Laboratory-University Collaboration Initiative (LUCI)

FY27 Scientific Areas of Interest
1. **Applied Mathematics and Computational Science**
2. **Networks and Artificial Intelligence**
3. **Neuroscience and Fundamentals of Cognition and Intelligence**
4. **Fundamentals of Bioengineering**
5. **Quantum Information Science**
6. **Electronics, Photonics and Quantum Materials**
7. **Soft Materials and Multiscale Structures**
8. **Material Science**
9. **Other Fields of Research**

Area 1: Applied Mathematics and Computational Science
Advances in mathematics and their implementation on advanced information systems provide
the basis for critical capabilities across a broad range of DoD applications. These range from
numerical simulations of physical systems with extreme complexities of scale and structure, to
revolutionary approaches to Artificial Intelligence (AI) with abstract reasoning abilities that
match or exceed that of humans. Advanced mathematical concepts underlying future AI systems
more accurately belong in Area 2 described below, and while there can be significant overlap,
this section is principally focused on areas in Applied Mathematics that can enable revolutionary
computational and modeling capabilities for the purpose of simulation and design of complex
physical and engineered systems. These may include optimization, uncertainty quantification,
numerical analysis, applied analysis, stochastics and statistics, as well as applied geometry and
topology, applied category theory, or other.

The predictive simulation of complex natural environments or engineered systems is a problem
of high relevance to the DoD. Of particular interest are extreme cases of multi-physics and multi-
scale problems, as well as conditions that challenge the assumptions behind reductionist
approaches, such as global interactions and/or far-from-equilibrium conditions, including data
representations. Engineered systems of interest can be connected or distributed, and controlled
dynamics can be local and global, and optimized decision-making may need to be synthesized
from distributed data sources and agents. There is a broad range of areas of study that are of
potential interest, including, for example: discrete, continuous and hybrid representation spaces
and dynamics; sub-scale dynamics; model discovery and/or reduction; stochasticity and
uncertainty; control and decision-making; optimization; composition; symmetry, geometry and
topology. This list is not exhaustive: all mathematical and computational approaches that can
yield revolutionary capabilities in spanning scales and domains under a broad range of
conditions, and redefine computational paradigms for emerging fields of science, are welcome.

The ability to obtain accurate solutions at very high rates is a key and enabling step for the
design, analysis and manufacturing of future platforms and networks for national defense.
Transformative, 'blue-sky' research in this topical area can therefore enable visionary concepts,
such as simulating complete virtual copies of highly complex engineered or natural systems for
accurate and time-relevant predictions. It can also stimulate advances in other scientific fields by

creating new levels of understanding of physical phenomena which can be difficult to accurately measure or reproduce in laboratory conditions. For example, understanding and predicting the dynamics and aging of materials under various environmental conditions is a challenging problem with a high impact on the life cycle and cost of military systems, but there are many examples of grand-challenge problems of high interest to the DoD. However, we emphasize that this topic is not looking for algorithm design and incremental advances in computational speed, but for fundamentally new and disruptive mathematical approaches. Rare and extreme events in natural and engineered systems can also have a profound impact on platform design and survivability, and fundamental advances in the long-term prediction of extreme events in a variety of physical, engineered or networked systems, are also of interest. These are just a few examples, and the DoD is interested in a broad range of applications, from physical, chemical, and biological systems, to artificial constructs (e.g., networks[1], robotics, aircrafts and other platforms).

This program is looking for new and comprehensive ideas, which may or may not be listed above, but with the potential to radically alter our frameworks and visions for advanced computing in the service of scientific discovery and modeling. All revolutionary approaches in applied mathematics and computing are of potential interest, as long as they can be argued to radically transform our abilities in information science, for enabling important, future DoD capabilities.

As a final note, although this research area is not restricted to computing performed on large-scale platforms, it is not concerned with new computer architectures, the design and manufacture of those being better suited elsewhere in this announcement. Similarly, quantum algorithms belong to the area of quantum information sciences (Area 5), but can be considered here as part of a general computational framework, e.g., leveraging quantum formalism or hybrid algorithmic approaches.

