Exhibit R-2, RDT&E Budget Item Justification: PB 2021 Defense Advanced Research Projects Agency	**Date:** February 2020
Appropriation/Budget Activity 0400: *Research, Development, Test & Evaluation, Defense-Wide* / BA 1: *Basic Research*	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*

COST ($ in Millions)	Prior Years	FY 2019	FY 2020	FY 2021 Base	FY 2021 OCO	FY 2021 Total	FY 2022	FY 2023	FY 2024	FY 2025	Cost To Complete	Total Cost
Total Program Element	-	423.895	432.284	479.958	-	479.958	415.112	394.290	383.616	400.581	-	-
CCS-02: *MATH AND COMPUTER SCIENCES*	-	202.334	220.824	289.803	-	289.803	234.234	220.423	217.700	253.493	-	-
CYS-01: *CYBER SCIENCES*	-	12.946	0.000	0.000	-	0.000	0.000	0.000	0.000	0.000	-	-
ES-01: *ELECTRONIC SCIENCES*	-	38.156	43.333	35.801	-	35.801	42.583	43.204	47.383	35.858	-	-
ES-02: *BEYOND SCALING SCIENCES*	-	51.283	47.000	59.025	-	59.025	38.700	53.290	53.290	53.290	-	-
MS-01: *MATERIALS SCIENCES*	-	72.181	63.412	52.560	-	52.560	66.647	48.638	41.138	37.138	-	-
TRS-01: *TRANSFORMATIVE SCIENCES*	-	46.995	57.715	42.769	-	42.769	32.948	28.735	24.105	20.802	-	-

A. Mission Description and Budget Item Justification

The Defense Research Sciences Program Element is budgeted in the Basic Research Budget Activity because it provides the technical foundation for long-term National Security enhancement through the discovery of new phenomena and the exploration of the potential of such phenomena for Defense applications. It supports the scientific study and experimentation that is the basis for more advanced knowledge and understanding in information, electronic, mathematical, computer, and materials sciences.

The Math and Computer Sciences project supports scientific study and experimentation on new mathematical and computational algorithms, models, and mechanisms in support of long-term national security objectives. Modern analytic and information technologies enable important new military capabilities and drive the productivity gains essential to U.S. economic competitiveness. Conversely, new classes of threats, in particular threats that operate in or through the cyber domain, put military systems, critical infrastructure, and the civilian economy at risk. This project aims to magnify these opportunities and mitigate these threats by leveraging emerging mathematical and computational capabilities including computational social science, artificial intelligence, machine learning and reasoning, data science, complex systems modeling and simulation, and theory of computation. The basic research conducted under the Math and Computer Sciences project will produce breakthroughs that enable new capabilities for national and homeland security.

The Cyber Sciences project supported long-term national security requirements through scientific research and experimentation in cyber security. Information technologies enabled important new military capabilities and drove the productivity gains essential to U.S. economic competitiveness. Meanwhile, cyber threats grew in sophistication and number, and put sensitive data, classified computer programs, mission-critical information systems, and future economic gains at risk. The basic research conducted under the Cyber Sciences project produced breakthroughs necessary to enhance the resilience of DoD information systems to current and emerging cyber threats.

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The Electronic Sciences project is for basic exploration of electronic and optoelectronic devices, circuits, and processing concepts to meet the military's need for near real-time information gathering, transmission, and processing. In seeking to continue the phenomenal progress in microelectronics innovation that has characterized the last few decades, the project should provide DoD with new, improved, or potentially revolutionary device options for accomplishing these critical functions. The resulting technologies should help maintain knowledge of the enemy, communicate decisions based on that knowledge, and substantially improve the cost and performance of military systems. Research areas include analog, mixed signal, and photonic circuitry for communications and other applications; alternative computer architectures; and magnetic components to reduce the size of Electromagnetic (EM) and sensing systems. Other research could support field-portable electronics with reduced power requirements, ultra-high density information storage "on-a-chip", and new approaches to nanometer-scale structures, molecules, and devices.

The Beyond Scaling Sciences project supports investigations into materials, devices, and architectures to provide continued improvements in electronics performance with or without the benefit of Moore's Law (silicon scaling). Within the next ten years, traditional scaling will start to encounter the fundamental physical limits of silicon, requiring fresh approaches to new electronic systems. Over the short term, DoD will therefore need to unleash circuit specialization in order to maximize the benefit of traditional silicon. Over the longer term, DoD and the nation will need to engage the computer, material, and mechanical sciences to explore electronics improvements through new non-volatile memory devices that combine computation, memory, and new automated design tools using machine learning. Other memory devices could also leverage an emerging understanding of the physics of magnetic states, electron spin properties, topological insulators, or phase-changing materials. Beyond Scaling programs will address fundamental exploration into each of these areas.

The Materials Sciences project provides the fundamental research that underpins the design, development, assembly, and optimization of advanced materials, devices, and systems for DoD applications in areas such as robust diagnostics and therapeutics, novel energetic materials, and complex hybrid systems.

The Transformative Sciences project supports research and analysis that leverages converging technological forces and transformational trends in information-intensive subareas of the social sciences, life sciences, and manufacturing. The project integrates these diverse disciplines to improve military adaptation to sudden changes in requirements, threats, and emerging/converging trends, especially trends that have the potential to disrupt military operations or threaten National Security. Specific research in this project will investigate technologies to enable detection of novel threat agents (e.g., bacterial pathogens) and maintain warfighter health and improve recovery. This project also includes efforts to create innovative materials of interest to the military (e.g., self-healing materials).

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Appropriation/Budget Activity
0400: *Research, Development, Test & Evaluation, Defense-Wide I* BA 1: *Basic Research*

R-1 Program Element (Number/Name)
PE 0601101E *I DEFENSE RESEARCH SCIENCES*

B. Program Change Summary ($ in Millions)	FY 2019	FY 2020	FY 2021 Base	FY 2021 OCO	FY 2021 Total
Previous President's Budget	422.680	432.284	431.356	-	431.356
Current President's Budget	423.895	432.284	479.958	-	479.958
Total Adjustments	1.215	0.000	48.602	-	48.602
• Congressional General Reductions	0.000	0.000			
• Congressional Directed Reductions	0.000	0.000			
• Congressional Rescissions	0.000	0.000			
• Congressional Adds	0.000	0.000			
• Congressional Directed Transfers	0.000	0.000			
• Reprogrammings	9.666	0.000			
• SBIR/STTR Transfer	-8.451	0.000			
• TotalOtherAdjustments	-	-	48.602	-	48.602

Congressional Add Details ($ in Millions, and Includes General Reductions)	FY 2019	FY 2020
Project: CCS-02: *MATH AND COMPUTER SCIENCES*		
Congressional Add: *DARPA Foundational and Applied Artificial Intelligence*	15.000	-
Congressional Add Subtotals for Project: CCS-02	15.000	-
Congressional Add Totals for all Projects	15.000	-

Change Summary Explanation

FY 2019: Increase reflects reprogrammings offset by the SBIR/STTR transfer.
FY 2020: N/A
FY 2021: Increase reflects expansion of Artificial Intelligence and Electronics Resurgence Initiative programs, offset by smaller program decreases.

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COST ($ in Millions)	Prior Years	FY 2019	FY 2020	FY 2021 Base	FY 2021 OCO	FY 2021 Total	FY 2022	FY 2023	FY 2024	FY 2025	Cost To Complete	Total Cost
CCS-02: *MATH AND COMPUTER SCIENCES*	-	202.334	220.824	289.803	-	289.803	234.234	220.423	217.700	253.493	-	-

A. Mission Description and Budget Item Justification

The Math and Computer Sciences project supports scientific study and experimentation on new mathematical and computational algorithms, models, and mechanisms in support of long-term national security objectives. Modern analytic and information technologies enable important new military capabilities and drive the productivity gains essential to U.S. economic competitiveness. Conversely, new classes of threats, in particular threats that operate in or through the cyber domain, put military systems, critical infrastructure, and the civilian economy at risk. This project aims to magnify these opportunities and mitigate these threats by leveraging emerging mathematical and computational capabilities including computational social science, artificial intelligence, machine learning and reasoning, data science, complex systems modeling and simulation, and theory of computation. The basic research conducted under the Math and Computer Sciences project will produce breakthroughs that enable new capabilities for national and homeland security.

B. Accomplishments/Planned Programs ($ in Millions)	**FY 2019**	**FY 2020**	**FY 2021**
Title: Human Social Systems	29.100	27.000	26.000
Description: The social sciences provide essential theories and models that can enable deeper understanding of human social systems and behaviors relevant to national security such as humanitarian aid, disaster relief, and stability support missions, as well as tactical, operational, strategic, and policy-level decision-making across the DoD. However, current limitations to the speed, scalability and reproducibility of empirical social science research continue to hamper its practical use by the DoD. Additionally, current social behavioral models often fail to accurately interpret social behaviors because they do not sufficiently capture diversity of context. The Human Social Systems thrust will address these limitations by focusing on the following technical challenges: (1) developing and validating new methods, models and tools to perform rigorous, reproducible experimental research at scales necessary to understand emergent properties of human social systems; (2) identifying methods to better characterize and quantify properties, dynamics, and behaviors of different social systems to enable better and more confident forecasting of changes in social systems, particularly when under stress; (3) developing an understanding of the complex effect of context and incorporating these effects into social science models; and (4) developing strategic forecasting and operational decision aiding capabilities that account for local contextual and cultural factors to assess the likely effectiveness of and/or responses to actions within an Area of Operations. This research thrust will provide DoD with new, reliable strategies to better understand and respond to social system issues at multiple scales (from small group to cities and/or regions) and will significantly improve DoD stabilization, deterrence, and/or gray zone mission outcomes. ***FY 2020 Plans:*** - Develop and deploy highly complex social simulations with known causal ground truth as test bed challenges for social science research communities.			

