# Current Research Topics for the DEVCOM ARL BAA For Foundational Research W911NF-23-S-0001

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W911NF-23-S-0001,
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Link to all current ARL research topics

# Available Army Research Office (ARO) Research Topics

The available Army Research Office (ARO) topics are listed in alphabetical order.

# Army Research Office (ARO) Research Topic

**Title:** Advanced Learning-Enabled Intelligent Cyber Physical Systems
**Announcement ID:** ARL-BAA-0032

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**ARL Office:** Army Research Office (ARO)
**Discipline:** Computer Science;Data Sciences and Informatics;Mathematics and Statistics
**ARL Foundational Research Competencies:** Military Information Sciences;Network, Cyber, and Computational Sciences
**Army Modernization Priorities:** Future Vertical Lift;Next Generation Combat Vehicle
**Keywords:** Intelligent Systems, Interaction, Assured Operations, Online learning, Robust Intelligence, World Models, Memory Systems, Causality

**Description:**
Intelligent cyber physical systems play an increasingly important role in civilian and military settings. With few exceptions, current intelligent systems are restricted to highly constrained environments for short duration missions. Future systems will need to perform a variety of tasks in complex, possibly contested, open worlds for extended periods of time. One important characteristic of open worlds is that the intelligent system will encounter new contexts, activities, and objects that will require it to adapt previously trained algorithms. Advanced capabilities in learning, reasoning, interaction, and assured operations are essential to the development of intelligent systems that can greatly enhance the Army's mobility, agility, lethality, and survivability in future conflicts.

***ON-LINE LEARNING THEORY, METHODOLOGY, AND TECHNIQUES***
Over the past 50 years, machine learning has made great strides in classification, natural language processing, and task learning. However, machine learning still lacks the rigor, agility, and flexibility necessary to operate in complex, contested open worlds. This thrust focuses on establishing a theoretical foundation for on-line or continuous machine learning. New learning approaches will need to address both the dimensionality challenges and temporal characteristics that may be evolving continuously. In addition, new techniques must address robustness to enable the learning system to deal with novelty, noise, observation errors and potentially malicious input that aim to disrupt learning. Innovative approaches to continuous learning will allow systems to adapt to changing contexts and environments while maintaining previously learned knowledge. Under this thrust, we investigate approaches that help the intelligent systems deal with dynamic environments, devise new, transferable skills, and cope with unknown situations.

While end-to-end learning may be important for certain applications, it may not be an effective approach for the complex environments typical of most battlefields. Instead, there is a need for compositional learning systems in which each component may learn primitive actions that are later combined, and adapted, to solve complex long-horizon manipulation problems. Research is needed to understand how to express and learn the preconditions and post-conditions for each of the primitive actions. Linking elements from a library of primitives and adapting the ensemble to solve an existing problem is also an outstanding issue. Automated curriculum learning in which


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the CPS devises its own learning strategy is an open research area. Important issues in this area include generating sample task environments from observation, memory and simulation; sequencing those task into an effective curriculum; and transferring the learning as the tasks become more complex.

***DECISION MAKING FOR THE OPEN WORLD***

Long duration operations require CPSs to continually reason, make decisions, or take actions with very limited knowledge of the pertinent events or objects that could impact those decisions. In real world missions, systems often address multiple near-simultaneous tasks to accomplish their objectives - on a battlefield, systems need to travel to a location while searching for potential adversaries and sharing information with teammates. Architectures that draw from psychological models for human decision making, such as Dual Process theory, may enable CPSs to effectively distribute the processing for near-simultaneous reasoning tasks. Advances in risk-aware online planning will enable autonomous systems to balance potentially conflicting objectives and operate safely in poorly understood environments. CPSs also need to develop a sense of "'causality" that discovers relationships between objects and events and allows the system to incorporate temporal and spatial information into the reasoning processes.

Storing and accessing information is vital to long term mission. Not all pertinent information is collected at the same time: new research in memory systems will enable cyber physical systems to determine what information, in what form, it needs to store to support future actions that may or may not relate to its current action. Memory systems are not simply information stores - processes like reflection, abstraction, and learning enable CPSs to develop new information. Retrieval mechanisms are very important - information is not useful unless the system can recall it when it is needed. Research to understand effective memory structure and processes will benefit from a collaboration with cognitive scientists to understand memory in biological systems. New approaches are needed to address potential issues with memory systems such as catastrophic or forgetting, limited storage capacity, and development of new methods to efficiently use external knowledge stores.

***INTERACTION***

Future autonomous systems must interact physically with humans and other intelligent systems operating in the same space, remotely with spatially distant entities, and virtually in cyberspace with intelligent software agents. New research in human-robot interaction and robot-robot teaming will enable humans and robots to share the same space and work together on complex tasks. Research in Ad-hoc teamwork will enable entities (human and systems) to dynamically join together to address a specific problem, then pursue separate tasks after the problem is solved. In this type of teaming, there is no prior coordination between agents and we cannot assume that the entities share the same types of learning algorithms or reward structures or that they have prior agreements regarding action coordination and information sharing. Some of the important research problems within ad-hoc teaming are: ensuring that actions are understandable to fellow teammates; modeling the capabilities of team members; including humans in the ad-hoc teams, and dynamically modeling the performance of both the team and the individuals.

Explicit Human-Robot interaction has been extensively explored throughout the last decade. Implicit Human-Robot interaction, on the other hand, is relatively unexplored. In this case, humans may not directly interact with an intelligent system but instead take actions that the system could use as input. The human actions may be intentional, unintentional or even



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unconscious but they are a rich source of signals for learning or cooperative actions. These implicit actions may also provide context information that could be used to adapt a previously learned behavior to a new environment. Some important research topics in this area include: identifying implicit signals, the value of implicit robot-human signals, and context-aware interaction.

***ASSURED OPERATIONS***

Assured operations require a deep understanding of how a complex system composed of several components, including mechanical systems, computational hardware, and software algorithms operates as a coordinated system. In much the same way as the community is trying to understand the behavior of neural networks, which are composed of layers of mathematical functions, this topic seeks to understand how information and actions flow from the lowest levels of the system to system level decisions and actions. Along those lines, new theory and principles are needed to understand the impact of both gradual and abrupt changes at the component level on the evolution of the entire system. Investigating modularity and compositionality will enable the system to address the multiple near-simultaneous problems it is likely to encounter in long term operations. New theories in information sharing in dynamic environments will lay the foundation for accountability and provide clear criteria for component-level and global input/output specification (in terms of computation, rate, semantics, ..) that can be used to: train a learning component, optimize outputs of a planning component, and test individual and systems level components. As these areas mature, they will provide a firm mathematical foundation for systems-level research in learning-based design, performance guarantees, and robustness to degraded components.

# Army Research Office (ARO) Research Topic

**Title:** Atomic and Molecular Physics (AMP)
**Announcement ID:** ARL-BAA-0022

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**ARL Office:** Army Research Office (ARO)
**Discipline:** Computer Science;Materials Science;Physics
**ARL Foundational Research Competencies:** Network, Cyber, and Computational Sciences;Photonics, Electronics, and Quantum Sciences;Weapons Sciences
**Army Modernization Priorities:** Assured PNT;Long Range Precision Fires;Network/C3I
**Keywords:**

**Description:**
Topics of interest within Atomic and Molecular Physics (AMP) include:

1. Quantum degenerate atomic gases, both Bose and Fermi, their excitations and properties, including mixed species, mixed state, and molecular;
2. Quantum enhanced precision metrology;
3. Nonlinear processes;
4. Quantum systems in cavities;
5. Collective and many-body states of matter; and
6. Emerging areas.

There is an interest in emerging areas of AMO physics such as collective states of matter, emergent lattices in quantum gases, non-equilibrium many body dynamics, advanced quantum simulation, and metrology in non-ideal environments. Research efforts within the AMP fall within two thrust areas: Advanced Quantum Capabilities and Novel Quantum Methods. It is anticipated that research efforts within these areas will lead to applications including novel materials, efficient computational platforms, and exquisite quantum sensors.

***Advanced Quantum Many-body Dynamics***
The focus of this thrust is the development and study of strongly correlated many-body systems. The quantum simulator portion of the thrust seeks research on novel techniques and studies that leverage our control and understanding of simple quantum mechanical systems to explore more complex quantum effects and materials. The effort seeks the validation of many-body quantum theories through the development of experimental tools including quantum gas microscopes, atom-array experiments, synthetic gauge fields, mixed species, and novel interactions. Complimenting this effort will be the inclusion of foundational investigations into quantum mechanics, such as entanglement, many-body localization, collective modes, and entropy. To take advantage of the precision inherent in future quantum devices, these systems will need to connect to the classical world in such a manner that allows them to sample the signal of interest while remaining robust to noisy environments. Consequently, studies of how the quantum system interacts with classical world, and the quantum-to-classical boundary are also of interest. Investigating how to maximize both the quality and quantity of entanglement within these systems will be a priority. General issues of quantum coherence, quantum interference,

entanglement growth, entanglement purity, and non-equilibrium phenomena, as well as discovering new scientific opportunities are also of interest.

***Novel Quantum Metrology***

The AMP Program has a general interest in exploring fundamental AMP that may impact future Army capabilities. This thrust is divided into two main areas: precision metrology beyond the standard limit and harnessing collective many-body states to improve quantum sensing. The Novel Quantum Metrology efforts will expand the foundations of quantum measurement into new areas that seek to exploit entanglement, spin-squeezing, harnessing collective-spin states, developing back-action avoidance measurements, and other areas that increase fundamental precision through interactions, including cavities and Rydberg atoms. It is expected that research in this thrust will complement efforts in the Advanced Quantum Many-body Dynamics thrust and vice versa. For example, collective many body states could be studied in optical lattices or quantum gas microscopes and foundational research of entanglement are anticipated to provide new metrological capabilities in non-ideal environments.


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# Army Research Office (ARO) Research Topic

**Title:** Biochemistry
**Announcement ID:** ARL-BAA-0017

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**Discipline:** Biological Sciences;Chemistry;Materials Science
**ARL Foundational Research Competencies:** Biological and Biotechnology Sciences;Sciences of Extreme Materials
**Army Modernization Priorities:**
**Keywords:** Biotechnology, Bioengineering, Biomaterials

**Description:**
This program emphasizes basic research focused on understanding and controlling the activity and assembly of biomolecules. Scientific advances supported by this program are anticipated to enable the development of novel systems, materials and processes that enhance Soldier protection and performance. Overarching goals of the program are to provide the scientific foundations to expand the chemical diversity accessible by biomolecules and to support biological activity outside of the cellular environment, including integration of biological systems with synthetic systems.

The Biomolecular Specificity and Regulation thrust is focused on novel approaches to engineer the specificity and regulation of biomolecules, either via modulation of natural mechanisms or via design of non-natural mechanisms. Approaches to expand the chemical diversity of ligands/substrates that are recognized/accepted by biomolecules and/or the products of biocatalytic reactions beyond elements and chemical bonds common to natural biological systems are of particular interest. This includes both individual enzymatic reactions as well as multi-step biocatalytic pathways. The goal of this thrust is to develop novel engineered approaches to modulate and control biomolecular activity, with emphasis on expanding the chemical diversity accessible by biomolecules and achieving biomolecular control in non-cellular contexts.

The Biomolecular Assembly and Organization thrust is focused on understanding the molecular interactions and design rules that govern self-assembly of biomolecules into both naturally occurring biomolecular structures and non-natural human-designed architectures. This thrust aims to elucidate fundamental understanding of sequence-structure-property relationships in natural biomolecular assemblies, biomaterials, and biological composites to enable rational design of biological and hybrid biological/abiological assemblies with tailored properties and functions. Biomolecular assembly across length scales is of interest, including discrete multi-protein complexes or nucleic acid structures, as well as hierarchical protein or nucleic acid assemblies and biological composites. This thrust includes homogeneous assemblies utilizing a single building block, as well as heterogeneous systems in which a mixture of different biomolecules and/or non-biological species (e.g., minerals, synthetic polymers) self-assemble. Of particular interest are approaches to expand the chemical diversity of biomolecular architectures beyond elements and chemical bonds common to natural biological systems. This research thrust also includes the design of self-assembled biomolecular or hybrid biological/abiological architectures that provide control over the chemical environment and spatial organization necessary to support complex biomolecular function in non-cellular contexts, including artificial cells and cell-free systems.

# Army Research Office (ARO) Research Topic

**Title:** Biogeochemistry
**Announcement ID:** ARL-BAA-0005

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**Discipline:** Biological Sciences;Chemistry;Earth and Environmental Sciences
**ARL Foundational Research Competencies:** Biological and Biotechnology Sciences;Energy Sciences;Humans in Complex Systems;Military Information Sciences
**Army Modernization Priorities:**
**Keywords:** Environment, Chemistry, Fate, Transport, Climate, Arctic

**Description:**
The Biogeochemistry program seeks to support transformative research to enable unprecedented detection, prediction, manipulation, and mitigation strategies in complex environmental matrices. This is an interdisciplinary program that incorporates recent discoveries in chemical, biological, and physical principles to enhance national security.

Current focus areas for this portfolio include, but are not limited to, the following:

**Transport and transformation** aims to elucidate and characterize novel biogeochemical mechanisms that drive (or prevent) the release and/or transformation of chemical and biological compounds of Army relevance within or across environmental reservoirs. Environmental reservoirs of interest include the lithosphere (e.g., soils and sediments), biosphere (e.g., plants and microbiome), hydrosphere, and atmosphere.

**Biogeochemistry and the built environment** supports research to understand the biogeochemical interactions that are unique to built and urban environments. The reactions in these environments are a function of the structure and partitioning of the compounds present, the chemical and physical properties of the built/artificial materials, and the microenvironments that form at the natural-built interface. Topics of interest include (but are not limited to) environmental/biofilm formation on Army-relevant built materials, biological and chemical transport in subterranean environments, and transport and transformation of chemical and biological compounds through diverse urban interfaces.

**Environmental forensics** strives to develop cutting-edge approaches to enable novel techniques for detection, tracking, source partitioning, and prediction of molecules of interest at military-relevant scales. Research that leverages recent discoveries in other scientific fields such as biochemistry, physics, network and data science, and computational modeling are encouraged. Topics that focus on instrument/sensor development and materials design are not supported.

**Biogeochemistry to inform national security** characterizes the role of biogeochemistry on resource competition (e.g., critical resource recovery), environmental security (e.g., permafrost degradation), and stability (e.g., water availability).

# Army Research Office (ARO) Research Topic

**Title:** Biomathematics
**Announcement ID:** ARL-BAA-0021

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**Discipline:** Biological Sciences;Data Sciences and Informatics;Earth and Environmental Sciences;Mathematics and Statistics;Network Science;Physics;Social Science
**ARL Foundational Research Competencies:** Biological and Biotechnology Sciences;Humans in Complex Systems
**Army Modernization Priorities:** Soldier Lethality
**Keywords:** biomathematics, mathematical biology, theoretical ecology, theoretical epidemiology, modeling

**Description:**
The introduction of Biomathematics as a separate area of basic research recognizes the importance and specialized nature of quantitative methods, specifically mechanistic modeling, in the biological sciences. Biology involves a large number of entities that interact with each other and their environment in complex ways, and at multiple spatial and temporal scales. Understanding how dynamics at different spatial scales come together to form a biological system and understanding the dynamics of a system at intermediate timescales, as opposed to its long term, asymptotic behavior, are critically important in biology, more so than in many other fields.

This complexity makes biomathematics a highly interdisciplinary field that requires unique and highly specialized mathematical competencies to quantify structure in these relationships. In fact, progress in mathematical models of biological systems has traditionally been achieved by making convenient simplifications; major advances in Biomathematics research continue to require removing these assumptions (for example, stationarity, ergodicity and deterministic nature) and finding ways to effectively model the essential complexity. Modeling techniques currently utilized in the field range from agent-based approaches for determining the results of individual behavior, whether those individuals be molecules, zooplankton, or humans, to multi-compartmental modeling in physiology, epidemiology and neurobiology, to network models involved in understanding ecosystem and human social dynamics, as well as encompassing both deterministic and stochastic approaches. Research in control techniques is also valuable for its potential application in militarily important areas such as bio warfare and disease spread. Exciting new opportunities to advance the field are found in high risk attempts to develop modeling techniques in areas of mathematics, such as algebra and topology, not traditionally brought to bear on biological problems, advances in Bayesian statistics, a growing recognition that the diffusion approximation is not necessarily adequate for many systems, and the availability of large amounts of complex biological data.

The ultimate goal of the Biomathematics Program focuses on adapting existing mathematics and creating new mathematical techniques to uncover fundamental relationships in biology, spanning different biological systems as well as multiple spatial and temporal scales. One area of special interest to the program is Neuromathematics, the mechanistic mathematical modeling of neural processes. Recent advances in neuroscience provide important foundations to begin understanding how the brain works. Combined with experimental data, innovative mathematical modeling provides an unparalleled opportunity to gain a revolutionary new understanding of brain physiology, cognition (including sensory processing, attention, decision-making, etc.), and neurological disease. With this new understanding, improved soldier performance, as well as treatments for Post-Traumatic Stress Disorder, Traumatic Brain Injury, and other brain-related disorders suffered by the warfighter will be able to be achieved more effectively, efficiently, and ethically than via experimentation alone.

Thrust areas of the Biomathematics Program are as follows:

***Fundamental Laws of Biology***
The field of physics has long been "'mathematized" so that fundamental principles such as Newton's Laws are not considered the application of mathematics to physics but physics itself. The field of biology is far behind physics in this respect; a similar process of mathematization is a basic and high-risk goal of the ARO Biomathematics Program. The identification and mathematical formulation of the fundamental principles of biological structure, function, and development applying across systems and scales will not only revolutionize the field of biology but will motivate the creation of new mathematics that will contribute in as-yet-unforeseen ways to biology and the field of mathematics itself. For example, heterogeneity/stochasticity is ubiquitous in biological systems; is heterogeneity necessary for tipping points that result in diseased individuals and epidemics and if so, what is its role? More generally, is heterogeneity in biological systems necessary for their functioning or a problem to be overcome, or is the answer system/function dependent?

***Multiscale Modeling/Inverse Problems***
Biological systems function through diversity, with large scale function emerging from the collective behavior of smaller scale heterogeneous elements. This "'forward" problem includes creating mechanistic mathematical models at different biological scales and synchronizing their connections from one level of organization to another, as well as an important sub problem, how to represent the heterogeneity of individual elements and how much heterogeneity to include in the model. For example, the currently increasing ability to generate large volumes of molecular data provides a significant opportunity for biomathematical modelers to develop advanced analytical procedures to elucidate the fundamental principles by which genes, proteins, cells, etc., are integrated and function as systems through the use of innovative mathematical and statistical techniques. The task is complicated by the fact that data collection methods are noisy, many biological mechanisms are not well understood, and, somewhat ironically, large volumes of data tend to obscure meaningful relationships. However, traditionally "'pure" mathematical fields such as differential geometry, algebra and topology, integration of Bayesian statistical methods with mathematical methods, and the new field of topological data analysis, among others, show promise in approaching these problems. Solutions to these types of multiscale problems will elucidate the connection, for example, of stem cells to tissue and organ development or of disease processes within the human body to the behavior of epidemics.

The "'inverse" problem is just as important as the forward problem. From an understanding of the overall behavior of a system, is it possible to determine the nature of the individual elements? For example, from knowledge of cell signaling, can we go back and retrieve information about the cell? Although inverse problems have been studied for a long time, significant progress has been elusive. This thrust area involves innovations in spatial and/or temporal modeling of multi-level biological elements with the goal of achieving a deeper understanding of biological systems and eventually connecting top-down (data-driven) and bottom-up (model-based) approaches.

***Hybrid Modeling***

While the Biomathematics Program has primarily been concerned with developing and using mathematical modeling techniques to understand the mechanisms behind biological system function, future predictions about a system have typically been achieved through statistical modeling using available data; these methods are limited by their ability to make trustworthy predictions only under the same situations under which the data was collected. This thrust seeks to develop new methods that will take advantage of the strengths of both types of modeling, still allowing the hypothesis and testing of biological mechanism while also allowing prediction under an expanded set of conditions. These new methods will facilitate the utilization of the increasingly available data in many areas of biology to expand our ability to understand and predict biological systems and may be furthered through the use and development of existing and new data analysis techniques. For example, can we develop a mechanistic model to understand a cell's ability to repair damage to its DNA by incorporating Machine Learning?


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# Army Research Office (ARO) Research Topic

**Title:** Bionic Electronics
**Announcement ID:** ARL-BAA-0069

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**Discipline:** Biological Sciences;Chemistry;Electronics;Materials Science;Physics
**ARL Foundational Research Competencies:** Biological and Biotechnology Sciences;Humans in Complex Systems
**Army Modernization Priorities:**
**Keywords:** bioelectronics, biotronics, bionic

**Description:**
This research area focuses on the discovery and manipulation of phenomena and the creation of new processes where electronics and biology overlap at the cellular / sub-cellular level. This length scale is where the amplitudes of many types of energies (e.g., electrostatic, mechanical, and chemical terms) converge, and correspondingly, where electronics can have fundamental biological impacts and where leveraging electronics capabilities at the nanoscale can yield unique new understanding of the cellular and intracellular processes.

New electronic structures and materials are now able to focus localized static electric and magnetic fields and electromagnetic fields at the nanoscale, which presents the opportunity to selectively address and manipulate the organelles and membranes making up the structure of the cell. Moreover, cell constituents can have a frequency dependent response to mechanical and electromagnetic excitation, resulting in unique electronically enabled and controlled biological experiments. Molecular and subcellular events at the biological interfaces or surfaces are key to downstream biological dynamics. The stimulation or manipulation of these events by electronic means provides the opportunity for unique control and experimentation that are orthogonal to existing biochemical or genetic approaches. Ion flow, which is fundamental to inter- and intra-cellular signaling and process control, is susceptible to electromagnetic influence and produces electromagnetic signatures of cellular processes. The dynamics of charged and polarized cellular components also produces minute displacement currents, and can produce very large field distributions in a confined nanoscale space (e.g., within a protein scaffold or across a lipid bilayer); both of which are subject to electromagnetic probing and analysis. The different geometries of organelles within a cell result in different electromagnetic signatures and sensitivities which can be leveraged for selective control of cellular processes. Proteins play a role in almost every cellular process. As extremely large and complex molecules, they should have electromagnetic and mechanical responses that can be exploited for control. The skeletal protein assemblies of the cell, in particular, may offer a highway for the introduction of electrical currents or mechanical vibrations. Bio-chemical or genetic alteration of the interface of the cell and its components can introduce new electromagnetic properties, for example a new capability for photosynthesis in bacteria or new electromagnetic responses. Cellular engineering of membranes, cellular organelles, and proteins by the introduction of nano-particles and bio-molecules can introduce new sensitivities and new functionality. Opto-genetics is a well-established procedure for interrogating cells. Early attempts at "'magneto-genetics" have been controversial, however "'electro- or RF-genetics" may offer new opportunities. There may also be inherently non-trivial quantum mechanical mechanisms linked to biological behaviors, such as navigation. Inherently quantum phenomena such as the tunneling of electrons and protons play a critical role in many intracellular processes and can be modulated or manipulated with nanoscale electric fields. This research area seeks understanding and control of inter- and intra-cellular phenomena at the micro- and nano-scale. The program facilitates highly innovative extensions of techniques based on the unique capabilities of electronics as well as totally new, complementary methods, addressing the internal function and electrical processes within a living entity. Biotronics seeks to accomplish this with unprecedented spatial and temporal resolution and with minimal disruption of '"normal" living cell function. The basic science questions being addressed by the Biotronics program are geared to achieve a natural evolution into bionic electronics. Through this evolution the goal is to us


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# Army Research Office (ARO) Research Topic

**Title:** Complex Dynamics and Systems
**Announcement ID:** ARL-BAA-0018

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**Discipline:** Data Sciences and Informatics;Materials Science;Mathematics and Statistics;Mechanics;Physics
**ARL Foundational Research Competencies:** Biological and Biotechnology Sciences;Energy Sciences;Humans in Complex Systems;Mechanical Sciences;Military Information Sciences;Network, Cyber, and Computational Sciences;Photonics, Electronics, and Quantum Sciences;Sciences of Extreme Materials;Terminal Effects;Weapons Sciences
**Army Modernization Priorities:** Air and Missile Defense;Future Vertical Lift;Network/C3I;Next Generation Combat Vehicle;Synthetic Training Environment
**Keywords:** nonlinear dynamics; mechanics; high dimensional; morphological computation; chaos; embodied intelligence; hierarchical mechanics; heterogeneous systems; stochastic control; stochastic learning

**Description:**
The Complex Dynamics and Systems program emphasizes fundamental understanding of the dynamics, both physical and information theoretic, of nonlinear and nonconservative systems as well as innovative scientific approaches for engineering and exploiting nonlinear and nonequilibrium physical and information theoretic dynamics for a broad range of future capabilities (e.g. novel energetic and entropic transduction, agile motion, and force generation). The program seeks to understand how information, momentum, energy, and entropy flows and transforms in nonlinear systems due to interactions with the system's surroundings or within the system itself. Research efforts are not solely limited to descriptive understanding, however. Central to the mission of the program is the additional emphasis on pushing beyond descriptive understanding toward engineering and exploiting time-varying interactions, fluctuations, inertial dynamics, phase space structures, modal interplay, practical control opportunities, and other consequences of nonlinearity in novel ways to enable the generation of useful work, agile motion, and engineered energetic and entropic transformations. Further information on the current scientific thrust areas are detailed in the paragraphs that follow.

