RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)	DATE: February 2008
APPROPRIATION/BUDGET ACTIVITY: RDT&E, Defense-wide; BA2 Applied Research	R-1 ITEM NOMENCLATURE: Cognitive Computing Systems; PE 0602304E

COST (In Millions)	FY 2007	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013
Total Program Element (PE) Cost	165.395	174.680	145.262	135.671	134.372	134.510	128.893
Cognitive Systems Computing Foundations COG-01	13.870	4.474	0.000	0.000	0.000	0.000	0.000
Cognitive Computing COG-02	94.945	94.987	88.392	78.688	79.392	79.530	79.857
Collective Cognitive Systems and Interfaces COG-03	56.580	75.219	56.870	56.983	54.980	54.980	49.036

(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 technology that will enable computational systems to have reasoning and learning capabilities and levels of autonomy far beyond those of today's systems. The ability to reason, learn and adapt will raise computing to new levels of capability and powerful new applications.

(U) Military command, control, communications, and intelligence/information systems must support warfighters in 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 nor with the capability 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.

(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.

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(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 2007**	**FY 2008**	**FY 2009**
Previous President's Budget	180.003	179.728	202.439
Current Budget	165.395	174.680	145.262
Total Adjustments	-14.608	-5.048	-57.177
Congressional program reductions	-10.000	-5.048	
Congressional increases	0.000		
Reprogrammings	0.000		
SBIR/STTR transfer	-4.608		

(U) Change Summary Explanation:

FY 2007	The decrease reflects the SBIR/STTR transfer and a $10 million decrease to the Architectures for Cognitive Information Processing program for the Section 8043 rescission.
FY 2008	The decrease reflects Congressional program reductions to Robust Robotics, Integrated Learning, and a reduction for Section 8097 Contractor Efficiencies and Section 8104 Economic Assumptions.
FY 2009	The decrease reflects transfer of maturing cognitive technologies from the Personalized Assistant that Learns (PAL) program to Budget Activity 3 for transition opportunities in command and control systems and reduced funding for collaborative cognition programs as they prepare for transition.

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COST (In Millions)	FY 2007	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013
Cognitive Systems Computing Foundations COG-01	13.870	4.474	0.000	0.000	0.000	0.000	0.000

(U) Mission Description:

(U) The Cognitive Systems Computing Foundations project seeks to make fundamental scientific improvements in our understanding of and ability to create more intelligent information and computing systems such as developing 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. Transition goals include next-generation network-centric systems and platform-specific information collection and processing systems. This project will complete with FY 2008 funding and on-going efforts will continue in other Program Elements.

(U) Program Accomplishments/Planned Programs:

	FY 2007	FY 2008	FY 2009
Self-Regenerative Systems (SRS)	12.770	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, exceed initial

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operating capability and approach 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.

(U) Program Plans:
FY 2007 Accomplishments:
- Developed technologies to expand capabilities to diagnose and assess damage, and repair and recover from damage caused by accidental faults or malicious activities.

FY 2008 Plans:
- Develop additional general strategies to automatically immunize systems against new attacks and preempt insider attacks; combining and correlating information from system layers using direct user challenges.

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

(U) Program Plans:
FY 2007 Accomplishments:
- Initiated research on Secure Open Systems.

(U) Other Program Funding Summary Cost:

- 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 2007	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013
Cognitive Computing COG-02	94.945	94.987	88.392	78.688	79.392	79.530	79.857

(U) Mission Description:

(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 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. 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, the Personalized Assistant that Learns program, have great applicability to command and control systems and are budgeted to begin transition to battlefield systems in FY 2008/2009. Candidate systems include the Strategic Command (STRATCOM) Global Strike Operations Center Strategic Knowledge Info Web (SKIWeb), the Army's Command Post of the Future (CPOF), the Navy's Composeable FORCENet (CFn), Navy Marine Corp Intranet (NMCI) and the Air Force's Air Tasking Order (ATO) programs. Additional details are provided under PE 0603760E, Project CCC-01.

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(U) Program Accomplishments/Planned Programs:

	FY 2007	FY 2008	FY 2009
Personalized Assistant that Learns (PAL)*	39.164	34.114	27.344

*Previously this was part of Integrated Cognitive Systems.

