanding the state-of-the-art in analog AESA-based communication systems by developing control architectures that preserve system flexibility while still allowing for adequate RF sensing and beamforming capabilities with multiple low-cost, modular AESAs from a variety of vendors. This involves foundational research in the following areas:

- Decoupling existing datalink sensing methods from specific hardware implementations so that they can be used with multiple AESA hardware configurations.
- Modelling and simulating pre-defined nulling techniques for AESAs and then implementing and characterizing these techniques.
- Identifying data-optimization techniques that balance the control latency and the desired RF performance of the AESA panel.
- Identifying traditional (non-adaptive, non-parametric) sensing techniques that can be modernized using the unique capabilities of analog AESAs.

We are also interested in applications-focused research on the use of highly directional, communication focused AESAs in contested environments. Examples include but are not limited to link discovery, high-capacity communications, directional communications for autonomous and semi-autonomous platforms, etc.

Event Detection and Predictive Assessment in Near-real Time Complex Systems

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The goal is to make best use of multi-point observations and sensor information for event detection and predictive assessment applicable to complex, near real time systems which are found in many military domains.

The first step in tackling these challenges is to analyze the data, remove any non-relevant information and concentrate efforts in understanding correlations between variables and events. The analysis is followed by designing and developing signal processing techniques that strengthen these correlations. The selected approach would end up transforming data that does not make much sense into a meaningful event prediction. This step is not an easy task because sensor readings and operator logs are sometimes inconsistent, unreliable, provide perishable data, generate outliers due to some catastrophic failure, or evolve in time in such way that data is almost impossible to predict.

Searching for strong correlations between data and events leads to choosing a model which can best assess the current conditions and then predict the possible outcomes for several possible scenarios. Scientists need to understand why a proposed method can be a potential solution.

Perhaps deterministic or statistical models can be simplified and solved; maybe a preprocessing stage can map data into a space where patterns are easily identified; it can be possible that solutions applied to other problems can be translated into the proposed problem, or there is an untested technique that can be applied to a dynamic model.

This is an opportunity for researchers to investigate event detection scenarios in the areas of telecommunications, radars, audio, imagery and video and support AFRL projects in sensor exploitation. An important element of this topic is brainstorming, testing ideas and to gain a general understanding of input data and output events.

Quantum Trust-G: Post-Quantum, Zero-Trust Security for AI-Enabled Autonomous Systems in Federated FutureG Enviroments

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AFRL is seeking to explore advanced research topics in the area of secure autonomy operating across emerging 5G and FutureG communications networks. This topic addresses the critical need for mission-assured, AI integrated, and post-quantum secure communications frameworks that do not rely on building new, siloed ecosystems. The FutureG environment presents unique challenges at the tactical edge, where adversarial manipulation of perception and communications can compromise autonomy, trust, and information superiority. AFRL is particularly interested in concepts that combine secure endpoint identity management using commercial SIM and eSIM-based trust anchors with a scalable zero-trust policy enforcement framework. Integration with Open RAN architectures, federated learning for anomaly detection, and quantum-resilient encryption mechanisms are within scope. Solutions should emphasize interoperability with existing commercial infrastructure and demonstrate pathways that enable the Department of Defense to securely adopt and harden commercial innovations without fragmenting the ecosystem. Proposals may include the development of experimental testbeds, simulation-based evaluations, attack injection modeling for sensor spoofing, and frameworks for quantifying trust in autonomous operations. Emphasis should be placed on dual-use viability, where the government can augment—rather than duplicate—industry capabilities. This topic encourages research that results in operationally practical, standards-aligned, and cost-conscious outcomes, reinforcing AFRL's role in securing next-generation autonomous mission systems.

Hardware Support for Secure Systems

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Military operations increasingly rely on cyberspace, making the security and resilience of the underlying hardware infrastructure paramount. While system- and application-level abstractions simplify design processes, they can also mask critical hardware vulnerabilities. These can be exploited to compromise systems and jeopardize mission success. This topic seeks to address the challenge of leveraging hardware's unique security capabilities to support overall system security *without* adding complexity to the design process or burden to the end-user.

The topic includes, but is not necessarily limited to, the following areas:

- Security for Internet of Things (IoT) devices and Cyber-Physical Systems (CPS)
- Field Programmable Gate Array (FPGA) security
- Secure processor features and implementations
- Hardware side-channel attacks, evaluations, and defenses
- Hardware support for cloud computing security
- Hardware fingerprinting and Physical Unclonable Functions (PUF)
- Hardware trojan evaluation and defense
- Identifying, evaluating and addressing supply chain concerns
- Evaluation and enhancement of commercial Trusted Execution Environments (TEE)
- Security of 5G and NextG hardware and protocols

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Audio & Acoustic Processing

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The acoustic processing work is involved in all aspects of researching and developing state of the art (SOA) acoustical analysis and processing capabilities, to address the needs and requirements that are unique to the DoD counter UAS program. This research area allows us to tackle topics, such as detecting, tracking, beamforming and classifying specific acoustical signatures in dynamic environments via array processing (using both stationary and mobile arrays). The group is focused on developing technology from a basic research level and advancing it to be implemented in the field. Other significant thrusts in noise estimation and noise mitigation (both spectral and spatial), acoustical identification are necessary components of the acoustical program. SOA techniques such as I-vectors, deep neural networks, bottleneck features, and extreme learning are used to pursue solutions for real-time and offline problems.

