RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)	DATE February 2007

APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research	R-1 ITEM NOMENCLATURE Cognitive Computing Systems PE 0602304E

COST (In Millions)	FY 2006	FY 2007	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013
Total Program Element (PE) Cost	159.244	180.003	179.728	202.439	220.494	219.243	224.243	236.038
Cognitive Systems Computing Foundations COG-01	12.878	22.053	4.474	0.000	0.000	0.000	0.000	0.000
Cognitive Computing COG-02	88.160	87.763	100.035	122.634	130.992	131.741	131.741	138.536
Collective Cognitive Systems and Interfaces COG-03	58.206	70.187	75.219	79.805	89.502	87.502	92.502	97.502

(U) Mission Description:

(U) The Cognitive Computing Systems program element is budgeted in the Applied Research budget activity because it is developing the next revolution in computing and information processing. The technology will allow computational systems to have reasoning and learning capabilities and levels of autonomy far beyond those of today's systems. With the ability to reason, learn and adapt, and with facilities for self-awareness, these systems will know what they are doing, enabling new levels of capability and powerful new applications.

(U) Military operations since the end of the Cold War illustrate that current theater-level command, control, communications, and intelligence/information systems lack the ability to fully support operations in complex, time-critical environments. Warfighters must be prepared for operations ranging from conflict and peacekeeping in urban centers to heavy battle actions in remote areas. Current capabilities do not provide the commander with real-time, secure, situational awareness or the ability to orchestrate high-tempo planning, rehearsal, and execution. The programs in this project are developing and testing innovative, secure architectures and tools to enhance information processing, dissemination, and presentation capabilities. The programs provide the commander insight into the disposition of enemy and friendly forces, a joint situational awareness picture that will improve planning, decision-making, and execution support capability, as well as secure multimedia information interfaces and software assurance to the warfighter "on the move." Integration of collection management, planning, and battlefield awareness are essential elements for achieving battlefield dominance through assured information systems.

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(U) The Cognitive Computing project will develop core technologies that enable computing systems to learn, reason and apply knowledge gained through experience, and respond intelligently to things that have not been previously encountered. These technologies will lead to systems demonstrating increased self-reliance, self-adaptive reconfiguration, intelligent negotiation, cooperative behavior and survivability with reduced human intervention.

(U) The Collective Cognitive Systems and Interfaces Project will dramatically improve warfighter and commander effectiveness and productivity using advanced cognitive approaches that enable faster, better informed, and more highly coordinated actions than those of our enemies. This will be accomplished by developing revolutionary methods that increase our information processing capabilities, enhance our situational awareness, and enable more cohesive group action by our forces. Critical technical areas addressed in this project include automated coordinated decision support, information sharing, and ensured communications.

(U) **Program Change Summary:** *(In Millions)*	FY 2006	FY 2007	FY 2008	FY 2009
Previous President's Budget	163.430	220.085	227.604	235.032
Current Budget	159.244	180.003	179.728	202.439
Total Adjustments	-4.186	-40.082	-47.876	-32.593
Congressional program reductions	0.000	-41.182		
Congressional increases	0.000	1.100		
Reprogrammings	0.000			
SBIR/STTR transfer	-4.186			

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(U) <u>Change Summary Explanation:</u>

FY 2006	The decrease reflects SBIR/STTR transfer.
FY 2007	The decrease reflects congressional program reductions and a reduction for Section 8106 Economic Assumptions offset by a congressional add for the Secure Open Systems Institute for Defense.
FY 2008/09	The decrease reflects program rephasings following congressional reductions, the transfer of maturing cognitive technologies to BA3 for transition opportunities into command and control systems, and the realignment and continuation of the self-regenerative systems work from Project COG-01 to PE 0602303E, Project IT-03 to more clearly categorize DARPA information assurance activities.

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APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research					R-1 ITEM NOMENCLATURE Cognitive Computing Systems PE 0602304E, Project COG-01			
COST (In Millions)	FY 2006	FY 2007	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013
Cognitive Systems Computing Foundations COG-01	12.878	22.053	4.474	0.000	0.000	0.000	0.000	0.000

(U) <u>Mission Description:</u>

(U) Cognitive systems are different from conventional computing systems in that they draw inferences from rich structured representations of knowledge, learn from experience, combine symbolic logical knowledge with uncertain and probabilistic information, allow reflective reasoning, and support the integration of perceptual (e.g., visual, auditory) data with symbolic information. The next generation of computer systems will rely upon reasoning, learning, and self-monitoring to handle increasingly complex tasks. These systems will be advisable, adaptable and able to cope with surprise. As a result, these novel forms of computation will revolutionize future military systems. The Cognitive Systems Foundations project will develop the necessary foundational hardware architectures and software methods to facilitate learning and inference capabilities that are crucial to intelligent computing. These new computing foundations will help us move far beyond today's standard Von Neumann computing model.

(U) Cognitive systems for military applications must be robust and resistant to both attacks and system failures. The military faces aggressive and agile threats that have sufficient technical resources to mount sophisticated attacks using easily accessible commercial information systems. The pervasive nature of both the threat and its means drives the need for systems to dynamically adapt, collect and assimilate large quantities of systems operation data, and remain robust even under aggressive attacks or failure conditions. Cognitive Systems Foundations will enable future computer systems to be more responsible for their own configuration, monitoring, protection and restoration to full functional and performance capabilities after an attack or failure.

(U) Overall, this project seeks to make fundamental scientific improvements in our understanding of, and ability to, create more intelligent information and computing systems. Transition goals include next-generation network-centric systems and platform-specific information collection and processing systems in space, air, sea and land.