(U) The Personalized Assistant that Learns (PAL) program 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 warfighter steadily increases. Modern computing systems, though powerful, are woefully lacking in the capability to self-configure, adapt, and learn. 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 PAL program will develop advanced technology to enable a new class of cognitive systems capable of assisting military commanders and decision makers. PAL will build upon prior DARPA programs that developed improved human-computer interaction capabilities and highly-responsive computing systems. PAL systems will be able to plan ahead and understand the world well enough to plausibly anticipate future events. Most importantly, PAL 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 PAL system to improve over time. 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.

(U) 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. PAL 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. Future capabilities to be inserted will result in the ability to

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turn 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:

FY 2007 Accomplishments:

- Developed, evaluated, and demonstrated the first instance of an intelligent cognitive assistant capable of learning the user's activities, topics of interest, expertise, information needs, priorities and organizational roles.
- Developed, evaluated, and demonstrated the use of learned knowledge by the cognitive system to (1) prepare information products such as briefings, (2) organize and prioritize emails, files, and documents, and (3) quickly find additional relevant information.
- Developed, demonstrated, and refined core machine learning, knowledge base and flexible planning technologies to enable development of a cognitive planning agent capable of recognizing what tasks the user is performing and how the user is performing them.
- Developed, evaluated, and demonstrated the use of learned planning knowledge by the planning agent to (1) provide suggestions, and additional information, (2) perform tasks automatically, and (3) delegate tasks to others and monitor their execution.
- Successfully demonstrated PAL technology on real-world data from the STRATCOM SKIWeb system.

FY 2008 Plans:

- Develop, demonstrate, and evaluate core physical awareness, cyber-awareness, multimodal dialogue, machine learning, and representation and reasoning technologies to support cognitive assistant executive functions.
- Formulate an approach for receiving user guidance and translating it into the precise machine language necessary for both implementation and verification of user purpose and intent.
- Demonstrate the utility of PAL technologies for the Army Knowledge Online's Company Commander.com.
- Optimize PAL technology to provide maximum benefit to STRATCOM SKIweb users.
- Demonstrate PAL technologies on data from the Army's Command Post of the Future (CPOF), Navy Marine Corp Intranet (NMCI) and the DoD-wide Web Timeline Analysis System (WebTAS). Use the results of these demonstrations as lessons-learned for integration activities being conducted in military environments including the CPOF, the CFn, NMCI, and the ATO Programs. (See PE 0603760E, Project CCC-01 for additional details).

FY 2009 Plans:

- Develop a dialogue system with general and domain-specific semantics for eliciting natural language advice from the warfighter and other end users of PAL technology and PAL-enhanced systems.

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- Develop the ability for an integrated cognitive system such as PAL to examine its own behavior and learn from that experience.
- Based on initial user feedback, extend, improve, and optimize PAL technology for implementation and operational use in STRATCOM's SKIweb, the Army's Command Post of the Future (CPOF), Navy Marine Corp Intranet (NMCI), and the DoD-wide Web Timeline Analysis System (WebTAS) Programs.

	FY 2007	FY 2008	FY 2009
Integrated Learning*	15.740	20.011	17.160

*Previously this was part of Foundational Learning Technology.

(U) The Integrated Learning program is creating 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 effort 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. Such a cognitive system will ultimately need the capability to build and update its own internal model of the world and the objects in it without human input.

(U) Program Plans:

FY 2007 Accomplishments:

- Successfully formulated learning as an integrated problem solving process and developed representation languages that enable different components, e.g., planning, reasoning, simulation, etc., to share information during the learning process.
- Constructed integrated systems that can learn air control order planning and military medical evacuation planning by being shown a single demonstration by a human expert.
- Evaluated systems via a competition of their learning performance against that of human novices.

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FY 2008 Plans:
- Enhance integrated learning systems so the systems form explicit learning goals, make plans to achieve these goals, create hypotheses about learned knowledge where appropriate, and resolve sources of uncertainty in learned knowledge where it exists.
- Expand systems so they combine different types of knowledge and reasoning, based on the situation and information that is available.
- Modify existing algorithms so they emit and track uncertainty about information.
- Evaluate systems by having them learn expanded/full air control order (ACO) planning processes and procedures and military medical evacuation planning.