Assurance in Mixed-Trust Cyber Environments

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Operations in and through cyberspace typically depend on many diverse components and systems that have a wide range of individual trust and assurance pedigrees. While some components and infrastructures are designed, built, owned and operated by trusted entities, others are leased, purchased off-the-shelf, outsourced, etc., and thus cannot be fully trusted. However, this heterogeneous collection of mixed-trust components and infrastructures must be composed in such a way as to provide measurable and dependable security guarantees for the information and missions that depend on them.

This research topic invites innovative research leading to the ability to conduct assured operations in and through cyberspace composed of many diverse components with varying degrees of trust. Topics of interest include, but are not limited to:

- Novel identity and access control primitives, models, and mechanisms.
- Secure protocol development and protocol analysis.
- Research addressing unique concerns of cyber-physical and wireless systems.
- Security architectures, mechanisms, and protocols applicable to private, proprietary, and Internet networks.
- Embedded system security, including secure microkernel (e.g., seL4) research and applications.
- Zero-trust computing paradigms and applications.
- Legacy and commercial system security enhancements that respect key constraints of the same, including cost and an inability to modify.
- Secure use of commercial cloud infrastructure in ways that leverage their inherent resilience and availability without vendor lock-in.
- Novel measurement algorithms and techniques that allow rapid and accurate assessment of operational security.
- Obfuscation, camouflage, and moving target defenses at all layers of networking and computer architecture.
- Attack- and degradation-recovery techniques that rapidly localize, isolate and repair vulnerabilities in hardware and software to ensure continuity of operations.
- Design of trustable systems composed of both trusted and untrusted hardware and software.
- Non-traditional approaches to maintaining the advantage in cyberspace, such as deception, confusion, dissuasion, and deterrence.

Assurance and Resilience through Zero-Trust Security

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Zero-trust cybersecurity is a security model that rigorously verifies every user and device before granting access to computing or network resources. Within cloud environments, this principle dictates that no entity, whether internal or external to commercial and public cloud systems (including the Cloud Service Provider), is trusted by default. While offering robust security, the practical implementation of zero-trust often relies on complex and resource-intensive technologies, such as public-key infrastructure and zero-knowledge proofs. This makes designing truly efficient and scalable solutions based on zero-trust a significant challenge.

This research topic seeks novel approaches to: 1) enabling warfighters to efficiently and securely outsource private data and computation with mission assurance and verifiable correctness of results to untrusted commercial clouds without relying on a Trusted Third Party (TTP); 2) improving the resilience and robustness of the Air Force's mission-critical applications by effectively distributing them across multiple heterogeneous CSPs to prevent a single point of failure, avoid technology/vendor lock-ins, and to enhance availability and survivability; 3) optimize the trade-off between strict zero-trust security and rigid performance requirements for time-sensitive mission applications. Research topics of interest include, but are not limited to:

- Decentralized identity and access control mechanisms and protocols, including those that support anonymity.
- Novel cryptographic primitives and protocols with application to zero-trust computing paradigms.
- Design cross-cloud, CSP-independent, privacy-aware protocols and frameworks that operate in the presence of emerging zero-trust security mechanisms.
- End-to-end data protection, concurrency, and consistency for multi-user multi-cloud environments.
- Access patterns and volume leakage prevention for oblivious data stores under malicious security.
- Verification and authentication schemes for query evaluation over encrypted and unencrypted data.

Discovery and Retrieval of Publicly Available Internet Information (PAI)

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This research topic seeks novel methodologies for conducting comprehensive and secure searches across the vast and continuously evolving landscape of Publicly Available Information (PAI) on the Internet. PAI is inherently multilingual and takes diverse forms, including online publications, news, blogs, social media, AI-generated content (e.g., from platforms like ChatGPT), and emerging data types.

The central challenge is to develop technologies that enable analysts to perform secure, efficient, and scalable PAI retrieval while rigorously protecting their identity and intent, and simultaneously preventing website owners and operators from tracking collection activities or linking them back to users or their agency.

We are particularly interested in novel technologies and approaches that address:

- **Confidential and Scalable PAI Collection:** Methods for confidential and scalable PAI gathering that do not rely on trusted third parties, modify source data, or require collaboration with PAI website operators.
- **Robust Attribution Management and Anonymization:** Advanced approaches for managing attribution and ensuring comprehensive web browsing anonymization.
- **Private Information Retrieval (PIR):** Innovative Private Information Retrieval (PIR) protocols, including computational, information-theoretic, and differentially private methods, to facilitate secure and private data access.

Novel Protocols for Robust Communication Anonymization and Covertness

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In an increasingly interconnected and surveilled digital landscape, the need for robust communication anonymization and covertness is paramount. This is critical for protecting sensitive operations, safeguarding individual and organizational privacy, enabling secure exchange information in hostile or censored environments, and resisting pervasive surveillance. While existing protocols offer some level of protection, they often face challenges related to scalability, performance overhead, resilience against advanced traffic analysis, metadata leakage, and strong deniability properties.