Area 2: Networks and Artificial Intelligence
New mathematical concepts are sought to model the extreme complexity of networks in a rapidly changing, stochastic and adversarial environment. This includes their dynamics, optimization, and resilience, and may involve a wide range of physical interactions, as well as information resource management, cybersecurity, and social and psychological interactions with human agents. Complex networks of interest are also found in biological, chemical and socio-technical systems, as well as in the combination of multiple domains. There are multiple cases of couplings between networks and across domains that are of high interest to the DoD, and this topic calls for rigorous and very novel approaches to solve such problems at scale, with the potential for generalizability to a wide range of applications.

This topic also calls for novel approaches in Machine Learning (ML) and Artificial Intelligence (AI). While AI is also covered in Topic #3 below, the key element here is the creation and development of new *mathematical* approaches to ML and AI. In particular, this topic welcomes original ideas that target behavior prediction of large scale and coupled networks of autonomous machines, capable of adaptive learning and decision-making – including distributed and

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[1] Also covered in Topic #2.

collective decision-making – under challenging or adversarial conditions. This includes their interactions with networks of human agents, such that both can learn and work in cooperative fashion. For example, the mathematical representation of both machine and human information and knowledge, as well as strategies and intents, towards common understanding and shared decision-making, is also of particular interest for this problem.

Standard methods in network science or machine learning are generally insufficient and of little interest in this program. Rather, we are seeking transformative and novel approaches that can address the extreme complexity of the most challenging problems, such as: combined and interacting physical and social dynamics; co-evolving agent dynamics and network topologies; non-equilibrium and open systems; uncertain games with multiple time scales and objectives, and with dynamic evolution of the rules of the game. Higher levels of data and knowledge representation and operations on those structures, can be needed to solve these problems. These are examples of challenging problems of interest, and others can be suggested under this topic.

Fundamental research in this topical area may come from different fields of mathematics and computational science, e.g., from distributed optimization, geometry and topology, and multi-agent game theory, but potentially radically new ideas may be leveraged from different fields, such as statistical physics, biology, and other.

Network science also underlies advances in robotics and autonomy. Despite the widespread use of artificial neural nets (ANN), there are still many opportunities for mathematical research that can provide deep insight into the design and optimization of radically new neural nets with transformative capabilities. Such advances are needed to create AI that can ultimately match or exceed human-level reasoning abilities. Again, these new mathematical approaches may rely on inspiration from disparate fields, whether as closely related as neuroscience, or as remote as quantum information theory. Of particular interest are approaches that provide a reasonable pathway towards accurately and efficiently formulating key activities associated with human intelligence. These include for example "common-sense" reasoning, physical "intuition" to rapidly learn constraints, or a theory of mind when interacting with AI agents. "Collective" intelligence can provide another exponential factor in learning and adaptability. The mathematics may also be intimately related to the architecture underlying the computational processes, such as neural network topologies and non-linear thresholding, memory kernels, time delays and analog transforms. Evolutionary (not in the sense of incremental) AI concepts are also of interest, from AI training AI to adaptive neural topology and hierarchical abstraction, based on the data environment, as well as sensory and physical interactions in the case of advanced robotics. Another example of particular interest is the ability of AI to demonstrate "creativity", well beyond the constrained framework of generative networks, and into the realm of ideas and concept generation, such as those required for scientific discovery. Finally, the relation between AI as implemented by ANNs and cognitive and psychological concepts such as behavior norms, e.g., "ethical" rules, is also of interest, leading to the question of algorithmic or mathematical formalization of such rules in a robust, resilient and adaptive fashion.

It is emphasized here that this topic does not call for data analytics or software development, but for mathematical concepts and methods specifically aimed at the complexity of scale and diversity of interactions. As with all scientific areas listed in this announcement, radically new

approaches are sought, rather than incremental research.