FY 2009 Plans:
- Modify the integrated learning systems so they can incorporate new software components dynamically and utilize the new capabilities while learning.
- Create control algorithms for the systems that manage credit-and-blame assignment on a component-by-component basis so that if conflicts arise the system can reason about which piece of conflicting information is more likely to be accurate.
- Create control algorithms that reason about the costs/benefits of resolving a particular conflict and direct system performance accordingly.
- Expand the scope of the problems being learned so the systems learn full air tasking order (ATO) planning processes and full military medical logistics planning.
- Evaluate systems by having them compete against novice humans.
- Enable cognitive systems to learn and manipulate their own models and concepts.

	FY 2007	FY 2008	FY 2009
Bootstrapped Learning*	5.266	6.673	9.081

*Previously this was part of Knowledge Representation and Reasoning.

(U) The Bootstrapped Learning program will provide computers with the capability to learn complex concepts the same way that people do, from a customized curriculum designed to teach a hierarchy of concepts at increasing levels of complexity, where learning each new level depends on having successfully learned the previous level. Such a capability is envisioned as revolutionary for cognitive systems in that bootstrapped learning systems will be "reprogrammable" in the field using the same modes of natural instruction used to train people, and without the need for

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software developers to modify the software code. In Bootstrapped Learning, 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. This will enable rapid learning of complex high-level concepts, a capability that is essential for autonomous military systems that will need to understand not only what to do but, ultimately, 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:

FY 2007 Accomplishments:

- Created a general purpose "Ladder Interface" used to decouple the bootstrapped learning system from the problem domains and instructional materials provided to them.
- Developed a pair of components that together implement both sides of the ladder interface and will serve as development aids.

FY 2008 Plans:

- Produce an initial prototype end-to-end system capable of bootstrapped learning, integrating different types of learning, input modalities, and repeatedly building on prior learning.
- Develop a complete electronic curriculum for three domains, including prerequisite knowledge, teaching algorithms, as well as curriculum development tools.
- Demonstrate a specific ability to learn a curriculum composed of at least three related lessons via at least three different interaction modalities and at least two different learning processes.

FY 2009 Plans:

- Demonstrate a single system capable of being instructed to perform in three diverse domains.
- Demonstrate the ability of a system to repeatedly acquire new knowledge that drives future learning and cumulatively adds to the system's knowledge.
- Validate that configuration and control of critical, autonomous military hardware can be addressed with bootstrapped learning technology.

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	FY 2007	FY 2008	FY 2009
Knowledge Representation and Reasoning Technology	1.147	2.346	7.807

(U) The Knowledge Representation and Reasoning Technology program 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 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) The cost of handcrafting information within the narrow confines of first order logic or other artificial intelligence (AI) formalisms is prohibitive for many applications. Machine reading addresses these issues by replacing the expert (and associated knowledge engineer) with un-supervised or self-supervised learning systems, systems that "read" natural text and insert it into AI knowledge bases, i.e. data stores especially encoded to support subsequent machine reasoning. Machine reading requires the integration of multiple technologies. Natural language processing must be used to transform the text into candidate internal representations. Knowledge representation and reasoning techniques must be used to test this new information, and determine how it is to be integrated into the system's evolving models so that it can be used for effective problem solving. While tremendous strides have been made in individual research areas, few efforts have attempted to integrate them to achieve machine reading.

(U) Program Plans:

FY 2007 Accomplishments:

– Developed the initial integrated knowledge representation and learning technology that enables effective representation of essential forms of knowledge.

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FY 2008 Plans:
- Explore novel methods for acquiring new knowledge including direct input through processing natural language text**.**
- Perform a proof-of-concept of learning-by-reading by the machine reading of small focused texts with the goal of encoding and querying at narrow but deep semantic levels.

FY 2009 Plans:
- Demonstrate the ability of a single system to acquire and organize information directly from unstructured narrative text in multiple domains.
- Extend knowledge representation to support machine reading of large (e.g. open source web) amounts of material with the goal of encoding and querying at broad but shallow semantic levels.
- Create a targeted reading capability to resolve conflicts and fill gaps in existing knowledge models.
- 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.
- 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.