***High-Dimensional Nonlinear Dynamics***
Classical dynamics has produced limited fundamental insight and theoretical methods concerning strongly nonlinear, high-dimensional, dissipative, and time-varying systems. For over a century, qualitative geometric approaches in low-dimensions have dominated research in dynamics. These approaches of reduced-order-modeling of high-dimensional dynamics are often premised on empirical and statistical model fitting and are incapable of capturing the effects of slowly growing instabilities and memory. The program seeks to develop novel theoretical and experimental methods for understanding the physical and information dynamics of driven dissipative continuous systems. It also seeks novel reduced-order-modeling methodologies capable of retaining time-dependent and global nonlinearities. Novel research pertaining to the analysis and fundamental physics of time-varying nonlinear systems and transient dynamics is a high-priority.

***Embodied and Distributed Control, Sensing, and Actuation***
This thrust develops deeper understanding, through supporting theory and experiment, of the role of embodiment and dynamics on a physical system's capability to process information and transform energy. Proposals emphasizing the mechanics and control of soft, continuous bodies are encouraged along with novel experimental paradigms leveraging programmable printed matter. Generally, this thrust strongly leverages advances in, and approaches from, sensory biomechanics, neuromechanics, underactuated systems theory, and mechanical locomotion dynamics to understand the motion of both articulated and continuum dynamical systems operating in highly-dynamic environments. The scientific principles sought, however, are not limited to biological movement and manipulation. Proposals are strongly encouraged that view morphology in an abstract sense. For example, understanding morphology as a system's symmetry, its confinement (e.g. chemical reactions), or its coupling topology.

***Statistical Physics of Control and Learning***
The program seeks to lay the foundations for an algorithmic theory of control and learning that goes significantly beyond the state-of-the-art in model predictive control and integrates novel learning methodologies that are not mere variations of artificial neural networks and deep learning. Additional goals of this program is to develop an experimentally tested theoretical framework for controlling and creating new types of critical dynamics, phase transitions, and universality classes by bringing together theory and physical principles in statistical dynamics with control and dynamical systems theory (controlling statistical dynamics).

Topics of interest relating to this include: nonlinear control of distributions with non-Gaussian uncertainty; non-Gaussian uncertainty representations; understanding relationships between work absorption and dynamics in the presence of fluctuations leading to emergent prediction and emergent centralization; steering multi-critical interacting dynamical systems toward desired universal scaling behaviors; externally controlling the strength of stochastic fluctuations and intrinsic noise in systems that are driven far from thermal equilibrium and display generic scale invariance; and selectively targeting and stabilizing specific self-generated spatio-temporal patterns in strongly fluctuating reaction-diffusion systems. Stochastic control at the microscale to enable novel manipulation of the dynamics of synthetic and natural biomolecular machines is also of interest.

***Mechanics of Hierarchical and Heterogeneous Systems***
Recent experimental, theoretical, and computational advancements have made it possible to challenge macroscopic, continuum representations of inherently hierarchical systems like never before - acknowledging that desirable macroscopic characteristics arise as a function of architecture and interaction between scales cascading all the way down to the nanoscopic environments within. This thrust in part seeks to develop reduced order and component-level models of nano-scale mechanisms in order to identify principles of physical interaction in these intricate (and in most cases only stochastically or empirically understood) systems. In addition to understanding the capabilities of component and mechanism design at the nano-scale, the program encourages the characterization of energy and information passing from one '"scale" to the next, as well as sensing and control strategies that tap into hierarchical and complex systems at different scales and locations.

Topics of interest include, but are certainly not limited to: magnetohydrodynamics; the control of plasmas; frontiers of dynamical systems theory exploring turbulence; modeling biochemical mechanisms in order to identify design principles that exceed their capabilities; locomotion at micro- and sub-micro-scales. The program highly encourages studies that approach these problems from the perspective of hierarchical structures as assemblies of known base units rather than continua whose emergent properties can be modeled by approximating the complexity of the structure within.


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# Army Research Office (ARO) Research Topic

**Title:** Computational Mathematics
**Announcement ID:** ARL-BAA-0034

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**Discipline:** Mathematics and Statistics;Physics
**ARL Foundational Research Competencies:** Mechanical Sciences;Network, Cyber, and Computational Sciences;Photonics, Electronics, and Quantum Sciences;Weapons Sciences
**Army Modernization Priorities:** Assured PNT;Network/C3I
**Keywords:** Mathematical modeling, Scientific computation, Fractional order methods, Mathematics of QIS, Atmospheric physics, Embedded simulation

**Description:**
The research strategy of this program is to focus on the following opportunities for crucial discoveries: innovative methodologies for solving currently intractable problems that take advantage of symmetry, conservation, and recurrence, that can adapt to both the evolving solution and to the evolving run-time resource allocation of modern computer architectures; novel algorithms that accommodate different mathematical models at different scales, interacting subsystems, and coupling between models and scales; methods that incorporate nonlocality through integral operators with advantageous representations. Research in this area will ultimately lead to the development of new mathematical principles that enable faster and higher fidelity computational methods, and new methods that will enable modeling of future problems.

Scientific computation is an essential component of scientific inquiry, complementing theory and experiment, and is also an essential element of engineering in both design and in failure autopsy. Simulations in support of inquiry, design, or autopsy often require expert knowledge in order to select methods that are compatible with the assumptions of the scenario at hand, require considerable skill to properly set up, require considerable time, memory, and storage on large scale parallel/distributed/heterogeneous systems to compute, and require considerable skill and effort to distill useful information from the massive data sets which result. Expert knowledge is also required to quantitatively estimate solution accuracy and to estimate the time and effort required to achieve a desired accuracy. Data has become ubiquitous and is potentially very valuable in increasing solution accuracy and/or decreasing the effort required to solve, but mathematically sound methods for incorporating data into accurate simulations are incomplete. Simulations are not always timely, with results often not being available until after they are needed, for example in calculating failure of New Orleans levees during Katrina and in revising those estimates based on real time surge data.

The emphasis in the Computational Mathematics program is on mathematical research directed towards developing capabilities in these and related areas. For problems that are not time-limited, research areas of interest include but are not limited to the following:

**Advances in Numerical Analysis.** Novel methodologies are sought for solving currently intractable problems. New ways of taking advantage of symmetry, conservation, and recurrence are of interest, as are new ways of creating sparsity and new computational structures which can adapt to both the evolving solution and to the evolving run-time resource allocation of modern computer architectures. Rigorous analysis is sought for each in order to enable error bounds, error distribution, and error control.

**Mathematics for Quantum Information Systems (QIS).** New mathematical constructs and understanding are sought in order to provide useful mathematical tools and language to others working to advance QIS. QIS goes far beyond quantum computing (QC), with focus also on quantum networking, quantum sensing, topological quantum computing, and topological phases of matter. Advances are sought in factors of von Neumann algebras, type II and type III, that are yet to be fully explored even after a century of studies from a QIS point of view. Topological quantum information processing going beyond anyons and in 3+1 spacetime dimensions are of interest. Exploration of noncommutative geometry from QIS point of view are important in pushing the field. Advances are sought in the language for quantum field theory as a basis for QIS and for the associated mathematical structures that are involved. New bases for QIS-based chemical and biological systems are just beginning; language and representations for these more-complex and messier-than-physics-based-systems are sought in order to enable new mathematical models. The QIS of metamaterials-based systems is very different from other systems, and new mathematics is sought that is capable of representing the unification of these disparate QIS themes.

**Fractional Order Methods.** As an alternative to high order methods and other less-local operators, fractional operators are another nonlocal operator that have proven to work well in modeling and have the advantage of not enforcing dubious assumptions of smoothness, especially at discontinuities and interfaces. However, the nonlocality of fractional operators also typically introduces a significant increase in computational load. Advances in novel efficient computational methods for these operators are of interest. Army systems often operate under rapidly-changing unpredictable and adverse conditions. It is desirable for models to be computationally simulated and fast enough to drive decision making, exercise control, and to help avoid disaster. Such simulations need to be created, run, and interpreted in better than real time. Research directed towards making this goal achievable is of interest, such as: Fast Methods for Atmospheric Physics. Modeling and prediction of local and mid-range atmospheric physics are a key part of the domain of operations. New exploratory efforts in fast algorithms for atmospheric physics have been identified as an area where new computational methods could make an important impact on problems of current and future Army interest. The emphasis of these efforts is on mathematical methods which have some promise of wider application rather than methods limited only to specific application areas.

**Reduced Order Models.** Full scale simulations are often not realizable in real time. In order to investigate the behavior of systems under a variety of possible scenarios, many runs are required. Reduced order models are one way to enable this. Possible methods to create these models include adaptive simplification methods based on singular value decompositions and reduced order numerics. To be useful, all such models should be equipped with reliable estimates of accuracy.

**Problem Solving Environments.** To enable rapid decision making that is driven by simulation, it is necessary to set up simulations very quickly and obtain results in an understandable format. Matlab is one current tool for such a problem solving environment. What are other approaches? Embedded Simulation. As algorithms become more efficient and computational devices shrink, it will become increasingly possible to use real-time simulation to drive control systems. New methods which address this goal are welcome, especially those which permit user- controlled and/or adaptively-controlled tradeoffs between speed and accuracy. Decision Making. One valid criticism of numerical simulation is that it takes so long to set up, run, and post-process the results that they cannot be used in a timely manner to guide decision making. Mathematical ideas that help address this problem are of interest.

# Army Research Office (ARO) Research Topic

**Title:** Dynamical Influences on Social Systems
**Announcement ID:** ARL-BAA-0102

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**ARL Office:** Army Research Office (ARO)
**Discipline:** Computer Science;Mathematics and Statistics;Social Science
**ARL Foundational Research Competencies:** Humans in Complex Systems;Military Information Sciences
**Army Modernization Priorities:**
**Keywords:**

**Description:**
The overall goal of this program is to enhance fundamental understanding of the interdependent, reciprocal, and complex relationships across social systems accounting for environmental factors needed to enhance future warfighters' performance across operational contexts. Performance is traditionally bounded to a task where the ability to successfully execute actions and achieve mission objectives is a result of training and leadership. This narrow focus on the task, however, does not account for the critical factors in everyday interactions that impacts performance: the social system that shapes the warfighters through shared norms, values, and expectations; lived experiences that support inter- and intra-dependence; and exogenous variables that directly and indirectly impact quality of life. A warfighter's social systems exists among other systems - whether embedded within larger systems, parallel to, in competition to, and/or in opposition of - that see reciprocal influence forces exchanged between them. These social systems transcend the task or operational environment to include garrison, schools, deployments, and other institutions to include those outside the military that co-exist with social systems, and in combination impact the warfighters' capabilities development. Therefore, it is important to take a holistic approach that accounts for the human, social, and environmental elements that interact and over time shape development to understand and predict performance levels and variability within and across missions.

The Dynamical Influences on Social Systems program supports fundamental research to understand how to construct, maintain, and, as necessary, reconstruct social systems within and across environments that promote the desired social behaviors necessary for effective performance. Successful projects will develop new innovative theoretical, methodological, and modeling approaches to understand scalable human behaviors within complex systems and across environments. This program has three focal areas of interest. First, create the scientific capability to identify and assess the influence of meaningful contextual factors that consciously and unconsciously impact ongoing affective, cognitive, and behavioral processes within and across individuals and collectives. Second, to enable the integration of the science of time (i.e., the experience and perception of time) to understand cascading effects beyond first and second order effects on social systems. Third, to understand the impact of advanced technologies that more closely mimic human characteristics and capabilities on the evolution of various social systems.

# Army Research Office (ARO) Research Topic

**Title:** Earth Materials and Processes
**Announcement ID:** ARL-BAA-0007

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**ARL Office:** Army Research Office (ARO)
**Discipline:** Data Sciences and Informatics;Earth and Environmental Sciences;Mechanics
**ARL Foundational Research Competencies:** Electromagnetic Spectrum Sciences;Humans in Complex Systems;Mechanical Sciences;Military Information Sciences;Network, Cyber, and Computational Sciences
**Army Modernization Priorities:**
**Keywords:** geoscience, earth science, environmental, civil engineering, urban, built environment, atmosphere, terrain

**Description:**
The Earth Materials and Processes program seeks to enable maneuver, communication and situational awareness in all terrain through understanding and prediction of the physical and mechanical properties and behaviors of rocks, soil, and man-made earth surfaces and their interactions with their surrounding environment. The Program is especially interested in interdisciplinary efforts that could be eligible for cross-discipline support. Topics for consideration include but are not limited to the following:

Investigations on the transmission of information (e.g., seismic, acoustic, or radio frequency) in challenging environments: Of special interest are urban, high-latitude, high-altitude, and forested environments. Access to new field areas and high-resolution data collection and modeling provide opportunities to differentiate sources and characterize terrain.

Research on fundamental processes within the built environment: How natural and artificial surfaces (e.g., soil, sand, or concrete) store and conduct energy depending on their spatial relationships, inherent material properties, and imparted features such as moisture storage and evapotranspiration. Detailed characterization of these environments will enable prediction of geophysical and environmental processes in diverse urban settings. Investigations that support the development, integrity, and resilience of cyber-physical systems as related to environmental sensing are of special interest.

Science to advance environmental security: These efforts must focus on the fundamental knowledge that will inform new approaches and tools to predict and mitigate risks posed by changing environments and extreme weather events and to ensure access to natural resources, including strategic minerals. Note that (1) the Program focus is on the science required to enable development of tools and products, not the development of the tools and products themselves, and (2) proposals must target specific Army-relevant challenges rather than general topics (e.g., extreme weather, climate change, natural hazards, as broadly defined). A discussion with the program manager is encouraged to determine if a topic sufficiently addresses an Army challenge.

# Army Research Office (ARO) Research Topic

**Title:** Electrochemistry
**Announcement ID:** ARL-BAA-0025

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**ARL Office:** Army Research Office (ARO)
**Discipline:** Chemistry;Materials Science
**ARL Foundational Research Competencies:** Energy Sciences;Sciences of Extreme Materials
**Army Modernization Priorities:**
**Keywords:** Electrochmistry, Redox, Chemistry, Transport, Electroactive

**Description:**
This Program supports fundamental electrochemical studies to understand and control the physics and chemistry that govern electrochemical redox reactions and transport of species, and how these are coupled with electrode, catalysis, electrolyte, and interface. Research includes ionic conduction in electrolytes, electrocatalysis, interfacial electron transfer, transport through coatings, surface films and polymer electrolytes, activation of carbon-hydrogen and carbon-carbon bonds, and spectroscopic techniques that selectively probe electrode surfaces and electrode-electrolyte interfaces. Novel electrochemical synthesis, investigations into the effect of microenvironment on chemical reactivity, quantitative models of electrochemical systems, and electrochemistry using excited electrons are also of interest. This Program is divided into two research thrusts, although other areas of electrochemical research may be considered:

***Reduction-oxidation (Redox) Chemistry and Electrocatalysis***
The Redox Chemistry and Electrocatalysis thrust supports research to understand how material and morphology affect electron transfer and electrocatalysis, to tailor electrodes and electrocatalysts at a molecular level, and to discover new spectroscopic and electrochemical techniques for probing surfaces and selected species on those surfaces.

***Transport of Electroactive Species***
The Transport of Electroactive Species thrust supports research to uncover the mechanisms of transport through heterogeneous, charged environments such as polymers and electrolytes, to design tailorable electrolytes based on new polymers and ionic liquids, and to explore new methodologies and computational approaches to study the selective transport of species in charged environments.


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# Army Research Office (ARO) Research Topic

**Title:** Electronic Sensing
**Announcement ID:** ARL-BAA-0027

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**ARL Office:** Army Research Office (ARO)
**Discipline:** Electronics;Materials Science;Physics
**ARL Foundational Research Competencies:** Photonics, Electronics, and Quantum Sciences
**Army Modernization Priorities:** Future Vertical Lift;Long Range Precision Fires;Soldier Lethality
**Keywords:**

**Description:**
This program focuses on basic research investigations leading to new electronic sensing science that enable 100% situational awareness to include day/night, all weather, non-line-of-sight and through natural and man-made obstructions for sensing of personnel, weapons, chemical and biological threats. The Electronic Sensing (ES) program is currently emphasizing research focused on materials development, including experimental, theoretical and computational studies that design, create, and understand novel materials functionalities and device operation concepts through advances in the fields of electronics, photonics, photoacoustics and piezo-phototronics to enhance or enable new detection capabilities. This program is divided into two thrusts: (i) Novel materials platforms and (ii) Advanced sensing concepts.

***Novel materials platforms***
This thrust seeks to push beyond the state of the art in conventional material systems, seeking novel advanced material platforms with functionality beyond the established limits on sensitivity. Research of interest is targeting fundamental understanding of nontraditional materials and nanostructures of high quality enabling new phenomena and unique properties that could lead to higher detectivity and ultrafast response at or near ambient temperature. This thrust also supports research aimed at exploring the properties and capabilities of artificially engineered materials platforms including, but not limited to: metamaterials; 2D vertical or lateral stacking; azimuthally twisted mono/bilayers or chiral twisted nanowires, which can enable exotic phenomena such as strong electron correlations, superconductivity or novel optically excited quasiparticles such as moire excitons or trions, leading to enhanced energy transport toward the quantum limits in efficiency. Engineered 3D photonic and artificially shaped 2D crystals into increasingly complex 3D structures, benefitting from expansion into the additional dimension that could allow enhanced interaction with light or enhanced chemical reactivity are also of interest. Advances in these areas require deep understanding of mechanisms of interface formation, new phenomena and properties arising from the unique integration of same or dissimilar materials, calling for innovative theoretical and experimental methods.

***Advanced sensing concepts***
This thrust emphasizes research in design and development of tailored device architectures based on different sensing concepts to achieve performance metrics surpassing current capabilities to detect, recognize and identify targets and threats. The goal of this thrust is to develop new engineered approaches to enhance the stimulus-response characteristics and improve the

signal-to-noise ratio and conversion (transduction) of the signal to another form with higher efficiency, while reducing all components of the noise (thermal, optical, mechanical, and electrical) and thus enabling higher sensitivity, reliability and resilience to various environmental factors. Of particular interest are research efforts exploring innovative hybrid architectures in pursue of novel or multi-functionality, benefiting from various combinations of optical and piezoelectric electromechanical resonances, nonlinear plasmonics, selective gating or field modulation and tailored band structure when targeting different sensing modalities, such as electro-optic, thermal, acoustic, chemical or biosensing. Other modalities and mixed concepts that meet the Army needs for highly sensitive, fast, tunable, flexible or multimodal sensors are also welcome. Advances in these areas require theory-guided experimental research paving the way towards development of new generation detectors with enhanced multi-band, broad-band or hyperspectral capabilities.


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# Army Research Office (ARO) Research Topic

**Title:** Fluid Dynamics
**Announcement ID:** ARL-BAA-0030

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**ARL Office:** Army Research Office (ARO)
**Discipline:** Mechanics
**ARL Foundational Research Competencies:** Weapons Sciences
**Army Modernization Priorities:** Future Vertical Lift;Long Range Precision Fires
**Keywords:** fluid, turbulence, dynamic stall,

**Description:**

Fluid dynamics plays a critical role in many Army operational capabilities. Accurate and efficient prediction of the flow physics required for the design of future advanced capabilities and improvements to the performance of existing systems is challenged by the nonlinear and high-dimensional character of the governing equations. In addition, Army relevant platforms are often dominated by flows with high degrees of unsteadiness, turbulence, and compressibility and are characterized by multiple and widely separated spatio-temporal scales and geometrical complexity of solid or flexible boundaries. The program seeks to support basic research investigations of fundamental and novel flow physics underpinning future concepts and capabilities for Army platforms.

The program seeks basic research proposals in the following three thrust areas:

***Dynamics of Unsteady and Separated Flows***

Efforts in this research area require novel and aggressive strategies for examination of the interplay between disparate spatio-temporal scales, the inclusion of physically significant sources of three dimensionality, and the characterization of the role of flow instabilities and nonlinear interactions across a range of Mach and Reynolds numbers appropriate to Army aerial vehicle and weapons systems. In all cases, the flow is characterized by a high degree of unsteadiness. Criteria for identifying the signatures of unsteady separation and/or incipient separation are of particular interest, as are diagnostics capable of real time measurements of such signatures. Historical management of complexity has often resulted in scientific approaches that lead to the elimination of potentially critical flow physics. Research efforts capable of gaining deep understanding of highly complicated flows are likely to allow these critical physics to be exploited.

***Nonlinear Flow Interactions and Turbulence***

Many Army relevant flows are governed by strong nonlinearities and are fundamentally turbulent in nature. Historically, many analysis tools developed for linear dynamics have been applied to gain understanding of flow behaviors. The practical usefulness of such techniques has saturated; the ability to gain global understanding of the evolution of flows requires the development and use of approaches that can deal directly with inherent nonlinearities. Operator theoretic methods are making great strides in tackling the perennial difficulties associated with the Navier-Stokes equations. Our understanding of turbulent flows is also benefitting from new approaches based in dynamical systems theory to build frameworks beyond the notions based on Reynolds averaging and stochastic dynamics. By leveraging the existence of underlying deterministic structures, significant advances in the ability to design systems capable of not just dealing with turbulence but exploiting its dynamics may become possible. Modeling turbulent flows near walls at high Reynolds is a continuing challenge for practical applications of scale-resolving simulation methods. Creative numerical and theoretical constructs may benefit from novel non-intrusive diagnostics that can accurately measure turbulent flow properties near walls.

***Dispersed-phase Interactions with Aerodynamic Surfaces***

Understanding the dynamics of the interaction of dispersed phases (sand, dust, rain, frozen precipitation) with aerodynamic surfaces is necessary to mitigate potential performance degradations and to expand the range of applicability of Army aerospace systems. Accurate prediction and description of dispersed-phase interactions within aerodynamic boundary layers, with solid surfaces, and with other dispersed-phase components is needed for a better understanding of the underlying flow physics.  Advances in modeling and simulation strategies capable of predicting near-surface dispersed phase and dense-phase effects are needed, as are quantitative diagnostics capable of interrogating local flow phenomena that impact overall aerodynamic performance.

# Army Research Office (ARO) Research Topic

**Title:** Genetics
**Announcement ID:** ARL-BAA-0035

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**ARL Office:** Army Research Office (ARO)
**Discipline:** Biological Sciences
**ARL Foundational Research Competencies:** Biological and Biotechnology Sciences
**Army Modernization Priorities:** Soldier Lethality
**Keywords:** genetics, genetic variation, DNA barcoding, mitochondria, oxidative stress

**Description:**
The Genetics program supports fundamental basic research in genetics, molecular biology, genomics, epigenetics, and systems biology in areas that are anticipated to enable improved cognitive and physical performance capabilities, increase survivability, and enable new Army capabilities in areas such as biomaterials, sensing and intelligence. This program emphasizes innovative high-risk fundamental research in areas such as identification and characterization of genetic variation, gene function, gene regulation, genetic interactions, gene pathways, gene expression patterns, epigenetics, mitochondrial regulation and biogenesis, and nuclear and mitochondrial DNA stability and instability. More specifically the Genetics program is currently focused on the following questions: Can we advance our understanding of the factors that affect mitochondrial integrity and oxidative stress? Can we further our understanding, characterization and exploitation of genetic variation within and between species? Can we fully identify, characterize and understand the relationships with and the effects of prokaryotes and fungi on larger eukaryotes, including in eukaryotic organs traditionally considered to be sterile? How can we exploit genetic pathways and genetic variation to protect soldiers and develop new Army capabilities?


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# Army Research Office (ARO) Research Topic

**Title:** Information Assurance
**Announcement ID:** ARL-BAA-0010

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**ARL Office:** Army Research Office (ARO)
**Discipline:** Computer Science;Data Sciences and Informatics;Network Science
**ARL Foundational Research Competencies:** Network, Cyber, and Computational Sciences
**Army Modernization Priorities:** Network/C3I
**Keywords:** cyber defense, resiliency and robustness, trusted computing and communication, wireless security

**Description:**
**Information Assurance**
The Information Assurance program establishes the scientific mathematical and information processing foundations for achieving information and decision dominance under threat conditions. Information provided to warfighters must be authentic, accurate, secure, reliable, and timely. The research program seeks the development of foundational science to assure information flows in autonomous cyber systems, protect their interactions with capable adversaries, and understand how to apply and account for deception. Central to program efforts is the resilience of complex systems in highly dynamic and congested environments that are contested by capable adversaries.