Area 3: Neuroscience and Fundamentals of Cognition and Intelligence

The DoD is interested in forward-thinking theoretical, computational, and experimental basic research in neuroscience and associated fields, which can potentially provide revolutionary insights into the foundations of brain function and development, towards a deeper and more comprehensive understanding of the neural processes underlying the various levels of cognition, including learning, reasoning, and intelligence. This improved understanding can guide the design of revolutionary approaches to Artificial Intelligence (AI), including, but not limited to, the reproduction of human-like capabilities. It also has the potential to enhance human capabilities, such as faster and more accurate information processing, more robust decision making, greater resilience, and more effective communication, in both human-human and human-machine teams. Fundamental research in neural activity and brain functions and development, from genetic programing of cellular growth and differentiation to mechanisms of network formation and reconfiguration, can also lead to the development of new brain-machine interfaces (BMIs) that could facilitate the integration of humans and future AI agents, offer new and enhanced sensing abilities, and allow smooth motion of motor augmentation devices (e.g., exoskeletons) or prosthetics, or help warfighters recover from brain injury. These are examples of applications of interest, and other visionary applications may also be considered.

Novel neuroimaging approaches and other comprehensive and high-precision measures of neural activity, artificial neural network (ANN) architecture experimentations and new learning strategies, as well as improved mathematical tools, potentially provide a foundation for novel computing architectures with high-level, human-like cognitive functions. This reverse-engineering of human and/or animal brain functions into ANNs could initiate an iterative feedback loop to bootstrap our understanding of the brain, make giant steps towards artificial general intelligence (AGI), and design brain-machine interfaces that can repair or augment brain functions. Fundamental research in experimental, computational and mathematical neuroscience could therefore provide key insights into perception, learning, inferential reasoning, and decision-making in future designs of ANNs, a key interest of this program.

Human operators are called upon relying on increasingly capable and sophisticated AI systems, but such interactions can be brittle, potentially with catastrophic consequences. Despite greater insight into the neural basis of some brain functions, we lack the ability to map between abstract thoughts or consciousness and specific neural pathways, and to make these high-level cognitive processes explainable to machines. Opportunities abound for the discovery of new theories that can rigorously link higher-level cognitive operations with lower-level biological and neurological mechanisms.

The human brain also does not mature in isolation; it is part of a body embedded in a complex physical and social environment. Human brains have developed the ability to reason using the subtle language of social interactions via physical cues or language. Understanding this ability at a fundamental level can help develop *new* ways to interact with future AI systems, and provide a basis for rigorous integration of human cognitive models into large scale social interaction models. These may eventually provide cues to the design of AI systems with social norms.

Understanding how cells are specified during embryonic development and the mechanisms controlling neural circuit formation could have a formidable impact in the field of neuroscience. This includes genetic control of cell differentiation, as well as bio-chemical and mechanical signaling, in a self-developing environment. Understanding and prediction, at scale, of these mechanisms can lead not only to novel treatments for brain injury and neuro-degenerative diseases, but also to revolutionary ANN models of brain function and cognition. It can also lay the foundational knowledge for augmenting/enhancing brain functions, or creating new ones *in-vitro*, whether inspired by evolutionary adaptation or tailored for artificial environments. The relation between brain function and biological processes, at any level of development, may also yield opportunities to re-examine the fundamental concepts of brain and intelligence, and widen the range of possibilities for organisms and living matter with cognitive functions.

We emphasize that this topic calls for fundamental, 'blue-sky' research, and should not be incremental but far-reaching and visionary. Inspiration and approaches may come from different directions and leverage various fields of study, approaches may be *in-vivo*, *in-silico* or *in-vitro*, or combinations thereof.

