Exhibit R-2, RDT&E Budget Item Justification: PB 2012 Defense Advanced Research Projects Agency										DATE: February 2011	
APPROPRIATION/BUDGET ACTIVITY 0400: *Research, Development, Test & Evaluation, Defense-Wide* BA 1: *Basic Research*				R-1 ITEM NOMENCLATURE PE 0601101E: *DEFENSE RESEARCH SCIENCES*							
COST ($ in Millions)	**FY 2010**	**FY 2011**	**FY 2012 Base**	**FY 2012 OCO**	**FY 2012 Total**	**FY 2013**	**FY 2014**	**FY 2015**	**FY 2016**	**Cost To Complete**	**Total Cost**
Total Program Element	194.031	328.195	290.773	-	290.773	299.049	319.167	341.688	362.021	Continuing	Continuing
BLS-01: *BIO/INFO/MICRO SCIENCES*	36.528	53.739	39.686	-	39.686	64.678	76.125	73.248	77.248	Continuing	Continuing
CCS-02: *MATH AND COMPUTER SCIENCES*	38.240	70.001	60.805	-	60.805	60.670	60.942	67.512	71.512	Continuing	Continuing
CYS-01: *CYBER SCIENCES*	-	-	16.667	-	16.667	25.000	33.333	41.667	50.000	Continuing	Continuing
ES-01: *ELECTRONIC SCIENCES*	49.586	73.023	46.109	-	46.109	30.413	33.876	33.876	31.876	Continuing	Continuing
MS-01: *MATERIALS SCIENCES*	69.677	89.854	97.506	-	97.506	78.019	75.450	76.824	78.824	Continuing	Continuing
TRS-01: *TRANSFORMATIVE SCIENCES*	-	41.578	30.000	-	30.000	40.269	39.441	48.561	52.561	Continuing	Continuing

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, biological and materials sciences.

The Bio/Info/Micro Sciences project will explore and develop potential technological breakthroughs that exist at the intersection of biology, information technology and micro/physical systems to exploit advances and leverage fundamental discoveries for the development of new technologies, techniques and systems of interest to the DoD. Programs in this project will draw upon information and physical sciences to discover properties of biological systems that cross multiple biological architectures and functions, from the molecular and genetic level through cellular, tissue, organ, and whole organism levels. Programs in this project also lay the groundwork for advances in military medicine and combat casualty care.

The Math and Computer Sciences project supports long term national security requirements through scientific research and experimentation in new computational models and mechanisms for reasoning and communication in complex, interconnected systems. The project is exploring novel means to exploit computer capabilities; enhance human-to-computer and computer-to-computer interaction technologies; advance innovative computer architectures; and discover new learning mechanisms and innovations in software composition. It is also fostering the computer science academic community to address the DoD's need for innovative computer and information science technologies. Additionally, this project explores the science of mathematics for potential defense applications.

The Cyber Sciences project supports long term national security requirements through scientific research and experimentation in cyber-security. Networked computing systems control virtually everything, from power plants and energy distribution, transportation systems, food and water distribution, financial systems, to defense

systems. Protecting the infrastructure on which these systems rely is a national security issue. The Cyber Sciences project will ensure DoD cyber-capabilities survive adversary attempts to degrade, disrupt, or deny military computing, communications, and networking systems. Basic research in cyber security is required to provide a basis for continuing progress in this area. Promising research results will transition to both technology development and system-level projects.

The Electronic Sciences project explores and demonstrates electronic and optoelectronic devices, circuits and processing concepts that will provide: 1) new technical options for meeting the information gathering, transmission and processing required to maintain near-real time knowledge of the enemy and the ability to communicate decisions based on that knowledge to all forces in near-real time; and 2) provide new means for achieving substantial increases in performance and cost reduction of military systems providing these capabilities.

The Materials Sciences project is concerned with the development of: high power density/high energy density mobile and portable power sources; processing and design approaches for nanoscale and/or bimolecular materials, interfaces and microsystems; materials and measurements for molecular-scale electronics and spin-dependent materials and devices.

The Transformative Sciences project supports scientific research and analysis that leverages converging technological forces and transformational trends in the areas of computing and the computing-reliant subareas of social sciences, life sciences, manufacturing, and commerce as a means of improving military adaptation to sudden changes in requirements, threats, and emerging converging trends.

B. Program Change Summary ($ in Millions)	FY 2010	FY 2011	FY 2012 Base	FY 2012 OCO	FY 2012 Total
Previous President's Budget	205.915	328.195	268.459	-	268.459
Current President's Budget	194.031	328.195	290.773	-	290.773
Total Adjustments	-11.884	-	22.314	-	22.314
• Congressional General Reductions		-			
• Congressional Directed Reductions		-			
• Congressional Rescissions	-	-			
• Congressional Adds		-			
• Congressional Directed Transfers		-			
• Reprogrammings	-6.422	-			
• SBIR/STTR Transfer	-5.462	-			
• TotalOtherAdjustments	-	-	22.314	-	22.314

Congressional Add Details ($ in Millions, and Includes General Reductions)	FY 2010	FY 2011
Project: BLS-01: *BIO/INFO/MICRO SCIENCES*		
Congressional Add: *Countermeasures to Combat Protozoan Parasites*	1.600	-
Congressional Add Subtotals for Project: BLS-01	1.600	-

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Congressional Add Details ($ in Millions, and Includes General Reductions)	FY 2010	FY 2011
Project: CCS-02: *MATH AND COMPUTER SCIENCES*		
Congressional Add: *Science, Technology, Engineering and Mathematics Initiative*	1.600	-
Congressional Add Subtotals for Project: CCS-02	1.600	-
Project: ES-01: *ELECTRONIC SCIENCES*		
Congressional Add: *Laboratory for Advanced Photonic Composites Research*	1.280	-
Congressional Add Subtotals for Project: ES-01	1.280	-
Project: MS-01: *MATERIALS SCIENCES*		
Congressional Add: *American Museum of Natural History Infectious Disease Research*	1.200	-
Congressional Add: *Institute for Collaborative Sciences Research*	2.080	-
Congressional Add: *Advanced Materials Research Institute*	0.800	-
Congressional Add: *Hydrogen Fuel Cell Research*	4.000	-
Congressional Add: *Solid Oxide Fuel Technology*	1.000	-
Congressional Add Subtotals for Project: MS-01	9.080	-
Congressional Add Totals for all Projects	13.560	-

Change Summary Explanation

FY 2010: Decrease reflects transfer of the "Security Protection using Ballistic Core Technologies" congressional add to the Army Research Lab, SBIR/STTR transfer and internal below threshold reprogrammings.

FY 2012: Increase reflects additional emphasis in basic research for transformative technologies such as social networking, synthetic biology, dialysis-like therapeutics and quantum devices, the establishment of a new project for Cyber Sciences (CYS-01), offset by a reduction for Defense Efficiencies for contractor staff support and studies.

Exhibit R-2A, RDT&E Project Justification: PB 2012 Defense Advanced Research Projects Agency			DATE: February 2011
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COST ($ in Millions)	FY 2010	FY 2011	FY 2012 Base	FY 2012 OCO	FY 2012 Total	FY 2013	FY 2014	FY 2015	FY 2016	Cost To Complete	Total Cost
BLS-01: *BIO/INFO/MICRO SCIENCES*	36.528	53.739	39.686	-	39.686	64.678	76.125	73.248	77.248	Continuing	Continuing

A. Mission Description and Budget Item Justification

This project is investigating and developing the intersections of biology, information technology and micro/physical systems to exploit important technological advances and leverage fundamental discoveries for the development of new technologies, techniques, and systems of interest to the DoD. This research is critical to the development of rapid responses to engineered biological warfare agents, radically new biomolecular computers, and novel materials for the DoD. Programs in this project will draw upon the information and physical sciences to discover properties of biological systems that cross multiple scales of biological architecture and function, from the molecular and genetic level through cellular, tissue, organ, and whole organism levels. This project will develop the basic research tools in biology that are unique to the application of biological-based solutions to critical Defense problems.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
Title: Bio Interfaces	2.000	2.000	5.000

Description: The Bio Interfaces program supports scientific study and experimentation, emphasizing the interfaces between biology and the physical and mathematical/computer sciences. This unique interaction will develop new mathematical and experimental tools for understanding biology in a way that will allow its application to a myriad of DoD problems. These tools will help exploit the advances in the complex modeling of physical and biological phenomena. It is also expected that understanding the fundamentals of biology will aid in developing tools to understand complex, non-linear networks and force structures. This program will also explore the fundamental nature of time in biology and medicine. This will include mapping basic clock circuitry in biological systems from the molecular level up through unique species level activities with a special emphasis on the applicability to human biology. Operational relevance of this research activity includes improving our understanding of sleep-wake cycles, increasing the scientific understanding of deployment cycle lengths, and enhancing our ability to model the dynamics of disease outbreaks.

FY 2010 Accomplishments:
- Tested theoretical mathematical formulations of developmental laws of biology and demonstrated the existence of fundamental biogenesis pathways that operate across plant and animal kingdoms.
- Developed novel mathematical tools that decipher complex cardiac signals to detect early warning signs of adverse medical events.
- Discovered a novel regulatory mechanism controlling cellular protein expression that expands the understanding of biological control systems and how they have evolved.

FY 2011 Plans:

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
- Apply scientific principles of mathematical decoding to elucidate basis temporal-spatial signatures within biological systems, particularly with respect to human biology. - Identify ecology-specific or reagent-specific nucleotide tags in a replicating organism which possess sufficient half-life to last 1000 generations. ***FY 2012 Plans:*** - Demonstrate two genomic indicators of geospatial origin of prokaryotic microorganisms. - Demonstrate the role of phage-bacteria in attack and defense in assigning temporal and geo-localizing data. - Demonstrate four variable determinations of global origin or residence in a simple mammalian system.			
Title: Preventing Violent Explosive Neurologic Trauma (PREVENT) - Medical ***Description:*** The Preventing Violent Explosive Neurologic Trauma (PREVENT) program seeks to understand the causes of blast-induced traumatic brain injury (TBI), an injury that while previously described in the warfighter population, has been referred to as a potential "hidden epidemic" in the current conflict. PREVENT will use a variety of modeling techniques based on in-theater conditions to assess potential TBI caused by blast in the absence of penetrating injury or concussion. Research will create a model that can be directly correlated to the epidemiology and etiology of injury seen in returning warfighters, and attempt to determine the physical and physiological underpinnings and causes of the injury. Mitigation and treatment strategies will be formulated based on our new knowledge of blast-induced brain injury with the eventual goal of reducing injury severity across the forces by over fifty percent, improving recovery time, and preventing future injuries. PREVENT is funded in the newly created Budget Activity 6.1 Medical Program Element 0601117E, beginning in FY 2012. ***FY 2010 Accomplishments:*** - Assessed the effect of commonly available pharmaceuticals in both acute and chronic mitigation of blast brain injury symptoms. - Validated diagnostic criteria for assessment of mild to severe blast brain injury. - Tested and validated fabricated device strategies to ensure that they appropriately mitigate the effects of blast brain injury. ***FY 2011 Plans:*** - Develop and design devices and diagnostic platforms suitable for blast brain injury detection in theater capable of early identification of blast neurotrauma from physiological, neurological, and behavioral changes. - Investigate the long-term effects of multiple exposures to blast on warfighters following return from deployment through comparison to pre-deployment baselining across a battery of psychological, neurological, and behavioral tests and correlation to data collected from in-theater blast events.	4.500	3.207	-
Title: Biological Adaptation, Assembly and Manufacturing	7.738	9.482	8.386

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012

Description: The Biological Adaptation, Assembly and Manufacturing program will examine the structure, function, and informational basis underlying biological system adaptation, and the factors employed by the organism to assemble and manufacture complex biological subsystems. The unique stability afforded biological systems in their ability to adapt to wide extremes of physical and endurance (e.g., heat, cold, and sleeplessness) parameters will be examined and exploited in order to engineer stability into biological systems required for the military (such as blood, bioengineered tissues or other therapeutics). In addition, the fault tolerance present in biological systems will be exploited in order to assemble and manufacture complex physical and multi-functional systems, both biological and abiotic (such as tissue constructs designed for reconstructive surgery). These systems include novel load-bearing bio-interactive materials and composites for repair of severe hard tissue trauma, including complex bone fractures. A key new antibody technology will develop the ideal antibody master molecule for use in unattended sensors that maintains high temperature stability and controllable affinity for threat agents. Using the Freytag triangle structure, the interplay of narratives or stories may reveal how they tap into an array of mechanisms implicated in memory, reasoning, and strategy behavior. Applications to Defense systems include the development of chemical and biological sensors, tools for strategic military decision-makers involved in public relations and information operations, and improved warfighter battlefield survivability.