	FY 2007	FY 2008	FY 2009
Foundational Learning Technology	17.317	14.603	12.000

(U) The Foundational Learning Technology program 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 and existing information stores. Foundational Learning technologies 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 efforts 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. This includes the integration and application of advanced machine learning techniques to further enable cognitive computing systems to learn from experience and adapt to changing situations. A very promising approach involves transfer learning techniques that 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

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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.

(U) Recent advances in neuroscience suggest that much of the rich and varied structure of the neo-cortex may be the natural consequence of a relatively simple cortical algorithm adapting itself to the structure latent in the input it receives from the world. It is therefore plausible to seek advances by modeling the sub-symbolic "instruction set" of the brain. Success here would provide alternatives to the symbolic approaches that currently predominate in areas such as perception, reasoning, and language.

(U) Program Plans:

FY 2007 Accomplishments:

- 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.
- Designed and developed 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.

FY 2008 Plans:

- Demonstrate the ability of a cognitive agent to learn, combine, and restructure knowledge in multiple domains and apply this to solve novel problems in those domains.
- Demonstrate the ability of a cognitive agent to generalize knowledge from particular domains and discover how to apply it to a problem in a new domain.
- Demonstrate the ability of a cognitive agent to synthesize knowledge and skills acquired from multiple domains, apply them effectively to problems in new domains, and demonstrate the ability to propose novel problem solution methods when specified resources are unavailable.

FY 2009 Plans:

- Conceptualize and propose algorithms that can take unorganized numeric inputs and, through interaction, "see" that these inputs represent some structured universe that obeys structured laws.
- Construct a single, massively parallel, general-purpose algorithm which could start with zero knowledge of its environment, and then grow to represent the structure latent in that environment.

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	FY 2007	FY 2008	FY 2009
Robust Robotics*	16.311	17.240	15.000

*Formerly Learning Locomotion and Navigation.

(U) The Robust Robotics program 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 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 program 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, 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

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collaborate in planning/traversing a diversity of routes and thereby enhance their likelihood of quickly finding a viable and/or (nearly) optimal path.

(U) Program Plans:

FY 2007 Accomplishments:

- 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.
- Funded technology development contracts and program planning support for the DARPA Urban Challenge.

FY 2008 Plans:

- Create new learning algorithms that use dynamic gaits to enable legged laboratory robots (that are small scale versions of operational sized platforms) to run over uneven terrain.
- Evaluate the new learning algorithms on a series of different terrain settings in a competitive fashion.
- 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.
- Fund prizes and support for the DARPA Urban Challenge.

FY 2009 Plans:

- Create new and modify existing learning algorithms to enable legged laboratory robots (that are small scale versions of operational sized platforms) to run over terrain at speeds proportional to humans.
- Evaluate the new learning algorithms on a series of different terrain settings in a competitive fashion.
- 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.

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(U) Other Program Funding Summary Cost:

- Not Applicable.

RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)						DATE February 2008	
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 2007	FY 2008	FY 2009	FY 2010	FY 2011	FY 2012	FY 2013
Collective Cognitive Systems and Interfaces COG-03	56.580	75.219	56.870	56.983	54.980	54.980	49.036

(U) Mission Description:

(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 an 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 2007	FY 2008	FY 2009
Collaborative Cognition	27.710	28.800	17.000

(U) The Collaborative Cognition program 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 program 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, 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 others capabilities. The Collaborative Cognition program consists of two efforts: Coordination Decision-Support Assistants (COORDINATORs), and Advanced Soldier Sensor Information System and Technology (ASSIST).

- The Coordination Decision-Support Assistants (COORDINATORs) effort 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) effort 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

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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 effort 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 (COORDINATORs)

FY 2007 Accomplishments:

-- Developed distributed coordination technology that reasons about making changes to task timings, assignments, and selection from pre-planned contingencies.
-- Tested coordination algorithms in a lab setting on large-scale coordination problems (100 COORDINATORs, 10,000 mission tasks), and demonstrated that algorithms achieve nearly optimal results in seconds.
-- Developed 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.
-- Developed 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.