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Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / *DEFENSE RESEARCH SCIENCES*	Project (Number/Name) CCS-02 / *MATH AND COMPUTER SCIENCES*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2019	FY 2020	FY 2021
- Quantify the diagnostic and predictive accuracy, robustness, and efficiency of social science representation and modeling tools by testing them against simulations. - Determine the capabilities and limitations of representation and modeling tools for understanding and predicting cause and effect in highly complex social systems. - Demonstrate efficiency and value of rapid, scalable replication capabilities for accelerating rigorous understanding of human social systems and behaviors. - Implement and test algorithms for automatically assigning quantitative confidence scores to social and behavioral science research. - Develop capabilities for adjusting algorithms based on user-specific needs and interests. - Develop framework for training and testing agents to represent community-level collective intelligence. - Design methodology for tracking and assessing aggregate indicators of socio-political behavior. - Explore novel artificial intelligence (AI) tools with potential to effectively elicit and impart acquired knowledge precisely when useful and applicable via user friendly interfaces. ***FY 2021 Plans:*** - Refine, implement, and test algorithms for automatically assigning quantitative confidence scores to social and behavioral science research. - Demonstrate expert and non-expert usability of algorithms for automatically assigning quantitative confidence scores. - Increase return rate efficiency of algorithms for automatically assigning quantitative confidence scores to social and behavioral science research. - Evaluate the efficacy of agents for representing community-level collective intelligence. - Begin testing methodology for tracking and assessing aggregate indicators of socio-political behavior for generalizability. ***FY 2020 to FY 2021 Increase/Decrease Statement:*** The FY 2021 decrease reflects a shift from design and development to testing and evaluation.			
Title: Machine Common Sense (MCS) ***Description:*** The Machine Common Sense (MCS) program is exploring approaches to enable commonsense reasoning by machines. Recent advances in machine learning have resulted in new artificial intelligence (AI) capabilities in areas such as image recognition, natural language processing, and strategy games such as Chess, Go and Poker. In all of these application domains, the machine reasoning is narrow and highly specialized, and the machine must be carefully trained or programmed for every situation. This program addresses the challenge of general machine reasoning on par with commonsense human cognition. MCS is developing computational models that mimic core systems of human cognitive development that are grounded in perceptual, motor, and memory modalities; a simulated interaction and learning environment to support machine manipulation	15.500	16.815	21.810

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B. Accomplishments/Planned Programs ($ in Millions)	**FY 2019**	**FY 2020**	**FY 2021**
of grounded concept models; and commonsense knowledge repositories to support AI system development. AI systems that are capable of more human-like reasoning will be able to behave more appropriately in unforeseen situations. ***FY 2020 Plans:*** - Develop a suite of core cognitive models using a variety of AI approaches, to include deep learning, probabilistic simulation, and symbolic reasoning. - Devise techniques for evaluating core cognitive models against human cognitive development capabilities within a simulation environment. - Construct a baseline simulation environment to evaluate models and machine learning methods against human cognitive performance for prediction tasks. - Assess performance of developed common knowledge services against a benchmark commonsense challenge problem suite. ***FY 2021 Plans:*** - Enhance core cognitive models with additional capabilities and evaluate model performance against increased levels of human cognitive performance for prediction tasks. - Develop core cognitive models with initial experience learning capabilities, and evaluate model performance against experience learning tasks. - Modify simulation environment for evaluation of additional machine learning methods, cognitive capabilities, prediction tasks, and experience learning tasks. - Enhance common knowledge services to handle commonsense phenomena of increased complexity, and assess performance of services against a benchmark commonsense challenge problem suite. ***FY 2020 to FY 2021 Increase/Decrease Statement:*** The FY 2021 increase reflects continued development of machine common sense technologies and simulation environment, and expanded efforts to assess performance against a benchmark commonsense challenge problem suite.			
Title: Guaranteeing AI Robustness against Deception (GARD) ***Description:*** The Guaranteeing AI Robustness against Deception (GARD) program is developing techniques to defend against deception attacks on machine learning (ML) and artificial intelligence (AI) systems. GARD addresses the need to defend against deception attacks, whereby an adversary inputs engineered data into an ML system intending to cause the system to produce erroneous results. Deception attacks can enable adversaries to take control of autonomous systems, alter conclusions of ML-based decision support applications, and compromise tools and systems that rely on ML and AI technologies. Current techniques for defending ML and AI have proven brittle due to a focus on individual attack methods and weak methods for testing and evaluation. Techniques developed under the GARD program will address the current limitations of defenses and produce ML and	7.600	17.244	19.100

B. Accomplishments/Planned Programs ($ in Millions)	FY 2019	FY 2020	FY 2021
AI systems suitable for use in adversarial environments. GARD aims to develop new algorithms and theory for ML and AI that are robust to deception attacks. ***FY 2020 Plans:*** - Identify sources of vulnerability and develop robustness metrics for ML algorithms in adversarial environments. - Characterize the defensibility of ML under various sensor modalities, and design ML defense algorithms for single sensor modalities. - Establish an evaluation framework to quantify the performance and robustness of new ML techniques. - Develop ensembles of highly-diverse models having orthogonal features, and evaluate the robustness of the ensembles to black-box adversarial attacks. ***FY 2021 Plans:*** - Develop a general framework for deception and related attacks on ML, and quantify the vulnerability of ML algorithm classes to an adaptive adversary. - Develop defenses that leverage multi-sensor data sources to reduce vulnerability to adversarial inputs. - Extend evaluation framework for testing ML defenses for multi-sensor scenarios, and implement and test ML defenses for use against an AI-enabled adversary. ***FY 2020 to FY 2021 Increase/Decrease Statement:*** The FY 2021 increase reflects continued development of robust ML techniques and an ML risk evaluation testbed, and expanded efforts to evaluate techniques for use against an AI-enabled adversary.			
Title: World Modelers ***Description:*** The World Modelers program is creating explanatory models for natural and human-mediated systems at regional and global scales. Because of macro-economic interdependence, disruption of natural resources, supply chains, and production systems can have widespread consequences. World Modelers capabilities are focused on regional and global systems with the goal of generating timely indications and warnings. Water and food security are application domains of particular interest, as persistent drought may cause crops to fail, leading to migration and regional conflicts. The World Modelers program aims to develop techniques for automating the creation, maintenance, and validation of large-scale integrated models using publicly available news and analyst reports as a structuring mechanism, and government and commercial data as quantitative inputs. ***FY 2020 Plans:*** - Develop models for acute, high-impact phenomena such as natural disasters that disrupt civilian infrastructure. - Extend the integrated workflow to operate on compressed temporal scales, and optimize the extended workflow on food security, migration, and acute, high-impact use cases.	16.800	17.500	19.050

B. Accomplishments/Planned Programs ($ in Millions)	FY 2019	FY 2020	FY 2021
- Perform evaluations on realistic scenarios in collaboration with DoD, Intelligence Community (IC), Department of Homeland Security (DHS), and other potential transition partners. ***FY 2021 Plans:*** - Refine models of acute, high-impact phenomena such as natural disasters that disrupt civilian infrastructure to enable ensemble forecasting and estimation of uncertainty. - Introduce more complex perturbations, and apply technology to additional use cases such as disease outbreak. - Perform additional evaluations incorporating new data sources, models, and factors for a diverse set of transition partners. ***FY 2020 to FY 2021 Increase/Decrease Statement:*** The FY 2021 increase reflects continued efforts to develop models for acute high-impact phenomena, and expanded efforts to evaluate techniques in collaboration with transition partners.			
Title: Synergistic Discovery and Design (SD2) ***Description:*** The Synergistic Discovery and Design (SD2) program is developing data-driven methods to accelerate scientific discovery and robust design in domains that lack complete models. Engineers regularly use high-fidelity simulations to create robust designs in complex domains such as aeronautics and integrated circuits. In contrast, robust design remains elusive in domains such as synthetic biology, neuro-computation, and synthetic chemistry due to the lack of high-fidelity models. The SD2 program will collect raw experimental data into a data and analysis hub, develop computational techniques that extract scientific knowledge directly from experimental data, and create data sharing tools and metrics that facilitate collaborative design. SD2 application domains include synthetic biology, solar cell chemistry, and protein design, which will impact future DoD capabilities in areas such as chemical and biological defense, and warfighter readiness. ***FY 2020 Plans:*** - Apply discovery algorithms to novel systems that have not been characterized by human experts, and extend algorithms that foster scientific understanding to accelerate novel design. - Integrate discovery algorithms with design protocols to automate the experimental process. - Improve experimental planning tools to reduce the experimental costs required to obtain a functional design. - Scale software and infrastructure to process experimental data, and evaluate tools by testing their ability to adapt protein and cellular circuit designs for use in biosensors. ***FY 2021 Plans:*** - Test design and discovery tools in supporting a design-test-build cycle to rapidly produce biosensors and stable solar materials. - Demonstrate automated experimental loops that provide rapid improvement in experimental performance. - Develop models of underlying scientific principles for domains such as complex systems design, biosynthesis, computational social science and information operations.	20.500	21.000	19.000

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2019	FY 2020	FY 2021
- Develop methods for extracting generalized and compressed knowledge representations for more adaptable and model based artificial intelligence (AI). - Extend software to integrate data, experimental protocols, and analysis methods from diverse research groups, and identify resilience strategies for automated experimental bio-cyber-physical laboratories. ***FY 2020 to FY 2021 Increase/Decrease Statement:*** The FY 2021 decrease reflects ramping down of development of computational techniques that extract scientific knowledge from data, and expanded efforts to demonstrate and test techniques on biosensor and protein design and solar material synthesis.			
Title: Learning with Less Labeling (LwLL) ***Description:*** The Learning with Less Labeling (LwLL) program is developing technology to greatly reduce the amount of labeled data required to train machine learning (ML) systems. In supervised ML, a system learns through the use of labeled training examples to recognize and categorize attributes of images, text, or speech. Humans provide these training-data examples to ML systems and with enough labeled data, it is generally possible to build useful models. Obtaining large amounts of labeled data can be costly. LwLL is addressing this problem by creating ML algorithms that learn and adapt more efficiently than current ML approaches, and by formally deriving the limits of machine learning and adaptation. LwLL aims to create ML systems that are easier to train and use in variable, unpredictable, real-world environments, especially where training data is costly or sparse. ***FY 2020 Plans:*** - Develop ML algorithms that are robust to distributional mismatch between the data on which the system is trained and the data on which the system operates post training. - Develop estimates for the rate at which an ML system will converge with increased training in terms of the hyperparameters of the system. - Construct challenge problems and associated labeled and unlabeled data sets, and demonstrate increased learning rates and distributional robustness of the new ML algorithms. ***FY 2021 Plans:*** - Develop approaches to label reduction via automated transfer learning that discovers similar problems and learns what is important for a given task. - Develop theoretical limits for transfer learning for problem classes and domains of interest to DoD. - Demonstrate the capability of new ML algorithms to learn with far fewer labels, and to generalize to multiple tasks and domains on datasets relevant to DoD. ***FY 2020 to FY 2021 Increase/Decrease Statement:***	7.750	14.500	17.650