This research topic seeks novel protocols and methodologies to achieve unprecedented levels of communication anonymization and covertness. We are particularly interested in interdisciplinary approaches that can overcome current limitations and provide practical, deployable solutions.

Specific areas of interest include, but are not limited to:

- **Next-Generation Anonymity Networks:** Designing and evaluating novel architectures for low-latency, high-throughput, and resilient anonymity networks that can withstand sophisticated traffic analysis, timing attacks, and deanonymization attempts.
- **Advanced Steganography and Covert Channels:** Developing new techniques for embedding hidden information within seemingly innocuous data streams or establishing truly undetectable communication channels, with a focus on high capacity, robustness against detection, and deniability.
- **Deniable Communication Protocols:** Creating protocols that allow parties to plausibly deny having engaged in communication or revealing its content, even under duress or in the face of sophisticated forensic analysis.
- **Metadata Protection and Obfuscation:** Innovative methods to prevent the leakage of sensitive metadata (e.g., sender/receiver identities, timing, volume, patterns) that can often bypass content encryption.

- **Cross-Layer Anonymity and Covertness:** Solutions that integrate anonymization and covertness mechanisms across multiple layers of the communication stack (e.g., network, transport, application) to provide end-to-end protection.
- **Formal Verification of Anonymity Properties:** Methodologies for formally proving the anonymity and covertness properties of new and existing protocols.

Note: Proposals should focus on the design, analysis, and evaluation of novel protocols and methodologies rather than solely on the development of new cryptographic primitive

Beyond Surface Artifacts: Designing and Developing Novel Cross-Modal Forensic Methodologies for the Attribution and Explainable Detection of Sophisticated AI-Generated Synthetic Media (Images, Video, Audio, Text, and their Combinations).

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This topic emphasizes the need for a comprehensive, cross-modal approach that can adapt to the rapid evolution of generative AI models. It calls for new frameworks that don't just detect individual modalities but understand the inconsistencies and fingerprints across different types of AI-generated media. Proposed projects should zero in on the challenge of detecting highly sophisticated AI-generated content that leaves fewer obvious "fingerprints." They should also highlight the critical need for *explainability* (understanding *why* something is flagged as AI-generated) and *attribution* (potentially tracing it back to a specific generation model or family). Developed methodologies not only need to be effective but also must be robust against adversarial attacks and designed to evade detection. The emphasis is on building future-proof systems for combating misinformation.

Successful research projects would involve:

- **Novelty:** Moving beyond incremental improvements to existing forensic techniques, cross-modal consistency analysis, and continuous learning systems.
- **Multimodality:** Addressing images, video, audio, text, and crucially, their *combinations* (e.g., a deepfake video with spoofed audio).
- **Robustness/Adaptability:** Methods that are resilient to evolving AI generation techniques, compression, and adversarial attacks.
- **Explainability:** The ability to provide reasons or confidence scores for why content is flagged as AI-generated, fostering trust and aiding human review.
- **Scalability & Real-time Capability:** Solutions that can process vast amounts of data efficiently and in near real-time.
- **Data Challenges:** The need for new, diverse, and dynamic datasets of both real and AI-generated content for training and evaluation.
- **Ethical Considerations:** Acknowledging the implications of such detection technologies, including privacy and potential misuse.

Assurance in Containerized Environments

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Containers are portable, but restricted, computing environments packaged with the bare requirements necessary for an application to run. Containers provide efficiency, speed, resilience, and management for the projects they support and have facilitated the characterization of DevSecOps as a force enabler. Containers and container orchestration technology are becoming more popular due to the performance benefits, portability, and the ability to leverage them in many different environments/architectures. However, security remains the barrier to widespread adoption in operational environments. The container threat model is headlined with the lack of high assurance and weak security isolation properties. As cloud and microservice architecture expansion continues, the assurance of container security has become a requirement.

This research topic invites innovative research providing high assurance computing capability in a variety of container architectures. Research areas of interest include, but are not limited to:

- Novel high assurance architectural designs
- Secure container technology for deployment in legacy technology stacks and/or commercially owned/operated cloud infrastructures
- Non-traditional and/or novel trustworthy virtualization methods lending to high assurance security with high performance benefits
- Secure deployment techniques to support DevSecOps
- Design of cloud-ready, container interfacing enclave solutions for data protection
- Novel data and tenant separation primitives, models, and mechanisms
- Methods for verifying data storage sanitization
- Approaches for remote attestation to assure that a container is running in an authorized environment
- Approaches to zero-trust in containerized environments
- Novel accreditation algorithms and techniques to provide rapid and accurate assessment of container images

Data Driven Approaches to Multimodal Sensor Data Information Extraction and Fusion for Collaborative Autonomy Designs in Detection, Estimation, and Characterization

