RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)						DATE: February 2006	
APPROPRIATION/BUDGET ACTIVITY: RDT&E, Defense-wide; BA2 Applied Research			R-1 ITEM NOMENCLATURE: Cognitive Computing Systems; PE 0602304E				
COST (In Millions)	FY 2005	FY2006	FY2007	FY 2008	FY 2009	FY 2010	FY 2011
Total Program Element (PE) Cost	145.833	163.430	220.085	227.604	235.032	247.494	246.243
Cognitive Systems Computing Foundations COG-01	19.800	26.678	37.635	40.184	42.651	43.751	43.751
Cognitive Computing COG-02	85.187	88.931	121.263	126.194	130.630	139.992	140.741
Collective Cognitive Systems and Interfaces COG-03	40.846	47.821	61.187	61.226	61.751	63.751	61.751

(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 will literally be systems that know what they are doing, enabling new levels of capability and powerful new applications.

(U) Cognitive Systems are different from conventional computing systems in that they manipulate rich structured representations of their knowledge, learn from experience and add to their store of knowledge, mix symbolic logical knowledge with uncertain and probabilistic information, allow reflective self-aware inference, and support the transition of perceptual (e.g., visual, auditory) data to symbolic information. These capabilities are not well matched to the architectures that support more conventional computing. The Cognitive Systems Computing Foundation project is developing the tools and architecture necessary to support the cognitive computing revolution.

(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.

RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)	DATE February 2006
APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research	R-1 ITEM NOMENCLATURE Cognitive Computing Systems PE 0602304E

(U) The Collective Cognitive Systems and Interfaces project will dramatically improve warfighter and commander effectiveness by developing revolutionary methods for users to interact with and direct cognitive systems (including the physical sensors and effectors). This research will improve the interaction among multiple large-scale cognitive systems, in support of the user's objectives. Specifically, this project will develop technologies to enable systems to detect and assess the user's cognitive state and adapt to optimize the user's understanding and effectiveness.

(U) **Program Change Summary:** *(In Millions)*	**FY 2005**	**FY 2006**	**FY 2007**
Previous President's Budget	149.782	200.799	241.006
Current Budget	145.833	163.430	220.085
Total Adjustments	-3.949	-37.369	-20.921
Congressional program reductions	-0.115	-37.369	
Congressional increases	0.000		
Reprogrammings	0.000		
SBIR/STTR transfer	-3.834		

RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)	DATE February 2006
APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research	R-1 ITEM NOMENCLATURE Cognitive Computing Systems PE 0602304E

(U) Change Summary Explanation:

FY 2005	The decrease reflects DOE transfer for P.L. 108-447 and SBIR/STTR transfer.
FY 2006	The decrease reflects the $35M congressional cut to Project COG-02; Cognitive Computing and undistributed reductions for Section 8125 and 1% reduction for Section 3803: Government-wide rescission.
FY 2007	Decrease reflects rephasing of efforts in response to FY 2006 congressional action.

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RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)							DATE February 2006
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 2005	FY 2006	FY 2007	FY 2008	FY 2009	FY 2010	FY 2011
Cognitive Systems Foundations COG-01	19.800	26.678	37.635	40.184	42.651	43.751	43.751

(U) Mission Description:

(U) Cognitive Systems are different from conventional computing systems in that they draw inferences from rich structured representations of their 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.

(U) The Security Aware Systems thrust previously budgeted in this project has been moved to PE 0602303E, Project IT-03 as it is more closely aligned with the programs in the Information Assurance and Survivability Project.

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RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)	DATE February 2006
APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research	R-1 ITEM NOMENCLATURE Cognitive Computing Systems PE 0602304E, Project COG-01

(U) Program Accomplishments/Planned Programs:

	FY 2005	FY 2006	FY 2007
Architectures for Cognitive Information Processing	9.895	14.043	19.000

(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. ACIP will develop the micro-architecture concepts, framework, and development environments that will provide the basis for and enable innovative and efficient cognitive information processing. 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:

- Selected innovative computer architecture(s) and in-context applications for cognitive architecture implementations, demonstrations and developments.
- Develop, simulate and evaluate innovative cognitive computer architecture concepts and evaluate in-context cognitive application baselines based on current approaches and “best-possible” implementations using existing processor architectures.
- Characterize the role of reflective reasoning in a cognitive system that reacts effectively to stimuli and uses deliberation to plan and solve problems.
- Explore a first-generation framework supporting cognitive approaches, algorithm development and architectural evaluation.

RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)	DATE February 2006
APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research	R-1 ITEM NOMENCLATURE Cognitive Computing Systems PE 0602304E, Project COG-01

- Develop, prototype, and demonstrate innovative cognitive computer architectures that will provide at least a 100X improvement over today's systems and a real-time adaptation for DoD cognitive applications.
- 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 vender-independent architecture.

	FY 2005	FY 2006	FY 2007
Self-Regenerative Systems	9.905	12.635	18.635

(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 development phase of 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 systems phase of 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 of 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.

RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)	DATE February 2006
APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research	R-1 ITEM NOMENCLATURE Cognitive Computing Systems PE 0602304E, Project COG-01

(U) Program Plans:

- Demonstrated scalable data redundancy for network-centric military applications and infrastructure services.
- Developed techniques for natural robustness via biological metaphors to counter vulnerabilities of software monocultures in military information systems.
- Develop technologies to diagnose and assess damage, repair and recover from damage caused by accidental faults, software aging or malicious activities, and enable systems to heal automatically.
- Develop strategies to preempt insider attacks, including inferring military system operator goals, enabling anomaly detection, combining and correlating information from system layers, and using direct user challenges.
- Develop a cognitive framework that ties the SRS technologies together and allows feedback and cognitive control of the overall system's survivability posture.
- Develop an exemplar self-regenerative system tailored to protect a representative military application in order to demonstrate the value to the warfighter.
- Develop operating system structures, building block mechanisms and application programming interfaces (APIs) that are individually survivable.

(U) Other Program Funding Summary Cost:

- Not Applicable.

RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)							DATE February 2006
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 2005	FY 2006	FY 2007	FY 2008	FY 2009	FY 2010	FY 2011
Cognitive Computing COG-02	85.187	88.931	121.263	126.194	130.630	139.992	140.741

(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, intelligent negotiation capability, 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.

RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)	DATE February 2006
APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research	R-1 ITEM NOMENCLATURE Cognitive Computing Systems PE 0602304E, Project COG-02

(U) Program Accomplishments/Planned Programs:

	FY 2005	FY 2006	FY 2007
Integrated Cognitive Systems	47.814	52.721	62.982

(U) The Integrated Cognitive Systems technology thrust will develop advanced technology to enable a new class of integrated, highly functional cognitive systems capable of greatly 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 seamlessly fuse perceptual inputs and tie newly perceived data to prior knowledge and experience. They will be able to plan ahead and will 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 responses. 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 and demonstrated in the Personalized Assistant that Learns (PAL) program.

(U) The Personalized Assistant that Learns (PAL) program will develop integrated cognitive systems that act as personalized, executive-style assistants to military commanders and decision makers. This program will demonstrate cognitive systems that use basic knowledge and past experience to help them understand and seek input. Initially the program will strive to create assistant programs that display basic interaction competencies with people and other assistant programs in an operational environment. Some of these basic competencies include sending and receiving information in a natural manner, relating information and activities in various media, interacting with the assistant's user and inferring preferences, executing procedures correctly; and accepting coaching and guidance expressed in natural language. In a unified multitasking, mixed-initiative architecture, these integrated cognitive systems will push the limits of technology for formal reasoning and learning. Methods for processing raw data will be learned in a way that optimizes performance of the entire system and enables the same purposeful perception that makes natural systems successful in dealing with huge amounts of input data and a constantly changing world. One of PAL's goals is the development of advisable systems technology that yields systems that warfighters and other end-users can control in a natural and flexible manner, e.g., by exchanging advice and instructions, rather than via menus or programming. The term "advice" refers to a series of instructions that span a spectrum ranging from high-level policy and goals, to intermediate preferences and constraints on system behavior, to specific direction and

RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)	DATE February 2006
APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research	R-1 ITEM NOMENCLATURE Cognitive Computing Systems PE 0602304E, Project COG-02

contingency actions. The end user will be able to engage in a natural dialogue with the system, and the advice will be translated into an executable form.