FY 2010 Accomplishments:
- Developed novel resorbable wet adhesives with the mechanical properties of natural bone, for inclusion into fracture putty formulation.
- Demonstrated fracture putty in small animal model of bone fracture.
- Initiated large animal studies of fracture putty for bone fracture repair.
- Identified fundamental mechanisms for controlling antibody stability and affinity.
- Initiated efforts to modify antibody affinity and temperature stability of the MS2 scFv antibody.
- Determined the baseline binding parameters of the anti-MS2 scFv and established the methodology for evaluating improvements in antibody performance.

FY 2011 Plans:
- Demonstrate fracture putty in large animal model of bone fracture, with independent validation.
- Initiate expanded large animal studies of fracture putty in preparation for human clinical trials.
- Demonstrate the ability to produce an antibody with thermal stability from room temperature up to 60 degrees Celsius.
- Combine identified antibody stability and affinity capabilities into a single "Master Antibody Molecule" that exhibits two target metrics against a single biological threat agent and deliver a minimum of two grams for testing by a government laboratory.
- Incorporate the identified "Master Antibody Molecule" into an existing biosensor platform and demonstrate advanced capability in terms of robustness and potential for multiplexing.

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
- Initiate investigations into the relationship between dopaminergic-driven learning systems, hormones/neurotransmitters such as oxytocin, emotion-cognition interactions, and narrative structures. ***FY 2012 Plans:*** - Further investigate use of fracture putty in fixation and healing of large animal injury. - Revise design of fracture putty compounds as appropriate for safety in human clinical trials. - Explore and refine foundational assumptions on the utility of the Freytag structure ("setup-climax-resolution") for narrative analysis, including determining relationships between decomposed stories and neuropsychological mechanisms, and understanding relationships between narratives and behavior. - Develop decomposition frameworks and initial cluster of neurobiological mechanisms to better understand their relationship. - Develop tools to link analytic frameworks, neural mechanisms, and environmental variables to a particular story.			
Title: Human Assisted Neural Devices - Medical ***Description:*** The Human Assisted Neural Devices program will develop the scientific foundation for understanding the language of the brain for application to a variety of emerging DoD challenges, including improving performance on the battlefield and returning active duty military to their units after injury. This will require an understanding of neuroscience, significant computational efforts, and new material design and implementation. Key advances expected from this research include determining the nature and means through which short-term memory is encoded, and discovering the mechanisms and dynamics underlying neural computation and reorganization. These advances will enable memory restoration through the use of devices programmed to bridge gaps in the injured brain. Further, modeling of the brain progresses to an unprecedented level with this novel approach. The programs funded under the Human Assisted Neural Devices are funded in the newly created Budget Activity 6.1 Medical Program Element 0601117E, in FY 2012. ***FY 2010 Accomplishments:*** - Identified neural processes for encoding short- and long-term memory in primates during a complex motor task. - Built hardware and software to implement pattern extraction and inter-individual verification of homogeneity of patterns between primates. - Created an interface that enables performance of a complex motor/sensory task through an assistive device without using either motor or sensory function. - Determined task performance changes resulting from learning and plasticity through observation of the development of functional networks in the primate and rodent brain over time. - Constructed algorithms and methods capable of more accurately describing and estimating neural signals from limited data. ***FY 2011 Plans:***	15.975	18.250	-

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
- Assess ability of primate to retain short-term memory encoding following simulated injury through use of neural codes. - Identify homogeneity of neural codes involving long-term memory between primates conducting similar long-term memory tasks. - Map dynamic functional motor and sensory networks and develop methods for characterizing brain-wide sensory/motor tasks. - Determine the role of specific neural pathways in a complex motor/sensory task through perturbation of existing and defined functional networks in primate and rodent experiments. - Investigate stimulation of sensory networks to determine how sensory information is encoded and utilized by the brain. - Improve learning and performance of primates during complex sensorimotor tasks through robust decoding of neural activity. - Develop models of neural behavior that more accurately approximate biological signaling. - Fabricate neural interfaces capable of stimulating and recording multiple channels of neural activity at distributed sites throughout the brain.			
Title: Mathematics of the Brain (MoB) ***Description:*** The Mathematics of the Brain (MoB) program will develop a new mathematical paradigm for understanding how to model reasoning processes for application to a variety of emerging DoD challenges. The program will develop powerful new symbolic computational capabilities for the DoD in a mathematical system that provides the ability to understand complex and evolving tasks without exponentially increasing software and hardware requirements. This includes a comprehensive mathematical theory to exploit information in signals at multiple acquisition levels, which would fundamentally generalize compressive sensing for multi-dimensional sources beyond domains typically used. This program will establish a functional mathematical basis on which to build future advances in cognitive neuroscience, computing capability, and signal processing across the DoD. ***FY 2010 Accomplishments:*** - Hypothesized a new mathematical theory of compressive measurement. ***FY 2011 Plans:*** - Develop a new comprehensive measurement theory to exploit information in signals. - Explore the comprehensive measurement theory's utility in applications such as imaging and radar. - Investigate novel forms of prior knowledge in order to improve sparse signal sampling. ***FY 2012 Plans:*** - Develop detailed mathematical prior-knowledge representations and associated models for imaging and radar applications. - Exploit the new theoretical measurement framework together with novel forms of prior knowledge in order to maximize information gathering from sparse sampling.	1.872	6.000	10.000

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
- Exploit the new theoretical measurement framework together with novel forms of prior knowledge in order to minimize resource requirements for sparse sampling. - Demonstrate the utility of new comprehensive measurement theory via improvements in imaging and radar applications.			
Title: Physics in Biology ***Description:*** Understanding the fundamental physical phenomena that underlie biological processes and functions will provide new insight and unique opportunities for understanding biological properties and exploiting such phenomena. Physics in biology will explore the role and impact of quantum effects in biological processes and systems. Using quantum theoretical models and mathematical algorithms, new understanding of quantum effects will enable exploitation in new and existing biomimetic applications. This includes exploiting manifestly quantum mechanical effects that exist in biological systems at room temperature to develop a revolutionary new class of robust, compact, high sensitivity and high selectivity sensors. Investigation into quantitative neurophysics will examine new modalities for biological injury which could yield a new class of non-invasive medical imagers. Leveraging neuroscience and physics will lead to new modeling of acoustic signatures based on perceptibility (detection, classification, recognition, identification and localization) involving ear-to-brain mechanisms. These computational models can be used to predict which acoustic signature changes would lead to reduced perceptibility and the brain's ability to learn and adapt to novel acoustic signatures. ***FY 2011 Plans:*** - Develop a detailed theoretical model for manifestly quantum mechanical effects in specific biological systems. - Formulate testable predictions for effects of perturbations on the biological system. - Experimentally verify that the biological system exploits quantum effect(s) at room temperature. ***FY 2012 Plans:*** - Develop theory for sensor utilizing biological quantum effects. - Design synthetic sensor based upon quantum mechanism employed by biological system(s). - Model sensor performance. - Experimentally probe the limits of biological sensors' exploitation of the quantum effects. - Demonstrate initial proof of concept of potential non-electrode based modalities of neural interface. - Identify potential quantitative methods to map structural neuroanatomy and system dynamics for afferent and efferent pathways. - Determine whether auditory percepts can be altered with respect to location of a heard object. - Investigate how auditory patterns are learned and recognized.	-	8.300	14.300
Title: Scaffold-Free Tissue Engineering	-	6.500	2.000

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
Description: The objective of the Scaffold-Free Tissue Engineering program is the development of tissue and organ construction platforms that utilize non-contact forces such as magnetic fields to achieve desired tissue architectures. The Scaffold-Free Tissue Engineering program is developing platforms that would circumvent current limitations by removing the use of a material scaffold and providing simultaneous control of multiple cell/tissue types for the construction of large, complex tissues in vitro and in vivo. The program will provide a paradigm shift versus current tissue engineering approaches using permanent or resorbable protein scaffolds. Such scaffolds are limited to construct sizes of 2-3 square millimeters due to oxygen and nutrient diffusion limitations, which severely limits the complexity of the tissue(s) constructed to a single cell type. In vivo, scaffold-based tissue engineering has not achieved anticipated widespread application due to the inability to properly control the cellular response to the implanted scaffold and due to difficulties in controlling the scaffold integrity/degradation. The initial Scaffold-Free Tissue Engineering program component is the development of non-contact cell positioning procedures. The fundamental goal is to correctly position target cells in a desired pattern for a sufficient period of time to allow the cells to synthesize their own scaffold. Potential approaches include magnetic field and/or dielectrophoretic positioning. Critical to early programmatic achievement is the capability to position at least two cell types through the identification of cellular magnetic taggants, characterization of cellular dielectric characteristics and determination of application dynamics (e.g., duration, cycles, amplitude) to achieve multicellular tissue construction in vitro. A potential transition to an in situ application would allow wound site reconstruction without the need to implant scaffold material. Construction of a stable implantable skeletal muscle construct (5 cm3) with vascular and neural components will be the final programmatic demonstration. ***FY 2011 Plans:*** - Identify non-contact approaches such as magnetic fields and dielectrophoresis that provide cell positioning in three dimensions without negatively impacting cell viability. - Demonstrate in vitro construction of multicellular tissue using one or more non-contact cell positioning approaches. - Demonstrate survival and functional implantation of a two cubic centimeter multicellular skeletal muscle scaffold-less construct into an appropriate in vivo model. ***FY 2012 Plans:*** - Demonstrate formation of vascular elements from endothelial cells within an existing three-dimensional skeletal muscle construct in vitro. - Demonstrate directed ingrowth of neurons in an existing three-dimensional skeletal muscle construct in vitro.			
Title: Nanostructure in Biology ***Description:*** The Nanostructure in Biology program investigated the nanostructure properties of biological materials to better understand their behavior and accelerate their exploitation for Defense applications. This new information about biomolecules	2.843	-	-

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
and complex cellular systems provided important new leads for the development of threat countermeasures, biomolecular probes and motors, and neuromorphic sensory systems. This program also developed approaches to mathematically predict a priori, the structure of biological materials, especially proteins, based on the desired performance. This enabled the rapid design of new biosensors against previously unknown threats and the design of advanced catalysts based on biological activity to produce new materials of interest to DoD (e.g., tailored explosives). The program also created technology to reliably integrate nanoscale and microsystems payloads on insects that will extract power, control locomotion, and also carry DoD relevant sensors. ***FY 2010 Accomplishments:*** - Discovered methods for precise flight control use in combinations of MEMS techniques originating in the previous fiscal year. - Developed neural interfaces to insect sensors to complement electronic sensors. - Continued development of a protein that preferentially binds to an invariant portion of the influenza virus. - Continued design of de novo inhibitory protein of smallpox.			
Accomplishments/Planned Programs Subtotals	34.928	53.739	39.686

	FY 2010	FY 2011
Congressional Add: Countermeasures to Combat Protozoan Parasites	1.600	-
FY 2010 Accomplishments: - Initiated research to develop countermeasures to combat protozoan parasites.		
Congressional Adds Subtotals	1.600	-

C. Other Program Funding Summary ($ in Millions)

N/A

D. Acquisition Strategy

N/A

E. Performance Metrics

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

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COST ($ in Millions)	FY 2010	FY 2011	FY 2012 Base	FY 2012 OCO	FY 2012 Total	FY 2013	FY 2014	FY 2015	FY 2016	Cost To Complete	Total Cost
CCS-02: *MATH AND COMPUTER SCIENCES*	38.240	70.001	60.805	-	60.805	60.670	60.942	67.512	71.512	Continuing	Continuing

A. Mission Description and Budget Item Justification

This project supports scientific study and experimentation on new computational models and mechanisms for reasoning and communication in complex, interconnected systems in support of long-term national security requirements. The project is exploring novel means of exploiting computer capabilities; practical, logical and heuristic reasoning by machines; development of enhanced human-to-computer and computer-to-computer interaction technologies; innovative approaches to the composition of software; innovative computer architectures; and new learning mechanisms for systematically upgrading and improving these capabilities. Additionally, this project explores mathematical programs and their potential for defense applications. Promising techniques will transition to both technology development and system-level projects.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
Title: Computer Science Study Group (CSSG)	6.931	10.550	11.550

Description: The Computer Science Study Group (CSSG) program supports emerging ideas from the computer science academic community to address the DoD's need for innovative computer and information science technologies; introduces a generation of junior researchers to the needs and priorities of the DoD; and enables the transition of those ideas and applications by promoting joint university, industry, and government projects. The CSSG project formalizes and focuses this research for efficiency and greater effectiveness.

