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

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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 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 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 atomic and molecular processes;
4. Quantum systems in cavities;
5. Collective and many-body states of matter; and
6. Emerging areas.

Cooling schemes for molecules are of importance for extending the range of systems that may be exploited. In addition, there is an interest in emerging areas of AMO physics such as collective states of matter, emergent lattices in quantum gases, opto-mechanical interfaces, non-equilibrium many body dynamics, 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 cooling, trapping, and the expansion of atomic and molecular species. The effort seeks the validation of many-body quantum theories through the development of experimental tools including quantum gas microscopes, 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. 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.

Army Research Office (ARO) Research Topic

Title: Biochemistry
Announcement ID: ARL-BAA-0017

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ARL Office: Army Research Office (ARO)
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: Biomathematics
Announcement ID: ARL-BAA-0021

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ARL Office: Army Research Office (ARO)
Discipline: Biological Sciences;Earth and Environmental Sciences;Mathematics and Statistics;Physics
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?

Army Research Office (ARO) Research Topic

Title: Biotronics
Announcement ID: ARL-BAA-0069

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ARL Office: Army Research Office (ARO)
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

Army Research Office (ARO) Research Topic

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

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ARL Office: Army Research Office (ARO)
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.

Army Research Office (ARO) Research Topic

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

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ARL Office: Army Research Office (ARO)
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: Condensed Matter Physics
Announcement ID: ARL-BAA-0029

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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: 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.

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.

Army Research Office (ARO) Research Topic

Title: Environmental Chemistry
Announcement ID: ARL-BAA-0005

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ARL Office: Army Research Office (ARO)
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 Environmental Chemistry program seeks to provide a complete and practical understanding of transport, degradation, and reaction processes for chemicals and other compounds of military interest. The goal of the research is to enable unprecedented detection, prediction, manipulation, and mitigation strategies in complex environmental matrices. The program will identify high risk, fundamental research opportunities in two main thrusts: (i) Transport and transformation in multiphase environments, (ii) Novel techniques for detection and prediction.

Transport and transformation in multiphase environments aims to determine the properties and processes that govern the fate of compounds in environments where chemical reactions and transport processes occur between solid, liquid, and/or gaseous matter. The reactions in these environments occur synergistically and dynamically and are a function of the compounds present, their structure and partitioning, and their chemical and physical properties. Therefore, understanding multiphase environments relies on basic research to characterize the structure and physio-chemical evolution of compounds, reactive centers, and products over a wide range of spatial and temporal scales. Multiphase environments include (but are not limited to) natural environments such as soil, subterranean, aqueous, and aerosol environments; built and urban environments; and complex or hazardous waste streams.

Novel techniques for detection and prediction aims to develop cutting-edge approaches to enable chemical agent detection and environmental prediction at military-relevant scales. Areas of interest include experimental and analytical techniques to advance environmental forensics, non-targeted detection, and trace detection; and the application of novel computational techniques to enhance modeling capabilities.

An emerging area of interest for the Environmental Chemistry Program focuses on environmental security and how dynamic and extreme climate conditions alters the speciation, partitioning, transformation, and recovery of chemical compounds and resources.

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, 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 to gain the necessary physical insights underpinning future concepts and capabilities spanning Army vehicles, munitions, manufacturing, and logistics.

The program is divided roughly into 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 signature of unsteady separation and/or incipient separation are of particular interest. 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 turbulent behaviors. 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 are capable of dealing directly with inherent nonlinearities. Operator theoretic methods are making great strides in tackling the perennial difficulties associated with the Navier-

Stokes equations. Turbulent dynamics are 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. Modeling flows near walls is a continuing challenge to accurate numerical prediction of complex physics that may benefit from novel non-intrusive diagnostics to inform creative numerical and theoretical constructs capable of efficiently producing a high degree of fidelity near physical boundaries.

Dynamics of Particle-Laden Flows

Understanding the dynamics and control of particle-laden flows has the potential to permit flow-assisted assembly of heterogeneous materials and address the role of dust, sand, and other particulates in degraded performance of Army systems. Accurate prediction and description of the interactional physics of particle-fluid, particle-particle, and particle-boundary interactions represents an exciting opportunity to contribute to the creation of next-generation materials and capabilities. Use of a variety of mechanisms, including (but not limited to) electro-kinetics, diffuseophoretics, or selective permeability, should allow the identification of fundamental mechanisms related to the dynamics and control of such multi-phase flows.

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?