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(U) <u>Program Accomplishments/Planned Programs:</u>

	FY 2006	FY 2007	FY 2008	FY 2009
Architectures for Cognitive Information Processing	6.428	10.790	0.000	0.000

(U) The Architectures for Cognitive Information Processing (ACIP) program is developing a new class of processing approaches, algorithms and architectures to efficiently enable and implement cognitive information processing, including the micro-architecture concepts, framework, and development environments. Current intelligent processing implementations depend on the use of existing numerically-based architectures and/or standard software architectures, and are therefore built on algorithms and processing foundations that are potentially ill-suited to cognitive tasks. Architectures that more directly mirror the symbolic reasoning, learning, and perception functions of a cognitive system are needed to enable major advances in this area. The ACIP program will establish core-processing capabilities that significantly advance the state of the art at all implementation processing levels – modules, systems, and underlying cognitive processing approaches, algorithms and architectures. In order to focus and establish context for the ACIP program, ACIP will pursue in-context DoD focused mission areas for the development of new data processing concepts. ACIP will develop implementations that span the areas of perception, reasoning and representation, learning, communication and interaction. The ACIP program will enable new classes of cognitive information processing applications that move the U.S. dramatically toward the overall goal of creating computer systems that know what they are doing.

(U) Program Plans:

- Developed initial cognitively-based processing techniques and architectural approaches in Phase I and demonstrated, with initial simulations, over two orders of magnitude improvement in performance.
- Evaluated initial common benchmarks, mini-applications, and metrics for the evaluation and comparative development of cognitive architectures.
- Develop multi-level programming models to support goal based and resource constrained cognitive application development.

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	FY 2006	FY 2007	FY 2008	FY 2009
Self-Regenerative Systems	6.450	10.163	4.474	0.000

(U) The Self-Regenerative Systems (SRS) program will design, develop, demonstrate and validate architectures, tools, and techniques for fielding systems capable of adapting to novel threats, unanticipated workloads and evolving system configurations. The technology developed under this program will employ innovative techniques like biologically-inspired diversity, cognitive immunity and healing, granular and scalable redundancy, and higher-level functions such as reasoning, reflection and learning. These technologies will make critical future information systems more robust, survivable and trustworthy. The SRS program will also develop technologies to mitigate the insider threat. The program will combine the SRS technology foundations in an exemplar military system that learns, regenerates itself, and automatically improves its ability to deliver critical services over time.

(U) SRS-enabled systems will be able to reconstitute their full functional and performance capabilities after experiencing an accidental component failure, software error, or even an intentional cyber-attack. SRS systems will show a positive trend in reliability, actually exceeding initial operating capability and approaching a theoretical optimal performance level over long time intervals. They will also maintain robustness and trustworthiness attributes even with growth and evolution in functionality and performance. The program will explore a self-regenerative operating system that will automatically recover after failure or attack on its configuration files, underlying devices or applications; and provide core survivability functionality, programming interfaces and system services that support rapid prototyping, construction, and deployment of survivable applications. In FY 2008, the follow-on phase of the Self-Regenerative Systems program will transition to PE 0602303E, Project IT-03, the host project for all of DARPA's information assurance and survivability programs.

(U) Program Plans:

- Developed technologies to diagnose and assess damage, repair and recover from damage caused by accidental faults, software aging or malicious activities.
- Developed general strategies to preempt insider attacks, enabling anomaly detection, combining and correlating information from system layers, and using direct user challenges.

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– Tailor an exemplar self-regenerative system representative of a military application, thereby demonstrating the protective value to the warfighter.

	FY 2006	FY 2007	FY 2008	FY 2009
Secure Open Systems Institute for Defense (SOSI)	0.000	1.100	0.000	0.000

(U) Program Plans:
– Initiate research on Secure Open Systems.

(U) <u>Other Program Funding Summary Cost:</u>

- Not Applicable.

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APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research				R-1 ITEM NOMENCLATURE Cognitive Computing Systems PE 0602304E, Project COG-02				
COST (In Millions)	FY 2006	FY 2007	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013
Cognitive Computing COG-02	88.160	87.763	100.035	122.634	130.992	131.741	131.741	138.536

(U) Mission Description:

(U) In the real-time environment of military operations, cognitive networks and systems that can learn, reason, draw on their experience, automatically adapt to maintain critical functionality, effectively assist their military user and improve their responses over time will be crucial to operational success. These capabilities will make the difference between mission success and mission degradation or failure, even in the event of cyber-attack or component attrition resulting from kinetic warfare or accidental faults and errors. Systems that learn and reason will reduce the requirement for skilled system administrators and dramatically reduce the overall cost of system maintenance. As the military moves towards a dynamic expeditionary force, it is critical for systems to become more self sufficient.

(U) The Cognitive Computing project will develop core technologies that enable computing systems to learn, reason and apply knowledge gained through experience, and to respond intelligently to new and unforeseen events. These technologies will lead to systems with increased self reliance, cooperative behavior, the capacity to reconfigure themselves, and survivability with reduced programmer intervention. In cognitive architectures, there are three primary types of processes: reactive, deliberative and reflective. Reactive processes respond quickly and directly to known stimuli; deliberative processes embody what is usually known as “thinking;” and reflective (higher-order) processes allow a system to “step back” and evaluate the environment and its own capabilities to decide the next appropriate course of action. Each of these processes will be improved through learning. Individual technical capabilities developed in this project include novel representations for knowledge, skill learning, algorithms for automated reasoning (deductive, abductive, planning, strategic inference, and hybrid approaches), pattern detection capabilities, and language learning. Overall, the project will extend fundamental computing capabilities to deal with real-world information complexity and uncertainty.