FY 2010 Accomplishments:
- Executed CSSG program plan by selecting twelve 2010 Class Phase 1 performers and nine 2009 Class Phase 2 performers.
- Obtained important technical results in several areas including text driven prediction of human behavior, haptic sensing, and deep analysis of computer vulnerabilities.

FY 2011 Plans:
- Select twelve promising faculty computer scientists to form Class of 2011.
- Award grants to at least nine Principle Investigators (PIs) from the Class of 2010 in support of groundbreaking research with high payoff potential to DoD.
- Award grants to at least three PIs from Class of 2009 who successfully transition their research into partnerships with other sources of funding from government or industry.

FY 2012 Plans:

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
- Select Class of 2012 and promote success of Classes 2010-2011.			
Title: Young Faculty Award (YFA)	12.867	14.500	15.255
Description: The goal of the Young Faculty Award (YFA) program is to encourage new faculty members of academic institutions with innovative ideas and concepts to participate in sponsored research programs that will impact capabilities to future defense systems. This program focuses on speculative technologies for greatly enhancing microsystems technologies, transformational convergence technologies, and defense sciences. The long term goal for this program is to develop the next generation of academic scientists, engineers, and mathematicians in key disciplines who will focus a significant portion of their career on DoD and National Security issues. Current activities include revolutionary advances in thirteen topic areas: Quantum Science and Technology; Applied Biology, Biomedical Devices and Bioinformatics; Mathematics; Structural Materials; Functional Materials; Power and Energy; Advanced Electronics; Micro/Nano Electro-Mechanical Systems (MEMS and NEMS); Photonics and Lasers; Manufacturing Science and Technology; Neuroscience; and Computational and Quantitative Social, Decision, and Behavioral Sciences. 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 visit/exercise to help them better understand DoD problems/needs. ***FY 2010 Accomplishments:*** - Continued the thirty-three FY 2009 awards into their 2nd year of research focused on enhancements and new concepts for microsystem technologies, transformational convergence technologies, and defense sciences. - Awarded thirty-three new grants in the following topic areas: Quantum Science and Technology (4); Applied Biology (3) ; Biomedical Devices and Bioinformatics (3); Mathematics (2); Structural Materials (2); Functional Materials (3); Power and Energy (3); Advanced Electronics (3); Micro/Nano Electro-Mechanical Systems (MEMS and NEMS) (1); Photonics and Lasers (4); Manufacturing Science and Technology (1); Neuroscience (2); and Computational and Quantitative Social, Decision, and Behavioral Sciences (2). - Established a mentorship component to the program to educate all of the academic performers on DoD needs and encourage focus of future work in this area. ***FY 2011 Plans:*** - Continue the 2nd year of the FY 2010 grants for research of enhancements and new concepts for microsystem technologies, transformational convergence technologies, and defense sciences. - Award FY 2011 grants for new two-year research efforts among the thirteen established topic areas. - Establish transition approaches for appropriate technologies and research activities to enhance development activities. - Continue education component on DoD needs and encourage focus of future work in this area. ***FY 2012 Plans:***			

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
- Continue the FY 2011 awards into their 2nd year of research focused on enhancements and new concepts for microsystem technologies, transformational convergence technologies, and defense sciences. - Award FY 2012 grants for new two-year research efforts among the thirteen established topic areas. - Continue education component on DoD needs and encourage focus of future work in this area. - Monitor and facilitate transition of appropriate technologies and research activities.			
Title: Strategic Social Interaction Modules (SSIM) ***Description:*** *Formerly Training for Adaptability The Strategic Social Interaction Modules (SSIM) program will take military training beyond traditional tactics, techniques, and procedures/standard operating procedures (TTPs/SOPs) to include cultural awareness and the knowledge, skills, and abilities necessary to develop close collaborative relationships with foreign peoples and leaders and, ultimately, for winning hearts and minds. Counter-insurgency (COIN) missions and stability and support operations (SASO) put U.S. service members in close contact with local populations. Historically, military training has not had to train soldiers on how to skillfully interact with foreign civilians. The current operational environment makes it imperative to develop rapport with local leaders and civilians as their cooperation will be necessary for success in COIN/SASO. SSIM will emphasize the foundational skills necessary to achieve cultural understanding in any social setting and the skills necessary for successful interactions across different social groups. SSIM will develop the requisite training technology including advanced gaming/simulation techniques that incorporate new methods for practicing social agility in cross-cultural encounters, as well as how to discover and learn culturally specific conduct, manners, and practices. ***FY 2011 Plans:*** - Conduct basic studies of interactions, negotiations, and relationships in cross-cultural social encounters. - Develop social interaction engines and expressive intelligence technologies for interpersonal simulations. ***FY 2012 Plans:*** - Create technologies to generate realistic training scenarios and user challenges, automate the evaluation of user responses, and support the expert authoring/editing of scenarios. - Develop tools to identify skillful performance in a training environment and for predicting the efficacy of the training in the intended operational/cultural environment. - Develop techniques for delivering training through a variety of mechanisms including over limited-bandwidth channels to users in theater.	-	8.364	9.500
Title: Engage	-	6.600	7.000

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
Description: The Engage program, previously part of the Training for Adaptability thrust, will develop the means for teaching problem solving in complex real-world settings not amenable to conventional curriculum-based approaches. Traditional modes of education place learning before problem solving, but Engage will take an alternative approach by moving problem solving to the core of the educational experience. This will be accomplished by creating problem-solving games that feature combined human-computer reasoning on complex problems and that provide users with immediate feedback and alternative solutions. Engage will also address the difficult problem of connecting performance in the virtual domain with performance in the real world and then will use this knowledge to drive the creation of more effective game-based training. ***FY 2011 Plans:*** - Explore game and problem-solving-based approaches to learning in complex real-world domains. - Develop approaches for extrapolating performance on computer-based training systems to performance in the real world. ***FY 2012 Plans:*** - Develop software infrastructure for an educational gaming environment that allows the methods of instruction to be varied in order to determine the best approaches. - Analyze educational methodologies using statistics based on data drawn from a large video game environment.			
Title: Mathematics of Sensing, Exploitation and Evaluation (MSEE) ***Description:*** The Mathematics of Sensing, Exploitation and Evaluation (MSEE) program is an outgrowth of the Focus Areas in Theoretical Mathematics program that seeks to create a comprehensive mathematical theory of information processing, strategy formulation and decision determination. Such a theory would incorporate techniques from diverse mathematical disciplines such as Stochastic Process Theory, Harmonic Analysis, Formal Languages and Theoretical Computer Science to construct a common framework wherein the quantitative value of data acquisition may be assessed relative to dynamically-varying context. In addition, the structure will accommodate the notion that data acquisition and information processing are coupled, requiring some degree of feedback and control, while simultaneously admitting the possibility of different logics, e.g., those that allow for incomplete and time-varying states of knowledge. The result of this effort will produce advances in fundamental domains of mathematics with the potential to reshape current DoD approaches to managing the battlespace. ***FY 2011 Plans:*** - Formalize mathematically the notions of information processing, strategizing and decision determination so that these can be modeled as a computational process.	-	3.000	7.500

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
- Investigate methods for constructing relevant models of DoD-relevant environments, and develop effective strategies for updating these as new information becomes available. ***FY 2012 Plans:*** - Incorporate statistical/stochastic concepts exploiting stochastic models and statistical reasoning to understand the nature of computations in human minds. - Explore open system concepts capable of demonstrating the ability to process information and determine best available responses, subject to time-varying context. - Begin to quantify notion of effective utility, which measures the relative value of a sensor or sensor system.			
Title: Math for Social Networks ***Description:*** Social networks are recent phenomena whose pervasiveness has become undeniable. Critical information potentially can be extracted by both observing network state at any given instant as well as by monitoring network dynamics. Standard tools for examining network behavior typically target systems of communication or computer nodes, and evaluate context-relevant yet straightforward metrics such as connectivity. When dealing with social networks, the knowledge that can be distilled is potentially more useful, and hence an entirely new set of techniques must be developed. This thrust will develop new mathematical methods to facilitate more complete analysis of social networks while simultaneously constructing mechanisms by which this elevated understanding may be best communicated. This approach could comprise, e.g., i) the application of spatiotemporal signal processing techniques to monitoring network activity, with an emphasis on identifying precursors to undesirable events; and, ii) incorporating fundamentally that the component nodes are humans (or groups of humans), and hence interact in ways subject to psychosocial evaluation. By incorporating sophisticated signal processing while recognizing the defining role of the human agent, this thrust will change how social networks are monitored and analyzed. Hence, we recast social network analysis into a mathematical framework that captures the biological nature of the component nodes intrinsically and exploits this knowledge to produce a unique DoD capability. ***FY 2012 Plans:*** - Create an enhanced network modeling theory that incorporates ability to perform spatiotemporal analysis. - Investigate impact of replacing generic network nodes with human agents whose behavior can be modeled statistically. - Perform small-scale analyses of dynamic networks and demonstrate ability to recognize event precursors.	-	-	10.000
Title: Foundational Computer Science ***Description:*** The Foundational Computer Science program supports research in broad areas of computational science having the potential for revolutionary advances in performance and other relevant metrics above and beyond extrapolations of current approaches. The research will yield significant advances in networking, software, hardware, and computational systems in a	1.896	8.276	-