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

From the Army perspective, Information Assurance must provide authentic, accurate, secure, reliable, timely information to warfighters to achieve information dominance, regardless of threat conditions. Computing and information processes may be carried out over distributed and heterogeneous systems, which may include mobile computing and communications systems, and high-performance information process systems that are inter-connected through both tactical and strategic communication systems.

Robust and Trusted Wireless Communication

Research is needed in the areas of theory, protocols, and techniques that will assure delivery of trustworthy information to support Army missions. Reconfigurable, survivable, and self-healing systems allow a combat unit to dynamically establish and maintain its command and communication capability under diversified and extreme battlefield situations. The Army requires a fully mobile, fully communicating, agile, and situation-aware force that operates in a highly dynamic, network centric environment. This force consists of a heterogeneous mixture of individual soldiers, ground vehicles, airborne platforms, unmanned aerial vehicles (UAVs), robotics, and unattended sensor networks such as battlefield internet of things (IoT) that operate in a complex wireless environment. Information theory has played a foundational role in the study of security. Across a wide range of application domains and security objectives, information theory leads to insight to the underlying tradeoffs between security and performance. The Army seeks novel ideas in fundamental research areas such as information-theoretic security, and the science of security that will provide direct guidance in the design of secure tactical wireless systems. Topics of interest include new paradigms for physical layer security (ranging from confidentiality to authentication to trustworthiness in physical layer communications), the fundamental bounds in trust management and data integrity in distributed systems, the exploitation of trust establishment and key/credential distribution protocols, and assured information delivery and dissemination in mobile environments. The corresponding constructions that would arise from such an investigation represents a significant avenue for improving future wireless communication as well as the corresponding secrecy capacity limits

that could serve as valuable guidelines in developing future systems with confidential and authenticated communications. New computing and communication protocols and techniques are needed to assure critical information processing and delivery even when such systems are under severe resource constraints or under persistent attacks.

Models and Metrics for Next Generation Robust Systems

The field of information assurance needs a foundational science to guide the design of systems and to quantitatively measure safety and the level of assurance of complex systems that the Soldier depends upon today. Assurance principles and metrics are needed to help define, develop, and evaluate future robust and resilient systems and network architectures that would survive sophisticated attacks and intrusions with measurable confidence. The program seeks the capability to measure a complex system and to provide trustworthiness and robustness guarantee of that system. In addition, human users need to be in the loop for system assurance analysis. Developing human centric security-usability metrics, computational models for usable security in stressful situations, and adaptive security protocols according to perceived threats are some of the research areas of interest for improving warfighter performance while maintaining sufficient security requirements. One new challenging area of research that offers great promise in stronger system robustness is the modeling of adversaries and defender interactions, since ultimately systems need to defend effectively against their attacks. A deeper understanding and more accurate modeling of adversarial behaviors will improve future system development. New concepts such as anti-fragility theory for better resiliency are also of interests.

Cyber Deception

Cyber deception is a proactive technique to manipulate the cognitive state and decision process of the adversary so that we can degrade and mitigate their attack effectiveness. Unique aspects of cyber deception may offer more opportunities but add more complexity to model and analyze: 1) Cyber artifacts (both genuine and fake) can be created easily and are not bounded by the laws of physical space. The velocity of cyber situation change could be very high; 2) while deceptions are normally played out between a defender and an attacker, users could be directly or indirectly entangled in the game due to the nature of shared infrastructure. Usability issues or negative impact to the mission need to be considered; 3) Social and cultural aspects are important elements in the cyber deception game. Key scientific understanding is still lacking in 1) Establishing effective human cognitive models for understanding and tracking the adversaries' intent, capability, and decision process, and 2) deception information formulation and communication techniques, which requires new thinking to provide a quantifiable measure on how a given deception approach will mislead adversarial decision process. Recent honeypots/decoy experiences gave initial insights on how to engage adversaries through fake cyber artifacts, but a clear understanding of the dynamics (especially mental interactions) between attackers and defenders is missing. A better learned adversarial model will be critical to the success of cyber deception. In addition, advanced honeypot like schemes are desired to engage adversaries in order to gain understanding of adversaries so that effective deception schemes can be crafted.

Principles of Moving Target Defense

Current cyber defenses are often static and governed by lengthy processes, while adversaries can plan their attacks carefully over time and launch the attacks at cyber speeds at times of their choosing. The program seeks a new class of defensive strategies to present adversaries with a moving target where the attack surface of a system keeps changing. Although such an idea of a "moving target" is a powerful paradigm for building systems robust to security threats, many fundamental aspects associated with such a strategy need to be further investigated and understood. For example, such a "moving target" system may operate under many different contexts, ranging from the use of frequency hopping in spread spectrum to software diversification. It is critical to establish new theories and models that can provide trade-off analysis between system robustness against attacks vs. performance/usability, and quantify the risks associated with system adaptation under an adversarial setting. Ultimately the understandings and analytical models obtained will establish an important foundation for creating robust tactical systems capable of maximizing the difficulties for the adversaries to attack while minimizing the impact to system performance and usability.