***Models and Metrics for Next Generation Systems***
The program seeks foundational science to measure a complex system and provide trustworthiness and robustness guarantees. Assurance principles and metrics are needed to help define, develop, and evaluate future resilient systems and networks that can, with measurable confidence, survive and recover from sophisticated attacks and intrusions. An enduring challenge is the proactive discovery of exploits and vulnerabilities in cyber-physical systems, neural networks, and other complex systems. Ideally, the subsequent mitigation process improves resilience against future attacks. Deep understanding and accurate modeling of attacker-defender interactions will also be important to improve future system development. In addition, some areas of interest for improving warfighter performance include the development of human-centric security and usability metrics, computational models for usable security in stressful situations, and adaptive security protocols according to perceived threats.

***Trusted Learning for Cyber Autonomy***
Future Army autonomous systems, especially cyber-physical systems working alongside soldiers, are subject to adversarial attacks during operations such as fault injection. While current testing and verification techniques help assure system integrity prior to deployment, few of them can help mitigate runtime risk or achieve automatic recovery after a compromise. Robustness certification or domain adaptation at both the data processing layer and the information/decision layer may lead to better mission sustainment and resiliency against adversarial manipulation and exploits. Also lacking is the ability to adapt to changing operational environments, mission requirements, and adversarial conditions. New research is sought to establish fundamental principles for cyber autonomous system adaptation, including trusted cyber-domain learning,

decision making, introspection, self-healing, and adaptation. Assurance of the autonomous response for safety and correctness is critical for defense systems to maintain mission assurance.

***Cyber Deception***

Cyber deception is a proactive technique to degrade the adversary's effectiveness by manipulating its cognitive state and decision process. Scientific understanding is required to establish effective models for understanding and tracking the adversary's tactics, techniques, and procedures (TTP) and quantify the effectiveness of deceptive maneuvers in steering the adversary's decision processes. Deceptive cyber artifacts have been used to engage adversaries but the dynamics between attackers and defenders, especially mental interactions, are not well understood. Advanced methods are sought to understand adversaries through neutralized engagements to inform effective deception schemes. Capable adversaries will also leverage deceptive techniques in engaging with Army networks; it is critical to model deceptive adversaries that attempt to mask their TTP, evade detection, and launch sophisticated attacks.

***Trustworthy Tactical Communication***

The program seeks direct guidance in the design of theory, protocols, and techniques that assure delivery of trustworthy information over tactical wireless systems. Novel ideas in fundamental research areas, such as information-theoretic security and game theory, may yield new paradigms for physical layer security (ranging from confidentiality to authentication to trustworthiness), fundamental bounds in trust management and data integrity in distributed systems, and assured information delivery and dissemination in tactical environments. The corresponding constructions stemming from such investigations represent a significant avenue for improving trustworthiness of future tactical wireless communications.

# Army Research Office (ARO) Research Topic

**Title:** Information Processing and Fusion
**Announcement ID:** ARL-BAA-0008

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**Discipline:** Computer Science;Data Sciences and Informatics;Mathematics and Statistics
**ARL Foundational Research Competencies:** Military Information Sciences
**Army Modernization Priorities:**
**Keywords:**

**Description:**
With ubiquitous data acquisition capabilities, effective data and information processing is of critical importance to defense missions. The Information Processing and Fusion program is concerned with the creation of innovative theories and algorithms for extracting actionable intelligence from diverse, distributed multimodal data to support Army operations.

**Foundations of Image and Multimodal Data Analysis**
Innovative research is sought concerning: (1) novel representations of multimodal data to enable the understanding of multimodal sensor data and contextual information, including nonstandard data types beyond image and video; (2) detection, localization, and recognition of objects and locations from image data with particular emphasis on provable performance guarantees; (3) detection of events, actions, and activities to extract activity-based intelligence, especially when no extensive training data is available; and (4) integrated approaches that enable semantic descriptions of objects and events including relations. Learning and adaptation should enable the representation at both low and high levels, where inputs from actual users of the systems are used to improve the performance of the algorithms and the fidelity of models at all levels of the modeling hierarchy. Of high interest are methods to exploit the structure of the data, capture its intrinsic dimensionality, and extract information content of data, and which go beyond correlative modeling to incorporate causality, symbolic reasoning, and physics. The development of an "'information/complexity theory" and a "'learning theory" specific for remote sensing, imaging data, and decision tasks is highly desirable.

**Data and Information Fusion**
Multimodal data acquisition systems are increasingly prevalent with disparate sensors and other information sources, ranging in design from a finite number of locally grouped sensors to a very large, geographically dispersed sensor network. This thrust seeks advanced mathematical theories and approaches for integrating multimodal data and contextual information to provide actionable intelligence. Of particular interest are systematic and unifying approaches for data and information fusion from diverse sources with heterogeneous fidelities and timescales, varying degrees of overlap, and differing levels of uncertainty. Scalable methods are needed for efficiently handling vast amounts of data, as are methods for preserving data provenance and identifying the key raw data used to generate fused representations or make predictions. Fusion in networked environments addressing issues such as adaptive, distributed, and cooperative fusion is emphasized. Theories and principles for performance analysis and guarantees at all fusion levels to support robust, uncertainty-aware data and information fusion are important to

ensure successful military operations.

**Active and Collaborative Sensing**

Modern sensing systems typically include multiple networked sensors with communication capabilities where the whole network can be thought of as a meta-sensor that can be controlled, in addition to each individual node having some controllable degrees of freedom such as mobility for unmanned aerial/ground systems, pan-tilt-zoom for infrastructure sensors, or waveform for agile radar. Depending on the task or query, it is desirable for the system to control the data acquisition process to acquire the "'most informative data" for the specific task or query, to minimize uncertainty, or to identify the type and deployment scheme of additional sensors required. Consequently, of particular interest are methods that address the integration of mobility, sensor-selection, modality selection, and active observation for real-time assessment and improvements of sensing performance. Another research area of interest is performance-driven active data collection, where a query is given to the system together with a desired performance bound. Where the confidence in answering the query is insufficient, the system should actively interrogate or control sensors to achieve the desired confidence. Such an active learning and information-driven sensor control should include the user in the feedback loop.

# Army Research Office (ARO) Research Topic

**Title:** Knowledge Systems
**Announcement ID:** ARL-BAA-0033

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**ARL Office:** Army Research Office (ARO)
**Discipline:** Computer Science;Data Sciences and Informatics;Economics;Mathematics and Statistics;Network Science;Social Science
**ARL Foundational Research Competencies:** Military Information Sciences
**Army Modernization Priorities:** Network/C3I;Next Generation Combat Vehicle;Synthetic Training Environment
**Keywords:** Game Theory; Natural Language Processing; Decision Making; AI as software; Problem Solving

**Description:**
The overall objective of the Knowledge Systems program is to augment human decision makers (both commanders and Soldiers) with enhanced-embedded battlefield intelligence that will provide them with the necessary situational awareness, reconnaissance, and decision making tools to decisively defeat any future adversarial threats. While software agents will likely be the decision aide, it turns out robots also need planning and decision tools and need to be able to understand their human handlers/ colleagues. Given these objectives, it becomes necessary to understand (a) fundamentals of what intelligence means in the context of autonomous systems and how to build intelligent systems especially as it relates to interaction amongst a network of humans and machines, and (b) foundational algorithmic issues in representation and reasoning about networks inherent in societies and nature.

***Information Networks***
In order to model network effects it is necessary to algorithmically represent large networks and reason about them. Unfortunately, information about networks is seldom complete - data available might be missing crucial pieces of information, might have contradictory pieces of information, or could be approximate (with associated notions of uncertainty). Representing and reasoning about these networks requires advances in knowledge representation, graph and data mining, natural language processing, algorithmic graph theory, machine learning, and uncertainty quantification and reasoning. Examples include the emerging area of Graphons which provide new tools for generating and reasoning about graphs that occur in practice (satisfying power law distributions), but also provide new tools for Machine Learning. In particular, a major goal of this thrust are tools and techniques that allow data driven approaches to capturing latent relationships with powers to both explain and predict. Advances in this thrust would not only lead to improved autonomous systems and algorithms, but also enhanced-embedded battlefield intelligence with tools for creating necessary situational awareness, reconnaissance, and decision making. Finally, it should be noted that algorithmic notions of approximations, tight performance bounds, probabilistic guarantees, etc., would be major concerns of the solution space.

***Adversarial Reasoning***
Development of appropriate mathematical tools to model and reason about societies and cultures,

that brings together tools from Game Theory, Social Sciences and Knowledge Representation. Research of interest includes, but is not limited to, Game Theory for security applications while accounting for bounded rationality, development of Game Theory based on data regarding cultural and adversarial groups, and Behavioral Game Theory that can explain intelligence in groups and societies. In particular, the role of human biases in decision making and game theory is of importance to this thrust of the program.

***Natural Language Processing and Affective Computing***
Inference algorithms work incredibly well when data is in a structured format. However, most reports, email, and conversations are written out as text with information embedded in them. This thrust seeks advances in purposeful Natural Language Processing at scale that can account for context and mode-switches by bringing together statistical and logical methods. Indeed, when combined with other signals, such as video signals, the inter-play of non-verbal and verbal/textual communication provides rich contextual information, which, in turn, leads to accurate information being gleaned from an interaction.

***Engineering AI Systems***
AI systems are insular, brittle, dependent on massive amounts of data, and with no avenues for composition. While notions of type systems, effect systems, assume-guarantee assertions, and procedural and process abstractions are all now available to describe and compose software components, similar notions of modularity are critically needed for building AI systems from small learning-based components. There are examples such as model-cards and data-sheets that are now available, which along with notions of Probabilistic Programming could provide the necessary basis. However, there are a number of problems, especially in the context of Deep Neural Networks, that still need to be addressed. The necessary science required to address AI safety - rigorous specifications for composition, run-time monitoring, self-healing, reasoning, etc., are all of interest to this program.

Afore mentioned problems of interest deal with tools for producing robust AI systems. However, the task of designing and building AI systems from scratch - from vague definitions of problem to be solved - is still open. An enormous amount of insight and effort may go into the process of turning an ambiguous description into a formal problem specification amenable to an AI solution. What data sources are relevant? What structure can be identified in the problem space? What makes one family of solution techniques better than another? Which measures should be adopted for evaluating the quality of a solution? Research on problem formulation and formalization can be found in the literature, with results in some specialized areas such as concept learning for DNNs, general game playing, and historical work on formalizing data analysis procedures. General solutions are lacking, however, which has a bearing on current challenges in AI (e.g. under-specification for ML systems) and may contribute to the relatively slow adoption of AI in some high-stakes domains (e.g. clinical practice in medicine). The need is more than simply for automated tools to assist AI developers. Rather, the scientific question to be answered concerns the extent to which the informal process of problem formulation can be formalized.

# Army Research Office (ARO) Research Topic

**Title:** Materials Design
**Announcement ID:** ARL-BAA-0012

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**ARL Office:** Army Research Office (ARO)
**Discipline:** Chemistry;Materials Science;Physics
**ARL Foundational Research Competencies:** Electromagnetic Spectrum Sciences;Photonics, Electronics, and Quantum Sciences;Sciences of Extreme Materials
**Army Modernization Priorities:** Soldier Lethality
**Keywords:** self-assembly, soft materials, colloids, functional materials, metamaterials,

**Description:**
The overarching goal of the Materials Design program is to establish new smart materials concepts by pursuing fundamental science that exploits multiple physical and chemical forces at play during directed self-assembly to create stimuli-responsive, multifunctional materials with designer geometries, hierarchical complexity, and the ability to dynamically switch among configurations, thereby enabling the future Warfighter to adapt to any environment or situation. Bottom-up materials science, functional materials, and soft matter are the unifying themes of the Materials Design program. The program supports experimental, theoretical, and computational advances to better design, create, understand, and manipulate novel functional materials from the bottom up. The foundations established here support the realization of 3D metamaterials, reconfigurable optics and electronics, bio-mimetic materials, and multi-functional materials that dynamically respond to their environment.

**The Science of Self-Assembly** supports basic research into the multiple physical and chemical forces at play during directed, bottom-up 3-D assembly into super-structures incorporating multiple components. The goal is to design novel self-assembled materials that would be impossible to create using top-down techniques. Self-assembling materials systems of interest include: colloids; nanocrystals; liquid crystals; functional biomaterials and bio-hybrid materials; and/or hybrids (e.g., polymeric composites) of these materials. Specific research interests include: non-equilibrium and dissipative self-assembly; 3-D photonic crystals and structural color; interactions between self-assembled materials and water; and non-traditional assembly directing forces (e.g., turbulence).

**Reconfigurable Materials** supports the design and synthesis of soft matter capable of reversible transformations. The goal is to elucidate the design rules for creating novel functional materials with dynamic property contrast and/or emergent behavior and develop new methods to '"program" materials with the ability to respond in specific ways to external stimuli. Reconfigurable materials systems of interest include: bio-mimetic materials; liquid crystal elastomers; colloidal metamaterials; 3D/4D metamaterials; and active matter. Specific research interests include: 3D/4D printing of functional materials with molecular-scale precision; materials that form reconfigurable networks; '"natural" (i.e., non-robotic) active matter capable of autonomous collective behavior and/or computation, and, in particular, materials capable of changing their shape, color, or texture.

**Computer-aided Materials Design** seeks to leverage recent advances in machine learning, artificial intelligence, computational materials science, and other numerical approaches to solve difficult materials design problems, particularly those in soft matter, self-assembly, and reconfigurable materials. Points of interest include inverse design of self-assembled materials; data-driven design of heterogeneous hierarchical materials; and novel models or algorithms for solving materials-specific problems. Specific research interests include: "'self-driving" materials simulations; unified simulation approaches that bridge all time- and length-scales of interest; and designing soft materials to perform AI/ML computations (e.g., physical artificial neural networks).

# Army Research Office (ARO) Research Topic

**Title:** Mechanical Behavior of Materials
**Announcement ID:** ARL-BAA-0001

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**ARL Office:** Army Research Office (ARO)
**Discipline:** Chemistry;Data Sciences and Informatics;Materials Science;Mathematics and Statistics;Mechanics;Network Science;Physics
**ARL Foundational Research Competencies:** Sciences of Extreme Materials;Terminal Effects;Weapons Sciences
**Army Modernization Priorities:**
**Keywords:**

**Description:**
This program focuses on basic research investigations that enable unprecedented mechanical properties in advanced structural materials in order to ensure high performance under a variety of extreme and highly variable operational conditions. Experimental, theoretical, and numerical efforts are encouraged, particularly those that promote understanding of the underlying physical mechanisms leading to extraordinary behaviors. Studies may focus on a variety of materials, including: metals, ceramics, polymers, composites, and hybrid structures. Research efforts that leverage recent discoveries in other scientific fields, such as Physics, Chemistry, Mathematics, Network Science and Data Science, are also highly encouraged. These investigations are expected to enable transformative capabilities for the Soldier in the areas of protection, maneuver, and sustainability. Current focus areas for this portfolio include, but are not limited to, the following:

Extreme Thermomechanical Behaviors. This thrust emphasizes foundational concepts that enable structural materials with extraordinary combinations of ultrahigh temperature stability and exceptional mechanical properties under non-equilibrium conditions, e.g. transient thermal loads, high g-loading, and/or variable oxidizing environments. Areas of interest include: Understanding, control, or confinement of deformation mechanisms; exploiting interface/interphase interactions in heterogeneous materials; and concepts enabling materials to undergo refinement under relevant conditions to enhance thermomechanical performance.

Disruptive Mechanical Responsiveness. This thrust focuses on structural materials with unprecedented mechanical responsiveness when subject to complex loading environments, e.g. severe and/or high strain rate events. Areas of interest include materials that actively respond to dynamic loading environments and other external stimuli through rapid adaptation of shape, topology, mechanical properties, and/or through the ability to intrinsically process information. In addition, this thrust seeks concepts for manipulation of mechanical forces within materials at specific spatial locations, particularly for the consideration of inelastic behaviors.

# Army Research Office (ARO) Research Topic

**Title:** Microbiology
**Announcement ID:** ARL-BAA-0006

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**ARL Office:** Army Research Office (ARO)
**Discipline:** Biological Sciences;Network Science
**ARL Foundational Research Competencies:** Biological and Biotechnology Sciences;Humans in Complex Systems;Network, Cyber, and Computational Sciences
**Army Modernization Priorities:**
**Keywords:**

**Description:**
This program supports basic research in fundamental microbiology that can help advance needs in Soldier protection and performance. There are two primary research thrusts within this program: (i) Microbial Survival Mechanisms in Challenging and Extreme Environments and (ii) Analysis and Engineering of Microbial Communities.

The Microbial Survival Mechanisms in Challenging and Extreme Environments thrust focuses on the study of the cellular and genetic mechanisms and responses that underlie bacterial, archaeal and fungal survival in the face of environmental stress, as well as the ability of these microbes to thrive under those conditions. These stressors include extremes in temperature, pH, or salinity; the presence of toxins including metals and toxic organic molecules; oxidative stress; and cellular starvation and the depletion of specific nutrients. Included here is the study of microbial metabolism under conditions of slow growth and the transitions into and out of slow growth phases. Research approaches can include fundamental studies of microbial physiology and metabolism, cell biology, and molecular genetics that examine key cellular networks linked to survival and environmental adaptation, microbial cell membrane structure, and the dissection of relevant critical signal transduction pathways and other sense-and-respond mechanisms.

The Analysis and Engineering of Microbial Communities thrust supports basic research that addresses the fundamental principles that drive the formation, proliferation, sustenance and robustness of microbial communities through reductionist, systems-level, ecological and evolutionary approaches. Bottom-up analysis of nutrient consumption, information exchange, signaling interactions, spatial/temporal effects, structure-function relationships, and biosynthetic output for single and multi-species communities within the context of planktonic and both native and engineered biofilm architectures is considered. The use of these approaches for the analysis of model microbial systems that address the biology of mammalian and environmental microbiomes are welcome. Of joint interest with the ARO Biomathematics Program, research efforts that advance the ability to work with biological data sets toward an understanding of microbiological systems marked by ever-increasing complexity are encouraged.


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# Army Research Office (ARO) Research Topic

**Title:** Modeling of Complex Systems
**Announcement ID:** ARL-BAA-0020

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**ARL Office:** Army Research Office (ARO)
**Discipline:** Mathematics and Statistics;Physics
**ARL Foundational Research Competencies:** Military Information Sciences;Network, Cyber, and Computational Sciences;Weapons Sciences
**Army Modernization Priorities:**
**Keywords:** data assimilation, inverse problems, model closure, geometric data analysis, information theory, sparsity, data compression

**Description:**
The Modeling of Complex Systems Program is a program of fundamental mathematics-oriented research directed at addressing the critical challenges resulting from the approximate nature of models for complex real-world phenomena. While models have traditionally relied on tuned, empirically justified approximations, this program seeks to rigorously explore the bounds of model predictive power through the development of coupled nonlinear uncertainty propagation methodologies and novel data assimilation techniques for the self-consistent integration of observed data within constrained modeling frameworks. The program particularly seeks modeling frameworks that can be adapted to span a variety of disciplines where first principle descriptions are unknown, incomplete, or computationally infeasible. While required prediction speed and accuracy are necessarily problem context dependent, typical applications ranging from planning to design and anomaly prediction all require methods to balance accuracy, computational performance, and data availability to efficiently inform decisions.

Although they break down into more specific research directions, the three thrust areas of interest to the Modeling of Complex Systems Program are 1) Adaptive Surrogates and Associated Closures 2) Dynamical Propagation of Uncertainty and Emergent Structures in Data 3) Integration of data with models for effective inference and validation methodologies.

1) Adaptive Surrogates and Associated Closures

This first program thrust focuses on methods for accelerating forward models while controlling errors. Truncation and simplifying approximations are ubiquitous in models of complex macroscopic phenomena. Adaptive models that are capable of scaling accuracy and uncertainty within a problem specific context are critical for efficient allocation of computational resources constrained by decision relevant timescales. Balancing these accuracy-cost tradeoffs is particularly critical in outer-loop problems requiring many forward model queries as encountered in design optimization, uncertainty quantification, model predictive control, and inverse problems. While surrogates adaptively constructed or learned from regularities observed in adjacent calculations and data have the potential to accelerate outer-loop search of high-dimensional spaces, significant open research challenges remain in addressing how and when such regularities justify their applicability between and beyond previously observed model inputs. Related areas of potential interest include the relationship between memory, truncation, and closability, evidence of uniqueness in input output maps, hierarchical problem decomposition and compression, randomized methods, and other transformations that convert model representation into spaces where more efficient predictions can be performed.

2) Propagation of Uncertainty

The second thrust concerns the study of the evolution of model uncertainties resulting from approximations introduced to facilitate computation. This area focuses on the dynamical growth of initial state uncertainty as well as its interactions with modeling errors and other sources of imperfect system knowledge such as incomplete system specification and uncertain open boundary conditions. Methods to exploit the impact of nonlinear mixing and contraction towards lower dimensional subspaces, when appropriate, are of particular interest, as is the propagation of uncertainty across boundaries in decomposed system-of-system models. Methods that enable efficient estimation of deterministic and stochastic probability flows in high dimensions as well as into and on embedded manifolds with associated foundations for required regularizations are of high interest. While full characterization of uncertainty distributions in very high dimension is likely to remain practically infeasible, methods to characterize over approximated reduced dimensional bounds for worst cases and typical cases, particularly in the context of high-cost decision boundary constraints are of high interest.

3) Integration of Data with Models

This third thrust concerns the use of real-world data sources to improve and validate models. While the prior thrusts are aimed at methods capable of estimating expected distributions of potential model outcomes, this thrust focuses on the relationships between these expected outcomes and actual observations. To the extent that uncertainty is expected to grow beyond acceptable error bounds, this thrust is also concerned with the efficient acquisition and use of data to refine state estimates and correct for model insufficiency in support of attaining satisfactory accuracy and uncertainty levels. While verification, validation, and uncertainty quantification are typically described in terms of problem specific "'quantities of interest" and prescribed satisfactory error bounds, this thrust is also particularly concerned with when such requirements are sufficient to provide an expectation of model uniqueness. Particularly in cases of highly parameterized models such as overparameterized neural networks, mitigating potential overfit in training to provide foundations for an expectation of future generalization is of critical importance.

What features of problems underpin expectations for generalization and provide statistical foundations for the acquisition of confidence in predicted outcomes? How can expectations for repeatability be established such that data from anecdotally distinct sources can be transferred and combined? Rather than introduced as modeling assumptions, how can properties such as stationarity, exchangeability, or underlying causal mechanisms be discovered and confirmed to high statistical confidence levels prior to or concurrent with their use? While these mechanisms may be well established for many physical problems allowing high confidence in their applicability, how can such confidence be established in complex and adaptive systems where the link between first principles and application may be broken? Even in physical systems with high expectations of repeatability, how can the anticipation of emergent large deviations from under resolved problem uncertainties be analyzed and what are appropriate expectations for their predicability? For which classes of systems and model requirements can continuous or potentially adversarial validation methodologies be designed to maximize information gain, actively interrogate model validity bounds, or drive uncertainty out of system models? Research that addresses any of these questions is relevant to the program.

Furthermore, due to the large approximation capacity of modern model classes, the modeling of complex systems program is particularly interested in development of models capable of synchronization with arbitrary permutations of mutually self-consistent independent system observables under the influence of stochastic perturbation and control input in support of the establishment of methods for constructing and validating computationally feasible predictive digital twins.


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# Army Research Office (ARO) Research Topic

**Title:** Modern Optics
**Announcement ID:** ARL-BAA-0009

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**ARL Office:** Army Research Office (ARO)
**Discipline:** Physics
**ARL Foundational Research Competencies:** Electromagnetic Spectrum Sciences;Network, Cyber, and Computational Sciences;Photonics, Electronics, and Quantum Sciences
**Army Modernization Priorities:**
**Keywords:**

**Description:**
The objective of this program is to promote a deeper understanding of the properties of light and the discovery of new optical effects that can improve Army capabilities. Most sensing and communications systems depend on light in some way. This program seeks transformational basic science discoveries in optical physics that are needed to enable dynamic control of light for remote sensing, information routing, and energy transmission. In order to accomplish this goal, the Modern Optics Program targets new or emerging phenomena related to quantum optics, light-matter interactions, structured light and ultra-short pulse lasers.