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
world where computing devices are ubiquitous and heterogeneous. The Foundational Computer Science program is addressing the need for highly reliable and trustworthy mission-critical information systems, including both software and hardware. New programming languages that facilitate parallel programming on multi-core processors, scalable formal methods, clean-slate execution models, co-design approaches for hardware and software, and other techniques will be used to guarantee the security, reliability, performance and robustness of a design while also reducing its complexity and cost. Research efforts in communications and sensor networks will address challenges related to dynamic heterogeneous multi-modal networks. The Foundational Computer Science program will also address problems that are inherently computationally complex and, in many cases, intractable. For example, the game of Go provides an ideal platform for creating the heuristic approaches and tools necessary to solve problems that typically require either enormous computer resources or simplification that sacrifices accuracy. The resulting technologies will be candidates for future command and control decision aids that can assess the consequences of specific actions and strategies to better predict future results in applications such as irregular warfare, cyber-security, supply chain optimization, networking and robotics. ***FY 2010 Accomplishments:*** - Developed improved methods of planning and reasoning to calculate Go best-next-move hypotheses from board positions and to use such hypotheses to develop a highly targeted search strategy. - Developed methods for visualization to determine similarity and differences in positional configurations. ***FY 2011 Plans:*** - Continue development of methods for visualization to determine similarity and differences in positional configurations. - Develop algorithms to introduce intelligence to massive search problems. - Combine algorithmic approaches to Go optimization with heuristic assessment of the value of information to introduce a new area of research in machine learning and planning.			
Title: Foundational Machine Intelligence ***Description:*** The Foundational Machine Intelligence program is supporting research on the foundations of artificial intelligence and machine learning and reasoning. One focus is on techniques that can efficiently process and "understand" massive data streams. Deeply layered machine learning engines will be created that use a single set of methods in multiple layers (at least three internally) to generate progressively more sophisticated representations of patterns, invariants, and correlations from data inputs. These will have far-reaching military implications with potential applications such as anomaly detection, object recognition, language understanding, information retrieval, pattern recognition, robotic task learning and automatic metadata extraction from video streams, sensor data, and multi-media objects. Foundational Machine Intelligence also examines the human aspects of computing, with interest in collaboration, interaction and information exchange; non-symbolic representation/reasoning paradigms	3.681	6.000	-

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
based upon a universal "cortical" algorithm; and modeling of human language acquisition by associating words with the real-world entities perceived through multiple modes of sensory input. ***FY 2010 Accomplishments:*** - Created machine learning techniques that can assimilate huge amounts of data by creating rich representations of the input data and applying them to multiple applications. - Constructed a single, general-purpose algorithm which started with zero linguistic knowledge of its environment, and then grew to represent the structure latent in that environment. ***FY 2011 Plans:*** - Create parameter-free methods that learn appropriate representations starting from raw inputs with a single architecture and learning algorithm. - Enable machines to incorporate sensory information in a robust way to improve situational awareness. - Extend sub-symbolic learning algorithms to work with richer, non-linguistic input and knowledge representations.			
Title: Information Theory for Wireless Mobile Ad Hoc Networks (ITMANET) ***Description:*** The Information Theory for Wireless Mobile Ad Hoc Networks (ITMANET) program is creating an information theory for ad hoc mobile wireless networking in the absence of wired infrastructure. Issues being addressed include quantifying network performance in terms of throughput, delay, reliability, and other critical parameters as a function of node mobility, network topology, channel access protocol, bandwidth efficiency, and the overhead incurred through the exchange of channel and network state information. The revolutionary new and powerful information theory developed under ITMANET will enable the next generation of DoD wireless networks and provide insight concerning the acquisition and deployment of nearer-term systems. ***FY 2010 Accomplishments:*** - Predicted performance in terms of throughput-delay-reliability for modest-sized MANETs with and without feedback. - Developed upper-bounding techniques that go beyond the classical bounds and inequalities for MANETs. ***FY 2011 Plans:*** - Predict performance in terms of throughput-delay-reliability for any MANET realization. - Develop protocols for interference alignment architectures that can approach the end-to-end MANET transmission capacity limit. - Develop a generalized theory of rate distortion and network utilization.	3.271	3.646	-
Title: Computer Science /Science, Technology, Engineering, and Mathematics Research Outreach	2.000	5.665	-

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
Description: The Computer Science, Science, Technology, Engineering, and Mathematics Research Outreach program will develop educational practices and programs that capture the scientific and technical interests of middle and high school students through compelling projects that require computer science, science, technology, engineering, and mathematics. ***FY 2010 Accomplishments:*** - Engaged high school study groups to work on selected ideas. - Initiated programs that capture the scientific and technical interests of middle and high school students through compelling projects that require computer science, science, technology, engineering, and mathematics. ***FY 2011 Plans:*** - Execute programs that capture the scientific and technical interests of middle and high school students through compelling projects that require computer science, science, technology, engineering, and mathematics.			
Title: Focus Areas in Theoretical Mathematics (FAThM) ***Description:*** The Focus Areas in Theoretical Mathematics (FAThM) program aims to foster major theoretical breakthroughs in pure mathematics whose potential for long-term defense implications is high. By supporting closely integrated and concentrated collaborations among small numbers of leading experts, FAThM will pioneer a new approach for conducting focused research to explore fundamental interconnections between key areas of mathematics where critical insights should lead to both new mathematics and innovative DoD applications. ***FY 2010 Accomplishments:*** - Established and exploited new relations between topology and symmetry groups of fundamental particles. - Established and exploited new relations between the analytic foundations of symmetry and algebraic computation. - Proved an equivalence between using microdifferential operators versus the more general formal microdifferential operators, in microlocal analysis of regular holonomic systems - specific types of differential equations. ***FY 2011 Plans:*** - Establish and exploit new relations between differential geometry, quantum field theories, and infinite dimensional global analysis. - Establish and exploit new relations between generalized homology theories and partial differential equations.	1.400	1.400	-
Title: 23 Mathematical Challenges ***Description:*** This program aims to revolutionize the mathematical tools used by DoD in both theory and applications, discover and generate powerful and innovative new mathematics, tackle long-standing mathematical problems, and create new mathematical disciplines to meet the long-term needs of the DoD across diverse scientific and technological areas.	1.500	2.000	-

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
FY 2010 Accomplishments: - Exploited novel mathematical techniques in combinatorics (the study of discrete objects) and geometry to build new capabilities in rigidity theory for applications such as robotics. - Developed an algorithm incorporating error that describes evolution of material structures and satisfies the generalized von Neumann relation. - Established new connections between number theory ("finite fields" and "elliptic curves") and geometry ("real structures on abelian varieties"); these connections are the first steps in solving long-standing problems in cryptography. ***FY 2011 Plans:*** - Extend known links between topology and algebra for continuous manifolds (e.g., de Rahm-Witt complexes and K-groups) to the case of discrete structures. Such an extension will impact cryptographic applications. - Improve understanding of differential equations appearing in number theory, as a tool for passing between number theory and geometry.			
Title: Programmable Matter ***Description:*** The Programmable Matter program explored a new functional form of matter constructed from mesoscale particles that assemble into complex 3-D objects upon external command. These objects exhibit all of the functionality of their conventional counterparts and ultimately have the ability to reverse back to the original components. ***FY 2010 Accomplishments:*** - Optimized Programmable Matter properties. - Demonstrated interlocking/adhesion of mesoscale particles to create bulk matter. - Demonstrated reversibility.	3.094	-	-
Accomplishments/Planned Programs Subtotals	36.640	70.001	60.805

	FY 2010	FY 2011
Congressional Add: Science, Technology, Engineering and Mathematics Initiative	1.600	-
FY 2010 Accomplishments: - Initiated research in the areas of science, technology, and engineering.		
Congressional Adds Subtotals	1.600	-

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C. Other Program Funding Summary ($ in Millions)

N/A

D. Acquisition Strategy

N/A

E. Performance Metrics

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

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COST ($ in Millions)	FY 2010	FY 2011	FY 2012 Base	FY 2012 OCO	FY 2012 Total	FY 2013	FY 2014	FY 2015	FY 2016	Cost To Complete	Total Cost
CYS-01: *CYBER SCIENCES*	-	-	16.667	-	16.667	25.000	33.333	41.667	50.000	Continuing	Continuing

A. Mission Description and Budget Item Justification

The Cyber Sciences project supports long term national security requirements through scientific research and experimentation in cyber-security. Networked computing systems control virtually everything, from power plants and energy distribution, transportation systems, food and water distribution, financial systems, to defense systems. Protecting the infrastructure on which these systems rely is a national security issue. Cyberspace is not only critical to our national security, it is fundamental to our way of life: over the past decade information technologies have driven the productivity gains essential to U.S. economic competitiveness. Unfortunately, during the same period, cyber-adversaries, which include nation-states, criminal/terrorist groups, transnational actors, and miscreants, have grown rapidly in sophistication and number. Due to its importance and the emergence of these threats, cyberspace is now recognized as a critical warfighting domain, equal in importance to the more traditional domains of sea, air, land, and space. The Cyber Sciences project will ensure DoD cyber-capabilities survive adversary attempts to degrade, disrupt, or deny military computing, communications, and networking systems. Basic research in cyber security is required to provide a basis for continuing progress in this area. Promising research results will transition to both technology development and system-level projects.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
Title: Crowd-Sourced Cyber	-	-	6.500
Description: The Crowd-Sourced Cyber program will develop crowd-sourced approaches for verifying the correctness of software systems. Coding errors are the root cause of many of the most serious security vulnerabilities in software systems. Program verification can reduce coding errors dramatically, but at an unacceptable development cost. Many core problems in code verification are undetectable by computers, so automation in and of itself cannot sufficiently reduce the cost enough to make program verification practical. The Crowd-Sourced Cyber environment will facilitate the mapping from the code/formal specification to the relevant components of the simulation. The Crowd-Sourced Cyber development environment will provide extensible and editable components and user interface items and will facilitate the automated inverse mapping that translates simulation results to code annotations. Crowd-Sourced Cyber is addressing one of the most vexing and long-standing problems in software development, and if successful will greatly increase the quality and security of software systems while reducing the cost. ***FY 2012 Plans:*** - Develop approaches for mapping high-level software specifications and codes into interactive computer simulations. - Develop techniques for inferring specification and coding errors from the results of these simulations and for automatically generating the appropriate annotations. - Develop web-based infrastructure to support large scale program verification workflow.			
Title: Risk-Managed Access Control (RMAC)	-	-	5.500

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
Description: The Risk-Managed Access Control (RMAC) program will develop the means to associate risk with access and use this as the basis for more effective identification, authentication, and authorization technologies. Currently, factors for identification and authentication require the user to know something like a password, possess something like a smart card, and/or to exhibit some intrinsic biometric trait like a fingerprint. Once authenticated, the user obtains authorization that defines the user's permissions, for example, what files the user can read. However, none of the current schemes for identification, authentication, and authorization incorporates any mechanism for automatically revisiting previous decisions. RMAC will create techniques and algorithms for quantifying the cumulative risks and benefits associated with a user's actions and incorporate such risk assessments in access control schemes that have additional control loops designed to mitigate the risks associated with large-scale information sharing. ***FY 2012 Plans:*** - Conceptualize methods for assigning a measure of risk to user activities. - Formulate new access control mechanisms that manage the cumulative risk associated with user actions. - Expand RMAC concepts to encompass possible approaches to multi-level security.			
Title: Cross-Layer Network Security ***Description:*** The Cross-Layer Network Security project will develop novel approaches for enhanced network security that involve multiple networked layers. This is in contrast to traditional approaches to network security that operate within a single layer, for example, standard Internet Protocol security is implemented in the network layer. Cross-layer approaches for wireless networks can exploit emerging path diversity technologies to introduce route diversity as a mechanism to counter eavesdroppers/jammers and compromised/malicious network nodes. These approaches have potential benefit for mobile ad-hoc networks and distributed sensor networks in adversarial wireless environments. Cross-layer approaches also hold promise for enhanced security for overlay networks and as the basis for new classes of virtual networks that provide security services. These could enable, for example, the capability to maintain quality of service through distributed denial of service attacks. ***FY 2012 Plans:*** - Conceptualize cross-layer approaches for enhanced security in wireless networks based on information-theoretic results in the areas of secrecy-capacity and secure broadcast channels. - Develop schemes that exploit path and route diversity technologies across the physical, data link, network, and transport layers. - Formulate new types of overlay/virtual networks that provide security-related services such as privacy and robust availability.	-	-	4.667
Accomplishments/Planned Programs Subtotals	-	-	16.667