Trusted Learning for Cyber Autonomy

Future Army autonomous systems, especially cyber-physical systems working side-by-side with Soldiers, are subject to various adversarial attacks during operations such as data poisoning or 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, nor can these systems adapt due to varying operational environments or adversarial conditions, which is inevitable for any cyber autonomous system. It is critical to establish fundamental principles that can allow future systems to perform trusted learning, introspection and self-updating at mission time in order to adapt to changing operational environments and to defend against attacks that may lead to mission failures. New research is sought in driving both the correctness and robustness in cyber domain learning, decision making and adaptation so that these autonomous defense systems can maintain critical mission assurance. To help survive varying adversarial conditions, new concepts such as robustness certification or domain adaptation at both the data processing layer and the knowledge/decision layer may lead to better resiliency against adversarial manipulation and exploits and more effectiveness in sustaining missions.

Army Research Office (ARO) Research Topic

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

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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
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, with particular emphasis on data in complex forms such as image or video data; (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. Also of interest are methods to exploit the structure of the data, capture its intrinsic dimensionality, and extract information content of data. 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. 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. Scalable methods are needed for efficiently handling vast amounts of data. 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 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 so as to acquire the “most informative data” for the specific task or query. 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. 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 in order to achieve the desired confidence. Such an active learning and information-driven sensor control should include the Soldier in the feedback loop.

Army Research Office (ARO) Research Topic

Title: Innovations in International Materials Science
Announcement ID: ARL-BAA-0004

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ARL Office: Army Research Office (ARO)
Discipline: Electronics;Materials Science;Mechanics;Physics
ARL Foundational Research Competencies: Mechanical Sciences;Photonics, Electronics, and Quantum Sciences;Sciences of Extreme Materials
Army Modernization Priorities:
Keywords: materials properties, novel materials, new materials, materials concepts, adaptive materials, extreme conditions, responsive materials, microstructure, reconfigurable materials, defect engineering

Description:
The Innovations in Materials Program is focused on supporting very fundamental multidisciplinary research at institutions outside of the U.S., with the goal of accelerating new discoveries in materials science. Collaborations between international partners or between US and international partners are also of interest. Potential investigators should contact the Program's TPOC for any questions regarding the geographic regions that can be considered for research proposals in this area.

The Innovations in Materials program seeks to determine unique strategies and new designs for optimizing materials with uncharacteristic or unexpected properties, architectures, and compositions. Research is focused on, but not limited to, areas such as: reconfigurable and hierarchical materials, novel and entirely new functional and structural materials, the science of self-assembly (including directed self-assembly with non-traditional driving forces), predictive design of materials, multi-component materials incorporating hierarchical constructs, materials compositions and architectures for unprecedented property development, functional integration of materials, analytical techniques for interrogating multi-dimensional evolution of structures, properties and failure, and defect science and engineering. New concepts for materials with a programmable or adaptive response to external stimuli, for materials with a dramatic improvement in behavior in extreme environments and dynamic driving forces, and for new materials with extraordinary behaviors are of interest. New concepts of fundamental mechanisms to achieve extraordinary electronic, photonic, magnetic, mechanical, and thermal properties, the engineering of imperfections and defects to achieve new functionality, and the optimal design and control of the processing-microstructure-property relationships for the fabrication of novel structural and functional materials are relevant to this program.

This is a program spanning the interests of the ARO materials program areas, in order to exploit new opportunities in materials science in the international community. This program area will concentrate on international research, research results, or research opportunities which are

unique and different from those accessible in the United States research community. Over time, new areas of research in fundamental materials science can develop that provide previously unforeseen opportunities for accelerating scientific progress, and this BAA is intended to cover these cases as well.

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 materials 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: polymers; colloids; nanocrystals; liquid crystals; functional biomaterials; and/or hybrids of these materials. Emerging research foci include: non-equilibrium and dissipative self-assembly; 3-D photonic crystals and structural color; interactions between self-assembled materials and water; non-traditional assembly directing forces (e.g., turbulence); and in situ reinforcement learning or evolutionary algorithms to direct assembly towards desired targets.

