Exhibit R-2, RDT&E Budget Item Justification: PB 2011 Defense Advanced Research Projects Agency										DATE: February 2010	
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 2009 Actual**	**FY 2010 Estimate**	**FY 2011 Base Estimate**	**FY 2011 OCO Estimate**	**FY 2011 Total Estimate**	**FY 2012 Estimate**	**FY 2013 Estimate**	**FY 2014 Estimate**	**FY 2015 Estimate**	**Cost To Complete**	**Total Cost**
Total Program Element	187.157	205.915	328.195	0.000	328.195	268.459	273.828	279.305	284.891	Continuing	Continuing
BLS-01: *BIO/INFO/MICRO SCIENCES*	39.488	39.541	53.835	0.000	53.835	34.327	35.425	40.925	40.925	Continuing	Continuing
CCS-02: *MATH AND COMPUTER SCIENCES*	33.345	46.558	73.211	0.000	73.211	67.199	77.401	80.501	80.951	Continuing	Continuing
ES-01: *ELECTRONIC SCIENCES*	62.174	57.057	70.193	0.000	70.193	66.503	68.252	62.752	62.752	Continuing	Continuing
MS-01: *MATERIALS SCIENCES*	52.150	62.759	78.456	0.000	78.456	90.430	82.750	85.127	90.263	Continuing	Continuing
TRS-01: *TRANSFORMATIVE SCIENCES*	0.000	0.000	52.500	0.000	52.500	10.000	10.000	10.000	10.000	Continuing	Continuing

A. Mission Description and Budget Item Justification

(U) 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.

(U) 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 organisms' levels.

(U) 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.

Exhibit R-2, RDT&E Budget Item Justification: PB 2011 Defense Advanced Research Projects Agency	DATE: February 2010
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(U) 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.

(U) 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.

(U) 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 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
Previous President's Budget	202.487	226.125	0.000	0.000	0.000
Current President's Budget	187.157	205.915	328.195	0.000	328.195
Total Adjustments	-15.330	-20.210	328.195	0.000	328.195
• Congressional General Reductions		-0.863			
• Congressional Directed Reductions		-36.807			
• Congressional Rescissions	-1.791	0.000			
• Congressional Adds		17.460			
• Congressional Directed Transfers		0.000			
• Reprogrammings	-7.849	0.000			
• SBIR/STTR Transfer	-5.690	0.000			
• TotalOtherAdjustments	0.000	0.000	328.195	0.000	328.195

Congressional Add Details ($ in Millions, and Includes General Reductions)	FY 2009	FY 2010
Project: BLS-01: *BIO/INFO/MICRO SCIENCES*		
Congressional Add: *Bio Butanol Production Research*	2.000	0.000
Congressional Add: *Countermeasures to Combat Protozoan Parasites*	0.000	1.600

Exhibit R-2, RDT&E Budget Item Justification: PB 2011 Defense Advanced Research Projects Agency	DATE: February 2010
APPROPRIATION/BUDGET ACTIVITY 0400: *Research, Development, Test & Evaluation, Defense-Wide* BA 1: *Basic Research*	R-1 ITEM NOMENCLATURE PE 0601101E: *DEFENSE RESEARCH SCIENCES*

Congressional Add Details ($ in Millions, and Includes General Reductions)	FY 2009	FY 2010
Congressional Add Subtotals for Project: BLS-01	2.000	1.600
Project: CCS-02: *MATH AND COMPUTER SCIENCES*		
Congressional Add: *Institute for Information Security*	2.500	0.000
Congressional Add: *Science, Technology, Engineering and Mathematics Initiative*	0.000	1.600
Congressional Add Subtotals for Project: CCS-02	2.500	1.600
Project: ES-01: *ELECTRONIC SCIENCES*		
Congressional Add: *Advanced Photonic Composites Research*	1.280	0.000
Congressional Add: *Laboratory for Advanced Photonic Composites Research*	0.000	1.280
Congressional Add Subtotals for Project: ES-01	1.280	1.280
Project: MS-01: *MATERIALS SCIENCES*		
Congressional Add: *Comparative Genomics for National Security Goals/Infectious Disease Research*	2.000	1.200
Congressional Add: *Institute for Collaborative Sciences Research*	1.200	2.080
Congressional Add: *Advanced Materials Research Institute*	2.400	0.800
Congressional Add: *Hydrogen Fuel Cell Research*	0.000	4.000
Congressional Add: *Solid Oxide Fuel Technology*	0.000	1.000
Congressional Add: *Security Protection using Ballistic CORE Technology*	0.000	3.900
Congressional Add Subtotals for Project: MS-01	5.600	12.980
Congressional Add Totals for all Projects	11.380	17.460

Change Summary Explanation

FY 2009

Decrease reflects Section 8042 rescission of the FY 2010 Appropriation Act, SBIR/STTR transfer and internal below threshold reprogramming.

Exhibit R-2, RDT&E Budget Item Justification: PB 2011 Defense Advanced Research Projects Agency	DATE: February 2010
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FY 2010

Decrease reflects reductions for the Section 8097 Economic Assumption, execution delays and FY 2010 new starts offset by congressional adds (as identified above).

FY 2011

Not Applicable

Exhibit R-2A, RDT&E Project Justification: PB 2011 Defense Advanced Research Projects Agency			DATE: February 2010
APPROPRIATION/BUDGET ACTIVITY 0400: *Research, Development, Test & Evaluation, Defense-Wide* BA 1: *Basic Research*	R-1 ITEM NOMENCLATURE PE 0601101E: *DEFENSE RESEARCH SCIENCES*	PROJECT BLS-01: *BIO/INFO/MICRO SCIENCES*	

COST ($ in Millions)	FY 2009 Actual	FY 2010 Estimate	FY 2011 Base Estimate	FY 2011 OCO Estimate	FY 2011 Total Estimate	FY 2012 Estimate	FY 2013 Estimate	FY 2014 Estimate	FY 2015 Estimate	Cost To Complete	Total Cost
BLS-01: *BIO/INFO/MICRO SCIENCES*	39.488	39.541	53.835	0.000	53.835	34.327	35.425	40.925	40.925	Continuing	Continuing

A. Mission Description and Budget Item Justification

(U) 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 Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
Bio Interfaces	6.099	2.707	0.000	0.000	0.000
(U) 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. *FY 2009 Accomplishments:* - Tested theoretical mathematical formulations of the laws of biology on simple systems. - Compared gene regulatory modules involved in the growth and development of plants and animals for similar functionality.					