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Modern, contested Air Force mission spaces are varied and complex involving many sensing modalities. Mission success within these spaces is equally critical to the engaged Warfighter, and, Command, Control, Communications, Computer, Cyber, and Intelligence (C5I) systems, which both leverage actionable information from these heterogeneous sensing landscapes. Interfering sources, low probability of intercept signals, and dynamic scenes all collude to deceive the Air Force's ability to derive accurate, relevant situational awareness in a timely fashion. Furthermore, legacy sensing systems which typically provide stove-piped human interpretable intelligence with potentially missing information are likely be more valuable and less vulnerable if aggregated with other sensing data upwardly located in their processing pipelines (i.e., upstream data fusion). Our overall research goal is to leverage all available signals, data from sensed environments, and domains leveraging collaborative/distributed systems for generating a cohesive situational awareness of a complete strategic/tactical space. The fundamental research objectives under this topic, within the context of emerging collaborative autonomy, includes areas such as multi-modal target association/fusion, multi-sensor/modal detection, tracking, characterization, multi-sensor selection, and parameter optimization for improved sensor fusion performance, interpretability, explainability, and optimization/orchestration tasking. We are interested in innovative discovery and designs within these areas that may come from a variety of novel discrete and stochastic methodologies (e.g., topological data analysis, artificial intelligence/machine learning, the interfacing of these approaches and other mathematical representations, Bayesian and information theory, etc.). These advancements, considered within the context of optimizing computational complexity and managing constrained communication/bandwidth, ideally must balance intelligent computational nodes and centralized/distributed processing to obtain desired deployment/transitional thresholds.

ML Red Teaming

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Adoption of AI/ML models and techniques has rapidly increased, creating larger attack surfaces that may be exploited by a malicious actor to subvert the AI/ML model or encompassing system. The near-ubiquitous nature of AI/ML requires development of analysis and red teaming methodologies to fully assess and improve a system's security. The literature surrounding model evaluation for privacy and efficacy is continuously growing and many have begun to foray into contextualizing these demonstrated adversarial threats through frameworks (e.g., MITRE ATLAS) and through actualization of attacks leveraging these vulnerabilities (e.g., [1]). In order to safely leverage AI/ML, it is imperative that we holistically view and evaluate the security implications by developing a comprehensive red teaming strategy that encompasses all components of an AI/ML-integrated system.

In this topic, we are interested in innovative approaches to finding vulnerabilities that are introduced by adopting an AI/ML model and/or pipeline and the effects that can propagate throughout a system. Topics of interest include, but are not limited to:

- Analysis of a target model for vulnerabilities (e.g., adversarial examples, model inversion, etc…)
- Analysis of the ML Ops pipeline for vulnerabilities
- TTPs for AI/ML testing and red team engagements

[1] IBM X-Force Red. (2025). "Disrupting the Model: Abusing MLOps Platforms to Compromise ML Models and Enterprise Data Lakes".

Topological Data Analysis for Cyber Assurance

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Topological Data Analysis (TDA) gives us rigorous theory and implementations for understanding the structure of collected heterogeneous data by the measuring, tracking, and algebraically encoding its topological characteristics and persistent features through compressed representations of high fidelity. However, existing TDA tools may not be sufficient for robust data driven analyses that fully supports the evolving mission success and decision speed of the USAF/USSF Warfighter in (hyper) contested environments containing various concentrations of physical (e.g., multimodal sensor data information) and human (e.g., multimedia sources) based data inundated with attenuation/adversarial deception. Furthermore, much of the data collected in cyberspace has complex topologies that are not suited for many of the existing TDA methods. One approach in this case is to embed the data into a graph and use TDA techniques on the graph structure. While this is useful, it is not clear from the existing body of research that this captures all the essential features of the data for the purposes of inference and decision-making. Within the emerging field of topological deep learning (TDL) Hajij et al. developed combinatorial complexes leveraging higher-dimensional features and n-ary (i.e., binary, trinary, …, n-ary) non-Euclidean relation analysis of graph-embedded data. This project aims to develop implementations and test beds for using these complexes to perform deep learning tasks within AFRL mission spaces of data assurance and information exploitation. Concurrently, we aim to develop TDL and other modern TDA methodology inspired novel approaches (e.g., multi-parameter persistent homology) for performing topologically informed autonomy on non-metrizable

Processing Publicly Available Information (PAI)

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Publicly Available Information (PAI) includes a multitude of digital unclassified sources such as news media, social media, blogs, traffic, weather, scholarly articles, the dark web, and others. Being able to extract relevant supplementary information on demand could be a valuable addition to conventional military intelligence.

It would be of interest to: (1) categorize trustworthy PAI sources, (2) pull in textual information in English (generate English translation over major foreign languages), and (3) setup a library of natural language processing (NLP) tools which will summarize entities, topics, and sentiments over English texts. Examples of trustworthy PAI sources include highly credible users that belong to major and local news, emergency responders, government, university, etc. Topics of interest relate to business and economics, conflicts, cybersecurity, infrastructure, disasters and weather, etc. Important to have capabilities to resolve location even in the absence of geotags. Finally need to have confidence metrics for all capabilities developed. The researcher may chose, based on their expertise, to work on a subset of the outlined tasks.