(U) The machine learning, reasoning, and human-machine dialogue techniques developed in this project, in particular, in the Integrated Cognitive Systems program, have great applicability to command and control systems and are budgeted to begin transition to battlefield systems in FY 2008. Candidate systems include the Army’s Command Post of the Future (CPOF), the Navy’s Composeable FORCENet and the Air Force’s Air Tasking Order Programs. Details are provided under PE 0603760E, Project CCC-01.

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(U) Program Accomplishments/Planned Programs:

	FY 2006	FY 2007	FY 2008	FY 2009
Integrated Cognitive Systems	49.454	32.982	36.231	40.576

(U) The Integrated Cognitive Systems technology thrust seeks to enable intelligence in information processing systems so that critical DoD systems can better support, not burden, the warfighter. Due to DoD/military reductions in manpower levels, and in spite of the integration of advanced information technologies and automation throughout defense systems, the workload on the war fighter steadily increases. Modern computing systems, though powerful, are woefully lacking in the capability to self-configure, adapt, and learn, i.e., they lack even rudimentary intelligence. This deficiency places a heavy burden on the warfighter to operate and maintain the very information technology on which modern warfare depends. The Integrated Cognitive Systems thrust will develop advanced technology to enable a new class of cognitive systems capable of assisting military commanders and decision makers. This thrust will build upon prior DARPA programs that developed improved human-computer interaction capabilities and highly-responsive computing systems. Integrated cognitive systems will be able to plan ahead and understand the world well enough to plausibly anticipate future events. Most importantly, these systems will have embedded learning capabilities that will allow them to retain prior learned knowledge, apply this knowledge to new scenarios and ultimately provide faster and more effective assistance. Overall, the ability to learn will enable the performance of a cognitive system to improve over time. The Integrated Cognitive Systems technologies will be developed in the Personalized Assistant that Learns (PAL) program. Cognitive Systems technologies developed in this program will be applied and demonstrated in the Increased Command and Control Effectiveness (ICE) program (PE 0603760E, Project CCC-01) prior to transition into Command Operations.

- The PAL program is creating a revolutionary technology for commanders and warfighters - the first comprehensive system that will dramatically empower commanders to understand at a glance all aspects of the current military situation, radically reduce manpower and labor required in command posts and in the field, and automate the massive number of administrative and analytical tasks characteristic of today's command centers. The PAL program is creating a new generation of machine learning technology that will enable information systems to automatically adjust to new environments and new users, helping commanders adapt to new enemy tactics, evolving situations and priorities, accelerating the incorporation of new personnel into command operations, and making more effective, focused use of resources. Applications developed in PAL will be adapted and hardened in order to be integrated into existing military systems.

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Ultimately, future capabilities to be inserted will enable: turning diverse, multi-source data into actionable information for commanders and warfighters; dramatic manpower reductions; corporate memory retention of both the larger conflict history and the history of each specific command center; and intelligent information presentation.

(U) Program Plans:

– Personalized Assistant that Learns
  - -- Developed, evaluated, and demonstrated the first instance of an intelligent cognitive assistant.
  - -- Developed, demonstrated, and refined core machine learning, knowledge base and flexible planning technologies to enable development of a cognitive planning agent.
  - -- Develop, demonstrate, and evaluate core physical awareness, cyber-awareness, multimodal dialogue, machine learning, and representation and reasoning technologies to support cognitive assistant executive functions.
  - -- Develop the ability for an integrated cognitive system to examine its own behavior and learn from that experience.
  - -- Develop a dialogue system with general and domain-specific semantics for eliciting natural language advice from the warfighter and other end users. This dialogue system will translate user guidance into the precise machine language necessary for both implementation and verification of purpose and intent.
  - -- Demonstrate PAL technology applied to warfighting problems, integrate with warfighting information systems, test during military exercises and validate that PAL technologies are robust to the dynamics and uncertainties associated with the battlefield.
  - -- Integrate PAL technology into military Command and Control (C2) systems such as the Command Post of the Future.

	FY 2006	FY 2007	FY 2008	FY 2009
Foundational Learning Technology	22.315	33.057	36.614	46.549

(U) The Foundational Learning Technology thrust seeks to develop advanced machine learning techniques that enable cognitive systems to continuously learn, adapt and respond to new situations by drawing inferences from past experience. The technologies developed in this thrust area have broad applicability to cognitive systems, and will result in military systems that are more robust, self-sufficient, and require minimal or no platform-specific customization. Current projects will develop hybrid learning techniques to create cognitive systems capable of learning military strategy, leveraging large amounts of prior knowledge, incorporating external guidance and applying prior knowledge in real-time to the naturally changing environment, all without programmer intervention. The Foundational Learning Technology thrust includes three programs: Real-World Learning, Integrated Learning, and Bio-Inspired Cognition.

- The Real-World Learning program will explore the integration and application of advanced machine learning techniques to further enable cognitive computing systems to learn from experience and adapt to changing situations. The program will emphasize Transfer Learning Techniques providing the ability to transfer knowledge and skills learned for specific situations to novel, unanticipated situations and perform appropriately and effectively the first time a novel situation is encountered. This is essential because most military operations occur in ever-changing environments, and U.S. forces and systems must be able to act appropriately and effectively the first time each novel situation is encountered. The program will drive the design and implementation of new hybrid learning technologies, such as large-scale transfer learning, multi-purpose extensible knowledge learning, learning with minimal direction, learning adaptable and efficient network structures, strategy learning, learning from text, learning intent of information, and learning generalized task models. The program will stress technologies that combine statistical learning techniques with knowledge techniques that take into account background knowledge and *a priori* experience. The resulting technologies will a) learn and represent vast amounts of knowledge in forms that can be applied to unknown situations and domains; b) generalize learned knowledge and apply it to dynamic and unpredictable situations; and c) reason about a situation or environment.