Reconfigurable and Hierarchical Materials supports the design and synthesis of materials capable of reversible transformations, as well as hierarchically structured materials. 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 and hierarchical materials systems of interest include: bio-mimetic materials; liquid crystal elastomers; colloidal metamaterials; 3D/4D metamaterials; and active matter. Emerging research foci include: 3D/4D printing off

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 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. Emerging research foci 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 behaviors across a broad spectrum of 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. high strain rate, multiaxial, and/or high cycle loading. Areas of interest include materials that actively respond to dynamic loading environments and other external stimuli through rapid adaptation of shape, topology, or mechanical properties. 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) Prokaryotic Survival Mechanisms in Challenging and Extreme Environments and (ii) Analysis and Engineering of Microbial Communities.

The Prokaryotic Survival Mechanisms in Challenging and Extreme Environments thrust focuses on the study of the cellular and genetic mechanisms and responses that underlie not just microbial survival in the face of environmental stress, but also the ability of specific 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 the mammalian microbiome 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.

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 mathematical models that are particularly exacerbated by complex macroscopic phenomena. While models have traditionally relied on tuned, empirically inspired closures, 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. By leveraging available prior knowledge such as conservation laws, invariances, symmetries, graph interaction structure, and information geometry, the program seeks to improve predictive horizons beyond naïve interpolative data fitting across a variety of disciplines. The program particularly seeks modeling frameworks that can be adapted to span a variety of disciplines where complete first principle descriptions are unavailable, computationally inaccessible, or that require inference of missing and incomplete information in problem descriptions to enable rapid predictions for applications ranging from anomaly detection to design and planning. Although they break down into more specific research directions, the three thrust areas of interest to the Modeling of Complex Systems Program are 1) development and analysis of new, general, outer-loop modeling and data assimilation frameworks 2) validation metrics for models of complex phenomena that avoid overfitting phenomena and 3) data topology, hierarchical compression, and nonlinear sparsity in quantifying optimal minimal model state representations across the range of observed emergent system complexities.

Note that the research in modeling of complex phenomena supported by the Modeling of Complex Systems Program is primarily mathematical analysis and not numerical analysis or computational mathematics. Rather than demonstrating asymptotic convergence of numerical methods to an assumed mathematical model form, the goal instead is in the development of frameworks capable of asymptotic convergence of predicted uncertainty bounds to observed distributions under the assumptions of finite complexity computation and limited data availability.

Models of particular complex systems that address and are to be utilized for more specific purposes and objectives will be assessed within the context of one of the program's other modeling thrust areas. Research carried out under this section should address the general theory and analysis of mathematical modeling from a broader perspective.

Furthermore, any modeling research effort that could be of benefit to military applications but that might not fall directly under one or more of the program thrust areas will still be considered, particularly if the innovation in the modeling and analysis are significant and noteworthy.

The three major areas and subsequent sub-areas of research for the Modeling of Complex Systems Program are described further below.

Outer-Loop Modeling Frameworks and Analysis
Mathematical modeling is fundamental to nearly every other direction of research in the physical, social, and computational sciences. A common element of modeling – even if the phenomenon in question is highly complex – is truncation and simplification that sacrifices realistic application and utility for computational tractability. This is particularly true for enabling outer-loop models such as those used in design optimization, uncertainty quantification, model predictive control, and inverse problems. Where necessary, data-driven simplifications motivated by observed regularity with corresponding uncertainty bounds are preferred to ad hoc assumptions. Modeling frameworks are desired that are able to eschew the usual computational simplification assumptions and realistically capture, adequately govern and/or control, and effectively operate within the particular complexities of real-world environments and phenomena, while maintaining sufficient computational tractability to provide testable predictions at relevant timescales. Of specific interest are hybrid model frameworks that capture both causal and predictive features, data assimilation in compressed spaces, probabilistic modeling frameworks for the nonlinear evolution of uncertainty, and applications of categorical models.

Validation Metrics
A critical component of any mathematical modeling framework, reliable validation metrics are required to attain confidence in model predictions. Traditional metrics, such as a few low moments of quantities of interest, often leave system characteristics unconstrained for phenomena in which observers in general and the Army in particular may later become interested. This is particularly true of rare event and heavy-tailed phenomena. With the application of increased model complexity to many complex phenomena, as in the case of highly parameterized purely data-driven models, new metrics need to be developed to balance model expressivity with the risk of overfitting. Approaches for understanding the bounds of model validity near mode transition boundaries where model assumptions fail are also particularly critical. As is the case for the modeling effort, these metrics should preferably be in a complete mathematical analytical framework, which is to say, in part, that they should derive from the problem in question and its inherent complexity as opposed to a situation in which one forces the model to fit an a priori chosen metric. Further, with the proliferation of post-hoc data-mining, development of rigorous metrics that are resilient to overfitting are particularly critical.