Quantum Photonics. This thrust seeks to push beyond the state of the art in photonics and integrated optical platforms, seeking novel functionality beyond classical limits on sensitivity, accuracy, and stability. Research efforts may include studies addressing complexity and loss in integrated optical systems, scalable realizations of multi-photon quantum states or quantum light sources, and novel laser platforms to probe or manipulate quantum information in physical qubits. Basic science understanding is needed to push integrated photonics into the quantum regime which will be essential for next generation quantum technology.

Meta-Optics. This thrust looks for novel functionality enabled by optical metamaterials. In this area, the conventional norms of classical optics will be broken. Examples include resolution beyond the diffraction limit, super-lensing, as well as subwavelength control of optical fields. Proposals related to non-Hermitian optics and the physics of exceptional points, where these concepts are utilized to fabricate photonic structures with novel properties and sensors with precision beyond the state of the art are sought. In general, any phenomena arising from optical metamaterials that would benefit the Soldier and improve Army capabilities will be considered.

Extreme Light. This thrust focuses on extreme light, meaning the examination of optical fields in extreme limits, such as shortest pulse and/or high intensity. General areas of study under this thrust include, THz formation, broadband localized radiation, coherent control of atomic and molecular energy states, plasma effects in materials, and relativistic plasma physics. Theoretical and experimental research efforts are needed to push beyond the state of the art in ultrafast science and to understand how extreme light interacts with matter.


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# Army Research Office (ARO) Research Topic

**Title:** Multi-Agent Network Control
**Announcement ID:** ARL-BAA-0031

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**Discipline:** Computer Science;Data Sciences and Informatics;Network Science
**ARL Foundational Research Competencies:** Military Information Sciences;Network, Cyber, and Computational Sciences;Weapons Sciences
**Army Modernization Priorities:** Long Range Precision Fires;Network/C3I;Next Generation Combat Vehicle
**Keywords:** Control, Reinforcement Learning, Quantum, Multi-Agent, Distributed, Data Driven, Networked Systems

**Description:**
The objective of the Multi-Agent Network Control program is to establish the physical, mathematical and information processing foundations for the control of complex dynamic networks with possibly multiple controllers that may operate using different information sets. The research program seeks the development of novel mathematical and computational methods for the modeling and control of the collective behavior of large-scale networked systems controlled by of heterogeneous agents which may or may not follow a common goal. Autonomy is central to program efforts to support anticipated dynamics of the future battle space. Requirements of such environments may include mobility, effective sensor coverage, efficient information flow, responsiveness to support the military goals of information superiority, dominant maneuver and precision engagement.

***Distributed and Time-Varying Control of Networked Systems***
Distributed control techniques play a major role in the analysis and synthesis of networked systems. They have been successfully used in robotics for replicating self-organized behaviors found in nature (e.g., bird flocking, fish schooling, and synchronization) and in developing applications such as formation control, rendezvous, robot coordination, and distributed estimation. Many dynamic systems are, or can be made time-varying, and they may be subject to possibly abrupt transitions of the states, and hard to predict disturbances and external effects. Innovative methods that incorporate, and even exploit time varying nature of distributed systems for establishing their stability, robustness and optimality is of interest. Analysis and control of networked non-linear systems where standard linearization methods are not satisfactorily applicable is also sought. Potential use of techniques such as geometry, graph theory, topological analysis and other innovative methods are encouraged.

***Data Driven Control and Learning***
Control of systems with unknown dynamics and methods to reduce their uncertainties has been part of mainstream control systems research, examples of which include Reinforcement Learning (RL), Adaptive Control, and in general data driven control. Reinforcement Learning is shown to be closely related to Stochastic Dynamic Programming, which enabled successful leveraging of significant body of research of the latter. However, data driven controls such as RL face significant challenges, including computational complexity, very long convergence times, and

lack of sufficiently rich training data. Hybrid approaches that properly incorporate prior or learned models of the systems to be controlled into the problem formulation are emerging and their furthering is encouraged in this program. Broadly, research to address fundamental issues in data driven control is sought. Those include, but not limited to, efficient computation methods that allow real-time operations without sacrificing precision, scalability, optimization algorithms that address the occurrence of multiple local minima encountered in learning and developing systematic methods for reliable transfer of learning from other experiments. Use and advancing of control theoretical tools such as stability analysis, non-convex optimization, and other innovative approaches to address these open problems is encouraged. New insights to RL algorithms which may extend, modify, or replace standard Markovian formulations are desired. Extensions of RL techniques to networked systems featuring multiple controllers with applications to autonomy and coordination among interacting agents are sought. Innovative research focused on adaptive control, and system identification techniques to reduce uncertainties and facilitate optimal or near-optimal control is also in scope.

***Control of Quantum Systems and novel applications of control theory***

Innovative tools and methodology from control theory could provide new insights and approaches to pave the path for solving some of the outstanding problems in quantum, such as maintaining coherence and stability of Quantum Qubits and their entangled states. Capabilities enabled by quantum computers are expected to surpass their classical counterparts in the future. However, maintaining the desired state of qubits remains a fundamental problem encountered in the realization of quantum computers and quantum networks. Adaptation of control theoretical tools and approaches in enhancing the stability of coherence of qubits and reducing the impact of noise in quantum gates and their operations could provide new research opportunities in the control of networked quantum systems.

Researching and devising other applications of control theory in areas that are relevant to the Army and that could advance the state of control theory itself is of interest. Among novel applications of potential interest is the study of control functions acting on neural circuits that are distributed in the brain. These interactions include synchronization, but their fundamental principles and underlying mechanisms are not well understood. Modeling and analysis of these phenomena could provide novel research opportunities in the control of networked systems. Similarly, study of biological systems has unveiled control architectures that are not encountered in industrial control systems. Understanding the principles, analyzing the effectiveness of such naturally occurring control systems and their potential adaptation to the control of man-made applications could be an area of fertile research.

# Army Research Office (ARO) Research Topic

**Title:** Neurophysiology of Cognition
**Announcement ID:** ARL-BAA-0016

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**ARL Office:** Army Research Office (ARO)
**Discipline:** Biological Sciences;Computer Science;Data Sciences and Informatics;Mathematics and Statistics;Network Science
**ARL Foundational Research Competencies:** Biological and Biotechnology Sciences;Humans in Complex Systems
**Army Modernization Priorities:**
**Keywords:**

**Description:**
The Neurophysiology of Cognition program supports non medically oriented high-risk high-reward basic research that will enable discovery of the appropriate molecular, cellular, systems and behavioral-level codes underlying cognition and performance across multiple time scales. An overarching goal of the program is to foster advances in a broad range of experimental, computational and theoretical approaches applied to animal models and humans as well as data. Inquiries are strongly encouraged for projects that include recent methodological advances to assess and augment the nervous system (i.e., electrophysiological, imaging or computational). Basic research opportunities are sought in two primary research thrusts within this program: (i) Evolutionary and Revolutionary Interactions and (ii) Neural Computation.

***Evolutionary and Revolutionary Interactions (with Real and Mixed Worlds)***
The Evolutionary and Revolutionary Interactions thrust aims to understand evolutionary neurophysiological processes that enable complex task performance in both unstructured and structured real-world environments. Foundational research is encouraged to uncover biological mechanisms and to concurrently develop efficient and adaptive computational and modeling frameworks that abstract cognitive phenomena such as anticipatory sensing, automatic learning, complex decision-making, and rapid adaptive action. How these neural phenomena translate across teams of human and AI agents and span wider ranges of spatiotemporal scales and task complexities is of particular importance. Experimental approaches building upon man-made structured and mixed environments with increasingly complex, information-rich/poor/deceptive and cooperative/competitive features will be most informative. Also, foundational research to understand and improve cognitive performance and to avoid cognitive failures by understanding (across neuromechanistic, glymphatic, and neurocomputational levels) sleep and mitigation of cognitive fatigue due to physiological and environmental stressors is of high value.

***Neural Computation, Information Coding, and Translation***
The Neural Computation thrust is focused on broadening understanding of the mechanisms employed by neural circuits and systems to generate desirable computations and to learn and adapt from few examples. Research in this thrust can broadly address research in areas such as studying aspects of multiscale information processing dynamics mediating computations among neurons, glial cells and blood vessels as well as identifying how these circuits and circuit architectures generate desirable computations over multiple timescales, discovering mechanisms

for bidirectional control. Mathematical and computational frameworks are encouraged for closed-loop prediction and control of neural dynamics and to translate across divergent information types (e.g. differing in information capacity, throughput, modality, processing architectures, levels of abstraction). Focus should be paid to uncovering fundamental principles of neural system adaptations required to solve unstructured problems, infer expectations of teammates and adversaries and of tasks and the environment, and estimating rewards for complex decisions. Integrative approaches involving combinations of experimentation, theory and mechanistic modeling are highly encouraged, for both biological and novel hybrid living-nonliving frameworks.

# Army Research Office (ARO) Research Topic

**Title:** Optoelectronics
**Announcement ID:** ARL-BAA-0019

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**ARL Office:** Army Research Office (ARO)
**Discipline:** Electronics
**ARL Foundational Research Competencies:** Electromagnetic Spectrum Sciences;Energy Sciences;Military Information Sciences;Network, Cyber, and Computational Sciences;Photonics, Electronics, and Quantum Sciences;Sciences of Extreme Materials
**Army Modernization Priorities:** Air and Missile Defense;Network/C3I;Next Generation Combat Vehicle
**Keywords:** optoelectronics, photonics, semiconductor

**Description:**
Research in this subarea includes novel semiconductor structures, processing techniques, and integrated optical components. The generation, guidance and control of UV through infrared signals in semiconductor, dielectric, and metallic materials are of interest. The Army has semiconductor laser research opportunities based on low dimensional semiconductor structures (quantum dots, wells, wires, etc.) operating in the eye-safer (>1.4), 3-5, and 8-12 microns regions for various applications, such as LIDAR, infrared countermeasures, and free space/integrated data links. Components and sources in the UV/visible spectral ranges (particularly < 300 nm) may be of interest as well. Research is necessary in semiconductor materials growth and device processing to improve the efficiency and reliability of the output of devices at these wavelengths. However, near infrared or wavelength agnostic device advances can be explored for potential impact on various material systems and wavelengths of interest.

Research that leads to an increase in the data rate of optoelectronic structures is sought. Interfacing of optoelectronic devices with electronic processors will be investigated for full utilization of available bandwidth. Electro-optic components will be studied for use in guided wave data links for interconnections and optoelectronic integration, all requirements for high-speed full situational awareness. Optical interconnect components are needed in guided-wave data links for computer interconnection and in free-space links for optical switching and processing. For high-speed optical signal processing as well as potential for power scaling, research on individual and 1 or 2-D arrays of surface or edge-emitting lasers is necessary. Spectral and coherent beam combining approaches for integrated photonics need more exploration. Research addressing efficient, novel optical components for high-speed switching based on electro-optic materials, nanostructures, metamaterials or other regimes may be of interest. Emitters and architectures for novel display and processing of battlefield imagery are important.

Research on components and sub-elements of photonic circuits used in neuromorphic photonic information processing and computation are of interest. Photonic processing within a photonic integrated circuit (PIC) requires smaller and more energy efficient modulator devices on the order of 5 microns and 1 femtojoule/bit. Modulation bandwidth of 10 Gb/s or more, and insertion loss of 0.1 dB or less are needed to cascade modulators with less than 1 dB/cm total loss. Modulation and bit resolutions of 12 bits or more and floating-point calculations will be required for PIC processor implementations. Other advances leading to enhanced analog computing performance regimes including energy efficient and high-speed photodetectors and light sources (most likely coherent) are sought. Exploration of ideas leading to enhanced use of photonic interactions in both 2D and 3D architectures that take advantage of photonic degrees of freedom (wavelength, polarization, spatial modes, etc.) will be considered. While quantum communications and quantum integrated photonics are not focused upon per se, low bit energy signals (photon count < 500) may be considered. Such research could impact single photon, quantum optics regimes due to similar signal to noise considerations.


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# Army Research Office (ARO) Research Topic

**Title:** Physical Properties of Materials
**Announcement ID:** ARL-BAA-0003

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**ARL Office:** Army Research Office (ARO)
**Discipline:** Chemistry;Electronics;Materials Science;Physics
**ARL Foundational Research Competencies:** Electromagnetic Spectrum Sciences;Energy Sciences;Photonics, Electronics, and Quantum Sciences
**Army Modernization Priorities:**
**Keywords:** Novel functional materials discovery, materials characterization techniques, materials defects

**Description:**
The Physical Properties of Materials program seeks to discover novel functional materials and elucidate fundamental mechanisms responsible for achieving extraordinary electronic, photonic/optical, magnetic and thermal properties in materials to enable future innovative Army applications. There are mainly three focus areas in this program:

Novel Functional Materials Discovery area supports the discovery of novel functional materials with unique compositions and/or structures to realize unique physical properties. Examples of materials include oxides, nitrides, carbides, chalcogenides, super-lattices, free-standing low dimensional (0D, 1D, 2D organic / inorganic) materials, hetero-structures, polymers, organic-inorganic hybrids, co-crystals, etc. Basic research ideas in the areas such as synthesis (thin films as well as bulk materials), modeling, and influence of external stimuli such as light, magnetic field etc. to determine unprecedented functional properties (semiconducting, superconducting, ferroelectric/multiferroic, photonic, magnetic, thermal etc.) are encouraged.

Science & Engineering of Crystal Imperfections area explores the influence (either positive or negative) of various crystalline imperfections (e.g., point, line, area, volume defects etc.) on the physical properties (electronic, optical, magnetic, and thermal) in functional materials. Basic research ideas in the areas such as elucidation of different mechanisms of incorporation/elimination of the defects during thin film growth/bulk materials processing of materials, characterization of novel defects, and influence of them on the extraordinary functional properties of the materials etc. are encouraged.

Novel materials characterization techniques: Development of novel characterization techniques to determine composition- structure- defects- stimuli- property relationships in functional materials.

# Army Research Office (ARO) Research Topic

**Title:** Polymer Chemistry
**Announcement ID:** ARL-BAA-0002

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**Discipline:** Chemistry;Materials Science
**ARL Foundational Research Competencies:** Mechanical Sciences;Sciences of Extreme Materials;Terminal Effects;Weapons Sciences
**Army Modernization Priorities:**
**Keywords:** polymers, stimuli-responsive materials, polymer-based composites, hybrid materials

**Description:**
The Polymer Chemistry program supports basic, foundational research in polymer design, synthesis, and characterization with the goal of linking polymer structure through the atomic/molecular- nano- and microstructural continuum to bulk macroscopic properties. Innovative methodologies are sought for synthesizing polymers with well-defined functionality and architecture with the objective of gaining a more acute understanding of how chemical structure influences microstructure, morphology, phase behavior, self-assembly, processing and ultimately, functional/structural properties. The continued development of these relationships is critical to creating new generations of materials with superior mechanical, thermal, optical, chemical, electrical, and other transport properties to perform well under extreme operating conditions. Research areas of interest include but are not limited to the following:

**Polymer Synthesis and Assembly** New synthetic approaches are sought for preparing polymers with well-defined molecular weight, functionality, architecture, tacticity, and sequence. This could include new methodologies for controlled polymerization, catalyst and initiator design for tacticity or sequence control, novel strategies for post-polymerization functionalization or transformation and accessing ultra-high molecular weights. Proposals which link molecular level control to polymer assembly to access increasingly complex structures with improved selectivity driven by non-covalent chemistry, solvent effects, and/or immiscibility are also desired. Assembly of dissimilar materials or polymer alloying concepts where mixing entropy suppresses phase separation are of particular interest. Biological routes to create or degrade polymers with stable, non-hydrolytic bonds will also be considered. Methodologies that leverage autonomy, high-throughput experimentation, and machine learning to accelerate the pace of discovery are also highly sought.

**Advanced Polymer Networks** Polymer networks find broad utility in defense applications yet suffer numerous limitations due to the nature of their polymerization and the resulting defects that are formed which tend to dominate their mechanical response. New architectures, topologies and synthetic approaches are desired to access polymer networks with limited or controlled defects and/or hierarchical structures leading to extraordinary properties. Incorporation of novel molecular mechanisms or cascades for energy dissipation, sensing, self-healing, actuation, and recyclability that are triggered by external forces such as light, stress, and electric or magnetic fields which enable reversible changes in physical properties. Mechanisms that induce responsiveness and local molecular motion in thermosets below $T_g/T_m$ and/or require low energy doses and offer spatiotemporal control are highly desired.

# Army Research Office (ARO) Research Topic

**Title:** Quantum Information Science
**Announcement ID:** ARL-BAA-0023

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**ARL Office:** Army Research Office (ARO)
**Discipline:** Computer Science;Materials Science;Physics
**ARL Foundational Research Competencies:** Military Information Sciences;Network, Cyber, and Computational Sciences;Photonics, Electronics, and Quantum Sciences
**Army Modernization Priorities:** Assured PNT;Network/C3I;Next Generation Combat Vehicle
**Keywords:** quantum information science, quantum sensing, quantum computing, quantum entanglement, quantum networking

**Description:**
Quantum mechanics provides the opportunity to perform highly non-classical operations that have the potential to result in beyond-classical capabilities in sensing, precision measurement, computation, and networking. The quantum information science program seeks to understand, control, and exploit such non-classical phenomena for revolutionary advances beyond those possible with classical systems. An overarching interest is the exploration of small systems involving small numbers of entangled particles. There are three primary areas of interest within the program.

***Foundational Quantum Physics***
Experimental investigations of a fundamental nature of quantum phenomena that are potentially useful for quantum information science are of interest. Examples include coherence properties, decoherence mechanisms, decoherence mitigation, entanglement creation and measurement, nondestructive measurement, complex quantum state manipulation, and quantum feedback. An important objective is to ascertain the limits of our ability to create, control, and utilize quantum information in multiple quantum entities in the presence of noise. Systematic materials science based and/or focused research which identifies and/or mitigates decoherence mechanisms is also of interest. Models of machine learning that are based on the foundations of quantum physics are of interest. Theoretical analyses of non-classical phenomena may also be of interest if the work is strongly coupled to a specific experimental investigation, such as proof-of-concept demonstrations in atomic, molecular, and optical (AMO) or other systems.

***Quantum Sensing and Metrology***
This research area seeks to explore, develop, and demonstrate multi-particle coherent systems to enable beyond classical capabilities in sensing and metrology. Central to this research area is the exploration of small systems involving a few entangled particles. Topics of interest include the discovery and exploration of (a) multi-particle quantum states advantageous for sensing and metrology, (b) quantum circuits that operate on multi-particle quantum states to enable beyond-classical capabilities, and (c) methods for the readout of quantum states. Other research topics of interest include theory to explore multi-particle quantum states useful for beyond classical capabilities, quantitative assessment of capabilities and comparison to classical systems, efficient state preparation, quantum circuits for processing these states as quantum bits, readout techniques, decoherence mitigation and error-correction for improved performance, supporting

algorithms as a basis for processing circuits, connections between the solution of hard computational problems and overcoming classical limitations in sensing and metrology, entanglement as a resource, and suitable physical systems and key demonstration experiments.

***Quantum Computation and Quantum Networking***

Quantum computing and networking will entail the control and manipulation of quantum bits with high fidelity. The objective is the experimental demonstration of quantum logic performed on several quantum bits operating simultaneously, which would represent a significant advance toward that ultimate goal of beyond classical capabilities in information processing. Demonstrations of quantum feedback and error correction for multiple quantum bit systems are also of interest. There is particular interest in developing quantum computation algorithms that efficiently solve classically hard problems, and are useful for applications involving resource optimization, imaging, and the simulation of complex physical systems. Examples include machine learning, parameter estimation, constrained optimization, and quantum chemistry, among others. The ability to transmit information through quantum entanglement distributed between spatially-separated quantum entities has opened the possibility for new approaches to information processing. Exploration of quantum networking of information and distributed quantum information processing based on entanglement is of interest. These include the exploration of long-range quantum entanglement, entanglement transfer among different quantum systems, and long-term quantum memory.

# Army Research Office (ARO) Research Topic

**Title:** Reactive Chemical Systems
**Announcement ID:** ARL-BAA-0067

**TPOC:** James F Berry, PhD - james.f.berry49.civ@army.mil - (410) 278-1519
**ARL Office:** Army Research Office (ARO)
**Discipline:** Chemistry;Materials Science
**ARL Foundational Research Competencies:** Energy Sciences;Sciences of Extreme Materials;Terminal Effects;Weapons Sciences
**Army Modernization Priorities:** Soldier Lethality
**Keywords:** responsive assemblies; surface science; catalysis; nanostructured materials

**Description:**
The goal of the Reactive Chemical Systems Program is to achieve a molecular level understanding of surface/interfacial activity and dynamic nanostructured chemical systems to provide leap-ahead advancements in Army relevant materials for the benefit of the Soldier. This program supports basic research in the areas of surfaces, catalysis, interfaces, coatings, and novel and stimuli-responsive chemical systems.
This program is divided into three areas: (i) Nanostructure Surface Interactions and Reactivity, (ii) Development of Per- and Polyfluoroalkyl Substances (PFAS) Alternatives, and (iii) Synthetic Molecular Systems.
***Nanostructure Surface Interactions and Reactivity***
This thrust seeks to understand the kinetics and mechanisms of reactions occurring at surfaces and interfaces, as well as the development of new methods to achieve precise control over the structure and function of chemical and biological molecules on surfaces. Areas of interest include adsorption, desorption, the catalytic and reactive processes occurring on surfaces and at interfaces, and the interfacial activity/reactivity between dissimilar materials to enhance systemic response to external stimuli. A topic of particular interest is the use of confinement of chemical species within a system to influence parameters of reactivity. Breakdown of both reactive (hazardous) and long-lived (stable) chemical species is relevant to this area. Also, characterization and novel methods to control how surfaces and interfaces of disparate materials respond to and/or degrade under extreme conditions are of interest. To achieve greater understanding of the phenomena that govern these interactions, rapid, in-situ characterization of material changes in extreme conditions is also covered.

***Development of Per- and Polyfluoroalkyl Substances (PFAS) Alternatives***
Development of robust alternatives to per- and polyfluoroalkyl substances (PFAS), including coatings/materials that provide performance equal or greater than these fluorine-containing systems, without the associated hazards, are covered in this area. Investigation of chemical surfaces and novel materials that enable superior thermal stability, hydrophobicity, oleophobicity, low surface tension, and low coefficients of friction are of interest. Basic research efforts for the development of the chemistry that enables these coatings to adhere to various form factors are of interest, in particular for their use in environmental extremes. Another area of interest is the exploration of the chemical space that imparts flammability mitigation, especially for high temperature applications.


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***Synthetic Molecular Systems***

This topic supports research that imparts multifunctionality, stimuli-responsive and dynamic behavior to synthetic molecular and chemical systems. Research of interest includes design and development of nanostructured scaffolds and sequential catalytic systems. Research aimed at exploring the properties and capabilities of porous supramolecular structures, including their functionality, and the downstream capabilities that can be integrated into the system, is also a priority. A specific technical area of interest is "targeting and triggering" in which a specific chemical (or event) is targeted (recognized) and that recognition triggers a response. Important technical challenges include selective and reversible recognition, amplification, and multi-responsive systems in which specific stimuli trigger distinct responses including shape and/or color change, subsequent generation of chemical species, and unmasking of catalytic functionalities are also relevant.


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# Army Research Office (ARO) Research Topic

**Title:** Social and Cognitive Networks
**Announcement ID:** ARL-BAA-0026

**TPOC:** Edward T. Palazzolo, PhD - edward.t.palazzolo.civ@army.mil - (919) 549-4234
**ARL Office:** Army Research Office (ARO)
**Discipline:** Data Sciences and Informatics;Economics;Education;Network Science;Social Science
**ARL Foundational Research Competencies:** Humans in Complex Systems;Military Information Sciences
**Army Modernization Priorities:**
**Keywords:** Social, Cognitive, Network, Behavior, Knowledge, Teams, Learning

**Description:**
The goal of the Social and Cognitive Networks program is to understand human behaviors and cognitive processes leading to collective level phenomena particularly relevant in military settings with an emphasis on high performance teams, computational social science, and collective resilience. Social networks are the underlying structure of interaction and exchanges between humans within both strategically designed and emergent or self-organized systems. Social networks allow for collective actions in which groups of people can communicate, collaborate, organize, mobilize, attack, and defend. The changing nature of DoD's missions greatly increase the need for models that capture the cognitive, organizational, and cultural factors that drive activities of co-present, virtual, or distributed groups, teams, and populations. Better understanding the human dimension of complexity will provide critical insights about emerging phenomena, social diffusion and propagation, thresholds, and tipping points.

The Social and Cognitive Networks program supports projects that contribute substantive knowledge to theories about human behavior and interaction and make methodological advancements in modeling and analyzing social network structures. This program funds projects successful in blending theories and methods from the social sciences with rigorous computational methods from computer science, engineering, and mathematical modeling. Advances in this program are expected to lead to development of measures, theories, and models that capture behavioral and cognitive processes leading to emergent phenomena in teams, organizations, and populations.