- The Integrated Learning program will create a new computer learning paradigm in which systems learn complex workflows from warfighters while the warfighters perform their regular duties. Current machine learning technologies cannot learn these complex workflows. The program is focused on military planning tasks such as air operations center (AOC) planning and military medical logistics. With this learning technology, it will be possible to create many different types of military decision support systems that learn by watching experts rather than relying on hand-encoded knowledge (which is expensive and error prone to produce). The new learning paradigm differs from conventional machine learning in that it does not rely on large amounts of carefully crafted training data. Rather, in the new paradigm the learner works to “figure things out” by combining many different types of learning, reasoning, and knowledge. For instance to learn AOC tasks, the computer learner combines what it observed the warfighters doing with the knowledge it has about aircraft, and reasons about airspace de-confliction to create a generalized model that can then be used to perform the entire AOC task, or provide intelligent instruction to other warfighters performing the same task.

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- The Bio-Inspired Cognition program has taken a fresh look at the design and implementation of bio-inspired cognitive architectures modeled after human cognition that combine principles from neuroscience and cognitive psychology with traditional artificial intelligence-based symbol processing and knowledge representation. The program draws on continuing advances in neurophysiology and cognitive psychology to guide and augment traditional artificial intelligence (AI) approaches to learning, reasoning, memory, knowledge acquisition and organization, and executive functions. The work has focused on new capabilities in memory, categorization, pattern recognition and fusion of perceptual/sensory information to emulate human performance by exploiting past experience in novel situations, learning in multiple ways, fusing multiple perceptual inputs in real-time, extracting concepts from specific experiences, forming hierarchies of associated memories and concepts, and directing attention through a complex executive process. Success is being measured by the ability of the systems developed to deal effectively with novel situations and respond appropriately in reasonable timeframes.

(U) Program Plans:

– Real-World Learning
  - -- Established several test beds of complex multi-agent environments for the generation of specific and novel situations that will be used to evaluate learning techniques and components.
  - -- Demonstrated the ability of a cognitive agent to learn large amounts of knowledge for performance in a specified domain on an unknown task within the same domain.
  - -- Explored novel methods for acquiring new knowledge including direct input through processing natural language text.
  - -- Design and develop hybrid learning systems that allow cognitive systems to generalize based on information gathered and learn to operate successfully in similar, but not identical situations, adapt to a wide variety of naturally-occurring situations, and perform better over time.
  - -- Demonstrate the ability of a cognitive agent to combine and restructure knowledge from multiple domains to solve novel problems. This includes the ability to generalize knowledge from a particular domain, recognize its applicability and apply it to a problem in a new domain. It also includes the ability to apply knowledge effectively, apply skills acquired for one purpose to other purposes, and demonstrate the ability to propose novel problem solution methods when specified resources are unavailable.
  - -- Demonstrate the ability of learning techniques to improve representation and reasoning performance in complex multi-agent environments.
  - -- Develop the ability of a cognitive agent to solve a problem with incomplete/partially inaccurate directions and achieve a goal that is only implicit in a specified task set of directions.

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-- Develop software tools that learn to adapt and optimally configure organizational structures, such as military commands, for robust complex decision making (e.g., logistics) and information sharing.
-- Develop software that integrates learning from examples, heuristic reasoning and textual analysis to recognize intent (i.e., cooperative or adversarial) behind human communications, and other information.
-- Develop the ability to learn information directly from large volumes of text using existing knowledge to guide the learning.

– Integrated Learning
-- Formulate learning as integrated problem solving. Develop techniques for representing and reasoning about explicit learning goals, formulating plans to achieve these goals, creating hypothesis where appropriate, and resolving sources of uncertainty.
-- Combine different types of knowledge and reasoning, flexibly. Enable learners to assemble information from many different sources including general-purpose world knowledge, more specific domain knowledge, reasoning, and simulation.
-- Develop a new set of learning algorithms that focus on learning structures or models rather than refining parameter values.
-- Develop learning algorithms that explicitly design experiments to test hypothesis about learned knowledge.
-- Develop knowledge sharing data structures that enable different learner subcomponents to share knowledge directly.
-- Test learning techniques by learning air operations center (AOC) and military medical logistics planning processes.

– Bio-Inspired Cognition
-- Investigated algorithms and general principles inspired by neuroscience to create new hybrid learning and adaptive systems.
-- Developed a set of cognitive architectures that modeled the major psychological and neurobiological aspects of human cognition.
-- Developed a battery of tests for evaluating cognitive architectures: a "cognitive decathalon" for assessing specific skills associated with cognition (e.g., visual perception, memory)."

	FY 2006	FY 2007	FY 2008	FY 2009
Learning Locomotion and Navigation	11.851	15.311	19.171	22.000

(U) The Learning Locomotion and Navigation thrust will develop advanced robotic technologies that will enable autonomous (unmanned) mobile platforms to perceive, understand, and model their environment; navigate through complex, irregular, and hazardous terrain; make

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intelligent decisions corresponding to previously programmed goals; and interact cooperatively with other autonomous and manned vehicles. These capabilities will enable robotic vehicles to support warfighters in a variety of situations and terrains, including transportation, logistics, reconnaissance, and active battle. A key objective is robust navigation and locomotion, since this underlies the ability to move through the difficult and unpredictable terrain of theater operations, which may include highly irregular and mountainous areas, partially-destroyed roads, rubble-filled urban terrain, and other vehicles and personnel. This program also supports the DARPA Urban Challenge.