Exhibit R-2A, RDT&E Project Justification: PB 2011 Defense Advanced Research Projects Agency		DATE: February 2010
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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
- Tested proposed mathematical theory of collective decision making in viruses. *FY 2010 Plans:* - Test theoretical mathematical formulations of the laws of biology on multi-scale systems. - Develop a generalized thermodynamic formalism for biological systems. - Develop theoretical mathematical formulation for rewiring of modules in regulatory pathways in bacterial evolution.					
Preventing Violent Explosive Neurologic Trauma (PREVENT) (U) The Preventing Violent Explosive Neurologic Trauma (PREVENT) program seeks to understand the causes of blast-induced traumatic brain injury, 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 the in-theater conditions to assess the potential traumatic brain injury 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. *FY 2009 Accomplishments:* - Examined protection and mitigation strategies that greatly reduce the number and extent of traumatic brain injuries in warfighter population due to explosion. - Continued studies on blast effects as needed to determine underlying physiological causes of blast induced brain injury. - Verified causes of blast brain injury through observations in warfighter population. - Assessed injurious role of electrical discharge from detonation of cased munitions on central nervous system.	8.839	4.325	4.775	0.000	4.775

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
FY 2010 Plans: - Assess the effect of commonly available pharmaceuticals in both acute and chronic mitigation of blast brain injury symptoms. - Validate diagnostic criteria for assessment of mild to severe blast brain injury. - Test and validate fabricated device strategies to ensure that they appropriately mitigate the effects of blast brain injury. *FY 2011 Base Plans:* - Develop devices and diagnostic platforms for blast brain injury in theater as needed. - Determine the physiological effects of blast on brain tissue as well as short-term and long-term behavior and cognition in non-human primates. - Coordinate with military medical community and Services as needed to ensure technology reaches adoption. - Investigate the long-term effects of exposure to blast on warfighters following return from deployment.					
Biological Adaptation, Assembly and Manufacturing (U) 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	4.500	7.347	9.217	0.000	9.217

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
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. Applications to Defense systems include the development of chemical and biological sensors, and improved battlefield survivability of the warfighter. *FY 2009 Accomplishments:* - Developed complete mathematical model for fracture putty/bone biomechanics. - Developed fracture putty material which approximates the mechanical properties and internal structure of natural bone. - Demonstrated mechanical properties of fracture putty for in vitro model of bone fracture. - Identified newly discovered bacteria with unique enzymatic activity on crystalline cellulose. *FY 2010 Plans:* - Develop novel resorbable wet adhesives with the mechanical properties of natural bone, for inclusion into fracture putty formulation. - Demonstrate fracture putty in small animal model of bone fracture. - Initiate large animal studies of fracture putty for bone fracture repair. - Identify candidate fundamental mechanisms for controlling antibody stability and affinity. - Demonstrate the ability to produce an antibody with thermal stability from room temperature up to 60 degrees Celsius. - Demonstrate the ability to produce an antibody with selectable affinity as measured by a binding constant (KD=dissociation constant) of 10 to the negative eighth power. *FY 2011 Base 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. - Combine identified antibody stability and affinity capabilities into a single “Master Antibody Molecule” that exhibits two target metrics against a single biological threat agent.					

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
- Provide a minimum of 2 grams of the identified “Master Antibody Molecule” for independent 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.					
Nanostructure in Biology	10.500	5.928	2.400	0.000	2.400
(U) The Nanostructure in Biology program will investigate the nanostructure properties of biological materials to better understand their behavior and accelerate their exploitation for Defense applications. This new information about biomolecules and complex cellular systems will provide important new leads for the development of threat countermeasures, biomolecular probes and motors, and neuromorphic sensory systems. This program will also develop approaches to mathematically predict a priori, the structure of biological materials, especially proteins, based on the desired performance. This will enable 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 will also create technology to reliably integrate nanoscale and microsystems payloads on insects that will extract power, control locomotion, and also carry DoD relevant sensors. *FY 2009 Accomplishments:* - Created a functional model of the mammalian object recognition pathway that is biologically valid and suitable for translation to algorithm development. - Optimized Micro Electro Mechanical Systems (MEMS) components for locomotion control, communications and power generation to consume less power and to reduce size, weight and cost. - Designed two protein-protein binding pairs with binding constants below one hundred nanomolar. - Extended catalytic activity of de novo designed enzymes to ten million for known chemistries.					

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
FY 2010 Plans: - Discover methods for precise flight control use in combinations of MEMS techniques originating in the previous fiscal year. - Develop neural interfaces to insect sensors to compliment electronic sensors. - Develop a protein that inhibits the activity of influenza by preferential binding. - Design de novo inhibitory protein of smallpox. *FY 2011 Base Plans:* - Exploiting protein design tools, modify the anthrax capsule-depolymerizing enzyme to increase stability in serum two-fold.					
Human Assisted Neural Devices (U) 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. 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 revolutionary 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. *FY 2009 Accomplishments:* - Identified memory neural codes that are specific to critical work related tasks, enabling possible potential memory restoration in a brain-wounded warfighter. - Developed new types of neural-electrical interfaces capable of continuous recording of neural patterns.	5.550	15.134	18.943	0.000	18.943

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
- Explored mechanisms of information transfer between disparate regions of the brain during sensorimotor tasks. *FY 2010 Plans:* - Identify neural processes for encoding short- and long-term memory in primates during a complex motor task. - Build hardware and software to implement pattern extraction and inter-individual verification of homogeneity of patterns between primates. - Create an interface that enables performance of a complex motor/sensory task through an assistive device without using either motor or sensory function. - Determine task performance changes resulting from learning and plasticity through observation of the development of functional networks in the primate and rodent brain over time. - Construct algorithms and methods capable of more accurately describing and estimating neural signals from limited data. *FY 2011 Base Plans:* - Assess ability of primate to retain short-term memory encoding following simulated injury through use of neural codes. - Determine potential for long-term memory encoding assisted through use of neural codes in primates with long-term memory deficit. - 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.					

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
- 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.					
Mathematics of the Brain (MoB)	2.000	2.500	6.000	0.000	6.000
(U) The Mathematics of the Brain program will develop a powerful new mathematical paradigm for understanding how to model reasoning processes for application to a variety of emerging DoD challenges. This will require constructing a novel mathematical architecture for a biologically consistent model of thought that moves beyond the state of the art to allow the ability to learn and reason. The program will also 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 2009 Accomplishments:* - Proposed a mathematical model of the brain that is consistent and predictive with brain function, rather than merely biologically inspired. - Leveraged recent advances in neuroscience and mathematics to explore an integrated theory that overcomes the difficulties present in traditional approaches, such as artificial intelligence and artificial neural networks. *FY 2010 Plans:* - Investigate a new mathematical theory of compressive measurement.					

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
FY 2011 Base Plans: - Develop a new comprehensive theory to exploit information in signals. - Exploit the new theoretical framework together with novel forms of prior knowledge in order to enable optimal information gathering from sparse signal sampling. - Demonstrate the utility of new theory via improvements to applications in communications, signals intelligence, and imaging.					
Physics in Biology (U) Understanding the fundamental physical phenomena that underlie biological processes and functions will provide 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 existing abiotic applications. This includes exploiting manifestly quantum mechanical effects that exist in biological systems at room temperature to develop a revolutionary new class of compact high sensitivity sensors. *FY 2011 Base Plans:* - Develop a quantum theoretical model of postulated non-trivial quantum mechanical effects in specific biological systems. - Experimentally verify that the biological system exploits the effect at room temperature. - Formulate testable predictions for impact of perturbations to the biological system.	0.000	0.000	6.000	0.000	6.000
Scaffold-Free Tissue Engineering (STF) (U) 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 STF-developed platforms would circumvent current limitations by removing the use of a material scaffold and providing simultaneous control of multiple cell/tissue types for the	0.000	0.000	6.500	0.000	6.500

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
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 STF 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 Base 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 2 cubic centimeter multicellular skeletal muscle scaffold-less construct into an appropriate in vivo model. - Develop cellular placement instrumentation for in vivo implementation of scaffoldless tissue construction.					
Accomplishments/Planned Programs Subtotals	37.488	37.941	53.835	0.000	53.835

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010
Congressional Add: Bio Butanol Production Research *FY 2009 Accomplishments:* - Investigated bio-butanol production capabilities.	2.000	0.000
Congressional Add: Countermeasures to Combat Protozoan Parasites *FY 2010 Plans:* Initiate research to develop countermeasures to combat protozoan parasites.	0.000	1.600
Congressional Adds Subtotals	2.000	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.