***Community Cognitive Resilience***
Cognitive resilience for sustained operations is a critical need within an evolving environment of work and family. There is a need to create verifiable models bridging cognitive and social networks to discover the developmental processes and science of cognitive and social well-being to establish cognitive resilience in individuals and communities. Research in this program focuses on rapid integration modalities of mindfulness and hypnotherapy for cognitive management and improvement as well as emotional regulation. Basic research in this thrust will explore the impact of these modalities on social science theories from psychology, communication, anthropology, and sociology. Research will use social networks methods to explore an individual's impact on and from the communities in which they are embedded. Research supported in this thrust will explore small- and large-scale network patterns that

support both individual cognitive resilience and collectively support the community. Priority will be given to fundamental science (nonclinical) efforts focused on illness to wellness related to PTSD, depression, anxiety, pain management, suicidal ideation and prevention, healthcare behaviors, and disease propagation.

***Human Behavior and Interaction***

This program supports research from disciplines such as communication, health and behavioral science, industrial and organizational and social psychology, library and information science, management science, and sociology that use a social networks lens to focus on the ways people think and interact whereby creating higher-order systems. Topics of interest include social influence, leadership, trust, team science, cooperation and competition, crisis management, and mis/disinformation. Such social influence and opinion dynamics research could focus on the formation and dissolution of civic-minded and violent ideological networks, mobilization of benign to hostile political movements, propagation of and enduring changes in attitudes leading to populations reaching consensus or contested states, and network-based interventions. Of particular interest in research focused on the inflection point between cyberspace and physical domains to understand the interaction space between the two and work towards predictive models for when human behaviors are likely to move from one to the other.

***Information and Knowledge Management***

This program supports social network centric research to study the ways people learn individually and collectively and how they utilize that information for decision making and goal attainment. Examples of relevant topics include transactive memories, public goods, collective action, information sharing, information fidelity, diffusion and propagation dynamics, and collective decision-making. Diffusion dynamics research will develop mechanistic understanding of opinion and behavior change associated with influence, contagion, and other social propagation processes. Collective decision-making research will contribute fundamental theories and models to predict, evaluate and simulate how teams organize, exchange information, build knowledge, influence, adapt, learn, and build consensus using cooperative strategies and emergent capabilities. Furthermore, topics of particular interest include social effects of human-agent teaming, especially related to information processing, cognitive biases, and support of multi-team systems and multilevel (nested) systems.


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# Army Research Office (ARO) Research Topic

**Title:** Solid Mechanics
**Announcement ID:** ARL-BAA-0011

**TPOC:** Denise C Ford, PhD - denise.c.ford2.civ@army.mil - (919) 549-4244
**ARL Office:** Army Research Office (ARO)
**Discipline:** Biological Sciences;Computer Science;Data Sciences and Informatics;Earth and Environmental Sciences;Materials Science;Mathematics and Statistics;Mechanics;Physics
**ARL Foundational Research Competencies:** Mechanical Sciences;Network, Cyber, and Computational Sciences;Sciences of Extreme Materials;Terminal Effects
**Army Modernization Priorities:**
**Keywords:**

**Description:**
The Solid Mechanics Program supports investigations of the behavior of material systems under extreme high loading and loading rate events, such as impact and blast, repetitive loading, and temperature and pressure extremes. Development of new computational techniques and enhanced understanding of the physical processes taking place during deformation, damage initiation and propagation, and failure are sought.

Advances in computational techniques should aim to connect phenomena occurring at different spatial and/or temporal scales, substantially improve efficiency and/or accuracy of predictions, integrate new physical relationships, apply a novel approach to studying a physical process, or expand the range of conditions at which processes can be studied.

Studies of physical processes should seek to uncover relationships or mechanisms rather than design or optimize a material system for a specific purpose. Studies of all material types, including brittle, ductile, soft, and composite will be considered. Novel or nature-inspired compositions, geometries, and structures are particularly encouraged. Studies of biological tissues or tissue surrogates will also be considered, and studies of interfaces between tissues are particularly encouraged.

# Army Research Office (ARO) Research Topic

**Title:** Solid State Physics
**Announcement ID:** ARL-BAA-0029

**TPOC:** Mahesh R Neupane, PhD - mahesh.r.neupane.civ@army.mil - (301) 467-0782
**ARL Office:** Army Research Office (ARO)
**Discipline:** Materials Science;Physics
**ARL Foundational Research Competencies:** Electromagnetic Spectrum Sciences;Photonics, Electronics, and Quantum Sciences;Sciences of Extreme Materials
**Army Modernization Priorities:** Assured PNT;Network/C3I
**Keywords:** Solid-state physics; Crystal lattices; Correlated oxides

**Description:**
This program strives to drive research that looks beyond the current understanding of natural and designed condensed matter, to lay a foundation for revolutionary electronic device concepts for future generations of warfighters.

Strong Correlations and Novel Quantum Phases of Matter. Understanding, predicting, and experimentally demonstrating novel phases of matter in strongly correlated solid state materials will lay a foundation for new technology paradigms for applications ranging from information processing to sensing to novel functional materials. Interest primarily involves strong correlations of electrons, but those of other particles or excitations are not excluded. This thrust is currently emphasizing endeavors to determine if material properties can be significantly altered by dressing bosonic states within materials with engineered fluctuations of the vacuum.

Topologically Non-Trivial Phases in Condensed Matter. Topologically non-trivial states of matter in solid state materials beyond the quantum Hall phases have shown a remarkable opportunity to advance our understanding of physics and provide a foundation for novel device concepts. This thrust emphasizes the interaction between magnetic order and topological states. A deeper understanding of these interactions is necessary to determine if meaningful device concepts can be built upon them. The thrust is also broadly interested in the discovery and engineering of new non-trivial phases, verification of non-trivial topologies and phase transitions between trivial and non-trivial topological states.

Unique Instrumentation Development. Advanced studies of SSP phenomena often require unique experimental techniques with tools that are not readily available. The construction and demonstration of new methods for probing and controlling unique quantum phenomena in solid state materials is of particular interest.

# Army Research Office (ARO) Research Topic

**Title:** Support to ARL Foundation Research Competencies
**Announcement ID:** ARL-BAA-0070

**TPOC:** Unspecified TPOC - arl_baa@army.mil
**ARL Office:** Army Research Office (ARO)
**Discipline:** Biological Sciences;Chemistry;Computer Science;Data Sciences and Informatics;Earth and Environmental Sciences;Economics;Education;Electronics;Materials Science;Mathematics and Statistics;Mechanics;Network Science;Physics;Social Science
**ARL Foundational Research Competencies:** Biological and Biotechnology Sciences;Electromagnetic Spectrum Sciences;Energy Sciences;Humans in Complex Systems;Mechanical Sciences;Military Information Sciences;Network, Cyber, and Computational Sciences;Photonics, Electronics, and Quantum Sciences;Sciences of Extreme Materials;Terminal Effects;Weapons Sciences
**Army Modernization Priorities:**
**Keywords:**

**Description:**
Under this topic, ARL will consider whitepapers and proposals that may not directly align to the current research topics published by an ARL TPOC, but can demonstrate a strong alignment to ARL's mission. ARL's research mission is executed within identified foundational research competencies that provide the Army foundational expertise and specialized capabilities grounded in scientific excellence and driven by unique Army challenges. ARL is always interested in innovative research whitepapers and proposals that demonstrate a strong alignment to ARL's foundational research competencies and potential to create discovery, innovation, and transition of technologies for Army transformational overmatch. To learn more about ARL's foundational research competencies visit the ARL website at https://www.arl.army.mil/what-we-do/competencies/.

White papers and proposals submitted under the "'Support to ARL Foundation Research Competencies" topic must clearly describe the research and objectives and will be considered by ARL if it is aligned to one or more of these foundational research competencies that support the ARL mission. Applicants interested in submitting a white paper or proposal under this topic are strongly encouraged to first make preliminary inquiries as to the potential alignment to an ARL foundational research competency, funding availability for the type of research effort contemplated, and identification of an ARL TPOC to receive and review potential white papers or proposals.

# Army Research Office (ARO) Research Topic

**Title:** Synthesis and Processing of Materials
**Announcement ID:** ARL-BAA-0013

**TPOC:** Jacob Charles Marx, PhD - jacob.c.marx3.civ@army.mil
**ARL Office:** Army Research Office (ARO)
**Discipline:** Materials Science;Mechanics;Physics
**ARL Foundational Research Competencies:** Mechanical Sciences;Sciences of Extreme Materials;Terminal Effects;Weapons Sciences
**Army Modernization Priorities:** Next Generation Combat Vehicle;Soldier Lethality
**Keywords:** synthesis, processing, structural, materials, additive manufacturing, ceramics, metals, composites

**Description:**
The Synthesis and Processing of Materials program seeks to discover and illuminate the governing processing-microstructure-property relationships to enable optimal design and fabrication of nano or micro structural bulk structural materials. Structural materials refer to materials such as metals, ceramics, and composites that in bulk are used in applications that support or transmit mechanical stresses.
**Elucidation of Phase Transformations** supports research focused on understanding the mechanisms by which materials transition from one state of matter to another in order to enable the creation of new structural materials. Potential research directions include but are not limited to: discovering the kinetic mechanisms governing phase transformations and new means of manipulating them to encourage or impair phase transformations, defining the relationships between properties of the prior phase and the structural properties of the transformed phase, the creation of specific short-range orders in amorphous materials with unique mechanical characteristics, and new routes or methods for synthesizing structural material phases previously accessible only via extreme pressures or temperatures.
**Advanced Methods for Structural Materials Processing** supports research focused on developing alternatives to conventional methods for the synthesis and processing of structural materials. Potential research should involve exploring new means and forces in order to establish the technical foundation for new processing methods for structural materials, or further exploring the underlying mechanisms of existing advanced manufacturing methods to enhance their capabilities. Examples of directions to potentially be explored include but are not limited to: ultrasonic arrangement, plasma manipulation and interactions, biological and novel molecular precursors, and electromagnetic field interactions.


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# Army Research Office (ARO) Research Topic

**Title:** Wireless Communications Networks
**Announcement ID:** ARL-BAA-0015

**TPOC:** Robert Ulman, PhD - robert.j.ulman.civ@army.mil - (919) 549-4330
**ARL Office:** Army Research Office (ARO)
**Discipline:** Computer Science;Electronics;Network Science
**ARL Foundational Research Competencies:** Electromagnetic Spectrum Sciences;Military Information Sciences;Network, Cyber, and Computational Sciences
**Army Modernization Priorities:** Network/C3I
**Keywords:** wireless networks, ad hoc networks, Internet of things

**Description:**
This program is concerned with the investigation and advancing of network science applied to communication networks in wireless and tactical environments, focusing on DoD and Army unique problems. Of primary interest is research applicable to infrastructure-less multi-hop wireless networks operating in congested and contested spectrum. Also of interest is the analysis of mutual interaction among the communications, social, and information networks.

***Wireless Network Theory***
Research is required in the broad area of wireless network science including fundamental limits, performance characterization, novel architectures, and high-fidelity simulation of multi-hop wireless networks with mobility, node loss, natural and man-made impairments and unpredictable, bursty traffic. Novel analytical tools and simulation techniques may be necessary to allow for the modeling of very large networking scenarios without losing the fidelity at the physical layer, which is critical in millimeter wave networks.

Emerging communications network paradigms of Software Defined Networking (SDN) and Network Function Virtualization (NFV) are also of interest as applied to wireless and hybrid networks. Concepts from SDN/NVF could be adapted for wireless ad hoc networks, centralization is not desirable, but policy control and hierarchical control of semi-autonomous systems could adapt to disconnected and limited connectivity networks. NFV, facilitated by SDN, should adapt resources according to the needs and objectives of the users is desired. Extending concepts of NVF and adapting the network to the mission can be extended to distributed data caching and processing.

***Ad Hoc and Sensor Networks***
Networks serving Army need to operate in highly dynamic environments with limited or no infrastructure support. Available spectrum may be highly congested and contested, and mobile nodes may only have access to noisy local information with limited awareness of remote nodes in the network. Novel networking approaches may be needed to account for the lack of full network state information and reduce the penalty incurred due to coordination while sustaining acceptable performance. Networking algorithms may need to choose between various radio interfaces, such as traditional military bands, mm wave, and commercial (e.g., cellular) to based on throughput, reliability, and security trade-offs.

Adaptive and specialized machine learning techniques are needed for dynamic allocation of network resources based on operation needs, traffic characteristics, mobility, natural and man-made spectrum interference conditions, and security considerations. Networking and sensing architectures for cognitive mobile ad hoc networks needs to be developed with qualitative and quantitative performance measures, and the impacts of mobility, fading, and multi-user interference needs to be investigated.

Networking in combat operations may need to cope with the presence adversarial actions of various types, including strategically inserted spectral impediments. New signal processing, information theory, game theory and network science methodologies are needed to provide reliable and efficient communications in the presence of various adversarial actions. The analysis and characterization of fundamental tradeoffs among conflicting objectives such as Low Probability of Detection (LPD) vs. rate of communications vs. operating in a limited frequency spectrum are needed, along with novel techniques to achieve optimally located areas in the trade-off boundaries.

***Novel and Revolutionary Methods in Communications and Networking***

The synergy among social networking and communication networking, particularly in a tactical mobile ad-hoc scenario, is a research area that could advance the design of new communication approaches. There are many social networking aspects that are common to mobile ad-hoc networking needs such as distributed decision making, robustness, cooperation, self-organization, and cluster formation.

Novel physical and MAC layer techniques are required to improve LPI / LPD / AJ capabilities as well as throughput. Examples include mm wave and (sub) THz. bands, which have unique characteristics to overcome or exploit, such as directivity, large bandwidth, and limited range. With limited bandwidth, the co-existence and dual use of communication and sensing signals should be explored. In addition, exploration of quantum information processing, teleportation and networked quantum information theory is of interest.

# Available Army Research Directorate (ARD) Research Topics

The available Army Research Directorate (ARD) topics are listed in alphabetical order.

# Army Research Directorate (ARD) Research Topic

**Title:** Active and Passive RF Sensing
**Announcement ID:** ARL-BAA-0061

**TPOC:** Timothy J. Garner, PhD - timothy.j.garner.civ@army.mil - (301) 394-2705
**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Electronics
**ARL Foundational Research Competencies:** Electromagnetic Spectrum Sciences
**Army Modernization Priorities:** Air and Missile Defense;Future Vertical Lift
**Keywords:** radar, spectrum awareness, synthetic aperature radar

**Description:**
ARL seeks to create and experimentally demonstrate concepts, algorithms and enabling technologies that will provide the Army with new capabilities in sensing across the entire RF spectrum up through millimeter-wave and THz frequencies. Both active and passive RF sensing are used for targeting, detection & tracking of airborne and ground-based threats, surveillance, imaging and maneuver. Key attributes of Army RF sensors are the ability to operate in harsh environments and constraints on size, weight and power consumption.

Topics of interest include:

- Air defense radar
- Airborne radar
- Ground surveillance radar
- Multi-static radar v. Signal processing
- Spectrum awareness
- Waveform design
- Multi-function radar
- Synthetic aperture radar
- Passive imaging

# Army Research Directorate (ARD) Research Topic

**Title:** Advanced Manufacturing Research in support of the Sciences of Extreme Materials Competency
**Announcement ID:** ARL-BAA-0075

**TPOC:** Brandon A. McWilliams - brandon.a.mcwilliams.civ@army.mil - (410) 306-2237
**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Materials Science;Mechanics
**ARL Foundational Research Competencies:** Sciences of Extreme Materials
**Army Modernization Priorities:**
**Keywords:**

**Description:**
Army modernization requires a set of robust manufacturing strategies and integrated capabilities that enable a highly connected and collaborative enterprise. Agile manufacturing involves digitally enabled advanced manufacturing (AdvM) technologies with ubiquitous access to rapid prototyping, small-scale production, materials by design, etc. that are capable of scalable, and on-demand distributed production of components and systems. Agile manufacturing integrates the procedures, resources, and preparation that are needed to respond to changes in the demand utilizing systems, resources, and practice to react to these demands and adapt quickly without jeopardizing the Army's ability to meet the performance requirements.
This area seeks transformational materials that can operate in extreme conditions, and methods to manufacture them readily in the organic US industrial base as well as in austere environments at the point of need. Next generation Army components and systems will need to integrate novel structures of unmatched geometric complexity, and novel materials produced using novel data driven digital manufacturing methods. Topics of interest include:

- Additive manufacturing
- Artificial intelligence (AI) and machine learning (ML) techniques for AdvM
- Printed hybrid electronics including multi-functional devices and structures
- Novel and robust design methodologies for convergent manufacturing
- Integrated computational materials engineering (ICME) for development of novel feedstocks for metallic, ceramic, electronic, and polymer additive manufacturing
- Tools for path planning for multi-axis multi-material manufacturing
- Digital twin and data management for AdvM
- Sensor development and in-situ process monitoring
- Interface science for heterogeneous structures
- Manufacturing across multiple length scales
- Integrated manufacturing of dissimilar and gradient materials
- Materials, processing techniques, and algorithms for multiple integrated simultaneous manufacturing operations
- Tools for rapid qualification and certification of new materials and components

# Army Research Directorate (ARD) Research Topic

**Title:** Advanced Unmanned Aerial Systems (UAS) Technologies
**Announcement ID:** ARL-BAA-0100

**TPOC:** John W Gerdes - john.w.gerdes.civ@army.mil - (410) 278-8735
**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Computer Science;Mechanics;Physics
**ARL Foundational Research Competencies:** Weapons Sciences
**Army Modernization Priorities:**
**Keywords:**

**Description:**
Unmanned aerial systems (UAS) are uniquely suited to project capability forward due to small size, low cost, and the potential to overwhelm adversaries through swarming. Innovative capabilities are needed to advance the capability provided by UAS, split into two main focus areas: platforms and payloads.

Platform capabilities sought include adaptive structures and airframes that enhance range, endurance, agility, resilience, and covertness. Associated technologies related to propulsion systems and actuators that advance these objectives are sought, including bio-inspired technology as well as hybrid platform designs that blend vertical takeoff, efficient cruising flight, and aggressive maneuvers. Single and multi-agent autonomy, teaming, coordination, maneuvering, and control are required, including route planning, GPS-denied robust navigation, obstacle avoidance, swarm planning, and associated modeling and simulation strategies. Control systems are sought that handle hybrid UAS designs, provide damage tolerance, and translate high-level mission objectives into low-level control commands for single agents and swarm coordination.

Payload capabilities sought include sensing hardware advances that provide advantageous size, weight, and power tradeoffs in Army-relevant fields. These include external sensing modalities, including intelligence, surveillance, and reconnaissance (ISR); electro-optical and infrared (EO/IR); and acoustic. Intrinsic sensing capabilities are sought related to self and swarm-state awareness, including angle of attack and airspeed, relative and absolute positioning and timing, and data processing and fusion techniques.

Technologies relevant to both platform and payload capabilities are sought that reduce reliance on heavy computing resources, facilitate cross-coordination among agents of a swarm, and allow for graceful degradation of performance with variable or absent inter-agent communications. In-flight and post-flight data analysis, reduction, and processing techniques are sought including neural networks, artificial intelligence, and other relevant methods that improve sensor readings, state awareness, and swarm awareness.

# Army Research Directorate (ARD) Research Topic

**Title:** Advanced Vertical Takeoff and Landing (VTOL) Aircraft Technologies
**Announcement ID:** ARL-BAA-0099

**TPOC:** Hao Kang - hao.kang2.civ@army.mil - (410) 278-6811
**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Computer Science;Mechanics;Physics
**ARL Foundational Research Competencies:** Weapons Sciences
**Army Modernization Priorities:** Future Vertical Lift
**Keywords:**

**Description:**
Innovative technologies are needed to achieve higher vehicle speeds and hover efficiency, greater vehicle ranges, increased payload, and reduced maintenance to achieve performance attributes for future VTOL platforms. Analytical and experimental capabilities to support development of advanced numerical methods and computational codes for assessing design, aeroelastic, aeromechanical, and structural dynamics performance are of interest. ARL conducts foundational aeromechanics, control, and acoustics research to enable future Army rotorcraft with performance capabilities that are currently infeasible.
ARL seeks proposals to

- develop algorithms, methods, and analysis tools for aeromechanics predictions, performance assessment, acoustics, flight mechanics, and design space exploration of VTOL vehicles for sizes ranging from small unmanned aerial systems (UAS) to large vehicles. These algorithms and methods include, but are not limited to, physics-based modeling and simulation, high-fidelity modeling and analysis, reduced-order modeling and approaches, AI/ML-based algorithms, and optimization algorithms.

- develop new technologies to achieve revolutionary improvements in vehicle performance across different flight regimes. These technologies include, but are not limited to, active flow control, passive and active structural shape control, adaptive morphologies, and AI/ML for flight control and improved aeromechanical behaviors.

- explore innovative vehicle and reconfigurable concepts for large VTOL platforms and micro/small autonomous air vehicles. Develop design tools for innovative vehicle platforms and reconfigurable concepts.

Novel proposal concepts from structural dynamics, aerodynamic performance, coupled fluids/structures, nonlinear dynamics, theoretic perspectives, and flight control are relevant.


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# Army Research Directorate (ARD) Research Topic

**Title:** AI Model Optimization for Real-Time, Scalable Data Analytics
**Announcement ID:** ARL-BAA-0043

**TPOC:** Venkateswara Rao Dasari - venkateswara.r.dasari.civ@army.mil - (410) 278-2846
**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Computer Science;Data Sciences and Informatics;Mathematics and Statistics
**ARL Foundational Research Competencies:** Network, Cyber, and Computational Sciences
**Army Modernization Priorities:** Network/C3I
**Keywords:**

**Description:**
Rapid increases in the number of radically distinct Artificial Intelligence (AI) model architectures deployed in complex areas with variable resource constraints makes it substantially challenging to apply unified and automated optimization of these heterogeneous models. Topics of interest include development of novel computing methods and neural architecture search, development of comprehensive objective functions, optimization algorithms, abstractions to encapsulate heterogeneity needed to achieve optimization objectives across various model architectures and inference engines, as well as theoretical and experimental approaches in support of generalized AI model optimization. The sheer magnitude of the data generated by experiments and simulations performed necessitates highly efficient and optimized AI assisted intelligent methods of processing to make it actionable. Proposed AI optimization architectures should be tailored to enable real-time large scale data analytics that balance performance, efficiency, and scalability, accommodating different types of AI models, targeting computing platforms that may be subject to computational and network resource constraints. We are seeking proposals that explore new frontiers in computational optimization research addressing problems of Army interest. We also encourage submissions that investigate related fields that can lead to discoveries at the intersections of these domains.

# Army Research Directorate (ARD) Research Topic

**Title:** Artificial Intelligence and Machine Learning with Extremely Sparse Data
**Announcement ID:** ARL-BAA-0038

**TPOC:** Rajgopal Kannan - rajgopal.kannan.civ@army.mil - (225) 802-0880
**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Data Sciences and Informatics
**ARL Foundational Research Competencies:** Military Information Sciences
**Army Modernization Priorities:**
**Keywords:**

**Description:**
The Army has limited data to train or adapt AI&ML systems to dynamic and diverse operating environments. ARL seeks research to enable Army platforms, intelligence systems and command systems to learn, infer and provide meaningful predictions in circumstances characterized by extreme epistemic uncertainty. We expect that combinations of data-driven learning and domain-expert-elicited rules will ease the need for data, and that uncertainty-aware processing that considers both aleatoric and epistemic uncertainty over neuro-symbolic architectures will enlighten the limits of inference due to data-driven learning.

Potential research goals include: 1) theories for optimal learning and inference when supervised training data is limited, 2) computationally efficient approximations to optimal processing, 3) determination of state transitions when and when not more traditional AI&ML models are sufficient in light of task difficulty and availability of data, 4) techniques for efficient processing on edge computing devices, and 5) methods for distributed learning and inference that leverage graphical neural networks.