Data Topology, Hierarchical Compression, and Nonlinear Sparsity

Representation of complex, irregular geometric objects and complicated, often high-dimensional, abstract phenomena, functions, and processes is fundamental for Army, DoD, and civilian needs. These compressed representations are often a critical initial step in modeling of any complex system. Such needs arise in the multiscale models of physical phenomena, coarse-graining, sociological and biological objects, information flow, and many other contexts. While any finite representation of real data is necessarily lossy, finding efficient spaces that retain the information necessary for a given prediction task is a critical component of building computationally tractable models. Any research that incorporates an innovative information geometric and/or topological approach to address a problem with military, defense, and intelligence applications is welcome and will be considered, but there are three specific threads that are of particular interest to this thrust of the program: 1) geometric data analysis, and 2) multiscale geometric modeling, including dynamics and physical modeling on domains with fine, complex, geometric and/or topological structure and 3) the fundamental mathematical structure of closure models.

Geometric data analysis includes – among other subfields – topological data analysis, subspace analysis, manifold learning, empirical dynamic modeling, and dimension reduction techniques. Current research directions of importance to Army applications include video, audio, and image processing (i.e. mathematical signal analysis), fast and accurate object recognition (i.e. reconstructing and matching geometric data through queries over a database), embedology, causal inference, geometrically motivated methods and structures for working effectively with large – and often real-time extracted – data sets that may be corrupted in some way (e.g. missing or distorted data), and the application of persistent homology in the detection and classification of signals by shape. New approximation theory that does not require the classical assumptions – primarily smoothness – and that provides structure for the many new non-smooth approximation techniques currently under investigation is required. Concurrently, research on the metrics by which we measure and evaluate the approximation is needed.
Additionally, approximation theory for information flow and other abstract phenomena in large wireless communication, sensor and social networks is also of interest. The approximation theory developed under support of this program is expected to provide building blocks for computational geometry, pattern recognition, automatic target recognition, visualization systems, information processing and network information flow.

Multiscale geometric modeling, analysis, and dynamics are of particular interest, both in the context of models of physical phenomena over real-world terrain and in the aforementioned complex, high-dimensional data structures. Models that make use of self-similar structures and recursively defined spaces (e.g. fractals, solenoids, etc.) would be of great interest in adapting or enhancing current techniques in areas such as data mining, fluid and heat flow, and search, evasion, deployment, and maneuver over complex terrain that exhibits self-similar properties (e.g. urban or mountainous terrain). Current techniques for dealing with complex dynamical processes and large, noisy, and possibly corrupted data sets could be greatly improved in both the time and efficiency realms by employing techniques from scale symmetry, which often allows one to reduce a large and unwieldy number of variables to a more manageable problem if the variables are appropriately scaled.

Finally, closure models, and particularly those that exploit self-similarity or other structural invariances, are of interest. However, reliance on model closures remains contingent on the development of rigorous mathematical foundations for highly parameterized models such as those arising from neural network approximations in establishing convergence properties, uniqueness, and equivalence of the resulting inferred maps.

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.

Army Research Office (ARO) Research Topic

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

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ARL Office: Army Research Office (ARO)
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 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) Multisensory Synthesis and (ii) Neuronal Computation.

Multisensory Synthesis
The Multisensory Synthesis thrust aims to understand how the human brain functions in relation to the interaction of sensory, cognitive and motor processes during its performance of real-world tasks via mapping, quantifying and modeling distributed neural and physiological processes that mediate human decision making, emotion and rapid adaptation to change. Research in this thrust can broadly address research in areas such as developing types of brain feature extraction that explain significantly more human behavioral variance than previously possible; predicting and measuring moment-to-moment human cognitive and emotional performance in complex environments; developing interfaces and methods that enable greater levels of bi-directional human-machine interface; defining the multiscale mechanisms underlying cognitive fatigue; or deploying computational tools concurrently with neurostimulation to understand, learn, and manipulate human cognitive performance and avoid cognitive failures.

Neuronal Computation
The Neuronal Computation thrust is focused on broadening understanding of the mechanisms employed by neuronal circuits to generate desirable computations, incorporate learning and facilitate evolutionary change. Research in this thrust can broadly address research in areas such as studying aspects of multiscale information processing dynamics mediating computations between neurons, glial cells and blood vessels as well as identifying how these circuits generate

desirable computations over multiple timescales; discovering mechanisms for bidirectional control within the microbiome-gut-brain axis and the impacts of environmental and physiological stressors on gut-brain circuits and cognitive performance; or exploring the interplay of small- scale multiphase flows with biochemical and neurophysiological processes to characterize regulatory mechanisms underlying brain glymphatic clearance and integration with sleep and circadian rhythms.