Exhibit R-2A, RDT&E Project Justification: PB 2011 Defense Advanced Research Projects Agency			DATE: February 2010
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COST ($ in Millions)	FY 2009 Actual	FY 2010 Estimate	FY 2011 Base Estimate	FY 2011 OCO Estimate	FY 2011 Total Estimate	FY 2012 Estimate	FY 2013 Estimate	FY 2014 Estimate	FY 2015 Estimate	Cost To Complete	Total Cost
CCS-02: *MATH AND COMPUTER SCIENCES*	33.345	46.558	73.211	0.000	73.211	67.199	77.401	80.501	80.951	Continuing	Continuing

A. Mission Description and Budget Item Justification

(U) 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 Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
Foundational Computer Science	2.344	5.612	9.450	0.000	9.450
(U) 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 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. Interest in communications and sensor networks addresses challenges related to dynamic heterogeneous multi-modal networks. The Foundational Computer Science program will also address problems that are inherently computationally					

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
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 2009 Accomplishments:* - Assessed the potential for the recently developed Upper Confidence Tree (UCT) algorithm to search trees with high branching factor. - Developed features for spatial description of board position for the game of Go. *FY 2010 Plans:* - Develop improved methods of planning and reasoning to calculate Go best-next-move hypotheses from board positions and use such hypotheses to develop a highly targeted search. - Develop methods for visualization to determine similarity and differences in positional configurations. - Create models for multiple, diverse, heterogeneous networks with new degrees of dynamics, changing network characteristics, and behavior. *FY 2011 Base 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. - Develop and apply new mathematical descriptions and characterizations that unify disparate network types and that address the dynamics, interactions, information flow, stability, and other critical aspects.					
Foundational Machine Intelligence*	0.000	3.681	9.000	0.000	9.000

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
*Previously in Foundational Computer Science. (U) 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 based upon a universal "cortical" algorithm; unmanned vehicles and intelligent agents that generate and manage their own goals within human-described mission constraints; and modeling of human language acquisition by associating words with the real-world entities perceived through multiple modes of sensory input. *FY 2010 Plans:* - Create machine learning techniques that can assimilate huge amounts of data by creating rich representations of the input data and applying them to multiple applications. - Construct a single, general-purpose algorithm which could start with zero knowledge of its environment, and then grow to represent the structure latent in that environment. *FY 2011 Base 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.					

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
- Demonstrate multiple general-purpose learning algorithms and characterize their performance and operational constraints. - Develop algorithms for automated problem recognition and goal management and create a language for computer-interpreted mission descriptions.					
Information Theory for Wireless Mobile Ad Hoc Networks (ITMANET)*	1.361	3.271	5.646	0.000	5.646
* Previously in Foundational Computer Science. (U) 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 2009 Accomplishments:* - Determined the multicast capacity region for large wireless MANETs. - Developed distributed algorithms that enable “interference alignment”, a technique that achieves increased wireless network capacity in the high signal-to-noise ratio regime. - Developed capacity-achieving routing protocols for multi-hop ad-hoc networks with highly mobile nodes that move arbitrarily. *FY 2010 Plans:* - Predict performance in terms of throughput-delay-reliability for modest-sized MANETs with and without feedback.					

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
- Develop upper-bounding techniques that go beyond the classical bounds and inequalities for MANETs. *FY 2011 Base 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.					
Centers of Excellence for Computational Science and Engineering (COECSE) (U) The Centers of Excellence for Computational Science and Engineering (COECSE) will address the most difficult and fundamental challenges facing computing today. Computing has reached three walls of security, energy (power consumption) and programmability that cannot be overcome by traditional, evolutionary techniques. Security and energy-efficiency are difficult roadblocks for all current architectural approaches. Revolutionary new architectures, ranging from microprocessors, memory and interfaces to full-scale systems, are needed if we are to sustain the rate of advancement to which we have become accustomed. Languages that make programming current and future multi-core processors far more tractable for the average application developer are needed if we are to reap the benefits of emerging processor paradigms such as massive multi-core. The current approach to security, which attempts to retrofit security onto an evolving, imprecisely known, and increasingly complex (even non-deterministic) COTS infrastructure, is ad hoc and ineffectual – more systematic approaches are required. (U) Traditionally, computing has sought to overcome these three walls separately, with security, processing architectures, and programming languages developed in isolation and applied independently. The Centers of Excellence Program for Computational Science and Engineering will create research centers engaging academics and industry to explore and develop a more holistic approach to breaking down these walls. Examples of the types of research of interest include co-	0.000	0.000	4.000	0.000	4.000

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
design approaches for hardware and software; parallel abstractions and new methods for expressing parallelism; software development environments for rapidly creating energy efficient embedded systems; computing components that have security “baked in” from the start for use at key points in the hardware and software stacks; provably secure clean-slate execution models; novel architectures for logic, memory, and data access to support secure execution; formal automated proof tools for security throughout the execution model; self-aware and learning capabilities to manage security at run-time; coordinated development of resiliency techniques (including detection and correction, fail-in-place self-healing, and learning); and new safe/secure computer languages and compilers. *FY 2011 Base Plans:* - Identify and develop new and holistic approaches to enhancing the security, energy-efficiency, and programmability of computing systems.					
Training for Adaptability (U) The Training for Adaptability program will develop adaptable environments and experiences to increase diversity and fidelity of leadership training. *FY 2011 Base Plans:* - Formulate an initial framework for the examination of different notions of leadership within complex social systems and environments. - Create leadership models that planners can use to evaluate alternative actions in human terrain problems and to develop effective commander’s intent statements.	0.000	0.000	5.000	0.000	5.000
Computer Science Study Group (CSSG) (U) 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	9.890	10.400	10.550	0.000	10.550

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
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 2009 Accomplishments:* - Developed a novel agent based simulation environment that allows persons without computer programming expertise, and warfighters on the ground, air or sea down to the lowest unit levels in particular, to develop realistic new training scenarios quickly and on demand. - Developed fundamental algorithms with provable guarantees of correctness and efficiency to enable effective learning from incomplete data and data corrupted with noise. - Explored bio-inspired computing emphasizing evolutionary computation and artificial neural networks (ANNs) to solve difficult real world tasks such as autonomous guidance of vehicles. - Developed new approaches for management of network security, authentication, mobility, and hand-off management with emphasis on self-organizing wireless networks in a battlefield environment. *FY 2010 Plans:* - Continue to identify and explore new computer science challenges that, when addressed, will yield extraordinary advances for DoD applications. - Develop high-performance parallel computing and interactive computer graphics. - Develop natural language processing techniques to enable substantial improvements in machine translation and paraphrasing, detection of deviations from normalcy and behavioral changes, and the management, sorting and accessing of textual data. - Develop reliable low-power embedded systems for continuous information gathering, access and communication; thermal and power consumption modeling for integrated circuit design. *FY 2011 Base Plans:* - Continue to identify and explore new computer science challenges that, when addressed, will yield extraordinary advances for DoD applications.					