(U) Program Plans:

- Personalized Assistant that Learns
  - -- Developed an understanding of user preferences and basic operational procedures.
  - -- Developed test problems and defined metrics to evaluate progress in integrated cognitive systems technology R&D. Conducted formal experiments annually.
  - -- Developed compelling scenarios to drive advisable technology research through a series of increasingly difficult challenge problems.
  - -- Developed, evaluated and improved an integrated research prototype. Effort continues on an extended prototype.
  - -- Develop, demonstrate and refine 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 and demonstrate the ability to learn quickly from a few examples, learning by accepting guidance from its user, and asking for guidance when needed.
  - -- Develop and evaluate techniques for learning in one domain and applying the learned knowledge in a new unanticipated domain.
  - -- 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 languages necessary for both implementation and verification of purpose and intent.

RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)	DATE February 2006
APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research	**R-1 ITEM NOMENCLATURE** Cognitive Computing Systems PE 0602304E, Project COG-02

	FY 2005	FY 2006	FY 2007
Foundational Learning Technology	22.857	19.819	33.057

(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 application of this technology 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 enable cognitive computing systems that learn from experience and adapt to changing situations. The program will emphasize Transfer Learning 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 currently, most military operations occur in ever changing environment 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, bootstrapped 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-based 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.

RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)	DATE February 2006
APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research	R-1 ITEM NOMENCLATURE Cognitive Computing Systems PE 0602304E, Project COG-02

- 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 AOC (air operations center) 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 the reasoning about airspace deconfliction 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.

- The Bio-Inspired Cognition program will draw 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 will focus on novel designs inspired by the function, representation and structure of the brain. This approach will expand traditional AI technologies from complex symbolic processing to new capabilities in memory, categorization, pattern recognition and fusion of perceptual/sensory information. Computational intelligence is in its infancy, whereas the human brain is the product of millions of years of evolutionary development. Thus, designing software inspired by the brain's processing schemes can offer leap-ahead advances in cognitive systems. These systems will seek to emulate human performance in 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. This thrust will take 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. Success will, in part, be measured by the ability of the systems developed to deal effectively with novel situations and respond appropriately in reasonable timeframes. This thrust has the potential to revolutionize a broad range of military applications through breakthrough performance of intelligent machines.

RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)	DATE February 2006
APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research	R-1 ITEM NOMENCLATURE Cognitive Computing Systems PE 0602304E, Project COG-02

(U) Program Plans:

– Real-World Learning.
  -- Selected several critical problems and scenarios to challenge machine learning technology in ways that will determine the essential value of individual techniques.
  -- Establish a testbed of complex multi-agent environments for the generation of specific and novel situations that will be used to evaluate learning techniques and components.
  -- Design and develop hybrid learning systems that allow cognitive systems to generalize based on information gathered and learned 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 learn large amounts of knowledge for performance in a specified domain on an unknown task within the same domain.
  -- 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 and partially inaccurate directions.
  -- Develop the ability of a cognitive agent to achieve a goal that is only implicit in a specified task set of directions.
  -- 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 technologies that allow systems to rapidly learn complex tasks and concepts by automatically understanding the components of complex tasks, and combining information, in a cumulative fashion, from multiple types of knowledge resources, such as manuals, texts, examples, expert behavior traces, and human advice**.**
  -- Develop the ability to learn information directly from large volumes of text using existing knowledge to guide the learning.

RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)	DATE February 2006
APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research	R-1 ITEM NOMENCLATURE Cognitive Computing Systems PE 0602304E, Project COG-02

– 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.
  -- Flexibly combine different types of knowledge and reasoning. 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 algorithms that reason about when learning systems should ask humans for explicit input and learn processes efficiently from humans as they perform work tasks.

– Bio-Inspired Cognition.
  -- Begin using a new generalized theory of learning and memory as well as modular biomorphic designs to implement and integrate simulation modules into a series of biomorphic learning systems.
  -- Investigate the role of parallel architectures, algorithms, and general principles inspired by neuroscience in hybrid learning and adaptive systems.
  -- Develop a battery of tests for evaluating cognitive architectures: a “cognitive decathlon” for assessing specific skills associated with cognition (e.g., visual perception, memory).
  -- Using this battery of tests, compare the performance of biomorphic learning technologies against those of traditional artificial intelligence.