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C. Other Program Funding Summary ($ in Millions)

N/A

D. Acquisition Strategy

TBD

E. Performance Metrics

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

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COST ($ in Millions)	FY 2010	FY 2011	FY 2012 Base	FY 2012 OCO	FY 2012 Total	FY 2013	FY 2014	FY 2015	FY 2016	Cost To Complete	Total Cost
ES-01: *ELECTRONIC SCIENCES*	49.586	73.023	46.109	-	46.109	30.413	33.876	33.876	31.876	Continuing	Continuing

A. Mission Description and Budget Item Justification

This project seeks to continue the phenomenal progress in microelectronics innovation that has characterized the last decades by exploring and demonstrating electronic and optoelectronic devices, circuits and processing concepts that will: 1) provide new technical options for meeting the information gathering, transmission and processing required to maintain near real-time knowledge of the enemy and the ability to communicate decisions based on that knowledge to all forces in near real-time; and 2) provide new means for achieving substantial increases in performance and cost reduction of military systems providing these capabilities. Research areas include new electronic and optoelectronic device and circuit concepts, operation of devices at higher frequency and lower power, extension of diode laser operation to new wavelength ranges relevant to military missions, development of uncooled and novel infrared detector materials for night vision and other sensor applications, development of innovative optical and electronic technologies for interconnecting modules in high performance systems, research to realize field portable electronics with reduced power requirements, and system and component level improvements to provide greater affordability and reliability. Additionally, electronically controlled microinstruments offer the possibility of nanometer-scale probing, sensing and manipulation for ultra-high density information storage "on-a-chip," for nanometer-scale patterning, and for molecular level analysis and synthesis. These microinstruments may also offer new approaches to integration, testing, controlling, manipulating and manufacturing nanometer-scale structures, molecules and devices.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
Title: Focus Center Research Program (FCRP)*	20.400	20.400	20.400
Description: *Formerly Semiconductor Technology Focus Centers. The Focus Center Research Program (FCRP) is a collaborative effort between the Defense Advanced Research Projects Agency (DARPA) and the semiconductor industry to concentrate research attention and resources to provide radical innovation in semiconductor technology. The program focuses on discovery research to provide solutions to barrier problems in the path of sustaining the historical productivity growth and performance enhancement of semiconductor integrated circuits. The overall goals of this collaborative effort between the DoD and industry is to sustain the unprecedented four decades of uninterrupted performance improvement in information processing power and fundamentally change the design cycle of electronic systems. ***FY 2010 Accomplishments:*** - Discovered new state of matter, the topological insulator, which is simultaneously an insulator and a special type of metal. - Grew first III-V nanolaser monolithically on silicon. - Demonstrated for the first time, nanoelectromechanical relay circuits with zero standby power. - Demonstrated a record setting W-Band amplifier in IBM 45nm Silicon-on-Insulator (SOI) process with 15 db gain and less than 6 db Noise Figure at 85 GHz, at a power consumption of ~25 mW.			

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
- Continued to develop innovative approaches to the design and fabrication of scaled devices, circuits, and microsystems within multi-investigator based research consortia. - Initiated a new center in the area of design of information systems across multiple spatial and temporal scales. ***FY 2011 Plans:*** - Design, synthesize, assemble and integrate materials on the nanoscale to enable extensible information processing systems. - Conceive and explore paths to overcome the limits of Silicon Complementary metal-oxide semiconductor (CMOS) scaling on the continuing evolution of electronics. - Discover and invent new electrical, optical, and thermal interconnect solutions that will meet or exceed International Technology Roadmap for Semiconductors (ITRS) projections and enable hyper-integration of heterogeneous components for future terascale systems. - Invent the circuits that sustain exponential increase in computing performance by exploiting the full capabilities of existing technologies. - Design (hardware and software) and demonstrate utilization (programming and interfacing) of information system platforms for defense applications. - Create a comprehensive and systematic solution to the distributed multi-scale system design challenge. ***FY 2012 Plans:*** - Continue to leverage industry funding for efforts, maintain formal and informal coupling and industry-based research for development and transition of technologies. - Transition innovative concepts developed with the university program to provide novel capabilities for DoD microelectronics systems.			
Title: Quantum Entanglement Science and Technology (QuEST) ***Description:*** The Quantum Entanglement Science and Technology (QuEST) program is exploring the research necessary to create new technologies based on quantum information science. Technical challenges include loss of information due to quantum decoherence, limited communication distance due to signal attenuation, protocols, and larger numbers of quantum bits (Qubits) and their entanglement. A key challenge is to integrate improved single and entangled photon and electron sources and detectors into quantum computation and communication networks. Error correction codes, fault tolerant schemes, and longer decoherence times will address the loss of information. Expected impacts include highly secure communications, algorithms for optimization in logistics, highly precise measurements of time and position on the earth and in space, and new image and signal processing methods for target tracking. ***FY 2010 Accomplishments:***	8.803	15.946	-

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
- Continued fundamental research in the area of quantum information. - Developed novel approach to improving decoherence times. - Demonstrated novel quantum algorithms. ***FY 2011 Plans:*** - Continue fundamental research in the area of quantum information. - Characterize and manipulate entangled quantum systems.			
Title: N/MEMS Science and Focus Centers ***Description:*** The goal of the N/MEMS Science and Focus Centers program is to support the development of an enhanced fundamental understanding in a number of technical issues considered to be critical to the continuing advance of nanoelectromechanical systems (NEMS) and microelectromechanical systems (MEMS) technologies and their transition into military systems. The basic research being conducted on the program is responsive to recognized challenges in a comprehensive range of technical areas pertinent to future DoD needs. Industrial cost sharing is an important element of the program, with industry matching DARPA resources on a 1:1 basis. ***FY 2010 Accomplishments:*** - Initiated the second phase of the program, which supports research efforts at seven university centers. Overall, the program supports work at more than 20 participating universities and involves cost-sharing by approximately 40 industry partners. - Completed studies to develop integrated nano/microfluidic components for new medical diagnostic platforms. - Demonstrated GaN optoelectronic nanowires and associated materials properties with silicon complimentary metal-oxide semiconductor (CMOS) substrates demonstrating the potential of heterogeneous integrated opto-electronic-MEMS systems. ***FY 2011 Plans:*** - Develop and integrate new technologies such as atomic layer deposition (ALD) for realizing full nano/microsystems with sensors, electronic signal processing, energy, and communications on a common chip. - Develop real human sample clean-up and pre-processing strategies for microfluidic diagnostic chips. - Continue studies of materials and interfaces leading to the realization of new, low-cost, and fully integrated infrared sensors and optical signal-processing elements. ***FY 2012 Plans:*** - Demonstrate an integrated microsystem driver with ALD/Molecular Layer Deposition (MLD)-sealed nanowire/graphene NEMS powered by an embedded battery charged by an embedded solar cell.	3.741	7.035	2.000

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
- Demonstrate emerging advanced guided self-assembly processes for integration of 3-D microsystems onto unconventional substrates and their application to an intraocular multi-sensor.			
Title: Nanoscaled Architecture for Coherent Hyper-Optic Sources (NACHOS) ***Description:*** The objective of the Nanoscaled Architecture for Coherent Hyper-Optic Sources (NACHOS) program is to demonstrate sub-wavelength semiconductor lasers by leveraging recent developments in reduced dimensionality and advanced feedback concepts. The specific program goal is to demonstrate Continuous Wave injection lasers operating at room temperature with cavity dimensions smaller than the vacuum wavelength of light they generate, wavelength < 1.5 micrometers. Nanoscale lasers will enable close integration of photonic and electronic devices needed in emerging high-speed processing-intense computing and communication platforms. In addition to reduced size, these lasers are expected to be power-efficient and offer unprecedented modulation bandwidth. New capabilities, such as the ability to place large numbers of lasers on silicon chips, will be enabled by these devices. ***FY 2010 Accomplishments:*** - Demonstrated sub-wavelength lasers. - Determined threshold gain under injection. ***FY 2011 Plans:*** - Demonstrate room temperature sub-wavelength laser operating at 1.55 microns in continuous mode. ***FY 2012 Plans:*** - Increase power level to be greater than 1mW.	1.689	5.689	2.103
Title: Tip-Based Nanofabrication (TBN) ***Description:*** The Tip-Based Nanofabrication (TBN) program will develop the capability to use Atomic Force Microscope (AFM) cantilevers and tips to controllably manufacture nano-scale structures such as nanowires, nanotubes, and quantum dots for selected defense applications. These applications include optical and biological sensors, diode lasers, light emitting diodes, infrared sensors, high density interconnects, and quantum computing. ***FY 2010 Accomplishments:*** - Fabricated multi-tip arrays (5 tips) for parallel manufacturing of locally-controlled nanostructures. - Demonstrated repeatable processes for fabrication of nanowires, quantum dots and other nanostructures with the ability to intentionally fabricate structures with different dimensions or other characteristics side-by-side. - Identified a specific nano-device, a Kane Q-bit, to use as the objective for all future TBN metrics and activities. ***FY 2011 Plans:***	5.895	11.618	4.606

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
- Fabricate a 30-tip array and an associated tool and manufacturing process. - Demonstrate operation of multi-tip arrays over extended periods of time for use in manufacturing complex components. - Demonstrate precision and control of the process and functionality of the resulting devices. - Develop semiconducting nanowires, graphene ribbons, quantum dots, q-bits, carbon nanotubes and other structures for specific device applications. ***FY 2012 Plans:*** - Use TBN-developed semiconducting nanowires, graphene ribbons, quantum dots, carbon nanotubes and other structures to build devices such as a single-electron transistor or Kane qu-bit.			
Title: Optical Radiation Cooling and Heating in Integrated Devices (ORCHID) ***Description:*** The objective of the Optical Radiation Cooling and Heating in Integrated Devices (ORCHID) program is to leverage advances in photonics and micro-fabrication to develop integrated chips capable of exploiting quantum optomechanical applications. Although light is usually thought of as carrying energy but relatively little momentum, light confined to a high-finesse cavity can exert significant force on the cavity mirrors. When the mirror is allowed to vibrate by coupling it to a mechanical (spring-like) system, energy can be transferred between coupled optomechanical resonators. Depending on the detuning of the cavity, one can obtain either damping (cooling) or amplification (heating) of the mirror motion. Notable achievements in this field are the demonstration of mirror cooling (damping of the internal degree of motion) to sub-Kelvin (6 mK) temperatures and demonstration of radiation driven high-Q, high-frequency (1 GHz) oscillators. With sufficiently high cavity finesse and Q's of the mechanical system, it is possible to reach a regime in which the mirror motion is no longer thermally limited. Instead, it becomes limited by the quantum mechanical radiation pressure force. Once this limit is reached, it is possible to take advantage of quantum mechanical effects without having to cool the system. It is anticipated this will result in a new generation of mass-sensing devices and ultra high-Q, high-frequency resonators controlled by light. In optical systems, it will be possible to efficiently squeeze light beyond the standard shot-noise limit producing light sources for infrared detection and quantum information applications. ***FY 2010 Accomplishments:*** - Demonstrated resonant frequency of 10 megahertz (MHz). - Demonstrated Mechanical Q of 1x10^6. ***FY 2011 Plans:*** - Demonstrate cavity finesse of 1x10^5. - Demonstrate mirror effective mass of 1 nanogram. - Demonstrate resonant frequency of 100 MHz.	3.411	5.263	1.500