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
- Exploit synergies in hardware/software co-design to enable transformational advances in reliability and security in the challenging low-power, low-memory, real-time operational environment of embedded computing systems. - Develop novel and highly-economical surface reconstruction and computer graphic rendering algorithms to enable visualization of and interaction with complex battlefield and other simulations in real time. - Develop novel machine learning algorithms that provide not only better predictive power, but also better explanatory power via exploitation of Bayesian statistics (the concept of probability) to leverage prior information and advanced techniques for fusion of heterogeneous information from multiple sources.					
Programmable Matter (U) The Programmable Matter program will develop a new functional form of matter, constructed from mesoscale particles that assemble into complex 3-Dimensional (3-D) objects upon external command. These objects will exhibit all of the functionality of their conventional counterparts and ultimately have the ability to reverse back to the original components. *FY 2009 Accomplishments:* - Built a mathematical model that theoretically confirms a viable procedure for constructing macroscopic 3-D solid objects with functional properties that have real world use. - Demonstrated externally-directed assembly of distinct macroscopic 3-D solids. *FY 2010 Plans:* - Optimize Programmable Matter properties. - Demonstrate interlocking/adhesion of mesoscale particles to create bulk matter. - Demonstrate reversibility.	4.000	3.094	0.000	0.000	0.000
Young Faculty Award	8.500	14.000	14.500	0.000	14.500

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
(U) The goal of the Young Faculty Award program is to encourage new faculty members of academic research institutions with innovative ideas and concepts to participate in sponsored research programs that can provide revolutionary capabilities to future defense systems. The program will also help innovative researchers better understand the needs of the DoD and interest them in working on problems with a defense relevance. The initial phase of this program focuses on speculative technologies for greatly enhancing microsystems technologies and in the development of ideas and concepts that can lead to focused defense research programs and associated development activities to deliver a compete technology. Current activities include revolutionary advances in physics, materials, and devices to enable breakthroughs in electronics, photonics, micro and nano electro mechanical systems (MEMS/NEMS), architectures, and algorithms. *FY 2009 Accomplishments:* - Initiated activities for research of new concepts for enhancing microsystem technologies. - Developed methodology for improving interactions between sponsored researchers and defense technologists. *FY 2010 Plans:* - Continue and initiate new activities for research of enhancements and new concepts for microsystem technologies. - Optimize approaches for obtaining maximum benefit from sponsored efforts. *FY 2011 Base Plans:* - Continue and initiate new activities for research of enhancements and new concepts for microsystem technologies. - Establish transition approaches for appropriate technologies and research activities to enhance development activities.					
Computer Science Futures/Science, Technology, Engineering, and Mathematics Research Outreach*	2.000	2.000	6.665	0.000	6.665

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
*Formerly High School Science Study Group/CS Futures. (U) The DARPA Grand and Urban Challenges inspired a number of high school-age students and exposed them to the rewards of a research career. The future of DoD research depends on the continuing engagement of these students in science- and technology-related fields. An offshoot of the Computer Science Study Group program, the Computer Science Futures program will fund efforts to identify the computer science interests of high school students, and involve them in high-level research at the high school level. In addition, the Computer Science, Science, Technology, Engineering, and Mathematics Research 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 2009 Accomplishments:* - Continued to engage high school study groups to work on selected ideas. - Continued evaluation of new potential ideas, including human computer interactions, computational models of environmental adaptation, and automated evaluation of physical function for applications in rehabilitation medicine. *FY 2010 Plans:* - Continue to engage high school study groups to work on selected ideas. - Continue evaluation of new potential ideas, including human computer interactions, computational models of environmental adaptation, and automated evaluation of physical function for applications in rehabilitation medicine. - Initiate 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.					

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
FY 2011 Base Plans: - Continue ongoing outreach and involvement of high school students in Computer Science research to increase excitement about solving important problems using technology. - Complete transition to industry and/or other partners thus establishing a self-sustaining program to encourage students to enter the Computer Science field. - 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.					
Focus Areas in Theoretical Mathematics (FAThM) (U) 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 2009 Accomplishments:* - Established and exploited new relations between number theory and symmetry groups of fundamental particles. - Tied advances in pure mathematics to defense applications in cryptography, quantum sciences, materials, and nano-level structures. *FY 2010 Plans:* - Establish and exploit new relations between topology and symmetry groups of fundamental particles. - Establish and exploit new relations between the analytic foundations of symmetry and algebraic computation.	1.350	1.400	2.400	0.000	2.400

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
FY 2011 Base 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.					
Fundamental Laws and Limits of Cyber Security (U) Based on advances from the Foundational Computer Science program, the Fundamental Laws and Limits of Cyber Security program seeks to establish a framework of fundamental laws and limits governing cyber security, which enables pro-active approaches to the complex task of making cyber systems secure. Research in this area focuses on creating a fundamental theory of security-oriented system complexity and a methodology for applying the theory to practical challenges of system security for systems ranging from simple programs on a single computer to large-scale distributed applications. Currently there is little understood on how to measure the efficiency of the huge variety of ad-hoc methods for improving system security and on how to know which of these methods should be used in each particular case. Therefore, the design, development, and integration of secure cyber systems are a continuous, evolving process. U.S. military computing systems are continuously vulnerable to malicious cyber attacks. This program's framework provides military planners the guidance on pro-active decision-making in system design, implementation, and deployment. The key steps in this effort include: 1) development of complexity-based metrics that would directly measure how hard it would be for system developers/integrators to create a system that would be free of security holes; 2) development of a security-oriented complexity hierarchy; 3) development of the requisite theory that would help explain how the system design and implementation affects the metrics; and 4) creation of a methodology for applying the theory to practical systems.	0.000	0.000	4.000	0.000	4.000

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
FY 2011 Base Plans: - Create new complexity-based metrics that would directly measure how hard it would be for system developers/integrators to create a system that would be free of security holes. - Define a security-oriented complexity hierarchy. - Initiate development of the requisite theory that would help explain how the system design and implementation affects the metrics.					
23 Mathematical Challenges	1.400	1.500	2.000	0.000	2.000
(U) 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. *FY 2009 Accomplishments:* - Developed advances in stratified Morse Theory and metric, algebraic, and hyperbolic geometries to investigate complex fluid flow. - Built and exploited deep mathematic dualities between Complex Algebraic Geometry, Algebraic and Geometrical Topology, Fourier Analysis, Geometrical Combinatorics, Theory of Oscillatory Sums, and Analytic Number Theory. *FY 2010 Plans:* - Develop integrated approaches merging analysis and algebra to create new polynomial optimization algorithms. - Build and exploit deep mathematic techniques in combinatorics (the study of discrete objects) and geometry to develop new capabilities in rigidity theory for diverse applications including protein folding. - Develop theoretical guidelines for filtering multi-scale turbulent signals, incorporating new theories of data assimilation, including sparse observations.					