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# Army Research Directorate (ARD) Research Topic

**Title:** Artificial Intelligence and Machine Learning_Managing Massive Data Sets
**Announcement ID:** ARL-BAA-0039

**TPOC:** AI/ML Managing Massive Data Sets Topic - usarmy.adelphi.devcom-arl.list.baa-topics@army.mil
**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Data Sciences and Informatics
**ARL Foundational Research Competencies:** Military Information Sciences
**Army Modernization Priorities:** Network/C3I
**Keywords:**

**Description:**
The Government collects more data than it can meaningfully process, including image data, video data, structured data sets for a variety of combat and non-combat missions (e.g. health, maintenance, logistics, and operations), and various stove-piped, unstructured, massive data sets that exist primarily in the form of text documents. The scale of data collection challenges human driven solutions to management and processing. ARL is seeking research proposals that may increase the government's capacity to process data by assisting and augmenting analysts with artificial intelligence (AI) and machine learning (ML). Potential research areas include:

- Experimental investigation and development of data analytic prototypes.
- Technologies that help analysts perceive and understand dynamic and unknown environments.
- Comprehensive models of real-world environments in which AI/ML entities facilitate course of action development, using intuition and improvisation characteristics in real-time, dynamic scenarios.
- Frameworks and tools for the creation of algorithms.
- Tailored algorithms to perform discrete tasks, particularly in the fields of computer vision and language.
- Innovative AI/ML computational environments.
- Labeling techniques to generate massive scale annotated data for supervised deep learning.
- Methods for edge computation that enable use of deep learning algorithms in constrained computational environments.
- Methods to evaluate and determine effectiveness of algorithmic approaches.
- Interfaces for display of, search of, and interaction with algorithmically derived metadata and tabular structured algorithmic output.
- Techniques, hardware, software, and tools for training, testing, and validating algorithms.
- Storage and indexing capabilities for local algorithmically produced data.

# Army Research Directorate (ARD) Research Topic

**Title:** Artificial Intelligence and Machine Learning-Enabling Technologies for Expeditionary Maneuver and Air/Ground Reconnaissance
**Announcement ID:** ARL-BAA-0037

**TPOC:** Daniel N. Cassenti, PhD - daniel.n.cassenti.civ@army.mil - (301) 394-3726
**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Data Sciences and Informatics
**ARL Foundational Research Competencies:** Military Information Sciences
**Army Modernization Priorities:** Next Generation Combat Vehicle
**Keywords:**

**Description:**
The Army must compete with near-peer adversaries in a dynamic battlefield that will increase in complexity with the rise of artificial intelligence and machine learning (AI/ML). Mixed-entity battlefields will require understanding of the strengths and weaknesses of human and autonomous actors, information processors and decision makers. Two mission types have great significance for Army research in AI/ML: Expeditionary maneuver and air/ground reconnaissance. Expeditionary maneuver refers to missions that require strategic placement and movement of Warfighters and their assets in a battlefield to gain overmatch versus adversaries. Air/ground reconnaissance refers to missions to obtain information about environmental threats and adversary activity from manned and autonomous sensor platforms on the ground and in the air. Optimal performance of these missions will require improvements in autonomous agents, sensors, and edge computing.

ARL seeks research proposals that advance the state-of-the-art in enabling technologies for expeditionary maneuver and ground reconnaissance, including: (1) scene understanding for adversarial threats, degraded visual environments, and tracking of moving objects; (2) robotic movement over rugged terrain with limited human engagement and correction; (3) secure and informative data sharing among multiple autonomous systems and human collaborators; (4) data processing algorithms to provide information to human decision-makers in ways that support the human's cognitive processing needs; and (5) expansion of a repository of proven AI/ML algorithms, data, and software. Examples of research products of interest to the Army include new robotic movement capabilities, cognitive modeling integration with AI processes, advances in cyber-security for autonomous agents, AI simulation processes, advanced sensing in degraded visual environments, improved object recognition, and advanced machine learning techniques.

# Army Research Directorate (ARD) Research Topic

**Title:** Autonomous Sensing and Information Fusion for Advanced Indications and Warnings
**Announcement ID:** ARL-BAA-0064

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**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Computer Science;Data Sciences and Informatics;Network Science
**ARL Foundational Research Competencies:** Photonics, Electronics, and Quantum Sciences
**Army Modernization Priorities:** Future Vertical Lift
**Keywords:** Autonomous Sensing, Information fusion, geophysical sensors, sensors on small UAS, networked sensors

**Description:**
This research effort will focus on developing and enhancing traditional and non-traditional sensing technologies for robust detection and exploitation of unique objects of predominately military interest, including targeting sensors. Fusion of multiple information sources; including unattended ground sensors, and relocatable unattended sensors, typified by small autonomous ground and air platforms, is essential - and much of the program will be focused on foundational work aimed at facilitating the correlation and reporting of relevant information between all sensing sources. The research also investigates end-to-end autonomy solutions enabling remote delivery of loosely integrated ground and relocatable sensors that operate cooperatively to detect, track, and identify targets. Fundamental research in the physical phenomenology of both traditional geo-physical modalities and imaging modalities as well as non-traditional modalities that will lead to improvements in persistent sensing applications involving unique detection, processing, exploitation, and novel reporting capabilities across diverse environments and meteorological conditions for low power, long mission life applications.

# Army Research Directorate (ARD) Research Topic

**Title:** Ballistic Science Research
**Announcement ID:** ARL-BAA-0097

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**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Materials Science;Mechanics
**ARL Foundational Research Competencies:** Terminal Effects
**Army Modernization Priorities:** Next Generation Combat Vehicle;Soldier Lethality
**Keywords:**

**Description:**
ARL seeks proposals to enhance the understanding and characterization of material behavior and failure during projectile target interactions at ballistic impact speeds.
Specific research areas include:

- Directed-energy means and effects.
- Laser studies and concepts associated with ballistics.
- Fundamental and applied physics research associated with ballistic impact, survivability, and protection.
- Electromagnetisms and concepts associated with ballistics.
- Plate- impact and Split-Hopkinson Bar (SHB) experiments for materials relevant to ballistic weapons and armors.
- Materials science research associated with improved ballistic performance.
- Molecular, meso-scale, multi-scale, and level modeling capability development, including material models, failure models, and analytical models associated with ballistic impact and penetration and effectiveness.
- Experimental techniques and diagnostics associated with ballistic research.
- Novel manufacturing and processing techniques are of interest, provided that the work will involve high strain rate relevant research scope.

# Army Research Directorate (ARD) Research Topic

**Title:** Computational Modeling of Aviation Systems
**Announcement ID:** ARL-BAA-0101

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**Discipline:** Computer Science;Mechanics;Physics
**ARL Foundational Research Competencies:** Weapons Sciences
**Army Modernization Priorities:**
**Keywords:**

**Description:**
Next-generation Army aviation platforms will need to integrate novel technologies in multiple areas including aerodynamics, acoustics, structural dynamics, and flight controls. These technologies will be evaluated in computational and experimental environments for real-world applications. Fundamental modeling and analysis capabilities also need to be developed at different degrees of fidelity from low fidelity for conceptual design and trade-space exploration to high fidelity for detailed design or scientific exploration.

Novel technologies for next-generation Army aviation platforms are sought, including both manned platforms and unmanned aerial systems (UAS). Associated modeling and simulation approaches for these technologies will be required at varying degrees of fidelity to accommodate assessments at different stages of design and analysis processes including conceptual, preliminary, and detailed design stages. Topics of interest include:

- Aerodynamics, acoustics, structural dynamics, and flight controls, including component designs or concepts and software or algorithms for computational modeling of those technology areas.
- Both physics-based and data-driven techniques for modeling and simulation
- Design methodologies for these new technologies
- Methods to incorporate complex physics such as interactional aerodynamics or electric powertrain models at a low computational cost suitable for conceptual or preliminary design.

# Army Research Directorate (ARD) Research Topic

**Title:** Computational Modeling of Complex Physical Systems
**Announcement ID:** ARL-BAA-0041

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**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Chemistry;Computer Science;Electronics;Materials Science;Mathematics and Statistics;Physics
**ARL Foundational Research Competencies:** Network, Cyber, and Computational Sciences
**Army Modernization Priorities:** Network/C3I;Next Generation Combat Vehicle
**Keywords:**

**Description:**
Concentrates on the fundamental aspects of computational science (CS) to enable multi-disciplinary and multi-scale modeling and simulation (M&S) to predict, quantify, assess, and optimize the performance and response of complex system and system of systems, enabling rapid design, development, and transition particularly in cases where laboratory experimental approaches are costly and difficult to conduct, and/or are not feasible. Proposals are requested for the following areas:

***Computational Mathematics and Algorithms***
Research encompasses a range of disciplines seeking new computational methodologies to solve fundamental equations. Solutions may be sought for existing equations or new equations may be developed expressly for the purpose of treating problems of Army relevance. Problems in which the equations can be expressed in the form of partial differential equations may stem from the basic science and engineering disciplines spanning characteristic length scales from sub-atomic to continuum, neural signals, stochastic variables, and design theory. Broad classes of problems may also require considerable specialization of solutions based on the platform used to obtain them.

***Uncertainty Quantification (UQ)***
Research is focused on assessing predictive capabilities of models, considering the range of conditions where models reproduce observed behavior within acceptable tolerances and establishing confidence levels. UQ research is concerned with novel and efficient concepts and methodologies for high-fidelity assessment of the level of agreement in sets of models relative to input and output data, as well as the variations in interdependent models due to various physics, mathematical, and numerical assumptions. UQ methodologies, integrated with data sciences and machine learning will enable tools for (i) identifying deficiencies in simulations; (ii) setting guidelines for adequacy of computational results; (iii) exploring the impact of known variability and uncertainty of input; and (iv) control of adaptive algorithms to achieve specified levels of accuracy to aid decisions from design to operational planning.

***Multi-scale Modeling***
Research focuses on the development of models of complex physical systems in order to significantly reduce development time and evaluation costs of these systems. This goal can be through development of 1) high-fidelity at-scale models and 2) computational methodologies

(numerical methods and associated algorithms) to enable rapid creation of new high-fidelity multi-scale models of complex systems from at-scale models capable of utilizing modern extreme-scale computing. The success of multi-scale modeling hinges on the ability to combine at-scale models into a multi-scale model. However, few numerical methodologies and associated algorithms have been developed so far to enable such scale-bridging. Moreover, many at-scale models are extremely demanding computationally and render any multi-scale model utilizing them unsuitable for practical applications. While surrogate modeling allows reduction of this computational cost, most methodologies for surrogate modeling are global and thus characterized by a relatively high cost. New adaptive non-local surrogate modeling methodologies are needed, which can bring the computational cost to tractable levels. Finally, at-scale models are frequently endowed with uncertainty due to various sources such as natural fluctuations, model parameters or model form. This uncertainty and natural variability must be consistently incorporated into multi-scale computer models to enable computational design.

***Machine Learning for Complex Physical Systems***
Many Army activities rely on the use of computer models to facilitate making purposeful decisions. These models often aim to capture behavior of physical systems with many degrees of freedom, complex dynamics and short time scales. Because of that, existing models often struggle to adequately span the problem space and cannot be effectively employed to optimize these Army systems for desired performance. The advent of data science and machine learning has opened for avenues for improved computer models of physical systems. Yet, direct applications of existing machine learning techniques to model physical systems are fraught with challenges. First and foremost, success of machine learning hinges on availability of vast amounts of data. In contrast, for many physical systems data are rarely obtainable in vast amounts due to high cost of acquisition and/or experimentation. In addition, the behavior of physical systems is customarily governed by well-established laws, for example conservation of mass and energy. Consequently, machine-learning models of physical systems must strictly obey these laws. Finally, for many physical systems under certain regimes, experimentation is not technically possible or prohibitively costly. In these circumstances, models of physical systems serve to extrapolate the description of system response outside of regimes where the experimentation is feasible. Current machine-learning approaches are known to perform poorly under extrapolation. Hence, novel approaches in machine learning are urgently needed to allow for construction of high-fidelity and predictive models of physical systems.

# Army Research Directorate (ARD) Research Topic

**Title:** Cyber Security
**Announcement ID:** ARL-BAA-0044

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**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Computer Science;Network Science
**ARL Foundational Research Competencies:** Network, Cyber, and Computational Sciences
**Army Modernization Priorities:** Network/C3I;Next Generation Combat Vehicle
**Keywords:**

**Description:**
The ARL Network Cyber and Computational Sciences foundational research competency of cyber-defense/cyber-security addresses the prevention, detection, mitigation, monitoring, and prediction of adversarial activities and their impacts within cyber space. The scope includes traditional enterprise level and tactical information networks as well as non-traditional networks such as communication buses found on vehicle platforms. This research effort will focus on developing the theories, understanding, models and methods to overcome existing barriers to the realization of effective cyber security defenses and maneuvers against adaptive and sophisticated adversaries in complex, uncertain and dynamic settings.

The goals of this work are:

- Pursue near-autonomous, rapid, resource-efficient monitoring, detection and identification of malicious cyber activity directed at friendly networks, data, machine learning algorithms and/or vehicle platform systems.
- Advance the predictive characterization of information networks and/or vehicle platform systems states, resilience and vulnerabilities to cyber-attacks and adversarial manipulation.
- Pursue methodologies for the reliable reconfiguration of friendly cyber assets to evade or recover from attack, to validate system resilience, and enable continued operations and mission success.
- Advance methods to rapidly and efficiently prepare and respond to adversarial activities in the cyber domain, including:
    - Intelligent preparation of the cyber battlespace and cyber situational awareness
    - Proactive and reactive cyber deception and counter-deception strategies
    - Covert means for collection of evidence and predictive analysis of enemy actions and capabilities
    - Countering the evasion and manipulation of machine learning algorithms
    - Building cyber resilience
- Pursue methodologies to deceive, degrade or destroy adversarial cyber assets with high certainty.

# Army Research Directorate (ARD) Research Topic

**Title:** Disruptive Energetic Materials and Concepts
**Announcement ID:** ARL-BAA-0066

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**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Chemistry;Materials Science;Physics
**ARL Foundational Research Competencies:** Weapons Sciences
**Army Modernization Priorities:** Air and Missile Defense;Long Range Precision Fires;Next Generation Combat Vehicle;Soldier Lethality
**Keywords:** energetic materials, explosives, propulsion, propellants, modeling, experimentation, synthesis, multiscale, range, lethality, reactive materials

**Description:**
Improved models, concepts, diagnostics and new energetic materials for propulsion and explosives are expected to provide enhanced lethality and range, speed of engagement, and maneuverability while maintaining weapons safety and surety. Additionally, game-changing energetic concepts with greater than state-of-the-art potential than previous energetics are being pursued and are expected to enable new approaches to lethality and range, particularly when partnered with emerging accuracy and precision advances.

These efforts will focus on the exploration and maturation of novel energetic materials and concepts for explosive and propulsive applications which are expected to provide revolutionary performance capabilities that are unachievable today. Research in this area seeks to synthesize high energy density materials with desired physical properties, scale-up techniques, novel manufacturing and processing techniques, understand and control energy release on desired timescales, novel diagnostic techniques capturing relevant chemistry and physics, advanced modeling and simulation of multiscale behavior, novel concepts maximizing work performed and minimizing losses, and predictive tools guiding performance, synthesis, and processing directions.

# Army Research Directorate (ARD) Research Topic

**Title:** Electric- and Magnetic-Field Sensor Technology
**Announcement ID:** ARL-BAA-0076

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**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Electronics;Physics
**ARL Foundational Research Competencies:** Electromagnetic Spectrum Sciences
**Army Modernization Priorities:**
**Keywords:**

**Description:**
Research proposals are desired that are related to small, rugged, low-power electric- and magnetic-field sensors that can be deployed on a battlefield using artillery-based delivery systems, or scattered from air or ground vehicles, or emplaced by individual soldiers. These sensors should be passive or semi-active (i.e., with no local field-generating element), and may operate at low frequencies in the quasi-static zone (or "near field"), where the electric and magnetic fields are not coupled. These sensors should be characterized by exceptionally low power, size, weight, and cost, and/or by exceptionally high sensitivity and low noise (i.e., with performance limited by the background environment). Sensor bandwidth generally falls between DC and ~1 MHz, but may be further limited for specific applications: e.g., 0.001-10 Hz for anomaly detection; 30-3000 Hz for electric-power sensing; 3-30 kHz for very low frequency (VLF) sensing.

Sensors should operate in an unattended mode, and should be able to detect, classify, identify, localize, and/or track tactically-significant targets, including ground vehicles (tanks and other tracked vehicles, and wheeled vehicles), air vehicles (fixed-wing, rotary-wing, unmanned aerial vehicles (UAV) / manned aerial vehicles (MAV), etc.), and/or other targets and events at tactically-useful distances. These other targets include, but are not limited to, armed individual soldiers, underground facilities, power and telephone lines, RF transmitters; other events including gunshots, mortar and artillery launches, and explosions.

These sensors may be used individually or as part of a wide-area sensor array for surveillance, target acquisition, and/or engagement. While individual sensors may or may not have exceptional individual performance, their low size, power, weight, and cost should permit them to be used on the battlefield in ways not previously contemplated. Moreover, arrays and/or networks of such sensors are expected to provide new sensing capabilities and levels of performance simply not available today.

Unattended surveillance sensors may be stationary or mounted on robotic platforms; these sensors will be integrated with local and networked signal processing and communications capabilities. They should operate unattended for weeks or months after deployment, and indefinitely with energy harvesting. The sensor output should be quantitative: e.g., analog voltage level(s) or digital word(s); it should contain target information, and possibly a confidence level, suitable for low-bandwidth transmission and/or inter-sensor fusion.

**Proposals will be accepted in six areas:**
i. Research on novel electric- and magnetic-field sensor concepts leading to quantification of detection distance(s), classification, identification, localization, and/or tracking of various classes of targets. High-performance, low-SWaP-C sensors should have exceptional sensitivity (limited by environmental noise), frequency and phase response, dynamic range (60 to 120+ dB), linearity, total harmonic distortion, hysteresis, cross-axis sensitivity, cross-modality sensitivity, etc. Arrays of sensors should be characterized by exceptional performance matching.

ii. Research directed at environmental and/or platform noise reduction, and/or reduction of sensor front-end noise (particularly 1/f noise).

iii. Research related to filtering and/or signal processing techniques, which are expected to improve the detectability of targets in a battlefield environment. Array processing, in-situ "imaging", and multi-modal processing are of particular interest. Processing should be resilient with performance that gracefully degrades in the presence of intermittent power, intermittent and/or unreliable networking, information assurance attacks, memory failures, and cosmic rays, etc.

iv. Computer-based modeling of targets and sensors that can provide a capability to perform trade-off analyses of sensor performance during prototype design.

v. Algorithms that can provide improved detection, classification, and/or identification of targets of interest in real-world environments. Proposed algorithms should be low-SWaP-C, portable to the Internet of Battlefield Things (IoBT), and usable in tactical networks.

vi. Research related to the novel application of electric- and magnetic-field sensors to analyze electric power system operation, including islanded microgrids and large fixed grids.


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# Army Research Directorate (ARD) Research Topic

**Title:** Electromechanical and magnetomechanical power conversion (INACTIVE)
**Announcement ID:** ARL-BAA-0058

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**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Electronics
**ARL Foundational Research Competencies:** Energy Sciences
**Army Modernization Priorities:** Future Vertical Lift;Next Generation Combat Vehicle
**Keywords:**

**Description:**
This research topic has 4 thrust areas:

1. High-torque-density and/or high-power-density electric machines with high efficiency.

2. Novel designs for higher-reliability electromechanical power conversion components, including magnetic bearings and magnetic gearboxes.

3. High-torque-density, high-efficiency noncontact magnetic gear boxes or magnetically geared machines, including designs for propulsion and actuation applications.

4. Novel magnetic, electrical, thermal, and/or structural materials for use in electric machines, magnetic gears, and transformers, including multifunctional materials and alternatives to rare-earth materials.

# Army Research Directorate (ARD) Research Topic

**Title:** Energy Awareness
**Announcement ID:** ARL-BAA-0056

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**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Data Sciences and Informatics;Electronics
**ARL Foundational Research Competencies:** Energy Sciences
**Army Modernization Priorities:** Future Vertical Lift;Next Generation Combat Vehicle
**Keywords:** energy sensing, energy optimization, energy forecasting

**Description:**
**Technologies providing energy sensors and virtual sensing techniques, at the component, system and platform level.** Primary interest areas are sensors to collect energy flow and use information; and virtual techniques to generate data on energy when direct sensing is not available or practical.

**Advanced cognitive techniques for real time adaptive prediction and optimization for real time energy awareness.** Primary interest areas are technologies to enable machine-based decision making for energy management that utilize heuristics and cognitive techniques. A key goal is to provide learned behavior with input from external sources such as operational data, weather, maintenance, and other factors.

# Army Research Directorate (ARD) Research Topic

**Title:** Environmental Security for Multi-Echelon Decision Making -Assessing and Mitigating Climate Risk
**Announcement ID:** ARL-BAA-0040

**TPOC:** Robb M. Randall, PhD - robb.m.randall.civ@army.mil - (575) 678-3123
**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Earth and Environmental Sciences
**ARL Foundational Research Competencies:** Military Information Sciences
**Army Modernization Priorities:**
**Keywords:**

**Description:**
ARL seeks proposals for basic and applied research that advances our understanding of environmental effects on DoD assets and operations within climatological time frames, to include dynamics and changes in the dynamics of the atmospheric boundary layer in complex environments (including high-relief and dense urban terrain) with emphasis on the atmospheric surface layer and the land-surface processes that effect the environmental state. Research work products should enable technologies for mission command decision support, interoperability of distributed networked systems, and mission planning.

# Army Research Directorate (ARD) Research Topic

**Title:** Estimating and Predicting Human Behavior
**Announcement ID:** ARL-BAA-0050

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**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Biological Sciences;Computer Science;Data Sciences and Informatics;Social Science
**ARL Foundational Research Competencies:** Humans in Complex Systems
**Army Modernization Priorities:** Future Vertical Lift;Network/C3I;Next Generation Combat Vehicle;Soldier Lethality;Synthetic Training Environment
**Keywords:** Human Variability, Human State Estimation, Human Performance, Human-Machine Teaming, Opportunistic Sensing

**Description:**
***Summary***
Within complex systems, human behavior and skills tends to be highly variable. This variability in behavior presents challenges for developing techniques for intelligently selecting the right person for the right job and providing intelligent agents the capability to understand their human teammates. In addition to these challenges, variability in human behavior also provides potential information regarding the local context. To address these challenges and capitalize on this potential information source, this research area focuses on developing novel approaches to estimate and predict human states (e.g stress, fatigue, task difficulty, intent) to enable technology adaptation and inference of the environmental context and to estimate and predict human knowledge, skills, and behaviors in order to forecast an individual's capability to effectively interact with intelligent systems.

***Background***
The research goals for estimating and predicting human behavior are to integrate empirical and theoretical efforts to generate novel concepts and approaches to generate high-resolution predictions of individual Soldier's performance variability in mixed human-agent teams across multiple time scales. In turn, these concepts and approaches will provide the foundation for future Army systems and processes to adapt to the individual Soldier's states, traits, behaviors, and intentions. Likewise, this will enable identification of the best Soldiers for specific roles and provide those Soldier the most favorable conditions to train, engage in operations, and team with intelligent systems and personnel from the U.S. and partner nations.
This research will provide the techniques to generate high resolution, multi-time scale, predictions of individual Soldier's internal and external behavioral and performance dynamics in mixed-agent team and across training and operational socio-technical environments. Critical breakthroughs are needed in two specific areas: (i) creating multi-faceted models to generate high resolution, moment-to-moment prediction of individual human state based on multi-modal, multi-time scale data with sufficient resolution to enable technology adaptation; (ii) developing models to predict an individual's technology fluency, defined as the ability to effectively interact with dynamic, adaptable, intelligent systems in future operating environments; and (iii) creating models to leverage information from human behavior and actions to make inferences about the environment or situation that they are operating within.

***Specific Questions of Interest***

- How do multi-timescale human processes influence individual's moment-to-moment capabilities, behaviors, and performance?
- What are the multi-disciplinary foundational theories and models required to understand individual dynamics and emergent team behavior in heterogeneous human-agent teams?
- Can models of individual and/or team technological fluency be developed that effectively predict performance?
- What are the knowledge, skills, and behaviors that enable specific individuals to be more technologically fluent (the ability to use and rapidly adapt novel and intelligent technologies without formal training on specific technologies) than others?
- What are the critical team factors (e.g., composition, interactions, shared situational awareness) that enable sufficient technological fluency to effectively adapt significant shifts in technological intelligence and behavior?
- Can human cognition be predicted in complex socio-technical setting and on a moment-to-moment basis with sufficient resolution to provide disruptive military relevant information?
- How can we use current and next-gen human sensing technologies to provide context and insight (i.e. via access to human cognition) into how individuals and teams understand complex real-world environments?