Area 4: Fundamentals of Bioengineering

Fundamental research in bioengineering harnesses the power of multi-disciplinary approaches to study and leverage biological processes that can transform multiple technologies of high importance to the DoD, and enable new ones. These may be, for example: new sensing modalities and self-assembled sensory networks; structural biomaterials and electronics with designed functionalities; synthetic and controlled synthesis of complex living matter, e.g., artificial organs or even complete organisms; and many new capabilities that are yet to be discovered. Fundamental and far-reaching advances are required in multiple, often inter-connected research directions to enable such revolutionary abilities. These include (but are not limited to): gene-editing, epigenetics, synthetic biology, computational biology and bioinformatics, biophysics and biochemistry, and other approaches to understand and design the interaction between living matter and conventionally engineered, abiotic systems, predict biological system response and evolution, and control their functionalities *ab-initio*, in realistic and dynamic environments.

One of the primary objectives of bio-engineering research for the DoD has been, and still remains, the design and manufacture of complex biomaterials. This interest extends beyond bulk biochemical processes, as biological functions are also the result of collective self-organization across multiple scales, from complex bio-molecular structures to subcellular and multicellular assemblies. The formation of specialized micro-structures, the result of a complex interplay between biochemical and physical processes, and improved understanding, prediction and control of these interactions toward revolutionary concepts of the first principles of biological processes, biomaterials, and physical structures, are of high interest.

Biomaterials are also interactive and can be subject to unpredictable environmental conditions. Precise engineering of the programmability of biochemical and biophysical functions within individual organisms or microbial consortia, and their transient response to environmental changes

and stimuli, are required for safe deployment and to prevent undesired natural activity. The openness, as well as the variability of the environment and time scales, make this problem particularly difficult. For example, predictable aging of abiotic materials is already a formidable challenge, which yet still pales in comparison with that of living materials. Thus, rigorous approaches to control, verifiability and trust are also of special interest, and perceived as key enablers to widespread development of bio-engineering technology.

There is also significant interest in the interfacing of biological and abiotic systems, leading to the design and engineering of hybrid materials, components, platforms, and systems, whether for electronics, chemical processing, sensing, or other functions with transformative potential. This includes biological/DNA computing, given the potential for biological systems to read, write, storage, and process information in massively parallel fashion, with negligible or unconventional power requirements. The leverage of biomaterials and structures for sensing, made exquisitely sensitive and optimized though eons of evolution in natural organisms, is another area where fundamental research may play a role, towards better understanding of the complex interactions and self-assembly of the sensory devices, and towards creating new pathways to similar abiotic or hybrid sensors. Generally speaking, the combination of such biological and abiotic components and functions has the potential to open a new design space for engineered systems with a revolutionary impact on DoD applications.

These are only suggested areas, and the LUCI program is interested in basic, innovative, and transformative proposals in all aspects of fundamental research in bioengineering, that are well beyond technology development. This program calls for new, transformative approaches to break the barriers limiting our understanding of underlying biological processes and to solve new or long existing problems, with far-reaching and visionary potential.

Area 5: Quantum Information Science
Quantum Information Science (QIS) focuses on the creation, control, manipulation, and detection of non-classical states of light and matter with the potential for exceeding classical limits in areas ranging from communications, sensing, metrology, and imaging to computing and simulation, and other applications yet to be discovered. Recent experiments have suggested that the regime of "quantum supremacy" has been reached, or is close at hand, and the field is continuously the subject of significant technological achievements and scientific discoveries, and constantly the source of surprise. There is high interest in QIS for its potential impact on DoD capabilities including, but not limited to: ensuring information security; enabling novel materials discovery and design; attaining precise navigation and positioning without GPS; greatly improving sensing (local and remote), imaging and metrology.

Despite the widespread research activity by the academic community and very substantial commercial investments, many fundamental scientific questions remain open. For instance, while entanglement is a critical quantum resource that underlies multiple subareas within QIS, the generation, characterization, manipulation, and measurement of multipartite, structured and distributed entanglement still need exploration. The uniqueness of quantum resources affords exceptional opportunities for inventions that push the boundaries of human imagination. Thus, theoretical and experimental understanding, as well as optimal harnessing of quantum resources, are pivotal for the development of multiple facets of QIS. Rigorous analysis of the parameter