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
- Develop a theoretical analysis of idealized data assimilation problems in an identified complex system. *FY 2011 Base Plans:* - Develop the high-dimensional mathematics needed to accurately model and predict behavior in large-scale distributed networks that evolve over time occurring in communication, biology, and the social sciences. - Develop new mathematics for constructing optimal globally symmetric structures via the process of nanoscale self-assembly. - Develop practical computational strategies for cheaper systematic treatment of model error in complex systems in high dimensions.					
Accomplishments/Planned Programs Subtotals	30.845	44.958	73.211	0.000	73.211

	FY 2009	FY 2010
Congressional Add: Institute for Information Security *FY 2009 Accomplishments:* - Completed information security initiatives.	2.500	0.000
Congressional Add: Science, Technology, Engineering and Mathematics Initiative *FY 2010 Plans:* - Initiate research in the areas of science, technology, and engineering.	0.000	1.600
Congressional Adds Subtotals	2.500	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 2009 Actual	FY 2010 Estimate	FY 2011 Base Estimate	FY 2011 OCO Estimate	FY 2011 Total Estimate	FY 2012 Estimate	FY 2013 Estimate	FY 2014 Estimate	FY 2015 Estimate	Cost To Complete	Total Cost
ES-01: *ELECTRONIC SCIENCES*	62.174	57.057	70.193	0.000	70.193	66.503	68.252	62.752	62.752	Continuing	Continuing

A. Mission Description and Budget Item Justification

(U) 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 Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
Semiconductor Technology Focus Centers	20.450	20.400	20.000	0.000	20.000
(U) The Semiconductor Technology Focus Centers research program is a collaborative effort between the Defense Advanced Research Projects Agency (DARPA), the Office of the Deputy Undersecretary of Defense for Science & Technology (DUSD/S&T), and the Microelectronics Advanced Research Corporation (MARCO) which will establish new Focus Centers in “Materials, Structures & Devices” and in “Circuits, Systems & Software” at U.S. Institutions of Higher Education. The Focus Centers will concentrate research attention and resources on a discovery research process to provide radical innovation in semiconductor technology that will provide solutions to barrier problems in the path of sustaining the historical productivity growth and performance enhancement of semiconductor integrated					

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
circuits. The overall goal of this collaborative effort between the Department of Defense and industry is to sustain the unprecedented four decades of uninterrupted performance improvement in information processing power. *FY 2009 Accomplishments:* - Developed novel device fabrication and integration approaches for deeply scaled transistors and architectures for high performance mixed signal circuits for military needs. - Developed concepts and validation methods in one or combinations of the following areas: electronics, photonics, micro-electro-mechanical systems (MEMS), architectures and algorithms. *FY 2010 Plans:* - Continue to develop innovative approaches to the design and fabrication of scaled devices, circuits, and microsystems within multi-investigator based research consortia. *FY 2011 Base Plans:* - Continue to leverage industry funding for efforts and maintain formal and informal coupling and industrial research for development and transition of technologies. - Transition innovative concepts developed with the university program to provide novel capabilities for DoD microelectronics systems.					
Quantum Entanglement Science and Technology (QuEST) (U) The Quantum Entanglement Science and Technology (QuEST) program will explore 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	14.804	10.669	15.946	0.000	15.946

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
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 2009 Accomplishments:* - Developed novel approaches to improving decoherence times. - Devised full characterization and manipulation of entangled quantum systems. - Formulated novel quantum algorithms. *FY 2010 Plans:* - Continue fundamental research in the area of Quantum Information and work towards program goals. - Develop novel approach to improving decoherence times. - Demonstrate novel quantum algorithms. *FY 2011 Base Plans:* - Continue fundamental research in the area of Quantum Information and work towards program goals. - Demonstrate full characterization and manipulation of entangled quantum systems.					
N/MEMS Science and Focus Centers (U) The goal of the N/MEMS Science and Focus Centers program is to support the development of an enhanced fundamental understanding of a number of important technical issues critical to the continuing advance of nanoelectromechanical systems (NEMS) and microelectromechanical systems (MEMS) technologies and their transition into military systems. The basic research work to be conducted under the program is responsive to recognized challenges in a comprehensive range of technical areas pertinent to future Department of Defense (DoD) needs. Industrial cost sharing is an important element of the overall effort.	9.423	7.028	4.903	0.000	4.903

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
FY 2009 Accomplishments: - Developed MEMS enabled reconfigurable electronics. - Developed ultra-high Q (energy ratio) nanoresonators. *FY 2010 Plans:* - Continue to improve the efforts for each of the eleven centers. - Incorporate new N/MEMS fabrication methods (i.e., self-assembly). - Commence integration of MEMS power supplies. *FY 2011 Base Plans:* - Finalize substantial scientific and technical interactions among the university and industrial partners. - Achieve a dynamic process for focusing center research evolution. - Develop a methodology for adding, deleting, and/or modifying research directions within the center.					
Nanoscaled Architecture for Coherent Hyper-Optic Sources (NACHOS) (U) 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 2009 Accomplishments:* - Demonstrated novel heterostructures capable of gain. - Established minimum Q factor for laser threshold.	3.555	3.117	1.725	0.000	1.725

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
FY 2010 Plans: - Demonstrate sub-wavelength lasers. - Determine threshold gain under injection. *FY 2011 Base Plans:* - Demonstrate room temperature sub wavelength laser operating at 1.55 microns in continuous mode.					
Tip-Based Nanofabrication (TBN) (U) 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 such as optical and biological sensors, diode lasers, light emitting diodes, infrared sensors, high-density interconnects, and quantum computing. *FY 2009 Accomplishments:* - Demonstrated nanofabrication process using a single-tip structure and associated tooling. *FY 2010 Plans:* - Fabricate a multi-tip array (5 tips) for parallel manufacturing. - Demonstrate a repeatable tip-based process and manufacturing capability. *FY 2011 Base Plans:* - Fabricate a 30-tip array and 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 structures.	10.662	10.424	10.100	0.000	10.100
Optical Radiation Cooling and Heating in Integrated Devices (ORCHID)*	0.000	2.000	2.000	0.000	2.000

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
*Formerly Quantum OptoMechanics Integrated on a Chip. (U) 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 Plans:* - Demonstrate resonant frequency of 10 megahertz (MHz). - Demonstrate Mechanical Q of 1x10^6. *FY 2011 Base Plans:* - Demonstrate cavity finesse of 1x10^5. - Demonstrate mirror effective mass of 1 nanogram. - Demonstrate resonant frequency of 100 MHz.					

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
- Demonstrate Mechanical Q of 1x10^7.					
Centers for Integrated Photonics Engineering Research (CIPhER)	0.000	2.139	8.000	0.000	8.000
(U) 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 Department of Defense. 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 Plans: - Initiate 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 Base Plans: - Exploit scaling and enhanced fabrication techniques to refine and continue development of novel Integrated Photonics concepts for the range of application domains.					