(U) Within the thrust area, efforts are being made to develop learning and reasoning technologies to address specific concerns in both wheeled and legged robotic systems. Current systems for autonomous ground robot navigation typically rely on hand-crafted, hand-tuned algorithms. While these systems may work well in open terrain or on roads with no traffic, performance falls far short in obstacle-rich and highly-irregular environments. In contrast, the approach taken here is to develop systems that automatically learn to interpret sensor data and apply this knowledge to actuator control to improve locomotion and navigation in complex environments. Learning techniques will include (but not be limited to) reinforcement learning and learning from examples. These advancements will open new horizons for unmanned military operations, surveillance and reconnaissance, and dramatically advance the capabilities of autonomous vehicles. Tasks requiring higher-level computation, such as perception-based navigation and a high degree of freedom articulation will greatly benefit as well.

(U) Although current approaches to autonomous navigation of unmanned vehicles have achieved notable success in recent years, they suffer from limitations due to having been developed for static environments and not for dynamic real-world environments. Examples of the challenges posed by a complex dynamic real-world environment include: (1) robotic vision outdoors, under windy conditions that result in the movement of vegetation, trees, and leaves and, when a body of water is present, waves; and (2) path-planning in the presence of moving "obstacles" such as people and other (manned or unmanned) vehicles. Improvements in robotic vision and scene understanding, including the capability to predict the future location and even the intent of moving objects, need to be integrated with more sophisticated approaches to path planning. This would set the stage for autonomous interacting robots that share information and collaborate in performing tasks. For example, interacting robots could collaborate in planning/traversing a diversity of routes and thereby enhance their likelihood of quickly finding a viable and/or (nearly) optimal path.

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(U) Program Plans:

– Learning Locomotion and Navigation
 - -- Explored various learning technologies that enabled rapid adaptation by robots to new physical environments and improved autonomous vehicle speed over rough terrain.
 - -- Developed several learning methods that allowed learned navigation algorithms to surpass the performance of a baseline system which was demonstrated through several experiments.
 - -- Explored "learning from example" and "reinforcement learning" applications to develop technology for autonomous vehicle systems to learn and gather experience without relying on a programmer to anticipate all eventualities. These learning approaches were evaluated through a series of tests in varying terrains.
 - -- Continue to explore the integration of various learning technologies to enable rapid adaptation by robots to new physical environments and improve autonomous vehicle speed over rough terrain.
 - -- Develop learning methods that allow their learned navigation algorithms to surpass the performance of a baseline system.
 - -- Transfer the best performing navigation methods learned on a small-scale vehicle to the large robotic vehicle, Crusher, to operate at increased speeds in complex environments.
 - -- Port learning locomotion algorithms to larger scale vehicles to increase mobility of larger scale robots.
 - -- Create learning locomotion toolkits that will control a diverse set of high degree-of-freedom vehicles on rough terrain.
 - -- Fund prizes, technology development contracts, and program planning support for the DARPA Urban Challenge.

	FY 2006	FY 2007	FY 2008	FY 2009
Knowledge Representation and Reasoning Technology	4.540	6.413	8.019	13.509

(U) This program will develop the technologies to achieve the next generation of intelligent, knowledge-intensive systems and is compromised of two thrusts; 1) Knowledge Representation and Reasoning Technology and 2) Bootstrapped Learning.

- The Knowledge Representation and Reasoning Technology thrust (formerly Knowledge-Based and Reasoning Technology) will develop enabling technologies to acquire, integrate, and use high performance reasoning strategies in knowledge-rich domains. Such technologies will provide DoD decision makers with rapid, relevant knowledge from a broad spectrum of sources that may be dynamic and/or

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inconsistent. Significant reasoning challenges arise from the fact that critical knowledge involves context, temporal information, complex belief structures, and uncertainty. To address these challenges new capabilities are needed to extract key information and metadata, and to exploit these via context-capable search and inference (both deductive and inductive). DoD systems sense, capture, and store information in the form of text, audio, imagery, and video. Therefore, advanced machine reasoning capabilities must extract knowledge from and reason about all types of multimedia data. Visual-spatial reasoning, which is perhaps the most powerful form of human reasoning, yet the one least covered by machine cognition, is of special interest. This research will explore new computational models to enable command and control systems to use conceptual representations to perform visual-spatial reasoning and to assist the commander in understanding and analyzing complex battlefield scenarios.

(U) People are able to learn complex concepts, but they require a customized curriculum designed to teach a hierarchy of concepts at different levels of representation where each level depends on having learned the previous level. Bootstrapped Learning (BL) will provide computers with the same capability, enabling rapid learning of complex high-level concepts. At each level, a rich set of knowledge sources (such as training manuals, examples, expert behaviors, simulators, and references and specifications that are typically used by people learning to perform complex tasks) will be combined and used to generate concepts and a similar set of knowledge sources for the next level. Key to this process is the ability to automatically re-represent these combined sources into a common representation as needed for learning and reasoning. The ability to perform BL is essential for autonomous military systems because they will need to understand not only what to do but why they are doing it, and when what they are doing may no longer be appropriate. To be useful, a military system must not only carry out the specific task/mission for which it is programmed but also be able to reflect on its own ability to do so, and do this in the context of its operator/controller's intent.

(U) Program Plans:

– Knowledge Representation and Reasoning Technology
  - -- Developed and implemented initial digital repository architecture.
  - -- Develop integrated knowledge representation and learning technology that enables effective representation of essential forms of knowledge.
  - -- Develop representations of events and methods for separating and tracking their association to merge multiple scenarios, assimilate one event within the context of the other, and identify where events deviate from the norm.
  - -- Develop a general inference engine based on spatial representations, transformations, and reasoning techniques, in order to provide a more intuitive, common sense, human-like and efficient visual reasoner.