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2019	FY 2020	FY 2021
The FY 2021 increase reflects continued development of ML techniques that require less labeled data for effective training, and increased efforts to demonstrate techniques on datasets relevant to DoD.			
Title: Young Faculty Award (YFA) ***Description:*** The goal of the Young Faculty Award (YFA) program is to encourage junior faculty at universities and their equivalent at non-profit science and technology research institutions to participate in sponsored research programs that will augment capabilities for future defense systems. This program focuses on cutting-edge technologies for greatly enhancing microsystems technologies, biological technologies and defense sciences. The long-term goal for this program is to develop the next generation of scientists, engineers and mathematicians in key disciplines who will focus a significant portion of their careers on DoD and national security issues. The aim is for YFA recipients to receive deep interactions with DARPA program managers, programs, performers and the user community. Current activities include research in fifteen topic areas spanning from Machine Learning and Many Body Physics, to Wideband Transmitter-Antenna Interfaces and Multi-Scale Models of Infectious Disease Dynamics. A key aspect of the YFA program is DARPA-sponsored military visits; all YFA Principal Investigators are expected to participate in one or more military site visits to help them better understand DoD needs. ***FY 2020 Plans:*** - Award new FY 2020 grants for new two-year research efforts across the topic areas, establishing a new set of appropriate technologies to solve current DoD problems. - Continue FY 2019 research on new concepts for microsystem, biological, strategic, and tactical technologies; information innovation; and defense sciences by exercising second year funding and by providing continued mentorship by program managers. - Award Director's Fellowships for top FY 2018 participants to refine technology further and align to DoD needs. ***FY 2021 Plans:*** - Award new FY 2021 grants for new two-year research efforts across the topic areas, establishing a new set of appropriate technologies to solve current DoD problems. - Continue FY 2020 research on new concepts for microsystem, biological, strategic, and tactical technologies; information innovation; and defense sciences by exercising second year funding and by providing continued mentorship by program managers. - Award Director's Fellowships for top FY 2019 participants to refine technology further and align to DoD needs.	17.000	17.000	17.000
Title: Safe Documents (SafeDocs) ***Description:*** The Safe Documents (SafeDocs) program is developing software technologies that reduce syntactic complexity of data formats, and improve the capability to reject invalid and maliciously crafted data in electronic documents and streaming data. The high complexity of electronic documents and streaming data greatly increases the computational attack surface. The	12.300	14.000	15.450

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2019	FY 2020	FY 2021
SafeDocs program is focused on simplifying existing data formats, with attention to compatibility, and advancing the state of the art in the security of document and data format parsers. Simplification is essential to enabling automated code verification and assuring that the conditions of data validity are enforced. SafeDocs technology aims to enable secure documents and streaming data. ***FY 2020 Plans:*** - Explore formal development approaches for reduced-complexity format variants for electronic documents and streaming data, and the associated processing software. - Design reduced-complexity format variants and parsers for electronic documents and streaming data, with attention to compatibility. - Initiate construction of verified functionally correct, efficient parsers for syntactically complex formats currently in use. ***FY 2021 Plans:*** - Create a safe subset for a widely used electronic data document format, and show that it supports the same functionality as the legacy standard specification. - Construct a program to convert a large majority of legacy format documents to safe format without loss of essential content, and show that the content produced by the program is secure against maliciously crafted data. - Demonstrate the ability to reduce common instances of streaming data formats to safe, simplified subsets that allow the same essential functionality under resource constraints representative of an embedded system. ***FY 2020 to FY 2021 Increase/Decrease Statement:*** The FY 2021 increase reflects continued efforts to develop reduced-complexity formats for electronic documents and streaming data and verified functionally correct, efficient parsers, and increased efforts to demonstrate techniques in representative systems.			
Title: Advanced Tools for Modeling and Simulation ***Description:*** The Advanced Tools for Modeling and Simulation thrust will develop foundational mathematical, computational, and multi-physics theories, approaches and tools to better represent, quantify and model complex DoD systems from multimodal data analysis through part/system design and fabrication. One focus area of this thrust is developing a unified mathematical framework to enable better visualization and analysis of massive, complex data sets. Rigorous mathematical theories are also being developed to address uncertainty in the modeling and design of complex multi-scale physical and engineering systems, incorporating capabilities to handle noisy data and model uncertainty that are well beyond the scope of current capabilities. Other work in this thrust focuses on developing the mathematical and computational tools required to generate and better manage the enormous complexity of design, ultimately allowing designers to more easily discover non-intuitive (yet realizable) designs that fully leverage new materials and advanced manufacturing approaches now available. Outcomes from this thrust will improve the speed and accuracy of modeling and simulation, as well as enable management of complexity across DoD devices, parts and	14.900	15.400	8.000

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2019	FY 2020	FY 2021
systems. Another focus area of this thrust is multi-physics models for predicting behavior and non-intuitive failure pathways for complex, dynamic physical systems. ***FY 2020 Plans:*** - Incorporate uncertainty into multi-physics analysis and synthesis capabilities. - Develop techniques based on data analysis and machine learning tools to guide design exploration and find promising designs. - Identify mathematics and algorithms that allow for direct generation of multi-physics/multi-scale simulation codes. - Identify and select DoD relevant challenge problems on which to evaluate the performance and accuracy of a novel computable model enabled simulator. ***FY 2021 Plans:*** - Initiate development of a computable model framework to generate multi-physics simulators with improved accuracy and reduced level of effort over current approaches. ***FY 2020 to FY 2021 Increase/Decrease Statement:*** The FY 2021 decrease reflects a shift in focus from testing and demonstration to development of new modeling.			
Title: Communicating With Computers (CWC) ***Description:*** The Communicating With Computers (CWC) program is advancing human-computer interaction by enabling computers to comprehend language, gesture, facial expression, and other communicative modalities in context. Human language is inherently ambiguous, so humans depend on additional communication pathways, including perception of the physical world and shared context, to communicate efficiently. CWC aims to provide computers with analogous capabilities to sense and encode aspects of the physical world in a perceptual structure, and to use this structure to disambiguate language. To accomplish this, CWC will apply and extend research in language, vision, gesture recognition and interpretation, dialog management, cognitive linguistics, and the psychology of visual encoding. CWC also aims to extend the communication techniques developed for physical contexts to nonphysical contexts and virtual constructs. ***FY 2020 Plans:*** - Demonstrate a collaborative agent for human-machine communication, extending and leveraging the human capacity to plan and execute diverse tasks across multiple domains. - Evaluate and optimize human-computer interaction technologies across multiple task domains and use cases. ***FY 2021 Plans:*** - Perform final human-computer interaction technology evaluations on multiple program use cases. ***FY 2020 to FY 2021 Increase/Decrease Statement:***	16.700	10.565	6.750

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2019	FY 2020	FY 2021
The FY 2021 decrease reflects ramping down of development of human-computer interaction technologies, and final demonstrations and evaluation of developed capabilities.			
Title: Complex Hybrid Systems ***Description:*** The Complex Hybrid Systems program thrust is focused on exploring fundamental science, mathematics, and computational approaches to collectives, complex hybrid (e.g., human-machine) systems and systems-of-systems across a variety of DoD-relevant domains. Efforts include development of foundational, quantitative theories and algorithms for the analysis and design of complex systems, as well as novel testing capabilities for assessing the value of these theories using experimental verification across multiple problem domains. Results from this thrust will better enable the systematic design of complex hybrid systems that can achieve unprecedented resilience and adaptability in unexpected environments. ***FY 2020 Plans:*** - Demonstrate simultaneous design and integrated exploration of team structure, capabilities, and problem solving strategies in a dynamic experimental environment. - Conduct multiple demonstrations of the use of knowledge representation and design tools to predict team structure and problem solving strategy of high performing teams with machine elements. - Demonstrate the capability to build, maintain, and reason over rich models of complex systems in diverse application domains to include hypersonics, epidemiology, and synthetic biology. ***FY 2021 Plans:*** - Demonstrate predictive power and generalizability of approaches for designing team structure and problem solving strategies against a scenario not utilized in the development of the approach. - Predict and explain team structure and problem solving strategy of high performing teams with machine elements in an additional experimental environment. ***FY 2020 to FY 2021 Increase/Decrease Statement:*** The FY 2021 decrease reflects minor program repricing.	9.000	6.500	6.250
Title: Foundational Artificial Intelligence (AI) Science ***Description:*** The Foundational Artificial Intelligence (AI) Science thrust will develop a fundamental scientific basis for understanding and quantifying performance expectations and limits of AI technologies. Current AI technologies are challenged in handling uncertainty and incompleteness of training protocols and data. This has prevented the successful integration of AI technology into many transformative DoD applications. To address these limitations the Foundational AI science thrust will focus on the development of new learning architectures that enhance AI systems' ability to handle uncertainty, reduce vulnerabilities, and improve robustness for DoD AI systems. One focus area of this thrust is the ability to embed known physics, mathematics,	-	16.500	35.900

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2019	FY 2020	FY 2021
and other prior knowledge to improve performance of AI systems, particularly for problem sets involving incomplete, sparse and noisy data. Another focus area is the development of a model framework for quantifying performance expectations and limits of AI systems as trusted human partners and collaborators. A third focus area is the development of new tools and methodologies that enable AI approaches for accelerated scientific discovery. The technology advances achieved under the Foundational AI Science thrust will ultimately remove technical barriers to exploiting AI technologies for scientific discovery, human-AI collaboration, and other DoD relevant applications. ***FY 2020 Plans:*** - Design, test and evaluate physics-based machine learning systems to achieve increased prediction accuracy and control of complex dynamical systems by incorporating physical symmetries, conservation laws, and generated data for training into AI architectures. - Begin development of hardware and control software for autonomous experimental chemistry systems. - Develop automated approaches for extracting data from chemistry text and diagrams, and demonstrate semi-autonomous experimentation informed by models. - Demonstrate the discovery of scientific laws governing equations on real-world problems in one or more relevant DoD domains where the behaviors are not known in advance. - Leverage advancement in machine learning techniques to initiate the development of introspective AI systems that are capable of generating compact representations of experiences from learning data. - Initiate the development of AI tools capable of abstracting task behaviors into generalized rules and rule dependencies. - Initiate efforts to develop generators and novelty-robust AI techniques to rapidly identify and respond appropriately to new classes of entities and attributes. - Identify novel, non-Von Neumann computer architectures based on new and unexplored mathematical paradigms exploring the actual boundary between classical and quantum computing. - Initiate efforts to explore frontiers in Artificial Intelligence with a focus on third wave AI. - Formulate AI-based approaches such as autoencoders, evolutionary programming, and neural sketch learning for analysis of computing systems at design stage, to prevent cyber attackers from executing unintended, emergent computations on critical infrastructure and DoD systems. - Formulate practical approaches to enable multiple parties to cooperate in improving each other's machine learning (ML) models while providing guarantees that each party's datasets and models remain private. - Formulate approaches for identifying attack methods from the signals and information in the images, video, text, and other communication modalities transmitted to ML systems or humans. ***FY 2021 Plans:*** - Develop automated approaches to extract data from electronic lab notebooks, tables, and figures.			