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
- Begin to transfer (through direct industrial collaborative interactions) those elements that are ready for further development toward applications.					
Molecular Photonics (MORPH) (U) The Molecular Photonics (MORPH) program explored large dendritic and other highly branched organic molecules that offered great potential for active photonic applications. Three-dimensional molecular structures and shapes can be engineered to orient and immobilize optically active substituents to achieve much higher electro-optic activity than with traditional polymer systems. The ability to engineer molecular structure, shape, energy transport, and chemical composition offers the potential for distinct electronic energy level engineering without the traditional semiconductor crystal lattice. Potential applications include: direct conversion of sunlight to power ("optical antenna"), inversion-less lasers and electromagnetically induced transparency (coherent organic emitters, and slow light materials), high performance photorefractive materials for signal processing and holographic memory, optical limiters and saturable absorbers as well as high performance modulators. *FY 2009 Accomplishments:* - Demonstrated a very high speed (100 gigahertz) polymetric electro-optic (EO) modulator. - Demonstrated organic materials for building ultra-high speed EO modulators. - Developed tailored organic materials as high-efficiency optical limiters in regions of the spectrum relevant to military sensor protection.	2.000	0.000	0.000	0.000	0.000
Breakthrough Biological and Medical Technologies (U) This program seeks to yield revolutionary advances across several key areas of biology and biomedical technologies of critical importance to the DoD. The overarching principle is to apply microsystem technology (electronics, microfluidics, photonics, micromechanics, etc.) to create leapfrog advances ranging from manipulation of single cells through soldier-worn protective and diagnostic instruments. Microsystem technologies have reached a state of maturity that they can be deployed as enablers to solving complex problems, the biological applications being particularly high-leverage.	0.000	0.000	7.519	0.000	7.519

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
On the cell-level of the scale, the aim is to be able to increase by several decades the speed with which we sequence, analyze and functionally edit cellular genomes. With microsystem approaches, a prime goal is to be able to address large populations of cells, select as few as one, capture it, make specific edits to its DNA, and examine or replicate the cell as needed. Such capability will be applicable to a wide variety of problems including biological weapons countermeasures and understanding the underpinnings of human cancers. At an intermediate scale, new insights into the interactions of photons with the nervous system tissues of mammals will allow the development of mm-scale microphotonic implants that have the potential to restore sensory and motor function to individuals with traumatic spinal injury, for example. On the other end of the size scale, a primary goal is to apply microsystem techniques to soldier-protective biomedical systems. One example is an in-canal hearing protection device that will provide enhanced hearing capabilities in some settings, but be able to instantly muffle loud sounds of weapons fire. This one example will improve inter-personnel communications and at the same time drastically reduce the incidence of hearing loss in combat situations. For these examples and many more, the goal is to bring exceptionally potent technical approaches to bear on biological and biomedical applications where their capabilities will be significant force multipliers for the DoD. *FY 2011 Base Plans:* - Demonstrate isolation and manipulation of primitive pluripotent stem cells. - Investigate problem statements that can be addressed using quantum information science and technology. - Develop roadmap to algorithm to compute protein folding using quantum computing, as example of speed-up enabled by quantum simulations. - Demonstrate microsystems elements such as inductors and microactuators using high permeability as proof of feasibility to integrate magnetic micro/nanomaterials in wafer-scale processes. - Investigate physical mechanism of cross grain boundary transport in nanocrystalline materials. - Simulate RF performance limits of nanocrystalline channel transistors including current density limits.					

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
Accomplishments/Planned Programs Subtotals	60.894	55.777	70.193	0.000	70.193

	FY 2009	FY 2010
Congressional Add: Advanced Photonic Composites Research *FY 2009 Accomplishments:* - Continued photonic composite development.	1.280	0.000
Congressional Add: Laboratory for Advanced Photonic Composites Research *FY 2010 Plans:* - Initiate laboratory research in photonic composites.	0.000	1.280
Congressional Adds Subtotals	1.280	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 2009 Actual	FY 2010 Estimate	FY 2011 Base Estimate	FY 2011 OCO Estimate	FY 2011 Total Estimate	FY 2012 Estimate	FY 2013 Estimate	FY 2014 Estimate	FY 2015 Estimate	Cost To Complete	Total Cost
MS-01: *MATERIALS SCIENCES*	52.150	62.759	78.456	0.000	78.456	90.430	82.750	85.127	90.263	Continuing	Continuing

A. Mission Description and Budget Item Justification

(U) 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 Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
Nanoscale/Bio-inspired and MetaMaterials	11.894	9.926	10.000	0.000	10.000

(U) 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 2009 Accomplishments:

- Demonstrated automated in-line adaptive optic to correct spatial distortions in high-power, ultra-fast laser wavefront.
- Simultaneously demonstrated infrared optical transmission comparable to spinel, and mechanical properties comparable to sapphire, in 75mm discs.
- Developed new materials with both optical properties and strength into 75mm flat discs.
- Characterized the material properties of 75mm discs through testing in relevant environments.
- Demonstrated the ability to provide surface strengthening through compressive materials.
- Investigated approaches to design and fabrication of biophotonic structures in the areas of chemical and physical activation for sensor and reflector-based operation.
- Developed a polymer-based, structurally biomimetic, electrically switchable photonic shutter.

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
FY 2010 Plans: - Develop new material compositions with optical transmission comparable to spinel and doubled mechanical strength, and thermal shock capabilities over single crystal sapphire. - Initiate fabrication of new materials into hemispherical domes with decreased optical scatter, doubled mechanical strength, and doubled thermal shock capabilities over single crystal sapphire. - Characterize the material properties of hemispherical domes through testing in relevant military environments. - Demonstrate understanding of biophotonic structure/function relationship and design requirements for index/structure actuation. - Demonstrate initial design and fabrication of biophotonic structures. - Initiate 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 Base Plans:* - Demonstrate control of fabrication of biophotonic structures. - Demonstrate physical and/or chemical activation of biophotonic structures. - Demonstrate dynamic control of activation. - Identify expected physical (and/or chemical) sensitivity in terms of reflectance change noted (percent change in reflectance/Volt, percent change in reflectance / molecule adsorbed). - 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 these 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 properties.					
Fundamentals of Nanoscale and Emergent Effects and Engineered Devices*	10.676	13.403	21.618	0.000	21.618

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
*Formerly known as Engineered Bio-Molecular Nano-Devices and Systems (U) 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, 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 2009 Accomplishments:* - Used ground-based assets to measure and provide initial characterizations of optical, RF, magnetic, X-ray and gamma ray events associated with rocket triggered lightning. - Obtained first-ever high-speed photographic image of stepped leader attachment process. - Developed unprecedented theoretical model of mysterious phenomena known as compact intracloud discharges. - Demonstrated a multiferroic magnetic sensor (with a field sensitivity of 20 pico-tesla root mean square (rms) per root hertz) that exceeds the sensitivity of any commercially available room temperature sensor. *FY 2010 Plans:* - Demonstrate, 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					

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
femtotesla rms per square root hertz (the earth's magnetic field strength varies with location between 30 to 60 microtesla, by comparison). - Demonstrate a 10 x 10 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. - Demonstrate a 10 x 10 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. - Develop and validate a 3-D model of critical conditions and processes in clouds and the atmosphere necessary for triggering lightning. - Identify minimum and maximum thresholds associated with lightning phenomena based on geographic location. - Develop a theory of intelligence as a fundamental physical phenomenon that explains the spontaneous creation of structure in the natural world, unifying ideas in thermodynamics, evolution, information, computation and other fields. - Investigate candidate electronic and chemical systems that are capable of self-organizing when placed in a complex environment; use computer simulation to select/refine/improve the candidate systems for further development. - Develop 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. *FY 2011 Base Plans:* - Build and equip facilities capable of launching rockets every thirty seconds in order to trigger lightning and measure associated phenomena. - Correlate terrestrial lightning events with ionospheric phenomena. - Develop a lightning safety model based on new multidimensional data collected during FY 2009-2010. - 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.					