Short-Arc Initial Orbit Determination for Low Earth Orbit Targets

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When new objects are discovered or lost objects rediscovered in Low Earth Orbit (LEO), very short arcs are obtained due to limited pass durations and geometrical constraints. This results in a wide range of feasible orbit solutions that may well-approximate the measurements. Addition of a second tracklet obtained a short time later – about a quarter of the orbit period or more – leads to substantially improved orbit estimates. However, the orbit estimates obtained from performing traditional Initial Orbit Determination (IOD) methods on these tracklets are often insufficient to reacquire the object from a different sensor a short time later, resulting in an inability to gain custody of the object. Existing research in this area has applied admissible regions and multi-hypothesis tracking to constrain the solutions and evaluate candidate orbits. These methods have been primarily applied to Medium Earth Orbit and Geostationary Orbit and have aimed to decrease the total uncertainty in the orbit states. The objective of this topic is to research and develop methods to minimize propagated measurement uncertainty for LEO objects at future times, as opposed to minimizing the orbit state uncertainty over the observed tracklet. This will improve the ability to reacquire the object over the course of the following orbit or orbits to form another tracklet, which will result in substantially better orbit solutions. Sensor tasking approaches which maximize the likelihood of re-acquisition are also of interest.

Feature-Based Prediction of Threats

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Methods have been developed to detect anomalous behaviors of adversaries as represented within sensor data, but autonomous predictions of actual threats to US assets require further investigation and development. The proposed research will investigate foundational mathematical representations and develop the algorithms that can predict the type of threat a red (adversary) asset poses to a blue (friendly) asset. The inputs to the system may be assumed to include: 1) an indication/warning mechanism that indicates the existence of anomalous behavior, and 2) a classification of the type of red/blue asset. Approaches to consider include, but are not limited to, predictions based on offensive/defensive guidance templates and techniques associated with machine learning, game theoretic approaches, etc.. The proposed approach should be applicable to a variety of threat scenarios.

The example that follows illustrates an application to U.S. satellite protection. The offensive template determines the type of threat. Mechanisms such as templates are used to predict whether or not this asset is a threat by comparing configuration changes with known threatening scenarios through probabilistic analyses, such as Bayesian inferences or game theoretic analyses. Robustness tests may be employed as well. (For example, a threat can be simulated that is not specific to one template.) Once the threat is determined, the classification algorithm provides notification of the type of asset. The classification approach is employed to (for example) determine whether the asset is intact or a fragment, its control states, the type of control state, and whether it is a rocket body, payload, or debris. (An example of an offensive assessment is a mass-inertia configuration change in an active red asset that is specific for robotic arm-type movements.) In the above example, a question to be answered is: can a combination of the templates handle this case? The defensive portion must also provide recommended countermeasures, i.e. as in the case of a blue satellite, thruster burns to move away from possible threats. Although our specific application interests for this research topic are represented by the above example, many application areas are likely to benefit from this research, including cyber defense, counter Unattended Aerial Systems (UASs), etc.

Data Fusion and Processing using Machine Learning

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Due to the volume, variety, complexity, and decision timelines associated with real-time data collection from air- and space-based platforms, it is not viable for human operators to monitor, comprehend and act. The aim of this research thrust is to investigate topological data analysis, artificial intelligence, and machine learning approaches to system analysis, anomaly and threat detection, graph/data representation and nodal analysis. These techniques can be applied to quantify threats, attacks, nodal analysis and graph cuts, patterns of life, landscape changes over time, critical infrastructure anomalies and (rare) events leading to cascading effects pertaining to large-scale cyber-physical systems. Machine learning approaches could speed these processes but require massively curated datasets for training and parameter tuning, must be robust to a variety of adversarial attacks, and be re-trained during execution time. This topic will explore approaches that include: data sensing, collection, fusion, and augmentation at the edge; processing and exploitation of multimodal data using machine learning and topological data analysis approaches; development of explainable AI models and incorporation of human interaction; including feedback loops to improve parameter tuning and real-time training; and identification and quantification of physical and digital attacks to AI/ML lifecycles; to include real-time identification of when a deployed model may be used out of context or beyond its training data. Special consideration will be given to proposals that include innovative approaches for in low-SWaP (Space Weight and Power) constrains.

Identification of Data Extracted from Altered Locations (IDEAL)

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The primary objective of this effort is to extract information from documents in real time, without the need to install additional software packages, utilize specialized development, or train agents to each source, even if the location of that data changes.

Seeking data from multiple documents is a manual, time consuming, undocumented process, which needs to be repeated every time an update, or change, to that data is requested. Automating this process is a challenge because the documents routinely change. Sometimes, the mere act of refreshing a web page changes the document as the ads cycle. Such changes are damaging to most of today's web scraping techniques. The lack of data, or inaccurate data, from failed updates during the extraction process also creates many problems when attempting to update the data, as unexpected results are returned. Extracting data from documents, typically requires training or expert analysis for each source before the data can be used. This means that documents must first be identified before a script or agent can be written to extract data from it by a developer. A user cannot discover a document, and immediately begin extracting data from it. This diverts time away from an analyst, as the analyst begins spending more time managing data, opposed to performing the intended analysis. Services that provide access to data such as RSS feeds, Web Services, and APIs, are useful, but are not necessarily what is needed by the requestor. For example, the Top Story from a news publisher may be available as an RSS feed, whereas the birth rate of the country may not be.

This assignment will focus heavily on enhancing the web browser extension prototype. The extension will be used for routine extraction of data elements from open source web pages/documents, and be developed for the Firefox web browser. In addition to Web Browser extension development, this assignment will include adding additional functionality such as visualization enhancements, search and transposition, crawl, and a process for identifying similar data. Consideration will also include expanding to additional web browsers such as Internet Explorer.