	FY 2005	FY 2006	FY 2007
Learning Locomotion and Navigation	12.038	11.851	18.811

(U) The Learning Locomotion and Navigation thrust will develop learning and reasoning technologies that specifically address concerns in robotic systems. The resulting robotic systems will automatically learn to interpret sensor data and apply this knowledge to the control of their actuators, which will improve locomotive and navigational autonomy in complex environments. Approaches in reinforcement learning and technologies for learning from example will be explored. These technologies will open new horizons for unmanned military operations,

RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)	DATE February 2006
APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research	R-1 ITEM NOMENCLATURE Cognitive Computing Systems PE 0602304E, Project COG-02

surveillance and reconnaissance and will dramatically advance the capabilities of autonomous vehicles. Tasks requiring higher-level computation, such as perception-based navigation, will also benefit.

(U) Program Plans:

- Learning Locomotion and Navigation.
  - -- 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, Spinner, to increase speeds in complex environments.
  - -- Explore "learning from example" and "reinforcement learning" applications to develop technology for autonomous vehicle systems to learn from example and from gathered experience without relying on a programmer to anticipate all eventualities.
  - -- Create learning locomotion toolkits that will control a diverse set of high degree-of-freedom vehicles on rough terrain.

	FY 2005	FY 2006	FY 2007
Knowledge-Based Technology	2.478	4.540	6.413

(U) The Knowledge-Based Technology thrust will develop enabling technologies, methodologies, ontologies and detailed knowledge bases to achieve the next generation of intelligent, knowledge-intensive systems. This work will focus on developing technology that spans the spectrum from large, strategic knowledge banks to small, individual knowledge-based systems. The Knowledge-Based Technology thrust comprises Knowledge-Based Systems and Bootstrapping Cognitive Systems with Implicit Semantic Knowledge.

- The Knowledge-Based Systems program will develop technologies to acquire, codify, link, integrate, and use complex and cross-disciplinary knowledge at varying scales. At a strategic level, this capability will provide DoD decision makers with rapid, as-needed access to relevant background knowledge from a broad spectrum of sources. The knowledge will be expressed in formal knowledge representation languages that allow computers to reason with the knowledge, consider its implications, imagine possible future scenarios and query the warfighter for clarification. The significant challenges are centered on the fact that critical knowledge involves temporal

RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)	DATE February 2006
APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research	R-1 ITEM NOMENCLATURE Cognitive Computing Systems PE 0602304E, Project COG-02

information, complex belief structures and uncertainty. Current representation technology is inadequate to capture such information. This program will develop technology needed to enable the creation of individual knowledge-based systems that would incorporate into the reasoning process (in a computer-understandable form) knowledge of the warfighter's responsibilities, approach, tasks and activities. Another goal of this program is to support the warfighter's ability to understand the "big picture" for mission planning, monitoring and re-planning. By formalizing situation-model representations, automated support will be provided to commanders and analysts for prediction of unforeseen events and determination of relevance of isolated or partial events to the evolving situation. To achieve these objectives, this program will develop analogical and case-based reasoning, languages and situation markup languages technologies, and formalized situation representations. An additional goal is the development of technologies for rich, high-fidelity simulation models of human learning, reasoning and behavior. The program will also explore new ways for knowledge to be transferred efficiently to a knowledge base by reading tutorial text intended to convey new concepts to a cognitive system.

- The Bootstrapping Cognitive Systems with Implicit Semantic Knowledge program will explore a new technique for creating cognitive systems that learn to perform actions in an intelligent fashion without detailed reasoning or reliance on detailed models of action. Instead, the technique uses large amounts of coarse grained information and usage statistics gathered by watching many warfighters at work. This body of knowledge enables the algorithms to "do the right thing" without detailed computation – replacing detailed knowledge-based inference or planning with statistical usage information. This new technique will lower the cost of creating cognitive systems that perform assistive tasks for our warfighters.

(U) Program Plans:

– Knowledge-Based Systems
  -- Developed initial techniques for representing and using common sense knowledge.
  -- Explored novel methods for acquiring new knowledge that is less onerous than traditional methods requiring hand-coding by experts including direct input through processing natural language text.
  -- Develop and evaluate methods, protocols, and tools for using interoperable knowledge modules resident on distributed knowledge servers.
  -- Develop integrated knowledge representation and learning technology that enables effective representation of essential forms of knowledge.

RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)	DATE February 2006
APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research	R-1 ITEM NOMENCLATURE Cognitive Computing Systems PE 0602304E, Project COG-02

-- Document a substantial library of formal declarative interoperable multi-use ontologies initially across single, then multiple domains.
-- Demonstrate and evaluate prototypes of strategic and individual knowledge-based systems.
-- 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.