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-safe (>1.55), 3-5, 8-12, and 18-24 microns regions for various applications, such as LADAR, 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. Research addressing efficient, novel optical components for high-speed switching based on plasmonics, quantum dots, metamaterials or other regimes may be of interest. Emitters and architectures for novel display and processing of battlefield imagery are important.

Recent advances in neuromorphic photonic information processing and computation are highlighted as a thrust of interest. Photonic processing within a photonic IC (PIC) requires smaller and more energy efficient modulator devices on the order of 5 microns or less and 1

femtojoule/bit. Speeds of modulation should be several Gb/s or higher, and the insertion loss should be < 0.1 dB to achieve cascaded modulators of < 1 dB/cm. Modulation at 16 bit or higher resolution will be required for PIC processor implementations. Other advances leading to enhanced 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 bosonic properties of light (over the limited fermionic charge) will be considered. While single photon, quantum communications and quantum integrated photonics are not focused upon here, low bit energy signals (photon count < 500) can be considered. Such research could impact single photon regime work with overlap due to similar quantum optics considerations.

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 Chemisty
Announcement ID: ARL-BAA-0002

TPOC: Dawanne E Poree, PhD - dawanne.e.poree.civ@army.mil - (919) 549-4238
ARL Office: Army Research Office (ARO)
Discipline: Chemistry;Materials Science
ARL Foundational Research Competencies: Biological and Biotechnology Sciences;Mechanical Sciences;Sciences of Extreme Materials
Army Modernization Priorities:
Keywords: polymers, stimuli-responsive materials, polymer-based composites, hybrid materials

Description:
The goal of this Program is to understand the molecular-level link between polymer microstructure, architecture, functionality, and the ensuing macroscopic properties. Research in this Program may ultimately enable the design and synthesis of functional polymeric materials that give the Soldier new and improved protective and sensing capabilities as well as capabilities not yet imagined. This Program is divided into two research thrusts: (i) Precision Polymeric Materials and (ii) Complex Adaptive Polymeric Systems. Within these thrusts, high-risk, high-payoff research is identified and supported to pursue the Program's long-term goal.

The Precision Polymeric Materials thrust supports research aimed at developing new approaches for synthesizing polymers with precisely-defined molecular weight, microstructure, architecture, and functional group location. Of particular interest are research efforts that focus on novel methods for achieving sequence and tacticity control in synthetic polymers as well as enabling the synthesis of novel 2D organic polymers. Also of interest to this thrust are research efforts that further explore how precise molecular structure influences polymer morphology and bulk macroscopic properties. Bulk properties of enduring interest include mechanical, optical, and transport. An area of particular interest is the rational design of polymers with enhanced intrinsic thermal transport properties.

The Complex Adaptive Polymeric Systems thrust seeks to understand how to precisely and predictably control polymer assembly and response to achieve polymeric systems with a diversity of functions and behaviors. Of interest to this thrust are research efforts that explore how polymer structure influences interactions with dissimilar materials (e.g., inorganic or biological materials) to render functional hybrid assemblies. Also of interest is the design and synthesis of polymeric materials that exhibit programmed molecular responses to external stimuli. Of interest in this regard are research efforts related to stimuli-responsive self-immolative polymers, polymer mechanochemistry, and stimuli-mediated polymer assembly. Additionally, an emerging area of interest lies in the integration of logic-based responsive behavior, computation, and feedback mechanisms to engender complex responsive behavior.

Army Research Office (ARO) Research Topic

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

TPOC: Sara Gamble, PhD - sara.j.gamble.civ@army.mil - (919) 549-4241
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: 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.

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.

Army Research Office (ARO) Research Topic

Title: Solid State Electronics and Electromagnetics
Announcement ID: ARL-BAA-0028

TPOC: Joe X. Qiu, PhD - joe.x.qiu.civ@army.mil - (919) 549-4297
ARL Office: Army Research Office (ARO)
Discipline: Electronics;Materials Science;Physics
ARL Foundational Research Competencies: Electromagnetic Spectrum Sciences;Network, Cyber, and Computational Sciences;Photonics, Electronics, and Quantum Sciences
Army Modernization Priorities: Network/C3I
Keywords: Electronics; Heterostructures; Devices

Description:
This research area emphasizes efforts to discover and create unique electromagnetic phenomena in solid-state materials and structures. Innovative research is sought in areas involving quantum phenomena, internally and externally induced stimulus, and novel transport and electromagnetic interaction effects in solid-state electronic structures. This basic research will address issues related to design, modeling, fabrication, testing and characterization to include the ability to individually address, control, and modify structures, materials and devices, and the assembly of such structures with atomic-scale control into systems. It will seek to realize advanced device concepts with revolutionary capabilities.