space where QIS can be most useful is still uncharted territory. On the theoretical side, new algorithms for physically realizable quantum systems are in eager demand, in order to push well beyond the classical possibilities in all aspects of information science, including generation, retention, transformation, protection, and transmission, as well as learning in the quantum machine learning (QML) paradigm. At the same time, significant innovations of the physical platforms are required, not simply to scale-up the number of qubits, but to extend their generalizability and practicality, as well as comprehend and exploit quantum mechanical behavior that incorporates interactions with other quantum information systems and the external environment. These couplings could be inadvertent by-products of the physical schemes, or cleverly designed to achieve optimal control and quantum coherence. Comprehensive approaches that effectively fuse theory with realistic experimental platforms are also welcome. Also of particular interest are fresh perspectives to quantum constructs that go beyond current circuit-based computational models or their theoretical equivalents, which may offer radically new concepts of quantum information processing. Furthermore, fundamental discoveries in the relationship between previously distinct disciplines, such as between quantum many-body systems and gravity in higher-dimensional space-time, raise the possibility of leveraging far-reaching ideas to create more general, hierarchical and powerful approaches to QIS (e.g. enhancing quantum computational complexity).

The LUCI program is interested in foundational theoretical and experimental concepts with broad impact that will significantly advance our understanding of quantum information and processes, and more notably, disrupt the current research directions of QIS. Approaches should be a departure from improvements aimed at narrow challenges or technological advancements of devices and components. Of particular interest are transformational ideas that reach beyond quantum analogies of classical concepts.

Area 6: Electronics, Photonics and Quantum Materials

Extraordinary physical phenomena in solid state materials remain a central research interest in the DoD, as nearly all new capabilities rely on advancing the state-of-the-art in material properties as well as material synthesis and processing. This topic focuses on innovative approaches to the discovery and predictive design of materials that exhibit previously unattainable – or unknown – electronic, photonic and/or other quantum functionalities. This topic also seeks advances in our fundamental understanding of the material properties, potentially opening new research directions in theoretical and computational physics, as well as new diagnostic methods with wide-ranging, transformative impact. It is expected that materials based on these new physical phenomena can ultimately lead to paradigm shifts in engineered platforms to modernize key DoD capabilities, from communications to sensing, computation, and other.

Remarkable electronic, photonic, and quantum mechanical phenomena can arise in materials under various circumstances, including the presence or breaking of various symmetries or quasi-symmetries (e.g., time-reversal, particle-hole, chiral, point group, etc.), existence or lifting of degeneracies, and/or manipulation, perhaps nonlinearly, by external excitations (electromagnetic waves, electric fields, magnetic fields, etc.). These new classes of materials can exhibit combinations of multiple phenomena, host various types of quasi-particles, or exhibit distinctive functionalities, including exceptionally enhanced or reduced sensitivities to external

perturbations. More broadly, such classes of materials can be found within bulks, interfaces, composites, photonic systems or even mechanical (phononic) ones, as well as for multiple dimensionalities, including synthetic ones. The interplay between local and global properties (e.g., topological order, non-classical entanglement), as well as the discovery and realization of new quantum phases, are also of particular interest. Fundamental issues may include new emergent physics, non-linear interactions, wave phenomena, coherence, dissipation, transport, fermionic/bosonic topological mode couplings, or anyonic statistics. Other considerations include the material physics in far-from-equilibrium conditions, such as those arising from coupling to ultra-fast excitations, driven states, high dimensional disorder, density of states, and thermodynamic trade-offs.

Many fundamental questions still remain to be answered, before bringing these new classes of materials across the threshold of practical applications, especially for the harsh operating environments frequently found in DoD-relevant scenarios. Unorthodox static and dynamic characterization approaches may need to be developed to directly probe and conclusively determine the origin of the electronic, photonic or quantum behavior. Clever approaches to scalable synthesis of materials are required to provide a pathway towards future applications. Radically new theoretical and computational approaches that are highly integrated with material characterization, synthesis and processing, are necessary to discover, understand and even predict the behavior, as well as guide physical realizations.