– Bootstrapping Cognitive Systems with Implicit Semantic Knowledge
-- Develop algorithms based on implicit semantic knowledge that enable cognitive systems to examine a current goal, and then decide how to achieve that goal based on what the warfighter has done in the past.
-- Evaluate and test the implicit semantic knowledge algorithms on a variety of different domains or application areas to assess the utility of the approach and its effectiveness for different applications.
-- Create distributed agent scribes that learn operations from warfighters and stores these operations along with the implicit semantic knowledge in a repository for future automation.

(U) Other Program Funding Summary Cost:

- Not Applicable.

RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)							DATE February 2006
APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research			R-1 ITEM NOMENCLATURE Cognitive Computing Systems PE 0602304E, Project COG-03				
COST (In Millions)	FY 2005	FY 2006	FY 2007	FY 2008	FY 2009	FY 2010	FY 2011
Collective Cognitive Systems and Interfaces COG-03	40.846	47.821	61.187	61.226	61.751	63.751	61.751

(U) Mission Description:

(U) The Collective Cognitive Systems and Interfaces project will dramatically improve warfighter and commander effectiveness and productivity by developing revolutionary methods that increase the individual warfighter's/commander's information processing capabilities, enhance situational awareness in urban and battlefield operations, and enable team collaboration through ensured network communications.

(U) A unique aspect of natural perceptual systems is their ability to filter and integrate vast amounts of raw sensor data, such as visual flow and rich auditory input; rapidly segment the resultant data into meaningful elements; and integrate them into a coherent picture. The human perceptual system is able to create perceptual units that parcel the world into objects and discrete entities that are then recognized, remembered and used in problem solving. Looking closely at these innate perception abilities will yield insights into how to build totally novel computational systems that identify important, low-frequency events in a noisy environment. This kind of approach should lead to dramatic improvements in the ability of a computer to process and analyze huge amounts of data to form a high-level understanding within its environment. Robust interaction among cognitive systems, legacy systems and warfighters will require incorporation of advanced models and control of the network infrastructure to ensure adequate provisioning of quality-of-service under dynamic loads. Together, these technologies will allow the warfighter to focus on high-level mission objectives rather than low-level maintenance of supporting systems. At the same time the technology will ensure that the warfighter maintains essential understanding of how (and how well) the system is implementing and responding to high-level direction.

(U) This project will focus on methods for users to interact with and direct cognitive systems (including the physical sensors and effectors); technologies to reduce the personnel and labor required for set up and maintenance of tactical and strategic networks; and techniques for retrieving and interpreting relevant collected information. High-level languages will be developed for rapid and precise specification of complex behavior in response to mission demands. Since it is equally important for the warfighter or commander to understand the system as it is for the system to understand the user's goals and needs, this project will develop technologies that give systems the ability to explain, perceive and reason about their behavior and actions. While development of stand-alone cognitive systems represents a huge leap forward, real, complex military missions require teams of these systems to work collaboratively. The project will also develop those technologies necessary to enable such systems to collaborate effectively and take advantage of the power of collective cognitive agents.

RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)	DATE February 2006
APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research	R-1 ITEM NOMENCLATURE Cognitive Computing Systems PE 0602304E, Project COG-03

(U) The suite of programs under this project will significantly advance the military's ability to address and deal with complex situations in operational environments.

(U) Program Accomplishments/Planned Programs:

	FY 2005	FY 2006	FY 2007
Improved Warfighter Information Processing	8.387	8.225	9.000

(U) The Improved Warfighter Information Processing (IWIP) technology thrust is developing technologies to enhance the warfighter's and commander's information management capacities and improve decision-making performance. The main thrust of this program is the Improving Warfighter Information Intake under Stress program. The Improving Warfighter Information Intake under Stress program will enhance operational effectiveness through a set of cognitive techniques that specifically improve 1) the amount of information that warfighters can handle, thereby reducing manpower requirements (e.g., one person doing the job of three); 2) attention management during stressful operations; and 3) information retention (memory). The program will develop the means, devices and infrastructure necessary to assess the warfighter's or commander's cognitive status in real time, and use adaptive strategies specific to his/her status to improve information processing and decision-making. The program will develop the technologies to integrate new digital devices that support memory, attention, and context recovery; and will culminate in the development of closed-loop systems that enable computer systems to adapt to the warfighter's or decision-maker's cognitive status. The research is also pursuing perceptual processing-based displays that are sensitive to information processing mechanisms inherent in the human perceptual system to invent, modify and redesign devices that more effectively deliver content to the operator. Such work will include designing and building adaptive multimodal interfaces that improve the battlefield and command center communications, and exploiting all of the digital information currently available in a static command environment. DARPA has established MOAs with the U.S. Army Research, Development and Engineering Command - Natick Soldier Center; Naval Air Systems Command; Air Force Research Laboratory Human Effectiveness Directorate; Office of Naval Research Expeditionary Warfare Operations Technology Division; and Deputy Chief of Naval Operations, Warfare Requirements and Programs for transition of this program.

RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)	DATE February 2006
APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research	R-1 ITEM NOMENCLATURE Cognitive Computing Systems PE 0602304E, Project COG-03

(U) Program Plans:

- Developed and integrated sensor technologies into an initial suite of operationally valid warfighter status "gauges."
- Assessed techniques for classifying warfighter status and operational context for automation engagement under stress.
- Quantified and characterized the information processing mechanisms inherent in the human perceptual system in order to improve warfighter decision-making capabilities, and design novel interactions within the command and control environment.
- Refine closed-loop computational interfaces to mitigate specific information-processing bottlenecks to improve performance and information flow in specific operational domains.
- Refine 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.
- Ruggedize the system to enable the assessment and enhancement of warfighter performance for an order-of-magnitude improvement in operator efficiency.
- Demonstrate ruggedized, operational prototypes for transition to service components.
- Design and demonstrate visual displays and rich audio interfaces to provide the foundation for adaptive displays that adjust to the operator, task and/or display device.
- Design and develop new mobile-adaptive multimodal processing techniques and interface concepts tailored to the user, task, and environment; test performance and usability advantages within multimodal systems and identify protocols for maximized information presentation.

RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)	DATE February 2006
APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research	R-1 ITEM NOMENCLATURE Cognitive Computing Systems PE 0602304E, Project COG-03

	FY 2005	FY 2006	FY 2007
Collaborative Cognition	20.546	21.304	24.001

(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 and include both software agents and people. Applications include collaborative surveillance and reconnaissance systems, logistics re-planning and decision support for unanticipated operational changes, situational analysis, prediction tools, and other aids to warfighter/commander decision making. 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.

RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)	DATE February 2006
APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research	R-1 ITEM NOMENCLATURE Cognitive Computing Systems PE 0602304E, Project COG-03

- 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 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-based 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
  -- 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.

RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)	DATE February 2006
APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research	R-1 ITEM NOMENCLATURE Cognitive Computing Systems PE 0602304E, Project COG-03

– Advanced Soldier Sensor Information System and Technology (ASSIST)
  -- Demonstrate the baseline capture and retrieval system prototype and evaluate the effectiveness of the integrated system in MOUT (Military Operations on Urban Terrain) field exercises.
  -- Develop algorithms to identify objects, events, and activities in captured data and assign correct labels.
  -- Exploit multimodal sensor streams and contextual information.
  -- Create a taxonomy of objects and events, collect test data, and develop procedures and metrics for advanced technology evaluation.
  -- Develop a laptop-based user search and visualization interface for accessing logged information captured by multiple soldiers.
  -- Demonstrate temporal event representation and outdoor spatial representation.
  -- Develop key technological components that enable in-field data sharing and retrieval on a handheld platform.
  -- 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 2005	FY 2006	FY 2007
Self-Sufficient Collective Systems	1.913	2.690	5.172

(U) The Self-Sufficient Collective Systems technology thrust will allow heterogeneous teams (e.g., people, software agents, robots) and/or organizations (e.g., coalition forces) to rapidly form, easily manage and maintain virtual alliances concerned with specific problems, tasks or requirements. The technology will improve information sharing and situational awareness by robustly and dynamically networking teams of agents and warfighters. Self-Sufficient Collective Systems concepts will enable warfighters to take full advantage of all available information and bring to bear all available assets in a rapid and flexible manner. This thrust includes the Cognitive Collectives for Autonomic Situation Awareness initiative, which will create software technologies that enable future warfighters to form collective units and share information automatically for broad tactical battlespace awareness. The selection, generation, sharing and display of information will be handled by cognitive software systems coupled with each warfighter, and the network of individual systems will form a collective. Each system will monitor the sensors attached to its

RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)	DATE February 2006
APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research	R-1 ITEM NOMENCLATURE Cognitive Computing Systems PE 0602304E, Project COG-03

associated soldier, collect situational information and reason about the soldiers' operational environment. Selected information will then be communicated to nearby units via their systems. As each unit continues to share information with nearby units, the information will be propagated throughout the collective to enhance the capability of the individual soldier.