This program will explore the latest developments in semiconductor materials and device physics, such as negative capacitance transistors, tunneling field effect transistors and ultra-wide bandgap materials. More importantly, it will emphasize scientific discoveries in the frontier of nanoelectronic materials and structures. Scientific opportunities in this research include, but are not limited to, quantum-confined structures (nano-tubes/-wires/-dots) and large- scale precise alignment and integration of these structures to create collective behaviors; 2D atomic crystals and their heterostructures; complex heterostructures of 2D crystals, topological insulators, Dirac and Wely semimetals and other dissimilar nanoelectronic materials potentially leading to unique interfacial phenomena; spintronic, valleytronic, and mixed domain (charge/spin/quantum degrees of freedom) device concepts. Of interest are quantum transport phenomena such as ballistic transport and hydrodynamic flow, dissipationless transport in topologically protected edge states, and pseudo-relativistic transport of massless Dirac fermions. Exotic electromagnetic phenomena which require theoretical formulations beyond the well-established Maxwell’s equations, such as axion electrodynamics, chiral anomaly and spontaneous symmetry breaking, are also relevant. Interfacial proximity effects in these heterostructures that lead to unique electromagnetic properties will also be considered.

Army Research Office (ARO) Research Topic

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

TPOC: Unspecified TPOC - ARL BAA Mailbox - arl_baa@army.mil - none
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: Michael P. Bakas, PhD - michael.p.bakas.civ@army.mil - (919) 549-4247
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 refers to materials such as metals, ceramics, and composites that in bulk are used in applications that support or transmit mechanical stresses.

Current Thrusts:

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 precursors, electromagnetic field interactions, and developing consistency in additive manufacturing processes.

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

TPOC: Carl E Busart, PhD - carl.e.busart.civ@army.mil - (301) 394-1266
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.

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) 394-2138
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: Artificial Intelligence and Machine Learning_Managing Massive Data Sets
Announcement ID: ARL-BAA-0039

TPOC: AI/ML Managing Massive Data Sets Topic - usarmy.adelphi.devcomarl.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: Autonomous Sensing and Information Fusion for Advanced Indications and Warnings
Announcement ID: ARL-BAA-0064

TPOC: Thomas W Walker - thomas.w.walker68.civ@army.mil - (301) 394-0756
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 non-traditional sensing technologies for robust detection and exploitation of unique objects of interest. Fusion of multiple information sources, not only static ground sensors but relocatable unattended ground sensors, typified by small autonomous platforms, is essential and much of the program will be focused on foundational work aimed at facilitating the correlation of relevant information between all sensing sources. 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.

Army Research Directorate (ARD) Research Topic

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

TPOC: Jaroslaw Knap, PhD - jaroslaw.knap.civ@army.mil - (410) 278-0420
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 SOTA 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: Electromechanical and magnetomechanical power conversion
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

TPOC: Bruce R Geil - bruce.r.geil.civ@army.mil - (301) 394-3190
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

TPOC: Amar R. Marathe, PhD - amar.r.marathe.civ@army.mil - (301) 873-2886
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: Extramural Program in Reactive Chemical Systems
Announcement ID: ARL-BAA-0067

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ARL Office: Army Research Directorate (ARD)
Discipline: Chemistry;Materials Science
ARL Foundational Research Competencies: Sciences of Extreme Materials
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 interfacial activity and dynamic nanostructured and self-assembled chemical systems to provide unprecedented hazardous materials management capabilities and soldier survivability. This Program supports basic research with Army relevance in surfaces, catalysis, organized assemblies, and stimuli-responsive chemical systems.

This program is divided into two thrusts: (i) Nanostructure Surface Interactions and Reactivity and (ii) Synthetic Molecular Systems.

Nanostructure Surface Interactions and Reactivity
This thrust supports research on understanding the kinetics and mechanisms of reactions occurring at surfaces and interfaces and the development of new methods to achieve precise control over the structure and function of chemical and biological molecules on surfaces. Specific areas of interest include adsorption, desorption, and the catalytic processes occurring at surfaces and interfaces and the interface between nanostructures and biomolecules to generate advanced materials.