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B. Accomplishments/Planned Programs ($ in Millions)	**FY 2019**	**FY 2020**	**FY 2021**
- Build and demonstrate property prediction models which are informed by and guide automated experimental platforms. - Develop introspective AI systems that are capable of expressing task competencies based on experiences, learned task rules and rule dependencies. - Demonstrate competency-aware machine learning behaviors and capabilities in machine learning applications. - Develop novelty generators and novelty-robust AI techniques to identify rapidly and respond appropriately to new relationships, representations, and capabilities. - Begin to evaluate novelty generators and novelty-robust AI techniques compared to non-robust methods performing on known tasks. - Initiate development of capabilities for AI systems with competency-awareness to understand, support, and exploit the interdependence between teammates - Initiate development of capabilities for AI systems to collaborate autonomously in novel tasks. - Demonstrate, in modeling and simulation, non-Von Neumann devices and circuits that have significant benefits over classical computers. - Continue efforts to explore frontiers in Artificial Intelligence with a focus on third wave AI. - Develop representations of computing designs such as layered application programming interfaces and processor microarchitectures, and demonstrate effective anticipation of emergent execution. - Develop and implement computationally feasible cryptographic techniques for securing the information exchange transactions implicit to cooperative training of ML models, and demonstrate their ability to preserve privacy when attacked by a sophisticated adversary. - Develop and implement algorithms for fingerprinting deception attacks, and demonstrate advanced capabilities such as online detection of attacks and attribution of the attacker. ***FY 2020 to FY 2021 Increase/Decrease Statement:*** The FY 2021 increase is due to program expansion into additional technology solution spaces.			
Title: Alternative Computing ***Description:*** The Alternative Computing thrust will explore and develop new computational primitives for modeling and simulating complex systems. Despite decades of rapid advancement in electronic computing, there remain important national security relevant challenge problems that do not lend themselves to achieving tractable solutions under size, weight, and power (SWaP) constrained conditions. For example, simulation of complex nonlinear phenomena such as turbulence, fluid flow and plasma dynamics can be challenging even using currently available high power computing resources. Building on technologies developed under the Advanced Tools for Modeling and Simulation thrust, also in this PE/Project, the goal of the Alternative Computing thrust is to develop novel architectural and algorithmic approaches to enable fast and accurate simulations for problems that are practically intractable using electronic computers. Approaches considered under this thrust include the following: (1) analog	-	9.800	20.913

B. Accomplishments/Planned Programs ($ in Millions)	FY 2019	FY 2020	FY 2021
computing substrates for efficiently simulating systems governed by complex non-linear phenomena; (2) multi-functional spin-based devices for scalable, efficient neuromorphic computing; (3) computing approaches that exploit the capacity of nonlinear systems to simulate nonlinear dynamical systems; and (4) quantum enabled optimization of complex systems. ***FY 2020 Plans:*** - Initiate efforts to determine instances where near term quantum processors can outperform classical computing in the optimization of complex systems. - Design and initiate development of a preliminary near term achievable quantum computer for the optimization of complex systems. ***FY 2021 Plans:*** - Identify families of instances where near term quantum computers can outperform classical computing in the optimization of complex systems. - Initiate efforts to quantify the speedup achievable with near term quantum computers over classical computing for the optimization of complex systems. - Demonstrate the use of a near term quantum computer for the optimization of complex systems. - Initiate proof-of-concept development for non-Von Neumann architectures that can scale to very large numbers of devices, be manufactured reliably and have significant projected performance over conventional computing methods. ***FY 2020 to FY 2021 Increase/Decrease Statement:*** The FY 2021 increase reflects a shift from system design to development and demonstration.			
Title: Artificial Social Intelligence for Successful Teams (ASIST)* ***Description:*** *Formerly Human-Machine Symbiosis The Artificial Social Intelligence for Successful Teams (ASIST) program is developing intelligent software agents that can create shared mental models to enable effective teaming with humans. Theory of mind and the ability to create shared mental models are key elements of human social intelligence. Together these skills enable human collaboration and teamwork at all scales, whether the setting is a playing field or a military mission. The ASIST program aims to develop technologies to enable machines to exhibit similar capabilities for collaboration and teamwork with humans, capabilities which can be termed artificial social intelligence. These would include the capability to infer the goals and situational knowledge of human partners, to predict what human partners will need, and to formulate context-aware actions having high value to a team. The ASIST program is developing proof-of-concept software agents that demonstrate a machine theory of mind and the capability to participate with humans in an effective team by representing and helping to maintain shared models. ASIST aims to provide the basis for machines that can participate effectively with humans on tasks where teamwork is required.	-	13.000	18.330

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B. Accomplishments/Planned Programs ($ in Millions)	**FY 2019**	**FY 2020**	**FY 2021**
FY 2020 Plans: - Implement software agents that exhibit machine theory of mind in interactions with a single human partner. - Collect and register hypotheses and design experiments to identify factors that influence the performance of human-machine teams. - Initiate development of a scalable virtual testbed for evaluating the software agents in environments with one human partner. - Investigate and derive performance predictions for computational agents capable of advising and guiding humans in the performance of complex tasks. ***FY 2021 Plans:*** - Develop software agents that exhibit machine theory of mind in interactions with multiple human partners. - Conduct experiments to test hypotheses and quantify the importance of factors such as trust, communication, social cognition, and collective intelligence that influence the performance of human-machine teams. - Extend the virtual testbed to model environments where there are more humans and teams, and to situations where greater robustness and adaptability are required. - Develop computational simulations of knowledge-seeking behavior, and combine these with human-machine dialog techniques that can automatically generate efficacious questions for human experts. ***FY 2020 to FY 2021 Increase/Decrease Statement:*** The FY 2021 increase reflects ramping up of efforts to develop software agents that exhibit machine theory of mind and initial experiments to quantify factors that influence the performance of human-machine teams.			
Title: Application-Tailored Artificial Intelligence (APTAI) ***Description:*** The Application-Tailored Artificial Intelligence (APTAI) program will develop concepts for AI capabilities whose designs and learning processes are influenced both by training data and by key concepts and features proposed by experts in the intended application domains. In this third wave approach, learning processes will incorporate both human experience and patterns extracted from data to converge on informative features, representations, abstractions, and inductive strategies. One expected benefit of this approach is the emphasis on features that humans find salient, thus reducing the number of counterintuitive mistakes made by AI methods and minimizing the vulnerability to adversarial attacks, both in training data and in operations. Another expected benefit relates to human interaction, because the use of domain concepts provides a built-in framing for explanations to human partners. An additional expected benefit is the facilitation of more rapid learning processes including potentially transfer learning and one-shot learning. The APTAI program will make use of specific national security domains to drive assessment and transition of these initial concepts. Candidate domains include undersea autonomous navigation, imagery analysis, multi-modal reasoning, and games in support of strategy and planning. ***FY 2021 Plans:***	-	-	20.000

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2019	FY 2020	FY 2021
- Formulate third wave learning processes that incorporate both human experience and patterns extracted from data to converge on informative features, representations, abstractions, and inductive strategies. - Propose multiple algorithms for advanced machine learning techniques such as transfer learning and one-shot learning, and develop complexity estimates to support feasibility assessments of competing approaches. - Develop concepts for national security domains potentially including undersea autonomous navigation, imagery analysis, multi-modal reasoning, and games in support of strategy and planning. ***FY 2020 to FY 2021 Increase/Decrease Statement:*** The FY 2021 increase reflects program initiation.			
Title: Formal Methods at Scale (FMaS) ***Description:*** The Formal Methods at Scale (FMaS) program will create new mathematical methodologies, techniques, and tools for proving and providing evidence of correctness for software systems whose size and complexity renders their modeling and analysis infeasible with current techniques. Formal methods are techniques for reasoning about and proving various properties for software code or design models, generally focusing on logical relationships that connect specifications and models with executable code. A key to scalability is to focus more narrowly on particular quality or functional attributes, such as security and safety, rather than address all features and functions of the components of a software system. A second key to scalability is to provide for composability, which enables trustworthy components to be efficiently assembled into trustworthy systems. The FMaS program will accelerate this new scalable formal methods paradigm by extending formal methods techniques, tools, and practices along several dimensions, including (1) the range of properties and qualities that are modeled and reasoned about, such as relating to security, safety, performance, fault tolerance, and real-time, (2) the complexity and the size of systems and their supply chains, including issues related to composability, (3) efficiency of formal methods-related modeling, tooling, and engineering practices, including more natural integration into mainstream tooling and practices, (4) ability to rapidly co-evolve systems and associated evidence, for example to respond to rapid evolution of threats and associated mission concepts, and (5) ease of use for non-expert developers and evaluators. FMaS aims to create formal methods applicable to software systems of the size and complexity commonly encountered in military and civilian mission-critical systems, and to speed the adoption of these methods into practice and tooling. ***FY 2021 Plans:*** - Formulate approaches for extending formal methods with respect to the range of properties and qualities that are modeled and reasoned about, such as relating to security, safety, performance, fault tolerance, real-time. - Address issues related to composability in order to increase the size and complexity of systems and their supply chains amenable to formal methods, including both custom mission-specific components, commodity components, and open source components.	-	-	10.000

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2019	FY 2020	FY 2021
- Develop approaches for increasing the efficiency of formal methods-related modeling, analysis, tooling, and engineering practices. - Initiate the implementation of scalable formal methods into tools for use by non-expert developers and evaluators. ***FY 2020 to FY 2021 Increase/Decrease Statement:*** The FY 2021 increase reflects program initiation.			
Title: Knowledge Management at Scale ***Description:*** The Knowledge Management at Scale thrust is focused on the development of knowledge management tools that can efficiently capture, analyze and reason with expertise, experience and data. The technology development under this thrust will help address a critical need for assimilating and preserving critical national security knowledge and expertise that is currently being lost due to attrition and other factors. Specific objectives include the following 1) effective, trustworthy and easily accepted approaches for domain agnostic knowledge acquisition at scale; 2) capabilities to identify correlations or hidden factors relating to knowledge acquired from different sources; and 3) techniques for incorporating domain models and other data sources for more extensive reasoning-based applications. Example approaches towards achieving these objectives include identifying and demonstrating robust knowledge acquisition tools, exploiting AI techniques to establish a framework for knowledge analysis and causal reasoning, and developing automation tools that effectively elicit and impart acquired knowledge via user friendly interfaces. ***FY 2021 Plans:*** - Develop automated methods to identify and capture, fuse, and apply tacit organizational knowledge implicit in processes and actions of people acting on data. - Design and evaluate comfortable, trusted, and enticing software tools to be used by groups of non-technical people to capture, resolve, and apply effectively and timely different and overlapping aspects of their shared experiences. ***FY 2020 to FY 2021 Increase/Decrease Statement:*** The FY 2021 increase reflects program initiation.	-	-	8.600
Title: Building Resource Adaptive Software from Specifications (BRASS) ***Description:*** The Building Resource Adaptive Software from Specifications (BRASS) program is developing an automated framework that permits software systems to seamlessly adapt to changing resource conditions in an evolving operational environment. The current manual adaptation paradigm is based on corrective patching, which is time-consuming, error-prone, and expensive. Predicting the myriad of possible environment changes that an application may encounter in its lifetime is problematic, and existing reactive approaches are brittle and often incorrect. Effective adaptation is realized through rigorously defined specifications that capture application resource assumptions and resource guarantees made by the environment.	13.770	4.000	-