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-- Create learning mechanisms for the discovery of novel object categories and then design, develop, and demonstrate an artificial system that is capable of context-sensitive visual scene interpretation and understanding.

– Bootstrapped Learning
  -- Create a general purpose "Ladder Interface" used to decouple the bootstrap learning system from the problem domains and instructional materials provided to them.
  -- Produce end-to-end systems capable of bootstrap learning, integrating different types of learning, input modalities, and repeatedly building on prior learning.
  -- Demonstrate a single system capable of being instructed to perform in three diverse domains.

(U) <u>Other Program Funding Summary Cost:</u>

- Not Applicable.

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COST (In Millions)	FY 2006	FY 2007	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013
Collective Cognitive Systems and Interfaces COG-03	58.206	70.187	75.219	79.805	89.502	87.502	92.502	97.502

(U) <u>Mission Description:</u>

(U) Warfighting is not an individual activity. Battles, engagements, and even peace keeping missions are won by teams of warfighters working in concert with each other and the automated systems that support them. These warfighters are operating in hard settings where action, information, and decision making are distributed and the situation is constantly changing. In these settings, communications, information sharing, and tools that support warfighter coordination are critical.

(U) The Collective Cognitive Systems and Interfaces Project will dramatically improve warfighter and commander effectiveness and productivity using advanced cognitive approaches that enable faster, better informed, and more highly coordinated actions than those of our enemies. This will be accomplished by developing revolutionary methods that increase our information processing capabilities, enhance our situational awareness, and enable more cohesive group action by our forces. Critical technical areas addressed in this project include automated coordinated decision support, information sharing, and ensured communications. Cognitive decision support tools reason about tasks, timings, and interactions so that when plans change or the enemy does not respond as anticipated, U.S. forces can quickly adapt. The quality of such decisions and the effectiveness of our actions depend critically on our ability to take full advantage of all available information in a rapid and flexible manner. This requires the capability to share information and to automatically integrate distributed information bases for broad tactical battlespace awareness. Finally, team cohesion requires effective and reliable communication in difficult environments such as the urban setting where radio signal propagation is complex. Here the approach is to develop cognitive communications management and control algorithms that reason about channel conditions, higher-level application connectivity requirements and related factors, and decide (often as a group) what parameters (e.g., frequency) each radio will use. The suite of programs under this project will significantly advance the military's ability to address and deal with complex situations in operational environments.

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(U) Program Accomplishments/Planned Programs:

	FY 2006	FY 2007	FY 2008	FY 2009
Collaborative Cognition	21.304	29.951	32.800	34.002

(U) The Collaborative Cognition thrust is aimed at developing technologies that enable individual cognitive agents to work together as a team to provide cooperative support to warfighters in complex military situations. Such situations typically require multiple coordinated tasks that involve information sharing and cooperative efforts. The Collaborative Cognition thrust will foster the design and implementation of collaborative software agents that operate in dynamic environments that include both software agents and people. Applications include collaborative surveillance and reconnaissance, logistics re-planning and decision support for unanticipated operational changes, situational analysis, prediction tools, and warfighter/commander decision aids. The technology will also allow software agents to cope with limited and/or noisy sensor information, limited communication capabilities, changing and unforeseen environments, other agents, and limited *a priori* knowledge of each other's capabilities. The Collaborative Cognition technology thrust consists of two programs: Coordination Decision-Support Assistants (COORDINATORs), and Advanced Soldier Sensor Information System and Technology (ASSIST).

- The Coordination Decision-Support Assistants (COORDINATORs) program will develop cognitive software coordination managers that provide support to fielded tactical teams. The coordination managers will help fielded units adapt their mission plans in response to inevitable, unanticipated changes in the mission by tracking personnel, resources, situational changes, and proposing and evaluating options (adjustments to task timings, changes to task assignments and selection from pre-planned contingencies). This will enable fielded units to respond faster and more accurately to the dynamically changing battlefield situation, requiring far fewer personnel in the re-planning process. COORDINATORs is a distributed technology. A single COORDINATOR will be partnered with each tactical unit or team, and will be able to collaborate and coordinate with other tactical units to optimize needed mission changes.

- A key lesson learned from Operation Iraqi Freedom (OIF) is the importance of accurate observational reporting by ground soldiers. The Advanced Soldier Sensor Information System and Technology (ASSIST) program will develop an integrated information system that exploits soldier-worn sensors to augment the soldier’s ability to capture, report, and share information in the field. Communication of

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timely and accurate information is vital for enhanced situational understanding and overall operational effectiveness in urban combat and post-conflict stability operations. While a range of standardized reporting mechanisms are in use today, the confusion of the battlefield/urban operations combined with physical and psychological stresses on the warfighters can make the task of reporting very difficult. Furthermore, existing verbal and text-format reports limit the soldier's ability to capture and convey the full picture, particularly annotated visual information. The ASSIST program will develop an integrated system using advanced technologies for processing, digitizing and analyzing information captured and collected by soldier-worn sensors. It will draw heavily on the experiences and lessons learned from previous OIF missions and other surveillance and reconnaissance missions. A baseline system will demonstrate the capture of video/still images together with voice annotations and location-stamping. The advanced system will demonstrate automatic identification and extraction of key objects, events, activities and scenes from soldier-collected data. The system will create knowledge representations that will serve as an input to an array of warfighter products including augmented maps, situational analysis tools, and query and answer capabilities.