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
- Evaluate the initial theories ability to describe the candidate electronic and chemical systems under development. - Using a combination of simulation and real system hardware, make a limited demonstration of a physical intelligent electronic or chemical system imbedded in an environment of limited complexity. - 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. - Demonstrate novel chemistries and processing techniques that allow for multi-scale (atomic to macro) control in order to synthesize complex material networks which emulate biological systems by self-modulating their properties (structural, visual, acoustic, etc.) in response to external stimulation.					
Atomic Scale Materials and Devices	13.980	14.150	21.888	0.000	21.888
(U) 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-Jules (aJ)/operation). *FY 2009 Accomplishments:* - Constructed rotationally sensitive chip-based atom interferometer with sensitivity greater than one radian per earth rotation rate.					

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
- Emulated two-dimensional (2-D) Bose-Hubbard Model phase diagram in less than twelve hours that confirmed theoretical calculations. - Installed flat-top beam profile system in experimental chamber; verified production of homogeneous optical lattice potential. - Developed theoretical techniques to extract relevant model-independent thermodynamic quantities from ensemble absorption images. - Demonstrated approximately 100 nm positioning accuracy of quantum dots. - Demonstrated important scalability criterion of microfluidic approach to controlled placement of quantum dots: sequentially built up 3x3 and 5x5 matrices of quantum dots by controlled placement and subsequent immobilization. - Demonstrated non-local modulation of bi-photon wavefunction and demonstrated single photon non-linear switch. *FY 2010 Plans:* - Develop cooling and precision thermometry techniques for fermionic atoms in optical lattice. - Develop quantum gas microscope with sufficient resolution to image individual atomic sites in 2-D optical lattice; verify by imaging atomic gas trapped in lattice. - Emulate XXZ quantum spin model using ion crystal array in less than twelve hours that confirms theoretical calculations. - Develop the materials fabrication techniques for switchable/storable, interfacial metal-insulator transitions to enable extremely low-power transistors for memory and logic. - Develop initial circuit architectures (e.g., logic gates with memory) employing these new transistors for use in new computer architectures. - Demonstrate initial Zeno-based switch using slot waveguides coated or filled with organic nonlinear absorptive materials. - Create a photonic crystal zeno mirror and waveguide with cavity Q > 1000, and loss < 0.1 dB. - Generate and focus X-rays with specific states of orbital angular momentum.					

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
- Initiate a series of 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. *FY 2011 Base Plans:* - Demonstrate functional transistors using interfacial metal-insulator transitions and understand their potential for large-scale integrated circuits. - Demonstrate the validity of the initial oxide transistor circuit architectures using computer simulations and/or semiconductor surrogates to approximate the function of these transistors. - Develop a simulator to test the new computer architecture and create tools for configuring and programming machines using the new architecture. - Demonstrate production of antiferromagnetically ordered states in 2-D and 3-D optical lattices. - Study and characterize supersolid behavior in spinor bose condensates. - Produce phase diagram of frustrated 2-D antiferromagnet in less than twelve hours. - Produce phase diagram 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. - Develop prediction of behavior and theoretical models that explore the consequences of controlled power injection, including triggering and amplification phenomena, based on optimal conditions quantitatively determined via measurements gathered in FY 2010.					

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
- Characterize ionospheric current drive (ICD), artificially stimulated emissions in the ionosphere, and ionospheric turbulence and associated scintillations.					
Basic Photon Science (U) This thrust examines 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. *FY 2011 Base Plans:* - Investigate the theoretical and practical limits to the information content of a single photon via rigorous application of information theory. - Demonstrate utility of information theoretic approach via improved low-light level imaging and/or high data rate communications. - Develop the basic science required for the exploitation of optical orbital angular momentum in both the classical and quantum realms. - Demonstrate the benefit of orbital angular momentum for communications applications via multi-level signaling and/or turbulence mitigation.	0.000	0.000	8.000	0.000	8.000
Enabling Quantum Technologies* *Previously part of Atomic Scale Materials and Devices (U) This thrust emphasizes a quantum focus on technology capabilities with the potential to revolutionize the approach to various military capabilities. It includes 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	2.000	4.000	10.150	0.000	10.150

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
novel capabilities in the quantum regime, such as GPS-independent navigation via atom interferometry as well as the potential to generate significant heat from deuterated palladium. *FY 2009 Accomplishments:* - Established parameters necessary to achieve high levels of deuterium loading with a minimum of electrochemical power. - Initiated development of the capability to reproducibly generate significant increases in excess heat using electrochemical and gas pressure loaded, highly deuterated palladium. *FY 2010 Plans:* - Quantify the effects of impurities and microstructure in palladium substrate material on the capability to generate excess heat. - Quantify the required dynamic loading and relaxation conditions and optimize the palladium substrate composition and microstructure required to achieve high levels of deuterium loading and tolerate the high stresses associated with these conditions. - Investigate use of ultra-cold atoms to probe nuclear spins in complex or heterogeneous materials. - Develop novel approaches to packaging of superconducting photodetectors enabling plug-and-play coupled quantum efficiencies greater than 50 percent. - Develop cryogenic readout electronics suitable for packaging in superconducting photodetector arrays. *FY 2011 Base Plans:* - Quantify material parameters that control degree of increase in excess heat generation and life expectancy of power cells. - Design physics package for optical clock including lasers, optomechanics, associated electronics, and environmental isolation and control subsystems. - Devise optical fiber-based time and frequency transport protocols and utilize these to design interface to optical clock.					