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2019	FY 2020	FY 2021
The use of specification-based adaptation will allow BRASS applications to be correctly restructured in real time whenever stated assumptions or guarantees are broken. This restructuring is optimized to trade off execution fidelity and functionality for continuance of operation. BRASS creates tools to automatically discover and monitor resource changes, build new analyses to infer deep resource-based specifications, and implement compiler and runtime transformations that can efficiently adapt to resource changes. ***FY 2020 Plans:*** - Perform final improvements to adaptation modules and systems and transition technologies to open source repositories, industry, and DoD. ***FY 2020 to FY 2021 Increase/Decrease Statement:*** The FY 2021 decrease reflects program completion.			
Title: Applied Mathematics ***Description:*** The Applied Mathematics thrust created the basic mathematics needed to support complex, multi-physics analysis ranging from uncertainty quantification to integrated, multi-system design. Focus areas of this thrust included application of geometry to challenge problems in optimization science and frameworks and advanced tools for propagating and managing uncertainty in the modeling and design of complex physical and engineering systems.	6.414	-	-
Accomplishments/Planned Programs Subtotals	187.334	220.824	289.803

	FY 2019	FY 2020
Congressional Add: DARPA Foundational and Applied Artificial Intelligence ***FY 2019 Accomplishments:*** - Developed approaches to build, maintain, and reason over rich models of complex systems by interpreting and exposing scientific knowledge and assumptions in existing code and documentation. - Devised hybrid supervised-unsupervised machine learning (ML) approaches that can be trained using both labeled and unlabeled data. - Created preliminary systems to extract scientific laws and governing equations from data and assess the adequacy of the supplied data, identifying regions where additional data would be most beneficial. - Initiated research into the computational principles and architecture of reduced-scale, low energy systems in miniaturized insect species that could identify new computing paradigms for improved AI with considerably reduced training times and power consumption.	15.000	-

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	FY 2019	FY 2020
- Identified role of sensor control and signaling mechanisms in reduced-scale insect species and postulated underlying computational model.		
Congressional Adds Subtotals	15.000	-

C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

D. Acquisition Strategy

N/A

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COST ($ in Millions)	Prior Years	FY 2019	FY 2020	FY 2021 Base	FY 2021 OCO	FY 2021 Total	FY 2022	FY 2023	FY 2024	FY 2025	Cost To Complete	Total Cost
CYS-01: *CYBER SCIENCES*	-	12.946	0.000	0.000	-	0.000	0.000	0.000	0.000	0.000	-	-

A. Mission Description and Budget Item Justification

The Cyber Sciences project supported long-term national security requirements through scientific research and experimentation in cyber security. Information technologies enabled important new military capabilities and drove the productivity gains essential to U.S. economic competitiveness. Meanwhile, cyber threats grew in sophistication and number, and put sensitive data, classified computer programs, mission-critical information systems, and future economic gains at risk. The basic research conducted under the Cyber Sciences project produced breakthroughs necessary to enhance the resilience of DoD information systems to current and emerging cyber threats.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2019	FY 2020	FY 2021
Title: Transparent Computing ***Description:*** The Transparent Computing program developed technologies that enabled the implementation of more effective security policies across distributed systems. The scale and complexity of modern information systems obscured the linkages between security-related events, making it hard to discover attacks such as advanced persistent threats (APTs). Transparent Computing technologies are particularly important for large integrated systems with diverse components such as distributed surveillance systems, autonomous systems, and enterprise information systems. The Transparent Computing program created the capability to propagate security-relevant information, track complete knowledge of event provenance, and ensured component interactions were consistent with established behavior profiles and policies.	9.346	-	-
Title: Space/Time Analysis for Cybersecurity (STAC) ***Description:*** The Space/Time Analysis for Cybersecurity (STAC) program developed techniques to detect algorithmic complexity vulnerabilities and side channel attacks in software. Historically, adversaries have exploited software implementation flaws through buffer and heap overflow attacks. Advances in operating systems have largely mitigated such attacks in modern systems, so cyber adversaries are now finding new ways of compromising software. Algorithmic complexity and side channel attacks are emerging as a new generation of attacks since they depend on intrinsic properties of software algorithms rather than implementation flaws. The STAC program developed analysis tools and techniques to detect vulnerabilities to these new attacks in the software on which the U.S. government, military, and economy depend.	3.600	-	-
Accomplishments/Planned Programs Subtotals	12.946	-	-

C. Other Program Funding Summary ($ in Millions)

N/A

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C. Other Program Funding Summary ($ in Millions)

Remarks

D. Acquisition Strategy

N/A

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COST ($ in Millions)	Prior Years	FY 2019	FY 2020	FY 2021 Base	FY 2021 OCO	FY 2021 Total	FY 2022	FY 2023	FY 2024	FY 2025	Cost To Complete	Total Cost
ES-01: *ELECTRONIC SCIENCES*	-	38.156	43.333	35.801	-	35.801	42.583	43.204	47.383	35.858	-	-

A. Mission Description and Budget Item Justification

The Electronic Sciences project is for basic exploration of electronic and optoelectronic devices, circuits, and processing concepts to meet the military's need for near real-time information gathering, transmission, and processing. In seeking to continue the phenomenal progress in microelectronics innovation that has characterized the last few decades, the project should provide DoD with new, improved, or potentially revolutionary device options for accomplishing these critical functions. The resulting technologies should help maintain knowledge of the enemy, communicate decisions based on that knowledge, and substantially improve the cost and performance of military systems. Research areas include analog, mixed signal, and photonic circuitry for communications and other applications; alternative computer architectures; and magnetic components to reduce the size of Electromagnetic (EM) and sensing systems. Other research could support field-portable electronics with reduced power requirements, ultra-high density information storage "on-a-chip", and new approaches to nanometer-scale structures, molecules, and devices.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2019	FY 2020	FY 2021
Title: Magnetic Miniaturized and Monolithically Integrated Components (M3IC) ***Description:*** The Magnetic Miniaturized and Monolithically Integrated Components (M3IC) program aims to integrate magnetic components onto semiconductor materials, improving the size and functionality of electromagnetic (EM) systems for communications, radar, and electronic warfare (EW). Current EM systems use magnetic components such as circulators, inductors, and isolators that are bulky and cannot be integrated with electronic circuitry. This limits the utility of the magnetic components as well as their ability to impact overall system performance and function. Reducing the size, weight, and power of magnetic components and integrating them onto semiconductor chips, however, could provide new mechanisms for the control and manipulation of EM signals as well as enable broader exploitation of magnetic materials. For instance, tighter integration could yield smaller radar systems, higher bandwidth communication over longer ranges, improved jam resistance, and more resilient EW systems. The M3IC program is divided into three technical areas: integration of magnetic materials and systems with semiconductor technology; accurate and efficient modeling of magnetic phenomena from the molecular to the component system level; and exploitation of magnetic phenomena in innovative component designs relevant to DoD EM systems. ***FY 2020 Plans:*** - Optimize micro-magnetic simulation codes and implement and insert models in industry-standard radio frequency (RF) circuit design tools. - Explore and demonstrate integrated or miniaturized components and new functionalities, such as circulators and frequency selective limiters, by incorporating new materials or integration methods. ***FY 2021 Plans:***	8.800	8.083	4.000

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2019	FY 2020	FY 2021
- Implement and optimize micro-magnetic codes and validate circuit models in industry-standard radio frequency (RF) circuit design tools. - Demonstrate improved performance of integrated miniature components by utilizing design tools developed in the M3IC program. ***FY 2020 to FY 2021 Increase/Decrease Statement:*** The FY 2021 decrease reflects conclusion of the development effort and a shift in focus to final demonstrations.			
Title: A MEchanically Based Antenna (AMEBA) ***Description:*** The A MEchanically Based Antenna (AMEBA) program seeks to develop efficient radio frequency (RF) transmitters operating in the Ultra-Low Frequency (ULF) and Very Low Frequency (VLF) ranges, for portable applications in underground and underwater communications. For classical antennas, the minimum antenna size for efficient transmission is related to the wavelength of the RF signal. This fundamental property prevents reducing the size of today's ULF and VLF transmitting antennas, which are up to a mile wide. Whereas traditional antennas generate electromagnetic waves by driving current through a conductive material, AMEBA takes a novel approach, mechanically moving an electrical charge or magnet to generate electromagnetic waves at ULF and VLF. This mechanical coupling provides unique advantages over traditional approaches at these frequencies, most notably greater than 1,000x reduction in antenna size. AMEBA will focus on developing both the materials and precision-controlled electromechanical systems required for an efficient transmitter system. This new capability would enable a range of applications including wireless communications for use over very long distances and short-range underground and underwater RF links. Other potential applications include terrestrial navigation systems for GPS-denied environments and ground-penetrating radar for detecting unexploded ordnance, underground facilities, and tunnels. ***FY 2020 Plans:*** - Demonstrate and deliver scaled VLF and ULF transmitters capable of transmitting signals that meet the program specifications for magnetic field, power consumption, and maximum linear dimension. - Further improve the efficiency of mechanical modulation techniques. ***FY 2021 Plans:*** - Combine material and modulation technique advances at the element level to demonstrate high-efficiency mechanical modulation in optimized transmitter elements. ***FY 2020 to FY 2021 Increase/Decrease Statement:*** The FY 2021 decrease reflects transition from development to final demonstration of high-efficiency mechanical modulation in optimized transmitter elements.	6.824	7.900	2.000
Title: SHort Range Independent Microrobotics Program (SHRIMP)	4.132	13.350	11.000

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2019	FY 2020	FY 2021
Description: The SHort Range Independent Microrobotics Program (SHRIMP) is developing microrobots with the ability to enter constrained disaster areas, such as collapsed buildings, for search and rescue operations. These sugar cube-sized microrobots will have integrated thermal, light, or audio sensors to assist with location of injured persons or critical infrastructure failures. The capabilities of the developed microrobots will be tested through a series of specific tests at the end of the program. The primary technical improvements needed for untethered mobility of centimeter-sized robotic platforms are in the efficiency, robustness, and force output of millimeter-scale actuators and in the power and energy capacity of batteries and chip-level power converters. Successful execution of the SHRIMP program will advance the micro-robotics field, allowing for practical robots to assist in disaster relief efforts in environments for which traditional robotics cannot efficiently operate due to their larger size. A companion applied research effort is funded in PE 0602716E, Project ELT-01. ***FY 2020 Plans:*** - Demonstrate actuator materials meeting program-defined metrics for volume, weight, and actuation force-displacement. - Demonstrate integrated power systems and batteries meeting program-defined metrics for volume, weight, length, and power performance. - Initiate development of high work density actuator mechanisms for microrobotic platforms. - Initiate development of improved integrated multi-mode power solutions with emphasis on smaller size, and performance across varied temperatures. ***FY 2021 Plans:*** - Demonstrate actuator materials and mechanisms meeting program-defined metrics for volume, weight, and actuation work density. - Demonstrate integrated power systems and batteries meeting program-defined metrics for length, weight, volume, and power performance. - Initiate development of actuator mechanisms for end-of-program tests. - Finalize power system and battery designs, including interfaces for pairing with actuator technologies for competition end-of-program tests. ***FY 2020 to FY 2021 Increase/Decrease Statement:*** The FY 2021 decrease reflects the program shifting from development to demonstration of actuator materials, integrated power systems, and batteries.			
Title: Atomic-Photonic Integration (A-PhI) ***Description:*** The Atomic-Photonic Integration (A-PhI) program is reducing the complexity of atomic clocks and gyroscopes by using integrated photonics for position, navigation, and timing (PNT) applications. A-PhI will demonstrate that a compact photonic integrated chip can replace the optical assembly for trapped atomic gyroscopes and clocks without degrading the performance of	5.000	14.000	13.000