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
- Demonstrate Mechanical Q of 1x10^7. ***FY 2012 Plans:*** - Demonstrate an opto-mechanical oscillator with frequency > 10 GHz. - Demonstrate an optical switch with switching time < 100 ns. - Demonstrate conditional squeezing between transmitted light and mechanical element. - Demonstrate an opto-mechanical mass sensor with 10 zeptogram sensitivity.			
Title: Centers for Integrated Photonics Engineering Research (CIPhER) ***Description:*** The Centers for Integrated Photonics Engineering Research (CIPhER) program will explore and enhance fundamental understanding in the development and application of integrated photonics, in which an entire photonic system is fabricated on a single chip. Much like integrated electronics, integrated photonics has the potential to enable photonics systems to reach revolutionary new levels of performance and functionality, but with a wider application range than electronics, including such areas as imaging, energy conversion, signal processing, and computing. The rise of integrated photonics as a viable, practical technology, combined with the utility of integrated photonics to many applications, is slated to result in a more rapid transition of basic photonics research to system applications of importance to the DoD. As such, photonics research that is supported by organizations with both fundamental and commercial interests is ideally suited to fostering the growth of the nation's integrated photonics industry. The CIPhER program will therefore use a government/industrial cost-share funding model to foster the next generation of fundamental university-based photonics research. The CIPhER program is directed toward achieving this objective through the establishment of collaborative theme-based focus centers. Focus centers will be comprised of university-led teams, with industrial partners, engaged in long-term basic research of photonic materials, devices, and microsystems. ***FY 2010 Accomplishments:*** - Initiated the development and investigation of new integrated photonics concepts for application to microsystems in: Imaging Science and Technology, Energy Conversion and Manipulation, Chip-scale Signal Processing and Computing, and Chemical/ Biological Sensing and Processing. ***FY 2011 Plans:*** - Exploit scaling and enhanced fabrication techniques to refine and continue development of novel integrated photonics concepts for the range of application domains. - Begin to transfer through direct industrial collaborative interactions those elements that are ready for further development toward applications.	4.367	7.072	-
Title: Advanced X-Ray Integrated Sources (AXIS)	-	-	5.500

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
Description: The objective of the Advanced X-Ray Integrated Sources (AXIS) program is to greatly reduce the size, weight and power of tunable X-ray sources while dramatically increasing their electrical efficiency through application of microscale engineering technologies such as MEMS and NEMS. Such imaging modalities should speed reverse engineering of integrated circuits to validate trustworthiness as well as contrast-free battlefield imaging of blood vessel injuries in blunt trauma. The Basic Research component of this effort will focus on defining the fundamental science necessary for the creation of compact and highly efficient synchrotron X-ray sources. These sources may lead to future developments in the tunable imaging field. This program also has efforts funded in PE 0602716E, Project ELT-01. ***FY 2012 Plans:*** - Define physical limitations for designing compact energy efficient X-ray sources.			
Title: Diverse & Accessible Heterogeneous Integration (DAHI) ***Description:*** Prior DARPA efforts have demonstrated the ability to monolithically integrate inherently different semiconductor types to achieve near-ideal "mix-and-match" capability for DoD circuit designers. Specifically, the Compound Semiconductor Materials On Silicon (COSMOS) program, in which transistors of Indium Phosphide (InP) can be freely mixed with Silicon complementary metal-oxide semiconductor (CMOS) circuits to obtain the benefits of both technologies (very high speed and very high circuit complexity/density, respectively). The Diverse & Accessible Heterogeneous Integration (DAHI) effort will take this capability to the next level, ultimately offering the seamless co-integration of a variety of semiconductor devices (e.g., GaN, InP, GaAs, ABCS), microelectromechanical (MEMS) sensors and actuators, photonic devices (e.g., lasers, photo-detectors) and thermal management structures. This capability will revolutionize our ability to build true "systems on a chip" (SoCs) and allow dramatic size, weight and volume reductions for a wide array of system applications. The Basic Research part of this effort will focus on the development of new hetero-integration processes and capabilities that if successful will ultimately be demonstrated in application specific circuits and transferred into the manufacturing flow. This program also has applied research efforts funded in PE 0602716E, Project ELT-01. ***FY 2012 Plans:*** - Explore heterogeneous integration of novel, emerging materials and devices. - Develop new CMOS-compatible processes to achieve heterogeneous integration with diverse types of compound semiconductor transistors, MEMS, and non-silicon photonic devices.	-	-	7.000
Title: Microscale Plasma Devices	-	-	3.000

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
Description: The Microscale Plasma Devices program will develop microscale plasma devices for the efficient, high pressure (up to or even including atmospheric pressure) generation of ions, radiofrequency energy, and light sources. Applications for such devices are far reaching, including the construction of complete high-frequency logic circuits, and integrated circuits with superior resistance to radiation and extreme temperatures. The Basic Research part of this effort will focus on microelectronic interconnects necessary for operating plasma devices at elevated pressures. This program also has efforts funded in PE 0602716E, Project ELT-01. ***FY 2012 Plans:*** - Identify requirements for maintaining long-term internal atmospheric conditions appropriate for plasma and hard-vacuum devices.			
Accomplishments/Planned Programs Subtotals	48.306	73.023	46.109

	FY 2010	FY 2011
Congressional Add: Laboratory for Advanced Photonic Composites Research	1.280	-
FY 2010 Accomplishments: - Initiated laboratory research in photonic composites.		
Congressional Adds Subtotals	1.280	-

C. Other Program Funding Summary ($ in Millions)

N/A

D. Acquisition Strategy

N/A

E. Performance Metrics

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

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COST ($ in Millions)	FY 2010	FY 2011	FY 2012 Base	FY 2012 OCO	FY 2012 Total	FY 2013	FY 2014	FY 2015	FY 2016	Cost To Complete	Total Cost
MS-01: *MATERIALS SCIENCES*	69.677	89.854	97.506	-	97.506	78.019	75.450	76.824	78.824	Continuing	Continuing

A. Mission Description and Budget Item Justification

This project provides the fundamental research that underpins the development of advanced nanoscale and bio-molecular materials, devices and electronics for DoD applications.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
Title: Nanoscale/Bio-inspired and MetaMaterials	9.255	9.567	8.000

Description: The research in this thrust area exploits advances in nanoscale and bio-inspired materials, including computationally based materials science, in order to develop unique microstructures and material properties. This area also includes efforts to develop the underlying physics for the behavior of materials whose properties have been engineered at the nanoscale level (metamaterials) and materials exhibiting a permanent electric charge (charged matter).

FY 2010 Accomplishments:

- Developed new material compositions with optical transmission comparable to spinel and doubled mechanical strength, and thermal shock capabilities over single crystal sapphire.
- Initiated fabrication of new materials into hemispherical domes with decreased optical scatter, doubled mechanical strength, and doubled thermal shock capabilities over single crystal sapphire.
- Characterized the material properties of nano-crystalline dome materials through testing in relevant military environments.
- Demonstrated understanding of biophotonic structure/function relationship and design requirements for index/structure actuation.
- Demonstrated initial design and fabrication of biophotonic structures.
- Initiated development of the capability to compute material properties as a function of the microstructural architectural parameters that govern them, and the extent to which material properties can be modified through the manipulation of these parameters.

FY 2011 Plans:

- Identify the strength-limiting flaws in nano-composite optical ceramics through fractographic analysis and relate to processing conditions.
- Demonstrate control of fabrication of biophotonic structures.
- Demonstrate physical and/or chemical activation of biophotonic structures.
- Identify expected physical (and/or chemical) sensitivity in terms of reflectance change noted (percent change in reflectance/Volt, percent change in reflectance/molecule adsorbed).

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
- Initiate establishment of experimental fabrication methodologies with level of control needed to produce the materials with architectural features necessary to exhibit predicted properties. - Demonstrate by computation that selected properties may be independently manipulated as a function of identified architectural parameters, to a regime currently unachievable. - Demonstrate fabrication methodologies to create the microstructural features with level of control predicted through computation necessary to achieve superior structural/functional properties. ***FY 2012 Plans:*** - Initiate fabrication of materials with architectural features necessary to exhibit predicted properties. - Experimentally characterize effects of varying architectural features on selected material properties. - Perform sensitivity analyses to develop and validate optimization algorithms for material properties. - Initiate development of multidimensional architecture-to-property design space fabrication of materials with architectural features necessary to exhibit predicted properties.			
Title: Fundamentals of Nanoscale and Emergent Effects and Engineered Devices ***Description:*** The Fundamentals of Nanoscale and Emergent Effects and Engineered Devices program seeks to understand and exploit physical phenomena for developing more efficient and powerful devices. This includes developing devices and structures to enable controllable photonic devices at multiple wavelengths, engineering palladium microstructures with large deuterium loadings to study absorption thermodynamics and effects, enabling real-time detection as well as analysis of signals and molecules and origin of emergent behavior in correlated electron devices. Arrays of engineered nanoscale devices will result in an order of magnitude (10 to 100 times) reduction in the time required for analysis and identification of known and unknown (engineered) molecules. This program will develop novel nanomaterials for exquisitely precise purification of materials, enabling such diverse applications as oxygen generation and desalination, ultra-high sensitivity magnetic sensors, and correlated electron effects such as superconductivity. This program will compare the phenomenology of various biological, physical and social systems and abstract the common features that are responsible for their properties of self-organization and emergent behavior. ***FY 2010 Accomplishments:*** - Demonstrated, in a laboratory environment, low power room temperature single magnetic sensors based on atomic vapor cell magnetometry and on multiferroic composites with sensitivities of 100 femtotesla root mean square (rms) per square root hertz (the earth's magnetic field strength varies with location between 30 to 60 microtesla, by comparison). - Demonstrated an array of magnetic sensors with an overall sensitivity of 1 picotesla rms per square root hertz based on multiferroic composites at a frequency of 1 hertz. - Demonstrated an array of magnetic sensors with an overall sensitivity of 1 picotesla rms per square root hertz based on atomic vapor cell magnetometry at a frequency of 1 hertz.	13.790	16.745	15.308

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
- Evaluated a broad array of natural phenomena and associated theories addressing the spontaneous creation of structure in the natural world, particularly from fields of thermodynamics, evolution, information, and computation. - Investigated candidate electronic and chemical systems that are capable of self-organizing when placed in a complex environment; used computer simulation to select/refine/improve the candidate systems for further development. - Developed initial analytical tools to measure physical intelligence, and show how these tools relate the activities of a physically intelligent entity to the environment in which it exists. - Quantified the effects of the substrate material composition and microstructure on deposited palladium particle size; and their effects on the capability to generate excess heat collaboratively with Italian Department of Energy. - Quantified the required dynamic loading and relaxation conditions for high surface area palladium foils required to achieve high levels of deuterium loading that will tolerate the stresses associated with these conditions in collaboration with the Italian Department of Energy.			
FY 2011 Plans: - Demonstrate a 50% yield for the fabrication of the magnetic sensors based on multiferroic composites, in a lot size of 10 units which have outputs (volt/tesla values) within a ± 10 percent of the specification. - Demonstrate a 50% yield for the fabrication of the magnetic sensors based on atomic vapor cells, in a lot size of 10 units which have outputs (volt/tesla values) within a ± 10 percent of the specification. - Demonstrate a multiferroic magnetic sensor with an optical circuit read-out. - Create an initial version of a unified theory of physical intelligence and show how it is consistent with the established theories on which it was constructed. - Using a combination of simulation and real system hardware, conduct a limited demonstration of a physical intelligent electronic or chemical system imbedded in an environment of limited complexity. - Evaluate the initial physical intelligence theory's ability to describe the candidate electronic and chemical systems. - Refine analytical tools to measure intelligence and demonstrate them on complex, real world systems and their associated data (e.g., biological networks, internet traffic). - Develop more complex demonstrations and extend the theoretical and analytical tools to more complex systems. - Quantify material parameters that control degree of increase in excess heat generation and life expectancy of power cells in collaboration with the Italian Department of Energy.			
FY 2012 Plans: - Demonstrate a fieldable magnetic sensor using multiferroic composite structures with a sensitivity of 0.1 femtotesla rms per square root hertz at a frequency of 1 hertz. - Demonstrate a fieldable magnetic sensor using atomic vapor cells with a sensitivity of 0.1 femtotesla rms per square root hertz at a frequency of 1 hertz.			