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
- Initiate development of unpackaged devices capable of resolving the number of incoming photons at wavelengths compatible with optical fiber. - Initiate development of unpackaged devices capable of generating single photons with high probability at wavelengths compatible with single mode optical fiber (1310 and 1550 nm).					
Surface Enhanced Raman Scattering (SERS) - Science and Technology Fundamentals (U) 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 2009 Accomplishments:* - Developed methods to engineer nanoparticles with one nanometer feature sizes (separation) on a macroscale. *FY 2010 Plans:* - Begin assembly or fabrication of one inch SERS active substrates capable of 10^9 enhancements.	8.000	5.000	0.000	0.000	0.000
Dynamics-Enabled Frequency Sources (DEFYS) (U) The Dynamics-Enabled Frequency Sources (DEFYS) program will build on 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 the frequency they produce will cascade into performance limitations of the larger system. This	0.000	3.300	6.800	0.000	6.800

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
uncertainty often takes the form of phase noise intrinsic to the oscillator or from deleterious external sources and limits performance of a wide range of both military and civilian systems including: radars, communications, sensors, and geo-positioning devices. DEFYS will develop nanoscale mechanical frequency sources that use novel mechanisms in the dynamics to provide a new level of performance in environments of high accelerations or vibrations and temperature variations. Sources developed in this program will provide an unprecedented performance density and will be flexible enough to be integrated into a wide range of applications. *FY 2010 Plans:* - Use nonlinearity-induced mechanisms to reduce phase noise. - Demonstrate acceleration/vibration robustness. - Maintain performance over a large temperature range. *FY 2011 Base Plans:* - Incorporate noise shaping to further reduce phase noise. - Improve acceleration and vibration tolerance. - Improve temperature stability. - Reduce device size.					
Accomplishments/Planned Programs Subtotals	46.550	49.779	78.456	0.000	78.456

	FY 2009	FY 2010
Congressional Add: Comparative Genomics for National Security Goals/Infectious Disease Research *FY 2009 Accomplishments:* - Promoted community interaction and created user groups to test software program and improve system.	2.000	1.200

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010
- Identified parameters needed for research areas of transition partners. *FY 2010 Plans:* - Continue to promote community interaction and creation of user groups to test software program and improve system. - Continue to identify parameters needed for research areas of transition partners.		
Congressional Add: Institute for Collaborative Sciences Research *FY 2009 Accomplishments:* - Investigated a collaborative sciences research effort. *FY 2010 Plans:* - Continue investigation of collaborative sciences research.	1.200	2.080
Congressional Add: Advanced Materials Research Institute *FY 2009 Accomplishments:* - Investigated nanoscale engineering of multiferroic materials, and completed design of voltage controlled ferromagnetic material for micro- and nano-scale devices. *FY 2010 Plans:* - Continue investigation of nanoscale engineering of multiferroic materials, and test design of voltage controlled ferromagnetic material for micro- and nano-scale devices.	2.400	0.800
Congressional Add: Hydrogen Fuel Cell Research *FY 2010 Plans:* - Initiate innovative research advances into hydrogen fuel cell technology.	0.000	4.000

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010
Congressional Add: Solid Oxide Fuel Technology *FY 2010 Plans:* - Investigate innovative advances into solid oxide fuel technology.	0.000	1.000
Congressional Add: Security Protection using Ballistic CORE Technology *FY 2010 Plans:* - Investigate the use of ballistic CORE technology for security protection.	0.000	3.900
Congressional Adds Subtotals	5.600	12.980

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 2009 Actual	FY 2010 Estimate	FY 2011 Base Estimate	FY 2011 OCO Estimate	FY 2011 Total Estimate	FY 2012 Estimate	FY 2013 Estimate	FY 2014 Estimate	FY 2015 Estimate	Cost To Complete	Total Cost
TRS-01: *TRANSFORMATIVE SCIENCES*	0.000	0.000	52.500	0.000	52.500	10.000	10.000	10.000	10.000	Continuing	Continuing

A. Mission Description and Budget Item Justification

(U) 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 as a means of improving military adaptation to sudden changes in requirements, threats, and emerging converging trends. The project has three key research interest areas: 1) Large-scale custom biological and non-biological manufacturing; 2) Harnessing the power of large-scale, human-centered networks to improve situational awareness; and 3) Adaptable and agile computer networks. Promising research will advance to both technology development and system-level projects.

B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
Transformative Sciences	0.000	0.000	10.000	0.000	10.000
(U) The Transformative Sciences project supports research into converging technological forces and transformational trends in the areas of computing and the computing-reliant subareas of social sciences, life sciences, manufacturing, and commerce. This research has the potential to position the DoD to anticipate the effects of potential discontinuities and gain the ability to adapt quickly and effectively whenever challenging disruptions occur. The research will identify and exploit emerging trends that have the potential to disrupt military operations. Examples of key emerging trends to be investigated include the potential military impact of large-scale custom manufacturing, including the emerging ability to seamlessly convert bits into manufactured objects; “crowd-sourcing”—large-scale, human-centered networks consisting of potentially thousands or millions of people working in collaboration with large-scale computing power, cloud computing, mobile communication devices, and large-scale statistical data analysis toward the solution of a unified goal; and “cyber-agility”—research into a “clean slate” approach to secure, adaptive and agile computer networks.					

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
FY 2011 Base Plans: - Develop revolutionary 3D printing capabilities to facilitate custom manufacturing on a large scale. - Develop engineered biological systems to create self-replicating materials for radical manufacturing methods. - 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, key experiences, and leverage points. - Conduct research into statistical and quasi-experimental analyses of existing data sets to derive answers to key tactical military questions. - Develop adaptable and agile wide-area networks. - Develop means of harnessing large numbers of researchers through "grand Artificial Intelligence (AI) challenges" to assess progress of intelligent systems technologies. - Develop applicable means of harnessing large numbers of networked people to collaboratively solve key problems in Intelligence, Surveillance and Reconnaissance (ISR), image processing, and other applications.					
Deep ISR Processing by Crowds (U) The Deep ISR Processing by Crowds Program goes beyond the concept of putting the human in the loop, and instead looks to harnessing the unique cognitive and creative abilities of large numbers of people to enhance dramatically the knowledge derived from ISR systems. This approach is unconventional in that it involves the massed exploitation of ISR products in concert with other sources of data 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.	0.000	0.000	13.000	0.000	13.000

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
FY 2011 Base Plans: - Establishment of exploitation framework including quantitative confidence assessment. - Perform large-scale experimentation and demonstration on sample data sets to quantify performance enhancement.					
Production of Knowledge Bases to Bridge Cultural Divides (U) 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 application in tactical contexts to aid analysts and operators in connecting the dots amid complex, conflicting, and incomplete data sets. In particular, this program will focus on tool sets to enable actionable exploitation in a timely manner. *FY 2011 Base Plans:* - Development of mathematical and algorithmic modeling and analysis tools. - Establishment of baseline performance and demonstration of enhanced principal component analysis using the tools. - Demonstration of automated and semi-automated processes for exploitation of data collected via experimental analyst assistant.	0.000	0.000	9.500	0.000	9.500
Synthetic Biology (U) 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 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 truly hierarchical biological systems with unbounded complexity. Research thrusts include automated process discovery, tool-	0.000	0.000	20.000	0.000	20.000

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B. Accomplishments/Planned Program ($ in Millions)

	FY 2009	FY 2010	FY 2011 Base	FY 2011 OCO	FY 2011 Total
chain development, novel approaches to process measurement and validation, and development of application demonstrations. *FY 2011 Base Plans:* - Design biological host organism and complete laboratory demonstration. - Design tool chain frame work and develop workable building blocks for functional outcomes.					
Accomplishments/Planned Programs Subtotals	0.000	0.000	52.500	0.000	52.500

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.