Classification of users in chat using Keystroke Dynamics

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Traditional username and password techniques, or Common Access Card, (CAC) login, does not continually monitor usage behavior over time. Keystroke Dynamics is a technique used to measure timing information for keys pressed/depressed on a computer keyboard and identifying unique signatures for the way an individual types. The current practice of Keystroke Dynamics, also known as Keystroke Biometrics, is understanding this rhythm, to distinguish between users for authentication – even after a successful login. Current enrollment techniques require users to establish a consistent baseline and is traditionally accomplished by typing common words multiple times.

While effective, this process is sometimes rejected by users who do not see the value in an extensive enrollment process by typing large volumes of data. The challenge is determining the balance between effective enrollment, and user satisfaction. This effort will identify the most important features that will be used to allow for accurate classification of users from keystroke data. Specifically, classifying commonly typed digraphs to verify the claimed identity of the user, by developing binary classifiers trained with Machine Learning (ML) algorithms, to identify the most efficient signatures generated from frequent keystroke patterns. The goal is to create a trusted chat exchange between users for secure communications beyond traditional encryption and authentication techniques.

Elegant Failure for Machine Learning Models

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The need for increased levels of autonomy has significantly risen within the Air Force. Thus, machine learning tools that enable intelligent systems have become essential. However, analysts and operators are often reluctant to adopt these tools due to a lack of understanding – treating machine learning as a black box that introduces significant mission risk. Although one may hope that improving machine learning performance would address this issue, there is in fact a trade-off: increased effectiveness often comes at the cost of increased complexity. Increased complexity then leads to a lack of transparency in understanding machine learning methods. In particular, it becomes unclear when such methods will succeed or fail, and why they will fail. This limits the adoption of intelligent systems.

This topic focuses on building trust in machine learning models by designing models that fail elegantly. Of particular interest are model calibration techniques for object detection and classification, novelty detection, open-set recognition, and post-hoc filters to identify instances prone to causing model failure. Other topics related to this area will also be considered.

Recommendations Under Dynamic Incomplete and Noisy Data

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The DoD conducts Intelligence Surveillance and Reconnaissance (ISR) by focusing on optimal sensor placement for coverage. During the execution of the ISR plan, the DoD utilizes an ad-hoc manual process to prioritize and track existing and emergent objects-of-interest. Automating the ranking of objects-of-interest in sensor coverage areas is a critical component of operating within these near-peer contested environments. In contested environments, we expect to encounter enemy countermeasures such as jamming, spoofing, etc. that reduce the quality of the data needed for continuous tracking. In other words, the central challenge of this effort is tracking objects-of-interest given the uncertainty and accuracy of the data.

AFRL seeks novel research into approaches that can utilize noisy and incomplete data to rank a set of trackable objects-of-interest. Experimental datasets can comprise some mix of semi-realistic or synthetic data representing both multi-int sensor information, as well as other higher level data sources for context. This topic is interested in exploring hybrid approaches that can represent conflicting data points. Given the model must represent these conflicting data points, non-linear approaches are desired. These approaches may include but are not limited to preference learning, active learning, and adaptive neural networks.

Recommendations with Human-on-the-Loop Interaction

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AFRL is focused on autonomous systems, as it pushes AI capabilities to the edge, to combat near-peer competitors. Increased emphasis on autonomy requires effective human-machine interaction to guarantee human judgment in decisions. This interaction should allow for a supervised autonomous mode i.e., 'Human on the Loop (HOTL). As stated, by General Terrence J. O'Shaughnessy, USAF (ret.), 'machine- enabled insights … can identify anomalous events, anticipate what will happen next, and generate options with associated repercussions and risks [https://warontherocks.com/2022/06/whats-wrong-with-wanting-a-human-in-the-loop/].

AFRL seeks novel research into various aspects of human-on-the-loop interactions including: representing context in encoding spaces, context aware recommendation methodologies, sorting and ranking methods for multi-criteria decision analysis, active learning to reinforce context within recommendations, and large language models for recommendations. Experimental datasets ideally include partially observable contextual information and can comprise a mix of semi-realistic or synthetic data. Additionally, contextual data can be represented as low-level attributes, as well as other higher-level information.

Adaptable Methods for Applying and Understanding Artificial Intelligence and Machine Learning

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Artificial intelligence and machine learning applications have exploded over the last decade. However, under some scenarios there has been slower adoption of such approaches.

While there are several potential reasons for slow adoption of AI/ML, one reason is that there must be trust and a responsible use of such approaches. This research topic is therefore interested in methods for instilling trust in AI/ML, either through better performance metrics or human understandable presentations of an AI/ML algorithms decision. This includes methods that explain the numerical impacts of training examples on the models being learned or novel methods that conceptually describe what an algorithm is learning. As part of understanding, this topic is also interested in new approaches that artificially alter or create data.

Additionally, a single model trained on specific data might not always allow for direct application to another use case. This research topic is therefore also interested in methods for applying models in unique scenarios, including at the edge. This might require advancements in the application of transfer-learning approaches or scenarios where it is necessary to fuse or correlate the output of multiple AI/ML models and/or algorithms. Hence, this research topic is interested in novel methods for fusing and building ensembles of pre-trained models that are task agnostic and can more easily mimic the agility that humans possess in the learning process.