(U) Program Plans:

- Create multi-layer cognitive software systems where lower layers respond in a reactive fashion and higher layers perform deliberation/reasoning, learning and diagnosis.
- Create learning algorithms that learn over time to distill the reasoning that happens at the higher levels into lower level autonomic responses.
- Design new approaches for reasoning about information longevity, information fusion, and handling conflicting information from different sources to enable the warfighter's systems to concurrently operate in multiple information collectives.
- Develop algorithms that reason about the edge-of-stability for learned/autonomic responses, i.e., understand when autonomic responses should be changed or updated because the situation has changed or these responses no longer apply.
- Develop new techniques for designing or organizing distributed computation to achieve a goal-directed behavior.
- Create a problem-solving infrastructure with the ability to dynamically organize and decompose problems.
- Plan for problem solving, monitor progress, and adapt to changing capabilities.
- Develop robust teamwork models with the ability to dynamically reconfigure teams of robots and humans to execute missions in rapidly changing adversarial environments.
- Transform software engineering by exploiting *meta-information* comprising ontology of intended environment, design constraints, and limitations.

RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)	DATE February 2006
APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research	R-1 ITEM NOMENCLATURE Cognitive Computing Systems PE 0602304E, Project COG-03

	FY 2005	FY 2006	FY 2007
Cognitive Networking	10.000	15.602	23.014

(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 enhanced radio" capability, which uses cognitive information processing to optimize communications based on current conditions, past experience and high-level user guidance. This research thrust will also explore adaptive command, control, communications and computers (C4) network planning and design capability that dramatically reduces life-threatening communication failures in complex communication networks. 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.

RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)	DATE February 2006
APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research	R-1 ITEM NOMENCLATURE Cognitive Computing Systems PE 0602304E, Project COG-03

- The Adaptive Cognition-Enhanced Radio Teams (ACERT) program will construct a distributed radio team that is able to use capabilities inherent in aggregating nodes, while leveraging advantages that are unique to a distributed system. Thus, ACERT platforms will focus on resource management to facilitate basic radio capabilities and accommodate the allocation of resources necessary for the individual radios to be combined into a team. In addition, since membership in a radio team strongly affects the capabilities of the aggregate, ACERT radios will provide robust access control for the radio team's resources. Therefore, resource management of ACERT platforms will be carried out at machine speeds to overcome intermittent connectivity, dynamic team membership, and the requirements of the individual team member radios. This capability will provide 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 RF (Radio Frequency) environments. BOSS adds collaborative processing capabilities to tactical software-defined radios to achieve specific military goals, such as understanding the adversary's organization. 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 capability for a performer-selected RF platform, using and refining the hardware-independent executable specifications of 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)
  -- Developed a suite of fundamental protocol components appropriate for these situations.
  -- Developed and implemented a selection and composition methodology to exploit situation awareness to construct a functioning network protocol adapted to the situation.
  -- Create and refine knowledge representations appropriate for describing 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 including automated learning of effective responses.
  -- Integrate and enhance prototypes and evaluate their performance.

RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)	DATE February 2006
APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research	R-1 ITEM NOMENCLATURE Cognitive Computing Systems PE 0602304E, Project COG-03

-- Perform analysis of requirements for C4 capabilities including contingent event specification and network requirements representation.
-- Identify strategies for automating the configuration reasoning tasks for C4 networks of realistic scale.

– Adaptive Cognition-Enhanced Radio Teams (ACERT)
-- Create models, algorithms, and prototypes for distributed control of radio resources and shared situational awareness.
-- Design and implement team access controls including new models for decentralized trust and new algorithms that take advantage of locality and density.
-- Manage collaborative channel characteristics including leveraging of the broadcast channel for shared awareness.
-- Develop cross-layer optimizations and possibilities for cognitive Media Access Control (MAC) layers that improve team performance over time.

– 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 that could, for example, locate and identify likely commanders and command posts.

(U) Other Program Funding Summary Cost:

- Not Applicable.