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Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** ES-01 / *ELECTRONIC SCIENCES*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2019	FY 2020	FY 2021
the device. PNT is a critical resource for all DoD missions such as communications, navigation, reconnaissance, and electronic warfare. While PNT needs are usually met by using the global positioning system (GPS), GPS signals are vulnerable to a variety of disruption modalities and a fallback from GPS is essential. Currently, in the absence of GPS, tactical grade clocks and tactical/navigation grade Inertial Measurement Units can provide GPS-like accuracy for the short term. However, longer-term GPS independent strategies are still desirable. A-PhI will enable long-term GPS independence and enable PNT accuracy better than GPS for short durations. ***FY 2020 Plans:*** - Perform a laboratory demonstration of a trapped atom gyroscope. - Demonstrate and characterize performance of a low phase noise oscillator. - Demonstrate a photonic integrated chip capable of atom trapping and cooling compatible with proposed clock architecture. ***FY 2021 Plans:*** - Demonstrate an atomic clock in an integrated photonic integrated circuit physics package. - Perform critical design of atomic gyroscope. ***FY 2020 to FY 2021 Increase/Decrease Statement:*** The FY 2021 decrease reflects a shift from preliminary design to fabrication and technology demonstration.			
Title: Ultra-Wide Bandgap Semiconductors (UWBG) ***Description:*** The Ultra-Wide Bandgap Semiconductors (UWBG) program will seek to develop an entirely new class of semiconductor materials that will offer performance breakthroughs for a range of applications when compared to existing compound semiconductors. Electrical bandgaps determine, among other things, a transistor's maximum operating voltage, current density, thermal resistance, frequency and color (wavelength) of light emission. Consequently, wide band gaps have considerable interest for the DoD due to the need for high operating temperatures, currents, voltages and frequencies often required by emerging high power, agile Radio Frequency (RF) sources for radar, communications, directed energy and electronic warfare. This program will overcome the fundamental materials and device challenges that currently prevent implementation of UWBG materials into power, RF, and optoelectronic devices and systems. These challenges include reliably manufacturing low-defect substrates, heteroepitaxial material growth, and high concentration p-type and/or n-type doping. ***FY 2021 Plans:*** - Characterize low-energy heterogeneous epitaxially-grown UWBG devices. - Develop theoretical models with experimental verification of high-energy performance and avalanche breakdown in UWBG materials. ***FY 2020 to FY 2021 Increase/Decrease Statement:***	-	-	5.801

Exhibit R-2A, RDT&E Project Justification: PB 2021 Defense Advanced Research Projects Agency		Date: February 2020
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** ES-01 / *ELECTRONIC SCIENCES*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2019	FY 2020	FY 2021
The FY 2021 increase reflects program initiation.			
Title: High power Amplifier using Vacuum electronics for Overmatch Capability (HAVOC) ***Description:*** The High power Amplifier using Vacuum electronics for Overmatch Capability (HAVOC) program sought to develop compact Radio Frequency (RF) signal amplifiers for air, ground, and ship-based communications, sensing, and radar systems. HAVOC funded basic research in vacuum electronics to improve understanding of the various phenomena governing vacuum electronic amplifiers operating at mm-wave frequencies above 75 GHz. Focus areas included modeling and simulation techniques, advanced manufacturing methods, novel beam-wave interaction structures, high current density and long-life cathodes, and other relevant topics. Applied research efforts were funded in PE 0602716E, Project ELT-01.	3.000	-	-
Title: Precise Robust Inertial Guidance for Munitions (PRIGM) ***Description:*** The Precise Robust Inertial Guidance for Munitions (PRIGM) program aimed to identify, investigate, and demonstrate inertial sensor technologies for Positioning, Navigation, and Timing (PNT) in GPS-denied environments. The program exploited recent advances in integrating photonic (light-manipulating) components into electronics and in employing Microelectromechanical Systems (MEMS) as high-performance inertial sensors for use in extreme environments. PRIGM focused on two areas: development and transition of a Navigation-Grade Inertial Measurement Unit (NGIMU), a state-of-the-art MEMS device, to DoD platforms; development of Advanced Inertial MEMS Sensors (AIMS) that can provide gun-hard, high-bandwidth, high dynamic range navigation for GPS-free munitions. Applied research efforts were funded in PE 0602716E, Project ELT-01, and advanced technology development for the program is budgeted in PE 0603739E, Project MT-15.	4.400	-	-
Title: Signal Processing at RF (SPAR) ***Description:*** The Signal Processing at RF (SPAR) program investigated advanced analog components to process radio frequency (RF) signals for communications, radar, and electronic warfare applications. By using advancements in new semiconductor materials, processing, and novel signal interaction mechanisms, SPAR components were able to pick out friendly RF signals from both intentional and unintentional jamming signals, even when those signals sat on top of one another in frequency. This capability has enabled a range of new applications including communications in contested battlefield RF environments, jamming the RF spectrum while maintaining communication, and full-duplex radio communication.	6.000	-	-
Accomplishments/Planned Programs Subtotals	38.156	43.333	35.801

C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

Exhibit R-2A, RDT&E Project Justification: PB 2021 Defense Advanced Research Projects Agency		**Date:** February 2020
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** ES-01 / *ELECTRONIC SCIENCES*

D. Acquisition Strategy

N/A

Exhibit R-2A, RDT&E Project Justification: PB 2021 Defense Advanced Research Projects Agency	Date: February 2020

Appropriation/Budget Activity	R-1 Program Element (Number/Name)	Project (Number/Name)
0400 / 1	PE 0601101E / *DEFENSE RESEARCH SCIENCES*	ES-02 / *BEYOND SCALING SCIENCES*

COST ($ in Millions)	Prior Years	FY 2019	FY 2020	FY 2021 Base	FY 2021 OCO	FY 2021 Total	FY 2022	FY 2023	FY 2024	FY 2025	Cost To Complete	Total Cost
ES-02: *BEYOND SCALING SCIENCES*	-	51.283	47.000	59.025	-	59.025	38.700	53.290	53.290	53.290	-	-

A. Mission Description and Budget Item Justification

The Beyond Scaling Sciences project supports investigations into materials, devices, and architectures to provide continued improvements in electronics performance with or without the benefit of Moore's Law (silicon scaling). Within the next ten years, traditional scaling will start to encounter the fundamental physical limits of silicon, requiring fresh approaches to new electronic systems. Over the short term, DoD will therefore need to unleash circuit specialization in order to maximize the benefit of traditional silicon. Over the longer term, DoD and the nation will need to engage the computer, material, and mechanical sciences to explore electronics improvements through new non-volatile memory devices that combine computation, memory, and new automated design tools using machine learning. Other memory devices could also leverage an emerging understanding of the physics of magnetic states, electron spin properties, topological insulators, or phase-changing materials. Beyond Scaling programs will address fundamental exploration into each of these areas.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2019	FY 2020	FY 2021
Title: Beyond Scaling - Materials	11.000	7.000	11.000

Description: The Beyond Scaling - Materials program will investigate new materials to support next-generation logic and memory components. Historically, the DoD provided leadership in shaping the electronics field through research in semiconductor materials, circuits, and processors. However, as DoD focuses on military-specific components and as commercial technology reaches an inflection point in Moore's Law (silicon scaling), there is risk that future DoD needs will not be met. The Beyond Scaling - Materials program will pursue potential enhancements in electronics that do not rely on Moore's Law, including research not only into new materials but also into the implications of those materials at the device, algorithm, and packaging levels. These basic explorations include, novel mechanisms for computation based on inherent material properties, new methods to accelerate the identification and utilization of emerging materials, and innovative processes to vertically integrate these materials with others to realize superior computational mechanisms. Applied research for this program is funded within PE 0602716E, Project ELT-02.

FY 2020 Plans:
- Identify preliminary DoD-relevant benchmark algorithms and applications.
- Complete detailed analysis using hardware emulation/simulation in process showing performance benefits of technology approach.
- Design and fabricate memory elements that support new computational circuit topologies, including in-memory computation and stochastic computing.

FY 2021 Plans:
- Test memory elements supporting in-memory computation and stochastic computing.

Exhibit R-2A, RDT&E Project Justification: PB 2021 Defense Advanced Research Projects Agency		Date: February 2020
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** ES-02 / *BEYOND SCALING SCIENCES*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2019	FY 2020	FY 2021
- Emulate and design functioning prototype to demonstrate system performance benefit of new computational circuit topologies. - Initiate new memory hardware studies to validate DoD-relevant applications and benefit of program approach. ***FY 2020 to FY 2021 Increase/Decrease Statement:*** The FY 2021 increase reflects a shift in focus on analysis and benchmarking of components developed in FY 2019.			
Title: Beyond Scaling - Architectures and Designs ***Description:*** The Beyond Scaling - Architectures and Design program will investigate circuit architectures and design tools at both the integrated circuit and board level to provide enhanced performance and security with or without the benefit of continued scaling in silicon transistors (Moore's Law). Currently, improvements in electronics largely depend on a regular reduction in the size of silicon components. As Moore's Law slows and the nation loses the benefit of free, exponential improvements in electronics performance, DoD will need to maximize the benefits of available silicon technologies through circuit specialization. This program will investigate the potential for lowering the barriers to designing specialized circuits and to incorporating privacy and security protections. Approaches include the use of machine learning and automated design tools to program specialized hardware blocks, integrate them into existing designs, and deploy them in complex systems. The program will also explore architecture options for physically protecting sensitive information. Advances under this program will support a new DoD capability to create secure and specialized hardware that does not depend on continued improvements in silicon transistors. Applied research for this program is funded within PE 0602716E, Project ELT-02. ***FY 2020 Plans:*** - Deliver open source software for physical layout of digital circuits verified against a set of open source benchmark circuits that will fully automate mixed signal system-on-chip, package, and printed circuit board layout. - Demonstrate rapid, automated generation of digital circuits at multiple technology nodes using an open source software platform. - Initiate research to develop a range of capabilities that can ensure separation of sensitive data, including verifiable bus standards and board support packages, while maintaining high reliable throughput. - Research and develop high-level languages, modeling, and compilation techniques capable of generating physical board layouts and binaries that ensure the privacy of transactions. ***FY 2021 Plans:*** - Extend research and development of high level languages and novel modeling techniques while reducing transaction overhead on embedded devices. - Source training data for chip-level layout from published journals to use for design tools using machine learning techniques.	6.183	5.800	14.000

Exhibit R-2A, RDT&E Project Justification: PB 2021 Defense Advanced Research Projects Agency		Date: February 2020
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** ES-02 / *BEYOND SCALING SCIENCES*