# Army Research Directorate (ARD) Research Topic

**Title:** Heat Transfer and Thermal Management
**Announcement ID:** ARL-BAA-0059

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**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Electronics
**ARL Foundational Research Competencies:** Energy Sciences
**Army Modernization Priorities:** Air and Missile Defense;Future Vertical Lift;Next Generation Combat Vehicle
**Keywords:**

**Description:**
This research topic has two thrust areas:

1. Materials, packaging, passive/active cooling techniques for thermal transfer and storage.
2. Fundamental thermal transport, switching, tunability, and phenomenon in nano/micro/macro-scales for enabling steady-state and fast-transient pulse power, switching, personnel, and environmental cooling modalities

# Army Research Directorate (ARD) Research Topic

**Title:** High Voltage/High Frequency Power Switching Devices
**Announcement ID:** ARL-BAA-0060

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**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Electronics
**ARL Foundational Research Competencies:** Electromagnetic Spectrum Sciences;Energy Sciences
**Army Modernization Priorities:** Air and Missile Defense;Future Vertical Lift;Next Generation Combat Vehicle
**Keywords:** HV semiconductors, power switches

**Description:**
Research into semiconductor power devices in the following three thrust areas:

1. Device design and fabrication of monolithic and hybrid voltage-controlled SiC or GaN high-temperature high-field power devices.
2. High-temperature high-field insulator materials for use as gate dielectric and field passivation layers for application to SiC and/or GaN power devices.
3. Advanced Technology Computer-Aided Design (TCAD) modeling methods, techniques and/or material models that advance computational efficiency or accuracy.

# Army Research Directorate (ARD) Research Topic

**Title:** Human-Guided System Adaptation
**Announcement ID:** ARL-BAA-0047

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**Discipline:** Biological Sciences;Computer Science;Data Sciences and Informatics;Network Science;Social Science
**ARL Foundational Research Competencies:** Humans in Complex Systems
**Army Modernization Priorities:** Future Vertical Lift;Network/C3I;Next Generation Combat Vehicle;Soldier Lethality;Synthetic Training Environment
**Keywords:** Interactive Machine Learning; Human-in-the-Loop Learning; Adaptation; Human-guided Machine Learning; Reinforcement Learning; Intelligent Technology; Imitation Learning; Training; Human Feedback

**Description:**
***Summary***
The rising capability to rapidly field blue and red force technologies, as well as the proliferation of Artificial Intelligence (AI) into the civilian environment, will force future Soldier-systems to have the capability to rapidly adapt. This research topic seeks novel methodologies to enable humans to efficiently guide the adaptation of blue force technologies through multiple forms of human interaction to develop new or upgraded human-system team capabilities.

***Background***
Human-guided system adaptation aims to integrate empirical and theoretical efforts to generate novel concepts and approaches for humans to influence and guide the evolving behavior of intelligent technologies for the purposes of effectively solving complex problems under variable resource and time constraints. We generally characterize the complex problems as more ambiguously structured with uncertain boundaries (if any) across time and space. Such complex problems are computationally intractable for common analytic solutions due to massive and perhaps unattainable data requirements to obtain complete certainty. These problems may not have singularly optimal solutions, because problems will often have multiple, competing criteria and all solutions will ultimately reflect trade-offs and reduction of optimality in meeting other criteria in the set.

Contextualized within the concept of enhancing adaptive human-autonomy teamwork, this topic specifically seeks to (i) discover a novel suite of mechanisms to extract human intelligence that ensures Soldiers in the field can efficiently train and adapt intelligent technologies; and (ii) elucidate principles of effective, stable mutual adaptation between humans and intelligent systems that improve performance in complex, dynamic environments. If successful, the science is envisioned to enable in-field human-machine adaptation capable of responding to novel mission demands, enemy actions, and technological surprise across a wide range of operational environments for all US Army Modernization areas.

***Specific Questions of Interest***

- How can human knowledge be leveraged to enable system adaptation in highly uncertain and poorly understood environments? How do you transfer knowledge of how to do a task from the Soldier to an intelligent technology in a way that requires little to no expert knowledge (i.e., without programming skills)? Can you create a suite of knowledge transfer mechanisms that in combination allow machine learning (ML) to infer intent under different environments and mission constraints?
- Can hierarchical reinforcement learning be extended to dynamic, partially-observed environments for both improved multi-task generalization and enhanced human interpretability and compatibility with human-in-the-loop feedback?
- Can behavior cloning, intervention learning, learning from human preferences, and learning from evaluative feedback be combined into a single learning framework with reinforcement learning to enable continuous adaptation and training of intelligent agents?
- How do you ensure long-term stability when allowing groups of people to train ML? How do you allow ML systems to be adaptable by multiple humans and when should that adaption occur?
- Can crowd-sourcing techniques be used to provide reward shaping and evaluative human feedback to rapidly train autonomous agents? What are the best methods and approaches to elicit the notion of "'functional equivalence" from crowd workers?


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# Army Research Directorate (ARD) Research Topic

**Title:** Human-System Team Interactions
**Announcement ID:** ARL-BAA-0046

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**Discipline:** Biological Sciences;Computer Science;Data Sciences and Informatics;Network Science;Social Science
**ARL Foundational Research Competencies:** Humans in Complex Systems
**Army Modernization Priorities:** Future Vertical Lift;Network/C3I;Next Generation Combat Vehicle;Soldier Lethality;Synthetic Training Environment
**Keywords:** Human-Machine Teaming; Human-Autonomy Teaming; HAT; Human Robot Interaction; Man-machine interface

**Description:**
***Summary***
A critical challenge facing the deployment of human-system teams is developing the necessary principles to enable dynamic interaction of Soldiers and advanced intelligent systems to effectively collaborate on complex tasks. This research area focuses on developing: a theoretical understanding of emergent team properties, techniques to link variability in individual agent performance to changes in overall team performance, approaches to develop and maintain a shared situation understanding, methods to dynamically allocate tasks across Soldiers and intelligent systems in complex adversarial environments. These team-level interactions must be developed to account for degradation or loss of team capabilities, changes in mission goals or priorities, and responding to adversarial actions.

***Background***
The research goals in human-system team interaction are to integrate empirical and theoretical efforts to generate novel concepts and approaches for future Army multi-, mixed-agent teams across distributed network systems. These technologies must effectively merge human and agent capabilities for collaborative decision-making and enhanced team performance; ensure that diverse teams of Soldiers comprehend new and critical information to maintain unprecedented situation awareness; and interact effectively with Soldiers and noncombatants to foster trust and gain community acceptance within complex, dynamic, environments. These heterogenous multi-agent networked teams will enable faster and better-informed decisions; reduce Soldier workload; provide otherwise unachievable levels of situation understanding and management; and maintain strategic and tactical advantages in future operating environments.

The objective of this research is to provide the critical technological breakthroughs needed to shape current and future operational environments consisting of Soldiers and heterogenous intelligent systems operating in distributed teams to: (i) rapidly comprehend new and critical information from a diverse set of battlefield sensors to achieve unprecedented situational awareness (ii) effectively enable collaborative decision-making and enhanced team performance in dynamic, and complex socio-technical environments; (iii) effectively coordinate distributed human-system behaviors to enable actions on an objective; and (iv) rapidly adapt team behaviors to dynamic battlefield events or unexpected threats across a wide range of operational environments for all U.S. Army Modernization areas.

***Specific Questions of Interest***

- What are the general principles that underlie the capability for human-technology teams to perform any mission, adapt to any situation, and overcome any adversary? How do these principles change as machine intelligence evolves?
- Can we discover novel theories, algorithms, methods modulating individual human-technology interaction that dramatically improve human-technology robustness in the presence of complex, real-world environment-task-technology novelty?
- Can we predict and optimize mixed teams of humans and agents across a wide spectrum of real world and future battlefield conditions?
- What novel and advanced methods are critical to enable rapid team reconfiguration, in mixed teams of humans and agents, in rapidly changing socio-technical environments?

# Army Research Directorate (ARD) Research Topic

**Title:** Hybrid Human-Technology Intelligence
**Announcement ID:** ARL-BAA-0049

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**Discipline:** Biological Sciences;Computer Science;Data Sciences and Informatics;Network Science;Social Science
**ARL Foundational Research Competencies:** Humans in Complex Systems
**Army Modernization Priorities:** Future Vertical Lift;Network/C3I;Next Generation Combat Vehicle;Soldier Lethality;Synthetic Training Environment
**Keywords:** Cognition; Intelligence; Command and Control; Decision Making; Adaptation; Ideation

**Description:**
***Summary***
Future operational environments will require faster than human decision-making within increasingly complex, dynamic and rapidly evolving sociotechnical environments to ensure a technological advantage over adversarial forces; current human-technology systems do not take full advantage of the unique capabilities of both human and machine intelligence. This research topic seeks anti-disciplinary research aimed at reconceiving human brain processes to optimize how humans and machines could jointly think (ideation, decision making, adaptation) to influence decisions and actions previously believed to be outside of human capabilities alone.

***Background***
Futurists envision seamless integration of humans with technology not only in the future battlefield of the US Army but also in our everyday lives. This concept extends to teams as it is well-documented that (i) intricate tasks are routinely implemented in multi-team and (ii) modern technology has infiltrated nearly every facet of the human experience. This future vision of the world, coupled with the prioritization of complex multi-domain (e.g., ground, air, cyber) operations creates substantial challenges to the US Army to maintain overmatch at the intersection of humans and technology. Briefly, these challenges span temporal and spatial scales and operate at several levels of complexity. Human-technology teams are expected to operate independently but coordinated with geographically distributed operations, accommodate incredibly rapid incoming complex information from distributed sources, and adapt to needs of different command echelons. With these challenges and needs we must consider human-technology hybrid systems that operate symbiotically to accomplish mission goals, account for the emergent hybridized cognitive capabilities of the system and reconceive human brain processes to optimize human-technology hybrid thinking, perhaps creating new forms of intelligence that transcends humans' current level of complexity.

This topic seeks to merge scientific advancements from human-guided machine learning (e.g., instantaneous crowdsourcing; interactive machine learning) with advancements from neuroscience (e.g., neuroprosthetics; neurostimulation) and/or team science and training (e.g., technology-enhanced human teaming; training for rapid human adaptation) to reimagine the how thoughts are processed in hybrid human-technology systems. If successful, the science is envisioned to allow for 10-1000x faster decision making, exponentially increase decision complexity, and open new opportunities for idea generation, which fundamentally can change how the US Army operates in including but not limited to command and control.

***Specific Questions of Interest***

- What brain processes may be hybridized for optimal, faster than human decision making? What is the limit to the scale of hybridization, in systems, agents, and groups? What new cognitive elements will arise after hybridizing uniquely human characteristics?
- Can agents (i.e., intelligent technologies) integrated with human teams generate novel ideas faster and more effectively than agents or teams alone? Can hybrid teams converge information into more effective decisions? Can neurostimulation paired with agents rapidly promote shared understanding and divergent thinking? Can humans' innate ability to adapt be made faster and extended to radically different forms of thinking (merged human-agent thinking)?
- Can humans be integrated with intelligent command and control (C2) agents to adapt C2 plans to live, incomplete and potentially erroneous data streams in real time to overcome semi-predictable and unforeseen events? Can intelligent C2 agent policies be effectively translated for humans to understand and interpret under stressful and time constrained conditions? Can a flexible, multi-faceted approach to human-AI interaction (AI as a tool, AI as a human decision enhancer, trainable AI) improve adaptability to semi-predictable and unforeseen events?

# Army Research Directorate (ARD) Research Topic

**Title:** Invincible Materials Research in support of the Sciences of Extreme Materials Competency
**Announcement ID:** ARL-BAA-0077

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**ARL Foundational Research Competencies:** Sciences of Extreme Materials
**Army Modernization Priorities:**
**Keywords:**

**Description:**
The invincible materials portfolio focuses on the fundamental, basic and applied material science and engineering to identify novel and emerging materials, systems and technologies for use across multiple high valued platforms and systems. The portfolio seeks to expand knowledge of materials and the related science and engineering of all materials classes with respect to synthesis, processing, development of novel materials or feedstocks, methods, advanced manufacturing techniques, experimentation, high through put techniques, machine learning, characterization, and modeling and simulation. The portfolio seeks to enable the discovery, development, design and integration of emerging structural, chemical and biological protection, electronic, laser and energy, materials in traditional and extreme environments such as materials under high rate and dynamic conditions. The portfolio also seeks material science and manufacturing technologies that supports the soldier, combat vehicles, combat support vehicles and other high valued assets to enable improved performance and survivability.

**Goals and Objectives:**

- Provide advances in materials through science and technology to enable improved protection and survivability of soldiers, combat equipment and combat support equipment and other high valued assets.

- Improve materials performance in extreme and non-traditional environments such as high rate/dynamic or within the electromagnetic spectrum (lasers for example).

- Decrease weight and improve power, energy and fuel efficiency for the soldier, combat vehicles, combat support vehicles and other high valued assets

- Utilize new or improve upon existing capabilities to rapidly discover, design and develop materials and the supporting science to enable solutions for the Army.


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# Army Research Directorate (ARD) Research Topic

**Title:** Invisible Materials Research in support of the Sciences of Extreme Materials Competency
**Announcement ID:** ARL-BAA-0078

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**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Chemistry;Data Sciences and Informatics;Materials Science;Mechanics;Physics
**ARL Foundational Research Competencies:** Sciences of Extreme Materials
**Army Modernization Priorities:**
**Keywords:**

**Description:**
The Invisible Materials Portfolio seeks to identify novel electromagnetic spectrum materials (EMS) for use in a wide range of military applications. The portfolio seeks materials with advanced capabilities to increase, decreases or alter the energy emitted, scattered or absorbed in a controlled manner.

**Mission**
Provide expertise and support for identifying emerging materials science technologies that can potentially transform how the military is detected by sensors across the entire EMS.

**Goals and Objectives**

1. Provide a suite of technologies that can be tailored and fused to improve the Army's ability to meet diverse platform/system/mission requirements.
2. Improve the ability to manage EMS emissions from Soldiers, Combat, and Combat support equipment.
3. Provide advances in EMS materials to allow future combat force to adapt to unknown threats across the electromagnetic spectrum (EMS) in real time.
4. Dramatically improve materials performance to allow extreme EMS performance in realistic military environments (temperature, UV exposure, humidity, low power, etc.).

# Army Research Directorate (ARD) Research Topic

**Title:** Isomer Power for Enhanced Mission Endurance
**Announcement ID:** ARL-BAA-0098

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**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Chemistry;Physics
**ARL Foundational Research Competencies:** Energy Sciences
**Army Modernization Priorities:** Future Vertical Lift;Next Generation Combat Vehicle
**Keywords:**

**Description:**
The Army faces significant challenges in meeting its future energy and power needs and is exploring the feasibility of tapping into nuclear-scale energies via radioisotope decays, whether natural or induced. For this topic, the emphasis is on the potential for induced energy release from metastable nuclear excited states (nuclear isomers), particularly when their half-lives are on the order of a year or longer and when their ground states can release additional energy by radioactive decay. A key to utilizing isomers as essentially nuclear batteries is the ability to move a population of nuclei from a long-lived isomeric state to the ground state via a nuclear reaction: this has been termed "'isomer switching" or "'isomer depletion" and has been discussed in the scientific literature (see the 2024 publication of "'Isomer Depletion" in the European Physical Journal - Special Topics). For most processes envisioned for isomer switching/depletion, the two general components are 1) a pathway of electromagnetic transitions within an isomeric nucleus that leads from the isomer to the ground state and 2) a mechanism by which to initiate the switching via the transition from the isomer to a higher-lying excited state that starts the switching/depletion pathway. The recent demonstration of nuclear excitation by electron capture (NEEC) shows one possible mechanism by which to initiate isomer switching/depletion, but there are also other known mechanisms that may be useful for some long-lived isomers. Other related research areas include the study of reactions by which to best produce isomers and ways to eventually convert the released energy of induced decays (following isomer switching/depletion) into useful energy and power.

ARL seeks research proposals that advance the state-of-the-art in research into isomer switching/depletion in the areas described above and which augment and/or expand ARL's existing internal efforts. Such proposals could be experimental in scope, providing new approaches to identifying switching/depletion pathways in nuclei having long-lived isomers, investigating NEEC or other switching/depletion mechanisms, or studying isomer-production reactions. Much of ARL's internal research into isomer switching/depletion have focused on beam-based approaches using facilities like that at Argonne National Laboratory ATLAS/Gammasphere using multi-fold gamma-ray spectroscopy. Proposals could follow similar methods, but could also suggest other approaches using implantation detectors, etc. Proposals could also be theoretical in scope, seeking to better understand the nuclear structure leading to effective switching/depletion pathways in nuclei of interest, or enhancing models for NEEC or other switching/depletion mechanisms. Proposals to study reactions for isomer production would also be of interest.

# Army Research Directorate (ARD) Research Topic

**Title:** Light Manipulating Materials and Devices
**Announcement ID:** ARL-BAA-0036

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**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Chemistry;Materials Science;Physics
**ARL Foundational Research Competencies:** Energy Sciences
**Army Modernization Priorities:** Future Vertical Lift;Next Generation Combat Vehicle;Soldier Lethality
**Keywords:** Nonlinear optics. metamaterials, novel optical materials, optical switching

**Description:**
Light manipulating materials and devices: The Energy Sciences Competency requires research in transparent nonlinear optical (NLO) materials, electro-optical (EO) materials, metamaterials, and related components and devices that can reduce their optical transmission across the visible, NIR, SWIR, MWIR, and/or LWIR wavelength range passively or actively, when subjected to an incident laser beam. Orders-of-magnitude of reduction of transmission, or optical density (OD), is desired. Materials and devices must be highly transmissive in the initial state.

Technical areas of interest include, but are not limited to, the following:

1. Development of optical materials with large nonlinearities and a broad wavelength and/or pulse-width response (fs to continuous wave). This can include molecular modeling, material synthesis, and characterization of nonlinear parameters as well as nonlinear transmission studies to determine structure-property relationships to improve their response. Materials can be organic, inorganic, or hybrid.
2. Modeling efforts to relate material properties to their ability to affect laser light. Modeling effort should include details on how the materials affect the propagation of incoming laser beams.
3. Development of metamaterial structures and nanoparticles, or other structured or engineered materials and devices that can reflect, scatter, or otherwise affect laser propagation, including modeling studies and characterization efforts.

# Army Research Directorate (ARD) Research Topic

**Title:** Mechanical Metamaterials for Advanced Protection
**Announcement ID:** ARL-BAA-0096

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**Discipline:** Chemistry;Materials Science;Mechanics
**ARL Foundational Research Competencies:** Terminal Effects
**Army Modernization Priorities:** Next Generation Combat Vehicle
**Keywords:**

**Description:**
DEVCOM ARL is seeking proposals on the exploration and maturation of mechanical metamaterials and associated concepts, testing/diagnostics methods for characterization, scale-up methods etc., in a manner relevant to ballistic impact conditions. Novel manufacturing and processing techniques are of interest, provided that the work will involve high strain rate relevant characterization. Research in this area seeks to understand and control/manipulate material behavior to ballistic advantage, understand behavior on various scales, advanced modeling and simulation associated with these materials for enhanced understanding and further design/development of mechanical metamaterials.

Specific research areas include:

- Mechanical metamaterials, nanostructured composites, engineered materials specifically built for manipulating shock and damage propagation due to ballistic impact and penetration.
- Special consideration for increasing thickness, towards building 3D mechanical metamaterials.
- Fundamental systematic studies to link manufacturing/synthesis process, nano/microstructure, mechanical properties, high strain rate properties, and ballistic performance.
- Use or development of machine learning based approaches to aid in material discovery and design of mechanical metamaterials when there is no ‘big data'.
- Modeling and simulation of such structures at various scales.
- Multi-scale modeling approaches, verification, and validation involving mechanical metamaterials.
- Developing/using experimental techniques and diagnostics to assess/characterize mechanical metamaterials. Scaling effects associated with small scale experimentation of such materials, and exploration of how they translate to continuum scale dynamic properties and performance.

# Army Research Directorate (ARD) Research Topic

**Title:** Multimodal Synthetic Data for Machine Learning
**Announcement ID:** ARL-BAA-0079

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**Discipline:** Data Sciences and Informatics
**ARL Foundational Research Competencies:** Military Information Sciences
**Army Modernization Priorities:** Next Generation Combat Vehicle
**Keywords:**

**Description:**
The use of artificial intelligence solutions for Army field applications will rely heavily on machine learning (ML) algorithms. Current ML algorithms need large amounts of mission-relevant training data to enable them to perform well in tasks such as object and activity recognition, and high-level decision making. Battlefield data sources can be heterogeneous, encompassing multiple sensing modalities. Present open-source data sets for training ML approaches provide inadequate representation of scenes and situations of interest to the Army, in both content and sensing modalities. There is a push to use synthetic data to make up for the paucity of real-world training data relevant to military multi-domain operations of the future. However, there are no systematic approaches for synthetic generation of data that provide any degree of assurance of improved real-world performance of the ML techniques trained on such data. The problem of effective synthetic data generation for ML raises deeper questions than that of artificially generating speech or imagery that humans find realistic.

Accordingly, ARL seeks research proposals in the following (1) Synthesis techniques for multimodal machine learning (2) Machine learning for synthesis of causality and hierarchical relationships (3) Continuous and/or incremental multimodal learning (3) Algorithms and architectures that learn physics or are endowed with relevant domain knowledge (4) Domain adaptation techniques with rich intermediate representations (5) Methods for providing insight into ML models' internal representations and comparison of synthetic versus real representations. Additional related areas will also be considered.

# Army Research Directorate (ARD) Research Topic

**Title:** Networking Structure, Dynamics, and Protocols
**Announcement ID:** ARL-BAA-0045

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**Discipline:** Computer Science;Electronics;Mathematics and Statistics;Network Science;Physics
**ARL Foundational Research Competencies:** Network, Cyber, and Computational Sciences
**Army Modernization Priorities:** Network/C3I
**Keywords:**

**Description:**
The Network, Cyber, and Computational Sciences (NC&CS) foundational research competency of Networking Structures, Dynamics, and Protocols addresses the increasingly complex battlefields (highly dynamic, wireless, mobile networking environment populated by hundreds to thousands of networked nodes) in which the Army must be able to communicate. Often, these environments are austere in terms of availability of resources for supporting and servicing the networking equipment. They are highly congested by multiple conflicting demands on bandwidth and severely contested by a capable adversary. Research in networking and communications will address these multiple and complex challenges by pursuing the following overarching goals:

- Diverse, effective channels-traditional and non-traditional-will be available for creating heterogeneous networks rapidly, predictably, and in a manner optimized for specific requirements and constraints of mission and environment, adapting intelligently to challenges of terrain, atmospheric conditions, local bandwidth congestion, and ensuring high performance along with energy efficiency and minimized probability of detection and interception by the adversary. Inclusion of quantum channels and networks may provide breakthrough capabilities beyond what is conventionally (classically) possible.

- The networks will be autonomously driven to meet performance goals/priories provided by the warfighter, through protocols and algorithms for control and processing of signal and information, as well as for self-organization of the network. These protocols/algorithms will ensure persistent high performance of the network, consistent with dynamically changing missions, supportive of rapid reorganization and mobility of friendly forces, and be highly robust against strong disruptions.

- Survivability and defensive properties will be integral to the future network, making it inherently secure and survivable against disruptions by adversarial attacks such as jamming and other forms of interference, in part by minimizing probability of the communications and networks detection, interception, penetration, and information exfiltration, as well as by responding to adversary actions by agile maneuver and recovery.

The NC&CS core competency on Networking Structure, Dynamics, and Protocols will provide underpinning technology for Army capabilities where it is critical to ensure communications remain reliable, robust, and resilient in the face of disruptive effects such as task reorganization, mobility of friendly forces, and adversarial attacks on friendly networks in future tactical environments.

# Army Research Directorate (ARD) Research Topic

**Title:** Neuroscience and Neurotechnology
**Announcement ID:** ARL-BAA-0048

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**Discipline:** Biological Sciences;Computer Science;Data Sciences and Informatics;Mathematics and Statistics;Network Science
**ARL Foundational Research Competencies:** Humans in Complex Systems
**Army Modernization Priorities:** Future Vertical Lift;Network/C3I;Next Generation Combat Vehicle;Soldier Lethality;Synthetic Training Environment
**Keywords:** Neuroscience; Intelligence; Decision Making; Adaptation; Ideation, Representation, Abstraction

**Description:**
***Summary***
The human nervous system is the most intelligent complex system in the known universe. This research area attempts to understand and harness the power of the nervous system for the advancement of future human-technology systems. This topic seeks to integrate neuroscience with traditional approaches to understanding Soldier behavior to enable system designs that maximize human-system performance, and also attempts to leverage an understanding of the nervous system to drive the development of novel computational approaches necessary for creating future intelligent systems.

***Background***
The future battlefield presents substantial challenges to the US Army to maintain overmatch at the intersection of humans and technology. This topic aims to harness the power of the human nervous system to enable neuroscientific principles to be used to maximize Soldier-system performance and to drive the understanding and development of novel computational approaches necessary for improving future algorithms and human machine teams. Specifically, the topic focuses on the properties of biological systems that allow them to rapidly adapt to changing context, robustly operate together to complete complex tasks, and quickly understand environmental constraints to perform actions.