The LUCI program is interested in all of the above, and in the discovery of new classes of electronic, photonic and quantum materials that can lead to breakthroughs for DoD capabilities of interest. Of particular interest are radically new and transformative concepts, and innovative approaches in unifying theoretical ideas, computational methods, tailored diagnostics, and precise synthesis to discover and design extraordinary physical properties of materials.

Area 7: Soft Materials and Multiscale Structures

New material properties are expected to emerge via the design and control of hierarchical architectures. By carefully controlling manufacturing parameters, from micrometers down to nanometers or even atomic scales, materials with exceptional bulk properties can be obtained. These include for example, super-lattices (e.g., Moire), heterogeneous assemblies of low-dimensional structures (2D or 1D), quantum dots, nanoparticles, or ordered arrays of nano-holes. These materials and structures have already found unique applications, e.g., as meta-materials which can manipulate light in exquisite fashion for imaging, communication, or coupling amplification. Such structures and properties are also found in natural and organic materials, the result of complex sequences of bio-chemical processes during growth and embryonic development in plants and animals. Through novel forms of multi-scale structural ordering, unexpected properties might emerge, and this provides an opportunity for transformative advances in the creation and design of materials and complex structures, reaching well beyond the traditional manufacturing approaches, inorganic compounds, and compositions.

These materials can be in various forms: rigid and with extreme strength and toughness, or flexible, morphing, and adaptive to multiple environmental constraints; a combination of manufactured and living matter; or components derived from processes found in natural

organisms, in their physiology and their biology. An important objective would be the *ab-initio* design of materials with tailored combinations of physical characteristics, such as thermal and transport properties, chemical reactivity, mechanical strength, optical or electromagnetic responses, etc. These could lead to innovative sensing methodologies, accessing new spectral and dynamic regimes, fusing and synthesizing multi-model information, performing computation in the material and structure itself, providing automatic and reflexive control and adaptation. Novel properties, integrated with power and control structures, may lead to revolutionary approaches to "soft"-robotics, where mechanical and dynamical properties, as well as sensory mechanisms and intelligence are embedded in the materials and structures. All these applications are of extreme interest to the DoD.

Dynamic behavior can also be integrated in this *ab-initio* design process for far-from-equilibrium effects, extreme non-linearities, and/or ultra-fast control. Structural and physico-chemical dynamics can lead to new capabilities in materials that can rapidly adapt to external stimuli, demonstrate geometric and topological transformations, or control phase change, towards radically new concepts of operation and platform designs, and means of survivability under extreme environmental conditions. Adaptability, in what is essentially an open system, is an important problem as conditions may be changing very rapidly, even in discontinuous fashion, creating significant challenges in the design of these materials and structures.

"Soft" materials are of special interest in this topic, whether organic or inorganic, biochemical or abiotic, or mixtures of all. The complexity of their rheological properties, and especially their potential controllability, whether programmed or as direct response to external stimuli, may open new approaches to the engineering of materials and structures. The design and optimization of their phase diagrams can yield devices with remarkable, life-like mechanical properties or novel forms of energy storage, thermal control, camouflage, or other applications. Programmed assembly and de-assembly at the molecular or nanoscopic scales can be a function of intrinsic variables, time, or specific environmental conditions. For example, one could potentially create materials that are solid or soft, yet induced to flow like liquids, diffuse or concentrate, create networks, chemically react, absorb molecules, or grasp objects like artificial versions of macrophages. In combination with novel electro-optical characteristics such as the ones described earlier in this topic, controllable soft materials can yield an entirely new spectrum of material types and properties with applications that have yet to be discovered.

These desired outcomes present formidable challenges, but also many opportunities for exploration. For example, how can self-assembly be programmed into the material design parameters? Can biological and bio-chemical processes be leveraged to build the material across multiple structural length scales? Evolution has produced biomaterials and organisms with exceptional features, and a question is whether a similar process can be used in the material design process, accelerated a billion-fold, and even embedded into the material itself for environmental adaptation (e.g., evolutionary by design). Extreme biomimetic approaches may have the potential to generate materials with complex structures, realizing artificial systems indistinguishable or superior to natural ones. To achieve these objectives, comprehensive approaches and unifying theories are also desired, in order to formulate predictive design rules that would replace accidental discovery.