B. Accomplishments/Planned Programs ($ in Millions)	**FY 2019**	**FY 2020**	**FY 2021**
- Improve accuracy and speed of machine-learning based algorithms for chip, package, and board design through incorporation of additional data. ***FY 2020 to FY 2021 Increase/Decrease Statement:*** The FY 2021 increase reflects the program shifting from research to development of circuit technologies and design tools.			
Title: Lifelong Learning Machines (L2M) ***Description:*** The Lifelong Learning Machines (L2M) program will research and develop fundamentally new machine learning mechanisms, enabling machines that learn continuously as they operate. Current learning machines are fully configured in advance of deployment, meaning that they have difficulty accounting for in-the-field mission changes or for unexpected deviations in the data being processed. To overcome this limitation, L2M will pursue learning approaches inspired by biological systems, which continuously learn and improve their skills without losing previous knowledge. L2M will explore network structures that improve performance by processing new data seen in the field, learn new tasks without forgetting previous tasks, and incorporate context into their understanding of the environment. These capabilities would impact a broad array of military applications that require processing and understanding data in real-time, often have limited data sets for training, and must be deployed in environments where unpredictable events may occur. ***FY 2020 Plans:*** - Generate common test data and distribute to performers for validating lifelong learning core capabilities. - Translate first sets of insights from biological experiments into machine learning algorithms, and show that developed algorithms improve lifelong learning capabilities. - Demonstrate first lifelong learning systems, each with core adaptation capabilities using performer test cases. - Demonstrate feasibility using the common test cases. ***FY 2021 Plans:*** - Study safety and security in L2M systems. - Refine the first set of algorithms on the common test cases, and add new algorithms to the test cases. - Integrate multiple L2M capabilities into a single system. ***FY 2020 to FY 2021 Increase/Decrease Statement:*** The FY 2021 decrease reflects minor program repricing.	16.100	16.200	16.025
Title: Joint University Microelectronics Program (JUMP) ***Description:*** The Joint University Microelectronics Program (JUMP) is a government-industry joint research program to explore computing, sensing, communication, and data storage innovations for applications beyond the 2030 horizon. The program recognizes that the densely interconnected microsystems of the future will be built through the use of groundbreaking materials,	18.000	18.000	18.000

Exhibit R-2A, RDT&E Project Justification: PB 2021 Defense Advanced Research Projects Agency		Date: February 2020
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** ES-02 / *BEYOND SCALING SCIENCES*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2019	FY 2020	FY 2021
revolutionary devices, advanced architectures, and unconventional computing. JUMP will therefore sponsor academic research teams focused on related key technology areas that will impact future DoD capabilities and national security. The JUMP program will not only push fundamental technology research but also establish long-range microelectronic research themes with greater emphasis on end-application and systems-level computation. By discovering the science underlying new technologies and overcoming engineering challenges, JUMP will enable DoD applications to exploit the entire electromagnetic spectrum from radio frequency (RF) to terahertz (THz) and to employ both distributed and centralized computing with embedded intelligence and memory. ***FY 2020 Plans:*** - Benchmark emerging materials, power efficient RF, THz, digital, and storage devices prototypes. - Demonstrate prototypes of novel distributed and centralized computing architectures and subsystems for efficient information extraction, processing, and autonomous control applications. - Identify new research directions and amend new projects to the JUMP university research portfolio. ***FY 2021 Plans:*** - Demonstrate promising materials, power efficient RF, THz, digital, and storage devices prototypes. - Explore next-generation distributed and centralized computing architectures and subsystems to enhance efficiency of information extraction, processing, and autonomous control. - Establish additional multidisciplinary projects across academic research teams to enrich their research agenda for future microsystems.			
Accomplishments/Planned Programs Subtotals	51.283	47.000	59.025

C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

D. Acquisition Strategy

N/A

Exhibit R-2A, RDT&E Project Justification: PB 2021 Defense Advanced Research Projects Agency			Date: February 2020
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** MS-01 / *MATERIALS SCIENCES*	

COST ($ in Millions)	Prior Years	FY 2019	FY 2020	FY 2021 Base	FY 2021 OCO	FY 2021 Total	FY 2022	FY 2023	FY 2024	FY 2025	Cost To Complete	Total Cost
MS-01: *MATERIALS SCIENCES*	-	72.181	63.412	52.560	-	52.560	66.647	48.638	41.138	37.138	-	-

A. Mission Description and Budget Item Justification

The Materials Sciences project provides the fundamental research that underpins the design, development, assembly, and optimization of advanced materials, devices, and systems for DoD applications in areas such as robust diagnostics and therapeutics, novel energetic materials, and complex hybrid systems.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2019	FY 2020	FY 2021
Title: Molecular Systems and Materials Assembly	16.319	12.000	3.000
Description: The Molecular Systems and Materials Assembly thrust is exploring new approaches for the synthesis, assembly, and characterization of molecules and materials from the atomic to the product scale. Ultimately, materials and methods developed in this thrust will support a wide range of DoD applications that span therapeutics, energetics, computation and next generation optical materials. Specific approaches include non-traditional synthetic approaches such as the use of extreme pressure and/or temperature conditions, engineering and controlling atomic-scale processing routes for designer microstructures, and the synthesis and rapid screening of many molecules to more quickly identify those with desired functions and/or properties. Efforts in this thrust also include assembly of these and other materials, such as subwavelength engineered shapes, into micro-to-macro-scale objects and devices, exploration of molecules for information storage and processing, and fundamental studies of the properties and function of these molecular ensembles and systems. ***FY 2020 Plans:*** - Define limitations associated with scale-up of nano- and micro-assembly processes. - Demonstrate operational molecular computing system by linking storage and processing components and execute processing approaches directly on molecular data. - Identify and quantify advantages of molecular computing over conventional computing and storage methods. - Characterize and mitigate error sources in storage and processing approaches and demonstrate repeatability of storage and processing approaches. ***FY 2021 Plans:*** - Establish projections for data access speeds of molecular storage methods with fully automated workflows. - Provide necessary design modifications to molecular computing systems to further improve input/output (I/O) rate, data read error, and computational accuracy. ***FY 2020 to FY 2021 Increase/Decrease Statement:*** The FY 2021 decrease due to program evolution from demonstrations to systems refinement.			
Title: Fundamental Limits	30.000	20.712	19.500

Exhibit R-2A, RDT&E Project Justification: PB 2021 Defense Advanced Research Projects Agency		Date: February 2020
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** MS-01 / *MATERIALS SCIENCES*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2019	FY 2020	FY 2021
Description: Understanding the Fundamental Limits (i.e., achievable boundaries) of scientific principles, processes and technologies is critical to better anticipate technological surprise for our adversaries and ourselves. This thrust explores boundaries across fields such as physics, chemistry, mathematics, biology, and engineering to address critical questions for national security. This thrust is addressing foundational theory and approaches that include, for example, the fundamental limitations of optical technologies, potential implications for basic biology on national security, and the ability for modeling and simulation to provide a better understanding of complex systems. ***FY 2020 Plans:*** - Extend capability of modeling tools to simulate centimeter-scale devices and confirm performance with characterization of cm-scale engineered materials. - Investigate the possibility of influencing electromagnetic biological sensing or regulation as a result of any newly discovered biological communications channels. - Demonstrate basic technical capabilities needed to validate and extend models for electromagnetic, or electromagnetically facilitated, biological signaling channels. - Develop experimental methods and setups to test predictive, parametric models of nascent light-matter interactions under investigation. - Analyze experimental results of nascent light-matter interactions and provide input back to parametric models to further optimize and refine the modeling framework. - Initiate development of multi-physics models that can predict atmospheric perturbations, such as plasma "holes" and acoustic shock waves, associated with small scale meteorological phenomena. ***FY 2021 Plans:*** - Use experimental methods and parametric models to demonstrate devices that meet government-approved challenge problem metrics. - Demonstrate in simulation the ability of multi-physics models to predict atmospheric perturbations, such as plasma "holes" and acoustic shock waves, associated with small scale meteorological phenomena. - Identify new approaches to improve the range and sensitivity of atmospheric measurements to enable routine characterization of the mesosphere. ***FY 2020 to FY 2021 Increase/Decrease Statement:*** The FY 2021 decrease is due to program focus shifting from developing extended capability to demonstrations.			
Title: Non-Equilibrium Materials ***Description:*** The Non-Equilibrium Materials thrust will explore materials and materials structures that acquire novel properties when driven far from equilibrium. Work in this thrust will examine the physical underpinnings and applications of these systems in	9.600	16.000	16.000

Exhibit R-2A, RDT&E Project Justification: PB 2021 Defense Advanced Research Projects Agency		Date: February 2020
Appropriation/Budget Activity 0400 / 1	R-1 Program Element (Number/Name) PE 0601101E / *DEFENSE RESEARCH SCIENCES*	Project (Number/Name) MS-01 / *MATERIALS SCIENCES*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2019	FY 2020	FY 2021
areas of interest to the DoD, including next generation electronics, high-performance computing, and sensing. Efforts will include the development of topologically protected excitations in electronic materials and fundamental studies of exotic quantum states of matter in periodically driven solid-state systems. ***FY 2020 Plans:*** - Demonstrate fast current-induced motion of topological excitations. - Develop prototype devices for topologically protected memory. - Implement braiding operations in topologically protected qubits. - Experimentally demonstrate the enhancement of coherence time in a large quantum system. - Demonstrate extended lifetime for a correlated electron phase. ***FY 2021 Plans:*** - Develop advanced metrology for high-resolution space and time-resolved spin-textures. - Scale up braiding operations in topologically protected qubits. - Demonstrate many-body localization and increased coherence time for high-fidelity multi-qubit gates in spin-based quantum information processors. - Demonstrate Higgs lasing phenomenon with entangled photon pair generation via parametric amplification. - Advance metrology, particularly atomic clocks, beyond the standard quantum limit via entangled quantum matter stabilization. - Demonstrate compact, room-temperature solid-state color center gyroscope with shock insensitivity in the order of 1,000,000 meters per second squared linear acceleration. - Demonstrate significant increase in the time and temperature scales of light-induced superconductivity.			
Title: Basic Photon Science ***Description:*** The Basic Photon Science thrust is examining the fundamental science of photons and their interactions in integrated devices for potential DoD-applications such as communications, signal processing, spectroscopic sensing and imaging. One focus area is development of novel, chip-scale optical frequency comb sources and associated technologies for spectroscopic sensing, identification, and quantification of multiple trace materials in spectrally cluttered backgrounds. Additional research will explore development of a complex theoretical framework for maximum information extraction from complex scenes to guide development of new imaging technologies. Work in this thrust will establish the first-principles limits of photon detector performance in a variety of detector technologies to enable better, more sensitive detectors. ***FY 2020 Plans:*** - Demonstrate the feasibility of non-line-of-sight imaging around corners at a government facility to government partners. - Experimentally evaluate design advances in detectors driven by new fundamental theoretical models for photon detection. - Initiate efforts to develop and integrate physical models for passive multi-dimensional imagers.	16.262	14.700	14.060