The topic has two discrete integrative, transdisciplinary thrust areas that aim to transcend a single biological system and be applicable to human-technology systems that span a wide variety of spatial and temporal scales. (i) The topic aims to abstract the human brain to uncover computational approaches that can be used to develop robust, human-compatible intelligent technologies by understanding how connectivity, unit dynamics, and parallel computation underlie the ability of biological nervous systems to generate abstract representations and predict future outcomes. If successful, the science is envisioned to generate intelligent algorithms demonstrating improved flexibility and ability to work ergonomically with human teammates. (ii) The topic aims to uncover foundational principles of the inter-brain system interactions underlying heterogeneous effective human-human and human-machine teams. Research is envisioned that builds off of recent analytical advances in neuroscience such as linking network features such as connectivity and unit dynamics to the brains ability to construct abstract representations and cognition, by the application of new methods to represent neuronal information such as manifolds, topological data analysis, network science, and dynamical systems theory.

***Specific Questions of Interest***

- How can current advances in computational methods that transcend disciplines modify our understanding of brain function? How will emerging (and converging) methods of neural recording shape our knowledge of brain function? How will new methods, developed on neural measurements transcend to other complex systems?
- What is the primary system to reach and mimic the human's ability to rapidly adapt to rapidly changing contexts? What are the functional properties of some of the most basic human properties?
- Can we create new machine architectures by mimicking the ability of humans to overcome uncertainty and context dependence?
- How can a mechanistic understanding of inter-brain system interactions enable team behavioral modification? What advances in computational approaches to detect and predict team states enable in neural enhancement? How will inter-brain network neural enhancement affect group behavior?

# Army Research Directorate (ARD) Research Topic

**Title:** New Developments in Antenna Apertures
**Announcement ID:** ARL-BAA-0062

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**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Electronics;Materials Science;Physics
**ARL Foundational Research Competencies:** Electromagnetic Spectrum Sciences
**Army Modernization Priorities:** Air and Missile Defense;Future Vertical Lift
**Keywords:** additive manufacturing, antennas, electromagnetic skins

**Description:**
ARL seeks to develop antenna apertures (i.e., antennas and antenna arrays) for future Army systems. To realize these radiating structures, there is interest in utilizing new man-made, or engineered materials, as well as novel processes such as additive manufacturing. Future platforms will require apertures that are low in profile and can be integrated into both ground and airborne platforms and are conformal to such platforms. Such apertures should have little or no visible signature as well as minimal or no obvious protrusion.

Topics of interest include:

- Antennas and arrays using engineered materials (e.g., metamaterials)
- Electrically thin antennas, integrated into platforms
- Electromagnetic skins for required functions
- Balun designs exploiting engineered materials and/or additive manufacturing
- Apertures with integrated flexible electronics
- Diversity schemes for enhanced performance
- Conformal antennas and arrays
- Additive manufacturing of antennas and RF devices
- Antennas that use bio and synthetic biomaterials
- Machine learning for development and enhancement of antennas and RF devices

# Army Research Directorate (ARD) Research Topic

**Title:** Novel Computing Architecture and Algorithm Co-design
**Announcement ID:** ARL-BAA-0042

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**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Computer Science;Electronics
**ARL Foundational Research Competencies:** Network, Cyber, and Computational Sciences
**Army Modernization Priorities:** Network/C3I
**Keywords:**

**Description:**
Theories, models, analyses and development of advanced and unconventional computing architectures and algorithms optimized to run on novel and emerging architectures. Spanning commercial off the shelf (COTS), domain- and application-specific computing architectures, such as lightweight, non-von-Neumann and other emerging architectures. Algorithms and methods for constrained resource computing with distributed/decentralized communication-, low size-weight-and-power (SWAP), and scalable computing.

Represented in this BAA for the NC&CS Competency are computer architecture, algorithmic, and hardware/software co-design goals that form a robust advanced computing foundation to understand and overcome complex fundamental challenges simultaneous to improving approaches of importance to the Army. These areas include weapon systems design; materials-by-design; information dominated and networked battle command applications; system-of-systems analyses; human performance modeling; platform maneuverability; and tactical supercomputers. Discoveries and innovations made in this area will exert a significant impact on the Army of the future. There are natural synergies among the challenges facing ARL's NC&CS Competency and ARL's other S&T Competencies. Synergistic advances across all competencies are expected to enable next generation scientific breakthroughs.

This topic concentrates on understanding and exploiting the fundamental aspects of hardware and associated software and algorithms for emergent and future computing for mobile, scientific, and data intensive applications. Primary technical areas within novel HW/SW and algorithmic co-design include tactical scalable computing, extremely low SWaP (Size, Weight, and Power) computing, and Next Generation Computing Architectures. Tactical scalable computing focuses on understanding scalable computing on the tactical network to include Emergent Computing Architectures cloudlets, vehicle born computing, or ad hoc network connected platforms. Numerous applications are envisioned for these types of system in the future and include artificial intelligence aids for decision making, processing large-scale datasets (text, video), and navigation systems for autonomous vehicles. Emergent Computing Architectures considers new non-von Neumann and domain specific architectures that may provide leap ahead capabilities for Army applications. Tactical Computing is at-the-edge computing capabilities to better understand algorithms that provide applications for use by the soldier and edge devices at the point of need. Finally, Next Generation Computing Architectures research is focused on non-traditional computing systems and envisioned to provide disruptive technologies for the Army. Cognitive computing, neuro-synaptic computing, and DNA computing are some emerging concepts.

# Army Research Directorate (ARD) Research Topic

**Title:** Novel Solid State Lasers and Laser Materials
**Announcement ID:** ARL-BAA-0053

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**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Materials Science;Physics
**ARL Foundational Research Competencies:** Energy Sciences
**Army Modernization Priorities:** Air and Missile Defense;Future Vertical Lift
**Keywords:** laser, Raman, solid-state, fiber, bulk, crystalline

**Description:**
The Army is interested in research on innovative gain media, for example laser-quality ceramics with emphasis on engineerable doping and index profile (e.g., gradient doping, sharp-step waveguiding structures, planar and circular, with sub-10-micrometer diffusion zone); solid-state materials for high-gain stimulated Brillouin scattering (SBS); specialty fibers and fiber lasers suitable for high average powers and power scaling (e.g., fibers with glass compositions having an ultra-low SBS gain and/or ultra-high Raman gain; low-loss fully crystalline double-clad, i.e., crystalline core/crystalline cladding, fibers; glass fiber designs with developed mode selection mechanisms or self-mode selection; fiber designs with specialty wavelength-selective properties, e.g., for Raman suppression); advanced laser materials for diode-pumped eyesafe lasers (e.g., based on high and ultra-high thermal conductivity hosts, environmentally stable ultra-low-phonon hosts, or gain materials with exceptionally high emission/absorption cross-sections).

# Army Research Directorate (ARD) Research Topic

**Title:** Platform Design and Control
**Announcement ID:** ARL-BAA-0065

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**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Mechanics
**ARL Foundational Research Competencies:** Mechanical Sciences
**Army Modernization Priorities:** Future Vertical Lift
**Keywords:** Platform Design, Control Algorithms for Platforms, Mobile Platforms

**Description:**
ARL seeks research proposals in platform design and control that will enable maneuverable, adaptive tactical mobility platforms for Army ground and air vehicles. Technical challenges include developing a computational framework for automated design of mechanical systems (soft/compliant robots and platforms) capable of performing morphological computation. Furthermore, control paradigms are required for non-linear adaptive structures for which maneuverability is being maximized. The goal is to address (1) structural adaptations (2) describing structural and aerodynamic performance in dynamic environments as well as (3) controlling these highly coupled vehicles.


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# Army Research Directorate (ARD) Research Topic

**Title:** Power Conversion
**Announcement ID:** ARL-BAA-0055

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**Discipline:** Electronics
**ARL Foundational Research Competencies:** Energy Sciences
**Army Modernization Priorities:** Air and Missile Defense;Future Vertical Lift;Next Generation Combat Vehicle
**Keywords:** Power conversion, inverter, converter, transformers, platform electrification

**Description:**
***Electrical Power Conversion***
The Army is searching for innovative technologies and techniques for reducing the size, weight, cost, and logistics footprint of power conversion systems across the full range of mobile and stationary Army applications. High efficiency and high temperature operation (for reduced cooling) are also critical requirements.

Some specific areas of interest include:

1. Novel power converter toopologies
2. Novel materials and designs for high-temperature power conditioning components including capacitors
3. inductors, transformers and other passive components
4. High performance components such as switches, transformers, and capacitors
5. Novel power conditioning components and control research in technologies for conversion of power between frequencies and voltages with the ability to scale system power levels based on needs
6. Pulse-Forming Network (PFNs) and power conversion technology for lethality, survivability and directed energy capabilities and future high power and high voltage loads
7. Thermal management materials and techniques for power switching and conversion components

# Army Research Directorate (ARD) Research Topic

**Title:** Power Electronics Packaging
**Announcement ID:** ARL-BAA-0057

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**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Electronics
**ARL Foundational Research Competencies:** Energy Sciences
**Army Modernization Priorities:** Air and Missile Defense;Future Vertical Lift;Next Generation Combat Vehicle
**Keywords:**

**Description:**
This topic has four thrust areas:

1. High performance packaging materials, methods and systems o enable the full performance level of wide bandgap power electronics. This includes high temperature (Tj> 200 degrees C), high voltage ( > 10 kV), and high frequency (Mhz range) operation.
2. Integrated design techniques and modeling that utilize co-engineering and/or co-design to improve power packaging design by understanding the power density, reliability, thermal performance, and electrical performance trade-offs.
3. Novel applications of standard additive manufacturing techniques as well as novel additive manufacturing techniques are desired to enable advanced and high-performance power packaging. In addition, techniques and methods to functionalize structural, aerodynamic and/or other structures by integrating power electronics features are of interest.
4. Intelligent control methods and techniques for in package control and monitoring of device performance.

# Army Research Directorate (ARD) Research Topic

**Title:** Quantum Entanglement Science and Efficient Light-Matter Interaction
**Announcement ID:** ARL-BAA-0052

**TPOC:** Brenda L VanMil - brenda.l.vanmil.civ@army.mil - (301) 394-0979
**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Materials Science;Physics
**ARL Foundational Research Competencies:** Photonics, Electronics, and Quantum Sciences
**Army Modernization Priorities:** Assured PNT;Network/C3I
**Keywords:** quantum; positioning, navigation, timing (PNT); quantum information science; atomic clocks; entanglement; quantum sensing;

**Description:**
Over the past century, the quantum principles of superposition, electronic structure, and uncertainty relations gave us tremendous advances in a number of applications relevant to the military, including atomic clocks, magnetometry, positioning/navigation/timing (PNT), and gravimetry. While these areas can still be improved through technological advances, next-generation gains in sensing and in secure communications will occur through the concept of quantum identicality and quantum entanglement.

Our efforts conduct cross-cutting foundational research to exploit quantum effects for (1) novel sensors and capabilities, (2) beyond-classical sensor performance limits using entanglement, and (3) entanglement-enhanced information processing, decision-making, and security. Research emphasizes strong light-matter interfaces, including cavity quantum electrodynamics (QED) and nanophotonic integration. Examples of relevant research include electromagnetic field sensing using Rydberg atoms, solid-state "atomic" clocks, solid-state defects for sensing and quantum information, nanophotonics, and building blocks of entanglement distribution (quantum memories, repeaters, hybrid interfaces, etc).


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# Army Research Directorate (ARD) Research Topic

**Title:** Quantum Information Science and Positioning, Navigation, and Timing (QIS-PNT)
**Announcement ID:** ARL-BAA-0051

**TPOC:** Adam Schofield, PhD - adam.r.schofield2.civ@army.mil - (443) 395-0621
**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Materials Science;Mechanics;Physics
**ARL Foundational Research Competencies:** Electromagnetic Spectrum Sciences;Photonics, Electronics, and Quantum Sciences
**Army Modernization Priorities:** Assured PNT
**Keywords:** positioning, navigation, and timing (PNT); quantum information science; quantum sensing

**Description:**
The Quantum Information Science and Positioning, Navigation, and Timing (QIS-PNT) Essential Research Program (ERP) is the Army's leader in continuously transforming quantum information science and PNT to outpace our adversaries through discovery and innovation of novel sensing capabilities and quantum approaches to ensure seamless navigation and communication across all combat environments.

***Mission***
provide the expertise and component technologies to foster transformational improvements to the accuracy and resiliency of Army PNT and quantum sensing capabilities that improve the maneuver, FIRES, and communication capabilities of the future force.

***Goals and Objectives***

1. Provide a suite of PNT technologies that can be tailored and fused to improve the Army's ability to meet diverse platform/system/mission requirements
    1. Improve availability and precision synchronization of time beyond current GPS time transfer capabilities
    2. Provide improved resilience of position information at GPS-level accuracy and precision greater than GPS
    3. Improve access to and integrity of navigation and communications information
2. Identify, develop, and evaluate quantum mechanical principles and quantum phenomena to support revolutionary advances in sensing capabilities, including clocks, sensing, and communications

# Army Research Directorate (ARD) Research Topic

**Title:** Quantum networking for communications, distributed entanglement and information processing
**Announcement ID:** ARL-BAA-0082

**TPOC:** Quantum Networking Team - devcom-arl-quantum-networking@army.mil
**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Computer Science;Network Science
**ARL Foundational Research Competencies:** Network, Cyber, and Computational Sciences
**Army Modernization Priorities:** Network/C3I
**Keywords:** Quantum optics, quantum information distribution, trapped ion quantum information, quantum entanglement distribution, quantum networking experiment/theory

**Description:**
The Army seeks proposals in the development of quantum networks to advance performance metrics across a range of applications, including information distribution/security/processing, logistics, conventional networking and computing.

Technical areas of interest include experimental and theoretical work in the following topics:

- Quantum network connectivity, including methods for preservation and characterization of quantum signals, including polarization preservation, frequency-control and timing distribution for network control.
- Development of quantum-based networking models involving quantum information distribution, processing, error-correction and protocols for state characterization and tomography.
- Strong light-matter interfaces including nanophotonic light manipulation and quantum frequency conversion.
- Trapped ion quantum networking, including photon-mediated entanglement-based networking.
- Quantum networking technologies for quantum nodes, quantum information generation, routing, detection, measurement and control.
- Entanglement-enhanced information processing, decision-making, and data security.

# Army Research Directorate (ARD) Research Topic

**Title:** RF Sensing Through Obscured Media
**Announcement ID:** ARL-BAA-0080

**TPOC:** Brian Phelan, PhD - brian.r.phelan.civ@army.mil - (301) 518-0713
**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Electronics
**ARL Foundational Research Competencies:** Electromagnetic Spectrum Sciences
**Army Modernization Priorities:**
**Keywords:**

**Description:**

ARL seeks to discover, innovate, and experimentally demonstrate adaptable, low-SWAP (SWAP = Size, Weight, and Power) transceivers, adaptable RF front-end concepts, algorithms, and enabling technologies that will provide new capabilities in standoff explosive threat sensing across the electromagnetic spectrum. Explosive threats are often obscured; sensor technologies need to be able to detect explosive threats in such situations. The sensor technologies should be configurable to operate on mobile platforms (ground-vehicle, and airborne platforms) for field evaluations and subsequent data collections. Novel techniques, such as distributed-radar concepts are of interest due to their potential to enable Low-Probability of Detection (LPD) operation. Furthermore, the sensor technologies should be able to perform standoff detection in congested, contested, and complex Electromagnetic Environments (EME) by implementing cognitive radar concepts. Due to continued congestion of the RF spectrum, decision-theory approaches and other adaptive, flexible, and reconfigurable algorithms and associated hardware as needed. Spatial, spectral, and temporal domains need to be leveraged to sense, react, and avoid. Active and passive RF sensing should be employed for targeting, detecting, and tracking airborne and ground-based threats.

Topics of interest include:

- Explosive Hazards
- Explosive Hazards Triggering Devices
- Transceivers for Passive & Active Capabilities
- Digital Backends
- Adaptative/Reconfigurable Frontends
- Integration of Transceivers on Ground- and Airborne Platforms
- Ground-to-Air Tracking Radar
- Ground-Surveillance Radar
- Multistatic Radar vs. Signal Processing
- Multifunction Radar
- Synthetic-Aperture Radar
- Distributed Radar
- Waveform Design & Agility
- Passive Imaging
- Decision Theory

- Spectrum Situational Awareness (SSA)
- Dynamic Spectrum Access (DSA)

# Army Research Directorate (ARD) Research Topic

**Title:** RF-to-THz Devices and Integrated Circuit Technology
**Announcement ID:** ARL-BAA-0063

**TPOC:** Dmitry A. Ruzmetov, PhD - dmitry.a.ruzmetov.civ@army.mil - (301) 394-0242
**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Electronics;Materials Science;Physics
**ARL Foundational Research Competencies:** Electromagnetic Spectrum Sciences
**Army Modernization Priorities:** Air and Missile Defense;Long Range Precision Fires
**Keywords:** RF, UWB, diamond

**Description:**
ARL is interested in research on innovative electronic substrates, epitaxial materials, devices, monolithic circuits, and integration techniques for digital, mixed-signal, RF, millimeter-wave to Terahertz (THz) applications, including radar, communications, electronic warfare, and sensor systems. Research should involve materials, devices, integrated circuits, and subsystems built upon advanced Si-based, III-V, III-nitride, and II-VI materials, ultra-wide bandgap semiconductors (i.e. diamond), novel device structures, nano-technology innovative circuit topology, and multi-level, and/or heterogeneous integration technology. The research may also include related device, circuit, subsystem, and system level CAD modeling and analysis to achieve optimal performance.


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# Army Research Directorate (ARD) Research Topic

**Title:** Super-Materials Research in support of the Sciences of Extreme Materials Competency
**Announcement ID:** ARL-BAA-0081

**TPOC:** Victoria L. Blair, PhD - victoria.l.blair3.civ@army.mil - (410) 306-4947
**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Chemistry;Data Sciences and Informatics;Materials Science;Mechanics;Physics
**ARL Foundational Research Competencies:** Sciences of Extreme Materials
**Army Modernization Priorities:**
**Keywords:**

**Description:**
This program focuses on basic and applied research investigations of materials synthesis, processing and characterization of structural materials which perform in high temperature, highly dynamic chemical, mechanical, and thermal environments. An example extreme environment for this topic would be transient thermal loads, high-g loading, oxidizing environments, and corrosive gases. Research efforts that are supported by both experimental and computational efforts are encouraged. Structural materials of interest can include, carbon-fiber reinforced composites, silicon carbide fiber reinforced composites, ultra-high temperature ceramics (with and without fiber reinforcement), refractory metals, metal matrix and ceramic matrix composites. Machine learning-driven materials discovery may be used to accelerate research progress but must be supported with experimental methods.

**Examples of research topics:**

- Fundamental discovery of crack propagation and failure mechanisms of materials in a computer-simulated use-environment or experimental environment.
- Processing relationship with materials properties and characteristics of interest including strength, hardness and toughness at temperatures exceeding 1000 degrees C. Thermal properties like thermal expansion, conductivity and emissivity.
- Development of high temperature material evaluation methods and linkages back to process-property relationships of exemplar materials.
- Mechanisms and characteristics of dissimilar material joints and interfaces.
- Examinations of novel processing methods to improve interfacial strength and performance.
- Examining multi-functionality, whereby an additional attribute beyond structural performance is optimized, such as high strength, thermal shock resistant materials that is also transparent to specific wavelengths of light.

# Army Research Directorate (ARD) Research Topic

**Title:** Support to ARL Foundation Research Competencies
**Announcement ID:** ARL-BAA-0071

**TPOC:** Unspecified TPOC - arl_baa@army.mil
**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Biological Sciences;Chemistry;Computer Science;Data Sciences and Informatics;Earth and Environmental Sciences;Economics;Education;Electronics;Materials Science;Mathematics and Statistics;Mechanics;Network Science;Physics;Social Science
**ARL Foundational Research Competencies:** Biological and Biotechnology Sciences;Electromagnetic Spectrum Sciences;Energy Sciences;Humans in Complex Systems;Mechanical Sciences;Military Information Sciences;Network, Cyber, and Computational Sciences;Photonics, Electronics, and Quantum Sciences;Sciences of Extreme Materials;Terminal Effects;Weapons Sciences
**Army Modernization Priorities:**
**Keywords:**

**Description:**
Under this topic, ARL will consider whitepapers and proposals that may not directly align to the current research topics published by an ARL TPOC, but can demonstrate a strong alignment to ARL's mission. ARL's research mission is executed within identified foundational research competencies that provide the Army foundational expertise and specialized capabilities grounded in scientific excellence and driven by unique Army challenges. ARL is always interested in innovative research whitepapers and proposals that demonstrate a strong alignment to ARL's foundational research competencies and potential to create discovery, innovation, and transition of technologies for Army transformational overmatch. To learn more about ARL's foundational research competencies visit the ARL website at https://www.arl.army.mil/what-we-do/competencies/.

White papers and proposals submitted under the "'Support to ARL Foundation Research Competencies" topic must clearly describe the research and objectives and will be considered by ARL if it is aligned to one or more of these foundational research competencies that support the ARL mission. Applicants interested in submitting a white paper or proposal under this topic are strongly encouraged to first make preliminary inquiries as to the potential alignment to an ARL foundational research competency, funding availability for the type of research effort contemplated, and identification of an ARL TPOC to receive and review potential white papers or proposals.

# Army Research Directorate (ARD) Research Topic

**Title:** Tactical Heterogeneous Sensing in Complex Environments, Aerosols, and Impacts
**Announcement ID:** ARL-BAA-0083

**TPOC:** Chatt C Williamson - chatt.c.williamson.civ@army.mil - (301) 394-1771
**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Chemistry;Data Sciences and Informatics;Earth and Environmental Sciences;Physics
**ARL Foundational Research Competencies:** Military Information Sciences
**Army Modernization Priorities:**
**Keywords:**

**Description:**
This program focuses on basic and applied research investigations designed to enhance situational and operational awareness with respect to operations in complex, multi-domain environments enabling C4ISR and maneuver capabilities. The research covers a broad portfolio including aerosol sciences, propagation of electro-optic (EO), electro-magnetic (EM), radio-frequency (RF) and acoustic signals in complex environments, impacts thereof, and heterogeneous sensing. Areas of specific interest are optical spectroscopy and characterization of aerosols, modeling of light interaction with material, atmospheric aerosol composition, heterogeneous remote sensing, and propagation modeling. Complex environments of particular interest are urban, littoral, forested, and domain interfaces.

**Examples of research topics:**

- Fundamental understanding of single aerosol particle interaction with open air factors and the impact of such interactions on optical signatures of such aerosols.
- Development and application of methods, techniques, and models representing physical interactions between light and materials (aerosols).
- Heterogeneous remote sensing that considers both environmental sensing (to include Doppler lidar and radar) and target detection (to include acoustic, EO, EM, RF).
- Fundamental research on the impact of the complex environment on propagation, characterization, and detection of signals.
- Innovative signal processing, computational methods, and instrumentation system concepts for autonomous heterogeneous sensing in complex environments.
- Exploratory research in AI/ML (or other advanced computational methods) for autonomous heterogenous remote sensing in clutter environments. Sensing nodes could include EO, EM, RF, and acoustic and different/varying bands, for both target and environmental sensing. Simultaneous environmental and target sensing should allow for characterization of the clutter, removal of the clutter for improved target detection, and characterization of the environment. Atmospheric state, topography, surface sea-state, and turbulence characterization are of interest.

# Army Research Directorate (ARD) Research Topic

**Title:** Techniques and Sources Enabling Major Power Scaling of Diode-Pumped Solid-State Lasers (fiber and bulk)
**Announcement ID:** ARL-BAA-0054

**TPOC:** Mark Dubinskiy, PhD - mark.dubinskiy.civ@army.mil - (301) 394-1821
**ARL Office:** Army Research Directorate (ARD)
**Discipline:** Materials Science;Physics
**ARL Foundational Research Competencies:** Energy Sciences
**Army Modernization Priorities:** Air and Missile Defense;Future Vertical Lift
**Keywords:** Pump couplers, splicing dislike materials, fiber-coupled diode modules

**Description:**
The Army is interested in innovative highly efficient pump-coupling techniques; innovative pump diode and active medium cooling techniques (e.g., cooling via optically transparent highly thermoconductive materials); passive and active laser beam/aperture combining methods; advanced fiber splicing techniques, as it pertains to splicing silica glass to dislike materials, e.g., alternative glasses, as well as YAG, Sapphire, silicon nitride materials; laser wavelength shifting techniques and materials for achieving high average powers with emphasis on eye-safety and emission in best atmospheric propagation bands; development of surface patterning techniques with anti-reflection and high reflection properties. Of special interest is research and development enabling fiber-coupled laser diode sources with output brightness exceeding current state-of-the-art by a factor of 10 or more.