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
- Design a magnetic field gradient imaging array with elements that have sensitivities of 0.1 femtotesla rms per square root hertz for use in imaging low-frequency magnetic anomalies. - Verify the initial unified physical intelligence theory and justify its underlying assumptions in the context of a model system that supports the emergence and evolution of novel structure. - Expand the theoretical effort to address correlated effects such as self-organized criticality renormalization, scaling, and punctuated equilibrium. - In real electro-chemical-physical systems that may include selected human interventions, demonstrate the spontaneous, abiotic evolution in any one of: biopolymers targeted against trace biochemical features in the environment; hydrocarbons from atmosphere, H2O, and sunlight in the environment; electrical networks that route information/energy to solve thermodynamic problems imposed by the structure of the environment; spontaneous information association capability (e.g. holography) in physical or chemical systems near a phase transition or other critical state in the presence of complex spatial/temporal electromagnetic and optical environments; complex spatial and temporal organization of non-equilibrium chemical reactions that are coupled to complex, adaptive electronic systems. - Demonstrate the ability to design an evolving electro-chemical-physical system and direct its evolution toward human-specified objectives. - Quantify the emergent structures that evolve from the demonstrated electro-chemical-physical systems. - Establish scalability and scaling parameters in excess heat generation processes in collaboration with the Italian Department of Energy.			
Title: Atomic Scale Materials and Devices	13.546	15.030	6.680
Description: This thrust examines the fundamental physics of materials at the atomic scale in order to develop new devices and capabilities. A major emphasis of this thrust is to provide the theoretical and experimental underpinnings of a new class of semiconductor electronics based on spin degree of freedom of the electron, in addition to (or in place of) the charge. A new all optical switch capability will also be investigated. It includes a new, non-invasive method to directly hyperpolarize biological tissues, leading to novel quantitative neurodiagnostics. Research on the basic physics and scaling of ionospheric processes utilizing the High Frequency Active Auroral Research Program (HAARP) transmitter will also be explored. New materials and prototype devices will be developed to demonstrate a new class of optoelectronics that operate with ultra-low energy dissipation (~100 atom-Joules (aJ)/operation). ***FY 2010 Accomplishments:*** - Developed spin gradient thermometry and demagnetization cooling techniques in ultracold atoms in an optical lattice. - Demonstrated a quantum gas microscope capable of imaging individual atoms in a 2-D optical lattice.			

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
- Emulated a frustrated quantum spin model using ion crystal array in three hours, confirming theoretical calculations to better than 92%. - Demonstrated an initial zeno-based switch using slot waveguides coated or filled with organic nonlinear absorptive materials. - Created a photonic crystal zeno mirror and waveguide with cavity Q > 1000, and loss < 0.1 Decibel (dB). - Generated and focused X-rays with specific state(s) of orbital angular momentum. ***FY 2011 Plans:*** - Demonstrate production of antiferromagnetically ordered states in 2-D and 3-D optical lattices. - Study and characterize supersolid behavior in multi-spin Bose condensates. - Produce phase diagrams of frustrated 2-D antiferromagnet in less than twelve hours. - Produce phase diagrams of 2-D Fermi-Hubbard model at near half-filling; determine presence or absence of superconducting phase. - Demonstrate all-optical switch (or equivalent device) based on optically-induced absorption. - Demonstrate total energy dissipation for an optical switch (or equivalent device) of less than 1 femtojoules per operation, and signal loss of less than 0.1 dB, excluding waveguide losses before and after device. - Demonstrate hyperpolarization of biologically relevant liquids, using photons with orbital angular momentum and measure the hydrogen and carbon-13 polarization. - Obtain hydrogen and carbon-13 spectra from biologically relevant liquid sample using quantum orbital resonance spectroscopy. ***FY 2012 Plans:*** - Load polar molecules into optical lattices to study long range character and ordering inside the optical lattice. - Demonstrate all-optical switch (or equivalent device) based on optically-induced absorption for a 25 nm range in input wavelength. - Demonstrate total energy dissipation for an optical switch (or equivalent device) of less than 100 attojoules per operation, and signal loss of less than 0.05 dB, excluding waveguide losses before and after device.			
Title: Basic Photon Science ***Description:*** Initiated under the fundamentals of nanoscale Devices effort, the Basic Photon Science thrust is examining the fundamental science of photons, from their inherent information carrying capability (both quantum mechanically and classically), to novel modulation techniques using not only amplitude and phase, but also orbital angular momentum. The new capabilities driven by this science will impact DoD through potentially novel approaches to communications and imaging applications, in addition to better understanding the physical limits of such advancement. For example, fully exploiting the computational imaging paradigm and associated emerging technologies to yield ultra-low size, weight, and power persistent/multi-functional intelligence, surveillance, and reconnaissance systems that greatly enhance soldier awareness, capability, security, and survivability.	-	12.000	21.500

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
FY 2011 Plans: - Investigate the theoretical and practical limits to the information content of a single photon via rigorous application of information theory. - Investigate the utility of information theoretic approach for design and improved receivers for high data rate communications. - Investigate the utility of information theoretic approach for improved low-light level imaging. - Develop the basic science required for the exploitation of orbital angular momentum in both the classical and quantum realms. - Identify fundamental limits of computational imaging by quantifying the space of cost and performance. - Develop the mathematical tools required to facilitate the joint optimization of physical and computational degrees of freedom. ***FY 2012 Plans:*** - Investigate the practical limits to the information content of a single photon via inclusion of various real-world imperfections. - Demonstrate the utility of information theoretic approach via highly photon efficient communications. - Demonstrate the utility of information theoretic approach via improved low-light level imaging. - Demonstrate the benefit of orbital angular momentum for communications applications. - Characterize surfaces of constant performance in the space of camera cost factors including optics, focal planes, and computation. - Study the fundamental limits of wafer scale optical fabrication and the capabilities of in situ 3-D optical metrology. - Investigate novel non-imaging measurements enabled by 3-D design and fabrication. - Develop a collection of candidate computational camera designs that yield high performance and low size, weight and power.			
Title: Enabling Quantum Technologies ***Description:*** This thrust emphasizes a quantum focus on technology capabilities including significantly improved single photon sources, detectors, and associated devices useful for quantum metrology, communications, and imaging applications. In addition, this thrust will examine other novel classes of materials and phenomena such as plasmons or Bose-Einstein Condensates (BEC) that have the potential to provide novel capabilities in the quantum regime, such as GPS-independent navigation via atom interferometry and communications, and ultrafast laser technologies. ***FY 2010 Accomplishments:*** - Designed and modeled two hybrid quantum interfaces that use ultracold atoms as magnetic sensors for nuclear spins and strongly-correlated materials. - Designed a mechanical interface to transfer quantum information with high fidelity between optical and microwave photons. ***FY 2011 Plans:***	4.000	6.000	14.000

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
- Design a physics package for an optical clock including lasers, optomechanics, associated electronics, and environmental isolation and control subsystems. - Determine the mechanical stability of doped-crystal Fabry-Perot optical cavities for use in time and frequency transfer between optical clocks. - Investigate techniques to improve the coherence properties of nitrogen-vacancy (NV) diamond nanocrystals for use in high resolution magnetometry. ***FY 2012 Plans:*** - Trap single atoms near the surface of a metal nanotip. Demonstrate coherent readout and control of atomic state. - Investigate Doppler-free two photon transitions in atomic vapor cells for use as an optical frequency standard. - Demonstrate coherent transfer of classical information between optical and microwave fields via a nanomechanical interface. - Demonstrate an entangled/squeezed quantum sensor that operates below the standard quantum limit. - Demonstrate a magnetometer with sensitivity 0.1 nanotesla/square root hertz with < 2 micron resolution. - Investigate the feasibility of high average power, ultrafast laser architectures suitable for high throughput industrial micromachining. - Explore schemes extending frequency combs from the extreme UV into the medium wavelength infrared (MWIR) and long wavelength infrared (LWIR) spectral regimes for applications of interest to the DoD. - Examine the utility of robust, compact attosecond probes for real-time control of atomic excitations, valence electron dynamics, and transport phenomena in ultra dense matter. - Expand the use of analog quantum simulators to the study of nonlinear optical materials and nuclear systems. - Develop technologies to enable physically separated parties to securely generate identical one-time pad pairs at Gigabit per second (Gb/s) rates. - Develop and demonstrate scalable architecture, capable of extending the range of quantum communications from 100 km to 5000 km.			
Title: Fundamentals of Physical Phenomena* ***Description:*** *Previously included in Fundamentals of Nanoscale and Emergent Effects and Engineered Devices, and Atomic Scale Materials and Devices. This thrust will obtain insights into physical aspects of natural phenomena such as magnetospheric sub-storms, fire, lightning, and geo-physical phenomena. A major emphasis of this thrust is to provide predictive models for the interactions between plasmas and electromagnetic waves across a range of energy and length scales, and into new regimes. Specific projects that fall under this heading are foundational studies on: the initiation, propagation, and attachment of lightning, and their associated emissions;	6.570	9.712	10.018

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
the critical factors affecting magnetospheric sub-storms; the generation and amplification of extremely low frequency (ELF)/ultra low frequency (ULF)/very low frequency (VLF) radiation in the ionosphere utilizing the High Frequency Active Aural Research Program (HAARP) transmitter; and understanding and quantifying the interaction of electromagnetic and acoustic waves with the plasma in flames. ***FY 2010 Accomplishments:*** - Initiated a series of HAARP experimental campaigns to study ionospheric and trans-ionospheric phenomena, including: optimization of high frequency to very low frequency conversion efficiency, wave-particle interaction, generation and propagation of ultra low frequencies, very low frequencies and artificial ducts, triggering and characterization of specific ionospheric instabilities. - Developed theoretical models for triggered lightning, transient luminous events, lightning-induced electron precipitation and related ionospheric phenomena. - Developed theoretical models for lightning initiation, propagation, and attachment. ***FY 2011 Plans:*** - Conduct a comprehensive series of ELF/ULF/VLF generation experiments to study the efficiency of density pre-conditioning. - Characterize ionospheric current drive (ICD), artificially stimulated emissions in the ionosphere, and ionospheric turbulence and associated scintillations. - Equip at least two facilities capable of launching rockets every thirty seconds in order to trigger lightning and measure all associated phenomena, including the initiation, propagation, attachment processes as well as all associated emissions such as gamma rays, RF and high power electromagnetic pulse. ***FY 2012 Plans:*** - Conduct comprehensive HAARP-ULF experiments to study the onset of noise under a variety of space-weather conditions. - Conduct a series of experiments to inject VLF waves into artificial ducts. - Develop, implement and test a continuously-operational, extensive array of instruments which will measure all atmospheric and electromagnetic components of tropospheric lightning and correlate this phenomenon with various ionospheric events. - Deploy balloons into thunderstorms to make in-situ electric field, X-ray and gamma-ray measurements. - Develop and deploy a constellation of receivers to study the radio emissions generated by lightning and associated ionospheric events.			
Title: MesoDynamical Architectures (Meso)* ***Description:*** *Formerly Dynamics-Enabled Frequency Sources (DEFYS).	8.889	20.000	22.000