Exhibit R-2A, RDT&E Project Justification: PB 2021 Defense Advanced Research Projects Agency		Date: February 2020
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2019	FY 2020	FY 2021
- Initiate efforts to explore the potential for sub-diffraction limit imaging and improved information retrieval using quantum insights and spectral estimation theory. ***FY 2021 Plans:*** - Perform spectral analysis of passive thermal emission to mathematically determine object structures. - Develop and demonstrate imaging models to understand fundamental tradeoffs in information gathering and 3D resolution. - Explore the potential for achieving multi-basis imaging techniques that do not require active illumination. - Utilize image models to understand fundamental tradeoffs in data acquisition, prior knowledge and information resolution. ***FY 2020 to FY 2021 Increase/Decrease Statement:*** The FY 2021 decrease reflects minor program repricing.			
Accomplishments/Planned Programs Subtotals	72.181	63.412	52.560

C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

D. Acquisition Strategy

N/A

Exhibit R-2A, RDT&E Project Justification: PB 2021 Defense Advanced Research Projects Agency		**Date:** February 2020
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COST ($ in Millions)	Prior Years	FY 2019	FY 2020	FY 2021 Base	FY 2021 OCO	FY 2021 Total	FY 2022	FY 2023	FY 2024	FY 2025	Cost To Complete	Total Cost
TRS-01: *TRANSFORMATIVE SCIENCES*	-	46.995	57.715	42.769	-	42.769	32.948	28.735	24.105	20.802	-	-

A. Mission Description and Budget Item Justification

The Transformative Sciences project supports research and analysis that leverages converging technological forces and transformational trends in information-intensive subareas of the social sciences, life sciences, and manufacturing. The project integrates these diverse disciplines to improve military adaptation to sudden changes in requirements, threats, and emerging/converging trends, especially trends that have the potential to disrupt military operations or threaten National Security. Specific research in this project will investigate technologies to enable detection of novel threat agents (e.g., bacterial pathogens) and maintain warfighter health and improve recovery. This project also includes efforts to create innovative materials of interest to the military (e.g., self-healing materials).

B. Accomplishments/Planned Programs ($ in Millions)	**FY 2019**	**FY 2020**	**FY 2021**
Title: Social Simulation (SocialSim)	13.014	12.952	11.215

Description: The Social Simulation (SocialSim) program is developing a computational capability to simulate the spread and evolution of information in the online environment. The global information environment is radically changing how and at what rate information spreads and evolves. Both nation-state and sub-state actors are incorporating messaging into their operations to great advantage. Existing approaches for understanding online information spread and evolution are largely based on specialized exercises that take considerable time to orchestrate and execute, and have limited accuracy. SocialSim aims to enable a deeper, more quantitative, and better validated understanding of adversaries' messaging campaigns and their likely outcomes, as well as exploration of potential responses.

FY 2020 Plans:
- Evaluate the performance of the extended models and mechanisms across multiple interconnected online environments.
- Integrate the multiple models and mechanisms into a prototype, and leverage ensemble modeling and meta-modeling techniques to support application of models.
- Demonstrate the capability to accurately represent online social phenomena, such as recurrent cascades of information, and to quantify the effects of small, persistent groups of information disseminators.

FY 2021 Plans:
- Evaluate performance on increasingly complex challenge scenarios, such as the spread of information on the dark web.
- Extend prototype using ensemble modeling and meta-modeling techniques, and evaluate application of the integrated models across multiple social media domains.
- Demonstrate and validate capabilities across multiple social media domains in applied settings relevant to operational users.

FY 2020 to FY 2021 Increase/Decrease Statement:

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2019	FY 2020	FY 2021
The FY 2021 decrease reflects a shift from model development and prototype integration to evaluation and demonstration on complex social media domains.			
Title: Biology for Security (BIOSEC) ***Description:*** Based on initial research conducted under the Biological Robustness in Complex Settings (BRICS) program, the Biology for Security (BIOSEC) program seeks to investigate novel approaches to address the DoD need for rapid detection of unknown and/or emerging biological threats from state actors or violent extremist organizations (VEOs). This program will investigate approaches for identifying pathogens based on specific behaviors, or phenotypes, such as niche finding or cell toxicity. Unlike current methods, which rely on a priori knowledge of the pathogen and cannot detect or otherwise analyze unknown threats, this approach will handle scenarios involving engineered or undiscovered bacterial pathogens that do not have known hallmarks. Advances in this area will produce a completely new capability to assess the emergence of pathogens and to detect pathogens that have been specifically engineered to evade detection by traditional methods. Resulting systems may be used to alert deployed military personnel operating around the world to new biothreats, or in response to a U.S.-based discovery, outbreak, or pandemic. ***FY 2020 Plans:*** - Demonstrate unbiased high-throughput isolation of microbes from complex samples. - Develop strategies for the maintenance and growth of all bacterial types from complex environmental samples. - Demonstrate effective processes for phenotyping small numbers of bacteria for the three principal classes of pathogenic traits: niche finding, attacking a membrane, and self-defense. - Implement data fusion and remedial algorithms for machine learning and modeling of pathogenicity. - Demonstrate isolation and bioinformatics protocols on complex samples that show the potential for integration into a unified platform. ***FY 2021 Plans:*** - Demonstrate continued platform integration (e.g., combined bacterial processing for isolation, integration, and data collection). - Demonstrate isolation and interrogation platforms on increasingly complex samples that simulate complex environments. - Demonstrate the ability to combine bacterial phenotypes and single-cell omics to support pathogenic trait mapping. - Demonstrate increased algorithmic performance on predicting pathogenicity of unknown bacteria. ***FY 2020 to FY 2021 Increase/Decrease Statement:*** The FY 2021 increase reflects additional efforts in high-throughput analyses and movement towards an integrated system.	12.890	13.347	15.100
Title: Native Bioelectronic Interfaces	-	12.116	14.254

Exhibit R-2A, RDT&E Project Justification: PB 2021 Defense Advanced Research Projects Agency		Date: February 2020
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2019	FY 2020	FY 2021
Description: The Native Bioelectronic Interfaces effort will address the DoD need for improving warfighter recovery from injury by developing technologies that can accelerate the restoration and repair of complex tissues. This program will develop approaches that combine high-resolution biosensors to track the healing process in real-time with bioactuators to stimulate restoration where and when needed. The primary challenge to achieving this is the lack of a closed-loop interface that can manipulate highly complex signaling pathways in wounds and the developmental interdependencies that scale from cell to tissue. The program will develop new methods to convert dense multi-modal information into the body's native repair processes, and will leverage artificial intelligence to guide the delivery of the signals necessary for healing. Advances from this program will produce bioactuators that can release diverse stimuli with high spatial and temporal resolution, and biosensors that provide the requisite in situ measurement to guide the healing process. ***FY 2020 Plans:*** - Identify effective stimuli for directing growth, development, and repair. - Identify critical physiological changes and biomarkers that can report on cell growth and differentiation. - Develop first set of algorithms that can deliver preliminary intervention strategies. ***FY 2021 Plans:*** - Demonstrate biocompatibility, reliable operation of actuators, and control of at least two physiological processes in animal models. - Demonstrate reliable operation of sensors able to track at least two physiological processes in an in vivo model. - Demonstrate that the algorithmic model is both descriptive and able to determine the current stage of healing from acquired sensor data. - Produce an in vivo sensor system that can accurately report the wound state to be delivered to the independent verification and validation (IV&V) team. ***FY 2020 to FY 2021 Increase/Decrease Statement:*** The FY 2021 increase reflects the initiation of IV&V efforts and demonstrations in animal models.			
Title: Engineered Living Materials (ELM) ***Description:*** The Engineered Living Materials (ELM) program is pursuing new approaches to engineer complex, multi-cellular systems for enhanced capabilities and functional materials to improve military infrastructure design and logistics. Complex biological materials and systems have unique properties (e.g., controlled porosity and high strength-to-weight ratios) not only because of the inherent components but also because of how those components are assembled together across length scales. Engineering biology tools and techniques are now at a stage to pursue the organization and function of multi-cellular systems for a new class of improved capabilities. This program is developing underlying technological platforms to enable information-driven assembly of hierarchical multi-cellular systems for the development of advanced materials. Advances in this program will	10.955	9.350	2.200

Exhibit R-2A, RDT&E Project Justification: PB 2021 Defense Advanced Research Projects Agency		Date: February 2020
Appropriation/Budget Activity 0400 / 1	**R-1 Program Element (Number/Name)** PE 0601101E / *DEFENSE RESEARCH SCIENCES*	**Project (Number/Name)** TRS-01 / *TRANSFORMATIVE SCIENCES*

B. Accomplishments/Planned Programs ($ in Millions)	FY 2019	FY 2020	FY 2021
impact military approaches to infrastructure design in austere environments as well as established methods for manufacture and maintenance of military platforms (e.g., tanks, planes, ships). ***FY 2020 Plans:*** - Demonstrate at least two-fold improvements in rate of growth and maintenance of the size and structure of produced material in controlled conditions. - Demonstrate engineered cell-cell interactions to organize and maintain the density/spacing of patterns. - Demonstrate increased strength, scaling, and robustness of materials in a built environment. - Demonstrate controlled healing in response to damage of advanced materials in controlled conditions. ***FY 2021 Plans:*** - Verify stability and scalability of material over a prolonged period under operational conditions. - Pressure test self-healing proficiency for deformation, puncture, and tearing resistance under operational conditions. ***FY 2020 to FY 2021 Increase/Decrease Statement:*** The FY 2021 decrease reflects completion of research and development efforts and demonstration of program technologies.			
Title: Biological Complexity (BioCom) ***Description:*** The Biological Complexity (BioCom) program seeks to enhance the understanding of the basic processes associated with biological network interactions, communication, and control to enable novel approaches and technology development to improve warfighter readiness and resilience. Key advances expected from this research will include the identification of approaches to create stable, predictable, and dynamic control mechanisms of biological networks. Such information will allow the determination of a biosystem's state and enable the prediction of state. Applications range from infectious disease mitigation or prevention, maintaining warfighter health, to leveraging biological systems for optimal production of therapeutics. ***FY 2020 Plans:*** - Demonstrate solutions that counter pathogens and antibiotic resistance, regulate inflammation from Traumatic Brain Injury (TBI), and maintain a healthy gut. - Deliver new experimental tools and algorithms to engineer control of biological system behavior that is robust to perturbation. - Demonstrate real time characterization of cell and molecular responses to control algorithms. - Establish the limits on reproducibility of performance of biological control systems. ***FY 2020 to FY 2021 Increase/Decrease Statement:***	10.136	9.950	-

Exhibit R-2A, RDT&E Project Justification: PB 2021 Defense Advanced Research Projects Agency		Date: February 2020
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B. Accomplishments/Planned Programs ($ in Millions)	FY 2019	FY 2020	FY 2021
The FY 2021 decrease reflects program completion.			
Accomplishments/Planned Programs Subtotals	46.995	57.715	42.769

C. Other Program Funding Summary ($ in Millions)

N/A

Remarks

D. Acquisition Strategy

N/A