This topic is particularly looking for highly innovative, high-risk but high-reward ideas that have the potential to realize these visionary outcomes and create new fields of materials science.

Area 8: Material Science
The DoD is consistently aiming to discover and exploit new materials that enable transformative functionalities and/or performance under extreme environmental or operational conditions. The discovery and *ab-initio* design of materials with tailored combinations of physical characteristics, such as thermal and transport properties, chemical reactivity, mechanical strength, optical or electromagnetic responses, etc., is advancing at a rapid pace, often supported by advances in Machine Learning (ML) tools. Dynamic behavior can be integrated in this *ab-initio* design process for far-from-equilibrium effects, extreme non-linearities, and/or ultra-fast control. This topic is concerned with the following question: what are the fundamental challenges to the optimization and inverse design problems in material science? New diagnostic methods, computational approaches, and theory may be needed to obtain a deeper understanding of the physics of materials at multiple scales of length and time, and within a high-dimensional parameter space. These time scales may extend well beyond the predicted operating lifetime, and involve degradation, aging, and disposition in the environment. The material design can build upon combinations of bulk, surface, and structural properties, as well as physical interactions between atomic, electronic, photonic, chemical, and other degrees of freedom.

This complex problem spans multiple scientific fields, and also pushes the boundaries of material science into new regimes, opening-up new research directions. Clearly, there is a limit to the range of coupling effects and domains that can be simultaneously investigated through a single-investigator effort like the Vannevar Bush fellowship. However, this program offers the opportunity to innovate deeply and create the conditions for stimulating future research and development by effecting a transformative advance in our knowledge of materials in specific directions. This may, for example, take the form of new diagnostics with exquisite precision, accuracy and resolution, which could revolutionize the level of our understanding of material properties and behavior. This may also be a new theoretical framework, or modeling capability that comprehensively and predictively provides a much deeper understanding of the material, at various scales and levels of structural organization.

Novel conceptual approaches to synthesis and manufacturing are also needed to build at scale and implement these novel capabilities at a very fundamental level, embedding the properties, dynamics, and information within the material, for producing material elements and artificial structures of unimaginable complexity and performance. These may leverage processes with carefully tailored external control, or self-assembly and growth approaches with intrinsic parameters, pre-designed for providing the rules of atomic, molecular or nanoscale assembly. Such approaches have an extraordinary potential for creating new materials and properties via multi-scale combinatorial complexity, and lead to exponential growth in material discovery. Another important question is whether there are fundamental limits to the controlled synthesis of such materials, from an information-theoretic perspective, or engineering constraints, given the possibility of defects and impurities, and how to circumvent current impediments.

This LUCI program seeks unparalleled, original ideas in all these fields, beyond the state of the

art in material and structural science, that can revolutionize our understanding and predictive capability at all scales, and that can generate new classes of materials with extraordinary combinations of physical characteristics.

Area 9: Other Fields of Research
The list of subjects provided above is by no means a comprehensive list of topics for which white papers and proposals may be accepted. Proposed research in all areas of relevance to DoD will be considered, including topics that are clearly multi-disciplinary and do not fit well with the descriptions above, as long as there is a transformative science problem to be investigated and whose solution may open new ways of thinking about the phenomena being studied. For example, fluid dynamics and plasma dynamics are absent in the topics above, yet remain core areas of high importance for their potential applications. All issues regarding information, its availability, security, capacity and speed, are of critical interest to all conventional domains of warfare, and if not already addressed in other topic areas, may possibly be relevant here. Other subjects may be proposed under this category as well, including topics are completely new and appear under-represented in the DoD's research enterprise, as long as applicants can ensure that they propose to conduct fundamental and transformative research, and can reasonably argue that it may lead to potential benefits in the long term for issues pertinent to National Defense.