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
The MesoDynamical Architectures (Meso) program will enable a new generation of sensing, communication, and computation by exploiting quantum collective behaviors. The program will achieve beyond-classical functionality in a number of devices and technologies, including transistors, broadband detectors, and high-efficiency thermal conductors. The majority of devices are expected to involve intrinsic (meso) scales in the nanometer to micrometer range and operate at room temperature. The program will exploit the recently discovered topologically insulating state of matter and use mechanisms in four related thrusts: the strong nonlinearities and fluctuations inherent to the mesoscale, quantum collective behaviors, efficient information transduction between fields and excitations (acoustic, electric, and optical), and coherent feedback control. This program also incorporates recent advances in very small mechanical systems, nonlinear dynamics, and noise management to revolutionize performance of reference oscillators. Since oscillators are a building block of modern electronics any uncertainty in frequency they produce will limit performance of the larger system including: radars, communications, sensors and geo-positioning devices. The exotic and novel devices enabled will provide new opportunities in both the military and commercial sectors. ***FY 2010 Accomplishments:*** - Initiated program with focus on exploiting nonlinear mechanisms to reduce oscillator phase noise. - Completed device designs and simulations. - Completed initial designs for maintaining performance in high acceleration/vibration environments. - Determined approaches for maintaining performance over a large temperature range. - Completed design for an optical coherent feedback controller and began building architecture for single controller demonstration. - Completed designs for two new devices based on collective coherence: Topological Quantum Interference Device and high-density, low power magnetic memory. ***FY 2011 Plans:*** - Demonstrate performance improvements by exploiting nonlinear mechanisms. - Complete designs and simulations for using noise shaping to further reduce phase noise. - Improve acceleration and vibration tolerance. - Improve temperature stability. - Meet device size requirement. - Demonstrate first generation of devices in the nonlinearity and fluctuation thrusts maintain performance despite acceleration/vibrations and temperature variations. - Define spectrum of devices to be produced in collective coherence, information transduction, and control thrusts. - Complete initial designs and simulations of devices in all thrusts. ***FY 2012 Plans:***			

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
- Establish background fluctuations that can be tuned to reduce phase noise in high performance frequency sources. - Demonstrate improved vibration insensitivity and temperature stability in 2nd generation of devices of frequency sources. - Provide frequency sources with better than -110 dBc/Hz phase noise, while simultaneously meeting metrics for acceleration and temperature stability. - Determine specific topological insulating devices, simulate architectures, and begin fabrication. - Demonstrate architectures exploiting transduction of signals between light, electricity, and sound. - Realize a quantum controller which provides better than 10 times stability to a coherent state. - Begin to demonstrate the integrability of the prototypes into existing systems.			
Title: Surface Enhanced Raman Scattering (SERS) - Science and Technology Fundamentals	4.547	0.800	-
Description: The Surface Enhanced Raman Scattering (SERS) - Science and Technology program focuses on the fundamental technical challenges facing potential sensor performance with respect to their sensitivity, selectivity, enhancement factors and development. SERS nanoparticles have considerable potential for both chemical and biochemical sensing applications due to: 1) their potential large spectral enhancement factors, 2) the nature of spectral fingerprints that can be expected to yield low false alarm rates, and 3) the capability for detecting targeted molecules at useful stand-off ranges. This program seeks to identify and overcome the key scientific and technical challenges necessary for replacing existing sensors of chemical and biological warfare (CBW) agents with SERS-based sensing approaches. ***FY 2010 Accomplishments:*** - Realization of one inch diameter SERS surfaces with enhancement factors of over 10e9. - Understanding of the role of localized radius of curvature on the electromagnetic field enhancement and molecule placement on metal nanoparticles. - Developed the use of non-noble metals to achieve plasmon resonances in the ultraviolet and near-infrared regions. - Used carbon nanotube functionalized Atomic Force Microscopy (AFM) tips to map and spatially correlate "hot spots" on SERS surfaces. ***FY 2011 Plans:*** - Scaling of SERS nanoparticle synthesis approaches compatible with 6 inch active substrates capable of 10e12 enhancements. - Shift laser wavelength (785 nm) to eye-safe near-infrared lasers at 1064 nm and 1530 nm. - Initiate research into micro-fluidic integration of SERS particles for producing sensors capable of sub-part-per-trillion (sub-ppt) explosive vapor detection. - Begin investigation into non-linear optical approaches to increasing enhancement.			

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
- Investigate the use of hyper-Raman Scattering and Surface Enhanced Coherent Anti-Stokes Raman for chemical/biological sensor applications.			
Accomplishments/Planned Programs Subtotals	60.597	89.854	97.506

	FY 2010	FY 2011
Congressional Add: American Museum of Natural History Infectious Disease Research ***FY 2010 Accomplishments:*** - Advanced diversity of interaction among different international surveillance and prediction groups to test phylogenetic analysis software program and improve SUPRAMAP system, a web application for integrating genetic, evolutionary, geospatial, and temporal data. - Continued integration of public health and animal surveillance communities to intensify parameters needed for research areas of transition partners. - Advanced integration of proprietary software into programs that are more deeply seated in the global surveillance community.	1.200	-
Congressional Add: Institute for Collaborative Sciences Research ***FY 2010 Accomplishments:*** - Continued investigation of collaborative sciences research.	2.080	-
Congressional Add: Advanced Materials Research Institute ***FY 2010 Accomplishments:*** - Conducted research related to nanoscale engineering of multiferroic materials and tested design of voltage controlled ferromagnetic material for micro- and nano-scale devices. - Investigated chemical synthesis of spinel and perovskite nanostructures with variable architectural complexity. - Developed plans to integrate magnetoelectric composites into functional devices: design, fabrication and testing.	0.800	-
Congressional Add: Hydrogen Fuel Cell Research ***FY 2010 Accomplishments:*** - Initiated innovative research advances into hydrogen fuel cell technology.	4.000	-
Congressional Add: Solid Oxide Fuel Technology ***FY 2010 Accomplishments:*** - Investigated innovative advances into solid oxide fuel technology to reduce the weight and increase the run time of batteries used to power battlefield devices.	1.000	-
Congressional Adds Subtotals	9.080	-

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C. Other Program Funding Summary ($ in Millions)

N/A

D. Acquisition Strategy

N/A

E. Performance Metrics

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.

Exhibit R-2A, RDT&E Project Justification: PB 2012 Defense Advanced Research Projects Agency			DATE: February 2011
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COST ($ in Millions)	FY 2010	FY 2011	FY 2012 Base	FY 2012 OCO	FY 2012 Total	FY 2013	FY 2014	FY 2015	FY 2016	Cost To Complete	Total Cost
TRS-01: *TRANSFORMATIVE SCIENCES*	-	41.578	30.000	-	30.000	40.269	39.441	48.561	52.561	Continuing	Continuing

A. Mission Description and Budget Item Justification

This project supports scientific research and analysis that leverages converging technological forces and transformational trends in the areas of computing and the computing-reliant subareas of social sciences, life sciences, manufacturing, and commerce in order to improve military adaptation to sudden changes in requirements, threats, and emerging/converging trends, especially trends that have the potential to disrupt military operations. The project has particular interest in custom manufacturing, large-scale, human-centered networks, and cyber-physical systems. Promising research will advance to both technology development and system-level projects.

B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
Title: Cognitive Cloud*	-	9.000	10.000

Description: *Formerly Transformative Sciences

The Cognitive Cloud program develops militarily-relevant basic science as suggested by emerging technological paradigms and societal trends. Two areas in which there is particular interest are "cloud computing" - internet-based, utility computing, and "crowd-sourcing" - large-scale, human-centered networks of web-enabled individuals working towards a unified goal. These will be combined to create solutions for highly complex military problems. Examples of such problems include intelligence, surveillance and reconnaissance of denied areas; modeling foreign societies, governments, and militaries; debugging large, complex software systems; and real-time understanding of activity patterns indicative of imminent cyber-attack. Cognitive Cloud research will combine the strengths of cloud computing (ubiquitous access to information) and crowd-sourcing (the wisdom of the crowd) to enable highly resilient and reactive computing/communication/information systems that respond to and survive attacks. These cloud-based cognitively-enabled cyber defense capabilities will be realized without the imposition of significant bandwidth and/or processing overhead.

FY 2011 Plans:

- Explore the use of crowd-sourcing and cloud cognition as the basis for highly sensitive cyber situational awareness and the capability for rapid and massed responses to emergent cyber threats.
- Develop and apply means of using social networking to dramatically improve military situational awareness, not only of the locations of people and installations, but also social maps and leverage points.
- Develop efficient approaches for reactive, adaptable, and survivable wide-area networks and computing systems.

FY 2012 Plans:

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
- Demonstrate how statistical and quasi-experimental analyses of existing data sets can be used to derive answers to key tactical military questions. - Demonstrate approaches for reactive, adaptable, and agile wide-area networks and computing systems.			
Title: Crowd-Sourced Analytics* ***Description:*** *Formerly Deep ISR Processing by Crowds The Crowd-Sourced Analytics program goes beyond the concept of putting the human in the loop, and instead looks to harness the unique cognitive and creative abilities of large numbers of people to dramatically enhance the knowledge derived from a broad range of sources. This approach is unconventional in that it involves the generation of analysis products based on distributed crowd sourcing across human/machine systems. Novel frameworks will be developed to capture the experience base of users and systems to allow optimum problem partitioning, quantitative confidence assessment, and validation in environments that may be partially compromised by adversaries. ***FY 2011 Plans:*** - Establish analytical framework including problem partitioning and quantitative confidence assessment. - Perform large-scale experimentation and demonstration on sample data sets to quantify performance enhancement. ***FY 2012 Plans:*** - Develop means for optimum problem partitioning across domains and quantitative confidence assessment under uncertain provenance. - Perform large-scale cross-domain experimentation and demonstration on real data sets to quantify performance enhancement.	-	7.000	8.000
Title: Production of Knowledge Bases to Bridge Cultural Divides ***Description:*** The Production of Knowledge Bases to Bridge Cultural Divides program will develop tools, techniques, and frameworks for the automated interpretation and quantitative analysis of social networks using emerging methods for edge finding and cluster analysis. These systems have important applications in tactical contexts to aid analysts and operators in connecting the dots amid complex, conflicting, and incomplete data sets. They also establish a foundation for cultural intelligence -- understanding the stability, governance, and economic indicators of a region. Beginning in FY 2012 this program is funded under Nexus 7 in PE 0602702E, Project TT-13. ***FY 2011 Plans:*** - Develop mathematical and algorithmic modeling and analysis tools. - Establish baseline performance and demonstration of enhanced analysis using the tools.	-	9.500	-

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B. Accomplishments/Planned Programs ($ in Millions)	FY 2010	FY 2011	FY 2012
- Demonstrate automated and semi-automated processes for exploitation of data collected via experimental analyst assistant.			
Title: Synthetic Biology ***Description:*** The Synthetic Biology program will develop and implement a revolutionary approach to the manufacture of bio-based materials that directly support a broad range of military capabilities, such as therapeutics, diagnostics, vaccine development, sensing of chemical/biological agents, production of bio-based fuels and chemicals, remediation of pollutants, and protection of the food supply chain. Synthetic Biology is based on a revolutionary framework for the algorithmic engineering of biological processes, enabling engineered biological systems that are tailored to provide novel solutions and enhancements to military needs and capabilities. Research thrusts include tools for creating synthetic regulatory genetic elements that can be used in mammalian cells, automated process discovery, tool-chain development, bio-foundry development, novel approaches to process measurement and validation, and development of application demonstrations. ***FY 2011 Plans:*** - Design biological host organism concepts. - Design tool-chain framework and workable building blocks for functional outcomes. - Develop synthetic regulatory elements for in vivo biomedical applications to detect threats to health or performance and prevent disease by vaccination. - Initiate development of new materials and synthetic molecular approaches to enable deployable diagnostics. ***FY 2012 Plans:*** - Initiate laboratory development. - Iterate tool-chain framework and building blocks for more efficient functional outcomes.	-	16.078	12.000
Accomplishments/Planned Programs Subtotals	-	41.578	30.000

C. Other Program Funding Summary ($ in Millions)

N/A

D. Acquisition Strategy

N/A

E. Performance Metrics

Specific programmatic performance metrics are listed above in the program accomplishments and plans section.