(U) Program Plans:

– Coordination Decision-Support Assistants
  - -- Tested coordination algorithms in a lab setting on small-scale coordination problems (8 COORDINATORs, 64 mission tasks) and demonstrated that algorithms achieve nearly optimal results in seconds.
  - -- Develop distributed coordination technology that reasons about making changes to task timings, assignments, and selection from preplanned contingencies.
  - -- Develop a coordination autonomy technology that learns which response options are most highly valued so that the COORDINATORs generate an appropriate option when the warfighters are occupied or cannot be interrupted.
  - -- Develop a meta-cognition technology that reasons about resource allocation (i.e., where a given COORDINATOR should spend its processing time), so the entire system can engage in difficult processing tasks but still respond in real time.
  - -- Create algorithms that reason about military decision-making policies and procedures so COORDINATORs follow correct information exchange protocols and ensure that decisions and recommendations stay within the scope of authorization.
  - -- Develop a Commander's COORDINATOR that can selectively "drill down" into portions of the mission structure and collect up-to-the-minute information, enabling a commander to make adjustments or recommendations.

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– Advanced Soldier Sensor Information System and Technology (ASSIST)
  - -- Demonstrated the baseline capture and retrieval system prototype and evaluated the effectiveness of the integrated system in MOUT (Military Operations on Urban Terrain) field exercises.
  - -- Developed algorithms to identify objects, events, and activities in captured data and to assign correct labels.
  - -- Exploited multimodal sensor streams and contextual information.
  - -- Created a taxonomy of objects and events, collected test data, and developed procedures and metrics for advanced technology evaluation.
  - -- Developed a laptop-based user search and visualization interface for accessing logged information captured by multiple soldiers.
  - -- Demonstrated temporal event representation and outdoor spatial representation.
  - -- Demonstrate real-time reporting using on-soldier sensors and intuitive information push/pull user interface.
  - -- Develop key technological components that enable in-field data sharing and retrieval on a wearable computing/sensor platform.
  - -- Demonstrate eyes-free, hands-free, attention-free collection of key events and experiences for reporting.
  - -- Demonstrate tools for analyzing blue-force and red-force trends and patterns.
  - -- Demonstrate the system's ability to improve its event and object classification performance through learning; demonstrate an accelerated capability for recognizing new classes of events, objects and activities.
  - -- Integrate advanced multimodal sensor event and object extraction techniques into advanced systems and evaluate the enhanced capabilities.

	FY 2006	FY 2007	FY 2008	FY 2009
Cognitive Networking	22.616	28.536	30.986	31.873

(U) The Cognitive Networking research thrust will develop technologies that provide information systems and communication networks with the ability to maintain their own functionality, reliability and survivability. These technologies will allow the military to focus its critical manpower resources on the mission rather than on the maintenance of its information systems and network infrastructure. Research in this area will create a radical new design for distributed computers, device networks, and the software to manage these systems. It will also attempt to create a "cognitive radio" capability, which uses cognitive information processing to optimize communications based on current conditions, past

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experience and high-level user guidance. The Cognitive Networking thrust comprises three programs: Situation-Aware Protocols in Edge Network Technologies, Adaptive Cognition-Enhanced Radio Teams, and Brood of Spectrum Supremacy.

- The Situation-Aware Protocols in Edge Network Technologies (SAPIENT) program will develop a new generation of cognitive protocol architectures to replace conventional protocols that fare poorly in extreme network conditions and do not provide adequate service for key applications. Technology developed in the SAPIENT program will have military utility wherever tactical communications are deployed. SAPIENT architectures will represent awareness with a knowledge base that is updated based on specification and observation. This technology enables the automatic adaptation of protocols to the operational environment. SAPIENT will exploit attributes of human cognition, such as learning and self-improvement, and apply them to the automated construction of network protocols. Key research challenges for the SAPIENT program are the use of these cognitive attributes to dramatically reduce the effect of network impairments on applications while demonstrating a positive trend in this capability as new situations are encountered and learned. Desired capabilities include interoperable knowledge representations and rapid incorporation of new knowledge about applications, network conditions and building blocks from which new protocols can be constructed.

- The Adaptive Cognition-Enhanced Radio Teams (ACERT) program is enabling distributed radio teams that are able to use capabilities inherent in aggregating nodes thereby leveraging advantages that are unique to a distributed system. ACERT focuses on techniques to enhance basic radio capabilities by combining the information available to the individual radios and making it available to the team. Of particular interest is sharing individual measurements of the radio channel to derive a shared common map of the local propagation conditions. Such a radio frequency propagation mapping capability can serve as the basis for improved message routing resulting in more reliable communications for small unit operations in urban environments.

- The Brood of Spectrum Supremacy (BOSS) program will provide actionable situational awareness to the warfighter in complex radio frequency (RF) environments. BOSS adds collaborative processing capabilities to tactical software-defined radios to achieve specific military goals. BOSS exploits cooperative use of computational, communication and sensory capabilities in a software radio, in aggregate, to generate breakthrough capabilities in the warfighter knowledge of their surroundings, with a particular focus on RF-rich urban operations. The BOSS program will initially focus on modeling and simulation, resulting in hardware-independent executable specifications of waveforms in an interoperable format. Once the modeling and simulation is verified, the BOSS program will develop a prototype demonstration for a performer-selected RF platform, using and refining the hardware-independent executable specifications of

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the waveforms. Ultimately this program will develop Software Communications Architecture (SCA)-compliant waveforms suitable for implementation on a tactical software radio system.

(U) Program Plans:

– Situation-Aware Protocols in Edge Network Technologies (SAPIENT)
  - -- Created knowledge representations appropriate for describing some situations encountered in tactical military networks (e.g., weak signals, propagation obstructions, message priorities and security requirements) and for enabling machine response to these situations.
  - -- Create and refine new knowledge representations appropriate for describing multiple link situations encountered in tactical military networks and for enabling machine response to these situations including automated learning of effective responses.
  - -- Demonstrate SAPIENT capabilities in laboratory and experimental airborne venues.
  - -- Integrate and enhance prototypes and evaluate their performance.