Being able to explain the impact of specific examples on the learning process, adapting a model to be deployed at the edge, and building novel algorithms and architectures will support the realization of more adaptable learning methods.

Data Driven Model Discovery for Dynamical Systems

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The discovery and extraction of dynamical systems models from data is fundamental to all science and engineering disciplines, and the recent explosion in both quantity and quality of available data demands new mathematical methods. While standard statistical and machine leaning approaches are capable of addressing static model discovery, they do not capture interdependent dynamic interactions which evolve over time or the underlying principles which govern the evolution. The goal of this effort is to research methods to discover complex time evolving systems from data. Key aspects include discovering the governing systems of equations underlying a dynamical system from large data sets and discovering dynamic causal relationships within data. In addition to model discovery, the need to understand relevant model dimensionality and dimension reduction methods are crucial. Approaches of interest include but are not limited to: model discovery based on Taken’s theorem, learning library approaches, multiresolution dynamic mode decomposition, and Koopman manifold reductions

Predictive Knowledge Graphs for Situational Awareness

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Knowledge Graphs capture information about entities and the relationships between those entities, represented as nodes and edges within a graph. Entities can be comprised of objects, events, situations, or concepts. Knowledge Graphs are typically constructed from various data sources with diverse types of data, creating a shared schema and context for formerly disparate pieces of data. As such, Knowledge Graphs provide a rich source of information, enabling capabilities like question and answering systems, information retrieval, and intelligent reasoning. Areas of specific interest for this topic include (but are not limited to): identification of information gaps (i.e. spatial, temporal, reasonability) in a KG, prediction of additional information to augment a KG, recommending visualization techniques (i.e. timeline, heatmap) based on KG content, and neural KG search techniques. This research should be in support of more efficient situational awareness, pattern of life analysis, threat detection, and targeting operations. Proposers are strongly encouraged to contact the topic POC to discuss possible proposals.

Exploring Relationships Among Ethical Decision Making, Computer Science, and Autonomous Systems

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The increased reliance on human-computer interactions, coupled with dynamic environments where outcomes and choice are ambiguous, creates opportunities for ethical decision making situations with serious consequences where errors could cost loss of life. We are developing approaches that make autonomous system decisions more apparent to its users, and capabilities for a system to tailor the amount of automation based on the situation and input from the decision maker. This allows for dynamically adjustable human/machine teaming addressing C2 challenges of Autonomous Systems, Manned/Unmanned Teaming, and Human Machine Interface and Trust. The work focuses on developing a system for modeling and supporting human decision making during critical situations, providing a mechanism for narrowing choice options for ethical decisions faced by military personnel in combat/non-combative environments.

We propose developing software (an “ethical advisor”) to identify and provide interventions in situations where ethical dilemmas arise and quick, reliable decision making is efficacious. Our unique approach combines behavioral data and model simulation in the development of an interactive model of decision making that emphasizes the human element of the decision process. In the long term, understanding the fundamental aspects of human ethical decision making will provide key insights in designing fully autonomous computational systems with decision processes that consider ethics. As autonomous systems emerge and military applications are identified, we will work to provide verifiable assurance that our autonomous systems are making decisions that reflect USAF moral and ethical values. The first step towards realizing this vision is focusing on human decision processes and clarifying those values in a quantifiable model. The team has developed an ethical framework and preliminary model of ethical decision making that will be more fully developed with the Air Force Academy (AFA) and Air University (AU). In Year 1, we will articulate the individual psychological characteristic and situational factors impacting ethical dilemmas and develop realistic ethical dilemmas and situations. These scenarios will use computational agents employing AI and military personnel, requiring ethical decisions to be made by personnel in combat and non-combative environments. In year 2, we will develop the Ethical Advisor prototype, test the individual psychological characteristics and situational factors, refine the scenarios, and establish and implement collaborations across different commands/services. In year 3, we will test and integrate the model and Ethical Advisor into a mission system, and conduct joint war game testing.

We are seeking individuals from a variety of educational disciplines (Psychology, Philosophy, Computer Science) with experience in data gathering and summarization techniques, programming, and testing. The gathered data would be used for developing algorithms and programming to begin enabling software to mimic human decision making in complex ethics-laden situations.

Enhancing Object Detection for Overhead Images Through Active Learning and Physics-Based Synthetic Data Generation

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Overhead imagery is essential for various Air Force applications. However, challenges like limited data, variable conditions, and small or occluded objects hinder overhead imagery object detection. This research aims to develop an integrated framework that combines active learning with physics-based synthetic data generation to overcome these issues. The generative pipeline creates synthetic imagery with controllable factors (e.g., sensor, atmosphere, illumination, scene), optimized through active learning to produce informative samples to robustly train object detection models that generalize well while minimizing the required synthetic data. Furthermore, the synthetic dataset can be enhanced using diffusion-based style transfer techniques, enabling simulations of various weather, seasonal, and environmental conditions. This work aims to establish a framework for scalable, adaptive, and robust model training.

The research topic emphasizes the advancement of cutting-edge active learning techniques for object detection. Areas of interest include, but are not limited to, deep clustering, active learning techniques, particularly LLM model-guided techniques, diffusion models, Unreal Engine/Unity asset development, and physics-based synthetic data generation methods.