The Synthetic Molecular Synthesis
This thrust supports research that imparts multifunctionality, stimuli-responsive and dynamic behavior to completely synthetic molecular and chemical systems. Research of interest includes design and development of nanostructured scaffolds and sequential catalytic systems. This thrust also supports research aimed at exploring the properties and capabilities of self-assembled and supramolecular structures, including their functionality, and how to control assembly in different environments. In addition, the emerging field of dynamic, responsive, multi-functional materials have great potential to provide revolutionary new capabilities. A specific technical area in this field is "targeting and triggering" in which a specific chemical (or event) is targeted (recognized) and that recognition triggers a response. Particular technical challenges of interest include selective and reversible recognition, amplification, and multi-responsive systems. Alternative approaches to selective, yet reversible, recognition are needed. Amplification includes an understanding of how to amplify the response from a single molecular recognition event to a multi-molecular response with approaches that promote chain reactions, self-amplification or

cascade-type reactions within a single system. Multi-responsive systems in which specific stimuli trigger distinct responses are also of interest.

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?

Army Research Directorate (ARD) Research Topic

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

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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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ARL Office: Army Research Directorate (ARD)
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: 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: Networking Structure, Dynamics, and Protocols
Announcement ID: ARL-BAA-0045

TPOC: Robert J Drost, PhD - robert.j.drost6.civ@army.mil - (301) 394-0158
ARL Office: Army Research Directorate (ARD)
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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ARL Office: Army Research Directorate (ARD)
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

TPOC: Gregory Mitchell, PhD - gregory.a.mitchell1.civ@army.mil - (301) 394-2322
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

TPOC: Song J Park - song.j.park.civ@army.mil - (410) 278-5444
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

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: 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

TPOC: Asha J Hall, PhD - asha.j.hall.civ@army.mil - (410) 278-2384
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.

Army Research Directorate (ARD) Research Topic

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

TPOC: Wes Wesley Tipton, PhD - charles.w.tipton6.civ@army.mil - (301) 394-5209
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: 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

TPOC: Michael Fish, PhD - michael.c.fish.civ@army.mil - (301) 394-3173
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° 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 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
2. Improve availability and precision synchronization of time beyond current GPS time transfer capabilities
3. Provide improved resilience of position information at GPS-level accuracy and precision greater than GPS
4. Improve access to and integrity of navigation and communications information
5. 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 Sciences
Announcement ID: ARL-BAA-0052

TPOC: Fredrik Fatemi, PhD - fredrik.k.fatemi.civ@army.mil - (301) 394-1531
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, 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 entanglement.

Our efforts conduct cross-cutting foundational research to exploit quantum effects for 1) novel sensors / 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 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).

Army Research Directorate (ARD) Research Topic

Title: Real-Time, Scalable Data Analytics for the Army
Announcement ID: ARL-BAA-0043

TPOC: Manuel M Vindiola - manuel.m.vindiola.civ@army.mil - (410) 278-0172
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:
This topic focuses on understanding and exploiting the fundamental aspects of large-scale, real time, multi-variate data analytics. Experiments, observations, and numerical simulations are on the verge of generating extreme quantities of data at ever increasing rates that must be processed for understanding and consumption. These massive amounts of data are distributed across disparate locations and pose a challenge in providing real-time analytics that support U.S. military operations. Technical areas of research include Brain-inspired computing, Computational Methods for Large-scale data analytics, Data Intensive Computing Methods, and Machine Learning and Artificial Intelligence research. Brain-inspired computing research addresses the fundamental question of how our understanding of neuroscience, brain structure, and function inform the development of computing architectures to address Army research challenges. The benefits of this research may be the discovery of computing structures that are more powerful and learn more generally than the structures currently used. Computational Methods for Large-scale data analytics research is focused on identifying, evolving, and maturing innovative computational algorithms and methodologies to describe, model, simulate, solve, explore, and optimize control and coordination of computational systems impacted through physical events. Data Intensive Computing Methods include the creation of scalable mathematical algorithms, predictive computational methods, real-time data analytics, model order reduction, human cognition based mathematical approaches, neuro- and biologically-inspired methods, science of analyzing large-scale data from wearable electronics/technologies, large-scale data sensing/compression methodologies, large-scale visual analytics, live-virtual methods for training, data mining/learning mathematical algorithms for distributed heterogeneous computing systems, and reinforcement learning. Machine Learning and Artificial Intelligence research focuses on the development of new methods and algorithms, and how to optimally implement these approaches on emerging and domain-specific processors.

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) 394-0423
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.

Army Research Directorate (ARD) Research Topic

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

TPOC: Unspecified TPOC - ARL BAA Mailbox - arl_baa@army.mil - none
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: 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.