– Adaptive Cognition-Enhanced Radio Teams (ACERT)
  - -- Identified the technology challenges associated with the establishment of collaborative radio teams.
  - -- Created models, algorithms and prototypes for distributed control of radio resources and shared situational awareness.
  - -- Demonstrated the capability to share channel characteristics across multiple distributed radio units and produce a map of radio frequency propagation.

– Brood of Spectrum Supremacy (BOSS)
  - -- Develop theoretical analyses of the software-defined radio trade space to assess the distributed aggregation of capabilities over different numbers of moving elements, elements with varying capabilities (e.g., RF and processing), and with different distances and locations.
  - -- Refine capabilities of Software Communications Architecture (SCA)-compliant platforms, while working within the software-defined radio trade space.
  - -- Validate algorithms and implementations for network understanding tasks.

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	FY 2006	FY 2007	FY 2008	FY 2009
Integrated Collective Systems	3.561	9.700	11.433	13.930

(U) The Integrated Collective Systems technology thrust (formerly Self-Sufficient Collective Systems) will enable warfighters to take full advantage of all available pertinent information in a rapid and flexible manner. It will create software technologies that enable future warfighters to share information and to automatically integrate distributed information bases for broad tactical battlespace awareness. Ultimately, the selection, generation, sharing, integration and display of information will be handled by cognitive software systems coupled with each warfighter, and as information is shared the network of individual systems will form a collective. Information integration is one of the most critical and challenging problems facing the DoD and continually tops the list of critical defense needs. The inability to share and integrate data and information results in a fragmented picture of the battlespace where only a fraction of the available information is actually used. For example, it has been reported that in many instances it was easier to re-task an asset to collect new information than it was to retrieve critical information from data already collected and analyzed. Integration of multimedia (text, video, digital photographs) is of particular interest as it may contain valuable intelligence "tidbits" with different degrees of subtlety that can be extremely time-consuming to manually analyze (this is the case today). Once analyzed, such data needs to be indexed and stored so it can be queried and retrieved. Automatic analysis, querying and correlation algorithms need to be developed to minimize manual intervention.

(U) Current practices in the area of digital storage and information management generally optimize file storage and retrieval for the individual but are poorly suited to the sharing of large volumes of digital information across workgroups and enterprises. The DARPA Network Archive (DNA) project is pursuing a network-based approach to information storage and management that will enable a network-based repository to hold all digital information. Because it resides on the network, the DNA repository will provide a mechanism for the virtual (i.e., logical, not physical) centralization of all enterprise information. DNA technology will enable and facilitate controlled access to information by approved and authenticated users across administrative domains, and in this fashion it will enable a collective view of enterprise information. Repositories built on DNA technology will, in addition, provide a single distributed platform/framework for additional document/content/information services including indexing, metadata creation, search, versioning, and records management, resulting in the warfighter's ability to take full advantage of all available pertinent information in a rapid and flexible manner.

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(U) Program Plans:

- Develop a comprehensive digital repository architecture to enable ubiquitous access from multiple devices while providing secure, effective, document sharing.
- Develop a prototype system with military applicability that could accommodate thousands of users and further facilitate an open, extensible, and vendor-independent architecture.
- Develop a variety of innovative services for the architecture and prototype subsystems to address such issues as access control, security, indexing and search, metadata creation and maintenance, and version tracking.
- Devise new approaches for reasoning about information, information fusion, and handling conflicting information from different sources to enable warfighter systems to concurrently operate in multiple information collectives/domains.
- Develop multimedia database techniques to store the raw content and associated metadata associated in order that search, correlation, and analysis are enabled.
- Develop data discovery techniques to automatically search multimedia databases, semi-structured collections of data, and unstructured text collections for correlations and actionable intelligence.
- Develop advanced automatic techniques for analyzing and correlating a wide variety of multimedia data with an emphasis on specific algorithms that can derive key analytic features without solving the general scene analysis problem.
- Create new multimedia analysis algorithms with an emphasis on using context to determine feature attributes.

	FY 2006	FY 2007	FY 2008	FY 2009
Improved Warfighter Information Processing (IWIP)	10.725	2.000	0.000	0.000

(U) The Improved Warfighter Information Processing (IWIP) technology thrust developed technologies to enhance the warfighter’s and commander’s information management capacities and improve decision-making performance. The main thrust of this program was the Improving Warfighter Information Intake under Stress program. The Improving Warfighter Information Intake under Stress program enhanced operational effectiveness through a set of cognitive techniques that specifically improve 1) the amount of information that warfighters can handle; 2) attention management during stressful operations; and 3) information retention (memory). The program developed the means, devices and infrastructure

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necessary to assess the warfighter's or commander's cognitive status in real time, and used adaptive strategies specific to his/her status to improve information processing and decision-making. The IWIP program is in the process of transitioning to the Army, Navy, and Air Force.

(U) Program Plans:
- Refined closed-loop computational interfaces to mitigate specific information-processing bottlenecks to improve performance and information flow in specific operational domains.
- Refined intelligent interruption strategies, adaptive attention management methods, cued memory retrieval strategies and modality switching techniques to effectively increase information processing capacities in complex environments under stressful, operationally realistic conditions.
- Ruggedized the system to enable the assessment and enhancement of warfighter performance for an order-of-magnitude improvement in operator efficiency.
- Demonstrated ruggedized, operational prototypes for transition to service components.

(U) <u>Other Program Funding Summary Cost:</u>

- Not Applicable.