Feature Extractor for Overhead Images

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ResNet, VGG, Inception, and AlexNet are some of the popular models that researchers used as image feature extractors. However, these models are usually pre-trained on ImageNet, which is not in an overhead perspective. Some researchers have fine-tuned these models on overhead imagery [1, 2]. Nevertheless, the attributes such as:

- Scale, rotation, and viewpoint invariance
- Spatial invariance
- Scene/background/context information understanding
- Adaptability and transferability
- Computation resource efficiency

need to be thoroughly studied and further improved. This research topic focuses on developing a state-of-the-art feature extractor for overhead images with these attributes. Some research areas of interest include but are not limited to unsupervised and self-supervised representation learning, such as contrastive learning models, mask image modeling, deep clustering, CLIP model, manifold learning techniques, and zero-shot learners.

[1] Artashes Arutiunian, Dev Vidhani, Goutham Venkatesh, Mayank Bhaskar, Rito-brata Ghosh, and Sujit Pal. 2021. Fine tuning CLIP with Remote Sensing (Satellite) images and captions. **https://huggingface.co/blog/fine-tune-clip-rsicd**

[2] Muhtar, Dilxat, et al. 2023. CMID: A Unified Self-Supervised Learning Framework for Remote Sensing Image Understanding. IEEE Transactions on Geoscience and Remote Sensing.

Adaptive Fusion of Instance-Wise Predictions

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Over the past decade, artificial intelligence and machine learning applications have seen tremendous growth. However, their adoption has been slower in certain high-stakes environments, where systems must provide accurate and timely predictions while navigating uncertainty and resource constraints, such as on the edge. This research focuses on developing instance-wise adaptive fusion frameworks that selectively integrate predictions from multiple prediction models, taking into account the confidence and computational cost associated with each. Instead of relying on static ensembles, this work seeks methods that dynamically determine which models to query for each input, facilitating efficient and reliable decision-making. Specifically, we aim to explore the dynamic model selection problem, with an emphasis on task-agnostic approaches. Other related topics in fusion and ensemble methods will also be considered.

Architecting Brain-Inspired AI for Enhanced Cognitive Abilities

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Developing Artificial General Intelligence (AGI) that rivals human intellect remains one of the most ambitious challenges in computer science. This project seeks to make significant strides towards this goal by exploring artificial neural architectures directly inspired by the structure and function of the human brain's neocortex. Crucially, we recognize that building truly intelligent machines requires not only creating powerful cognitive systems but also developing robust frameworks for assessing their intelligence.

Objectives:

1. **Design Integrated Neural Network Architectures:** Develop hybrid architectures that combine different computational paradigms (e.g., spiking neural networks, deep learning, symbolic reasoning) to emulate the functional organization of the neocortex. Focus on efficiency and adaptability while reducing SWaP constraints.
2. **Empower Cognitive Reasoning:** Integrate symbolic and sub-symbolic representations within these architectures to enable robust reasoning abilities. Explore methods for commonsense knowledge representation, logical inference, and problem-solving in complex real-world scenarios.
3. **Facilitate Learning & Adaptation:** Develop learning paradigms inspired by the brain's plasticity, focusing on unsupervised and self-supervised learning techniques to allow machines to learn from diverse data modalities and adapt to changing environments.
4. **Establish Robust Intelligence Assessment Frameworks:** This is a central focus of this project. We will create novel metrics and benchmarks that go beyond traditional accuracy measures to capture higher-level cognitive functions like reasoning, planning, creativity, and social intelligence. These frameworks will be essential for accurately evaluating the progress of brain-inspired AI and guiding its development towards true general intelligence.

Impact: This research has the potential to significantly advance AGI by developing intelligent systems capable of tackling complex problems across diverse domains. It will contribute to a deeper understanding of both biological and artificial intelligence, paving the way for truly intelligent machines.

Dataset Coordinated Optimization of Heterogeneous ISR Sensors for Target State Estimation in Contested Maritime Environments

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Future ISR systems must autonomously operate, navigate, and coordinate across a heterogeneous mix of traditional, tactical, and space-based sensors. A key challenge lies in integrating these diverse platforms—such as emerging Space-Based Radars (SBR), traditional airborne assets, and tactical edge platforms like drones—into existing and future command-and-control networks. In highly contested environments, ISR assets face constraints in time-on-station and navigable access, leading to temporal and spatial coverage gaps. Stand-off assets have limited target access due to range or availability, while tactical platforms often lack persistence, resulting in incomplete tracking and degraded target state estimation.

AFRL seeks novel research into **distributed and coordinated optimization algorithms** capable of fusing multi-entity sensor inputs to collectively achieve a **global objective of maximizing target state estimation**. Proposed solutions should address **resilience to incomplete or intermittent sensor coverage**, leveraging autonomous coordination and decision-making strategies. The focus is on ISR operations in **contested maritime domains**, where adaptive, decentralized approaches must handle dynamic operational constraints, sensor dropouts, and information gaps. Desired techniques may include distributed optimization, cooperative multi-agent systems, reinforcement learning, or resilient sensor fusion frameworks.

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