FY 2008 Plans:

-- Modify coordination algorithms so they can reason about the physical geolocation of units and coordinate changes in unit location.
-- Modify coordination algorithms so they can operate effectively in network situations where latency may impact communications as it does in field settings.
-- Develop a coordination autonomy controller that enables a COORDINATOR system to interact intelligently with its human user, generating desired options and waiting for appropriate periods of time for the human to respond.
-- Develop a change evaluation module that couples the COORDINATOR technology to GPS units so the system automatically knows the location of a given unit.

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-- Develop a basic representation for military decision making policies and procedures so the COORDINATORs follow said procedures, and decisions are made at the proper levels.
-- Evaluate COORDINATORs technologies in a field setting.

FY 2009 Plans:
-- Develop a full and general purpose representation for military decision making policies and procedures so the COORDINATORs know when information must be propagated, and to whom, and reason about the full spectrum of decision authority.
-- Add learning algorithms to the change evaluation module so it can learn to anticipate problems before they arise.
-- Add resources and models of resources to the plan representation language and modify the coordination algorithms to coordinate over resources, (e.g., troop transportation vehicles).
-- Integrate COORDINATORs technologies with SOFTools, a planning system used by U.S. Special Operations Command.
-- Continue evaluating COORDINATORs in a field setting.

– Advanced Soldier Sensor Information System and Technology (ASSIST)

FY 2007 Accomplishments:
-- Demonstrated the baseline capture and retrieval system prototype and evaluated the effectiveness of the integrated system in Military Operations on Urban Terrain (MOUT) 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.
-- Deployed a research prototype to Iraq.
-- Incorporated lessons-learned from the experimental fielding to improve product for the warfighter.

FY 2008 Plans:
-- Demonstrate an automated, sensor-cued collection system for ground patrols.
-- Develop a software system to interpret and automatically index soldier-centric activities, events, scenes, and objects.
-- Develop analysis tools for the collected data.
-- Prototype a two-way capability for alerting patrols in the field.

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FY 2009 Plans:

-- Demonstrate real-time reporting using on-soldier sensors and an intuitive information push/pull user interface.
-- Address the technical challenges associated with providing ASSIST as a real-time capability for the dismounted soldier in the field.
-- Develop and demonstrate a real-time variant for use by dismounted soldiers, with enhancements that include video feeds from airborne platforms.
-- 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 2007	FY 2008	FY 2009
Cognitive Networking	20.523	30.986	25.263

(U) The Cognitive Networking research program 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. Cognitive information processing will be used to optimize networked communications based on current conditions, past experience and high-level user guidance. The Cognitive Networking program comprises three efforts: Situation-Aware Protocols in Edge Network Technologies, Local Area Network droid, and Brood of Spectrum Supremacy.

- The Situation-Aware Protocols in Edge Network Technologies (SAPIENT) effort 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 effort will have military utility wherever tactical communications are deployed.

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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 effort 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 Local Area Network droid (LANdroid) effort will give warfighters reliable communications in urban settings. LANdroid will accomplish this by creating robotic radio relay nodes that move autonomously to configure and maintain a communications mesh by reasoning about their positions relative to one another and relative to the warfighters. LANdroids will also move as the warfighters move – keeping them covered with communications throughout their operations. LANdroids will be pocket-sized so warfighters can carry several and drop or deploy them as they move through a given area. The effort is creating both the intelligent radio control software and the small radio platforms on which it runs. The technologies will be tested in a physical setting (i.e., not simulated) and at an operationally relevant scale.

- The Brood of Spectrum Supremacy (BOSS) effort 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 effort 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 effort will develop a prototype demonstration for a performer-selected RF platform, using and refining the hardware-independent executable specifications of the waveforms. Ultimately this effort will develop Software Communications Architecture (SCA)-compliant waveforms suitable for implementation on a tactical software radio system.

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(U) Program Plans:

– Situation-Aware Protocols in Edge Network Technologies (SAPIENT)

FY 2007 Accomplishments:

-- 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.
-- Demonstrated SAPIENT capabilities in laboratory venues.
-- Evaluated the impact of mobility on communications.

FY 2008 Plans:

-- Integrate and enhance prototypes and evaluate their performance.
-- 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.
-- Refine protocol selection and composition strategies with an integrated learning capability.
-- Demonstrate SAPIENT capabilities in laboratory and experimental airborne venues.

FY 2009 Plans:

-- Integrate and enhance prototypes and evaluate their performance.
-- Implement a functional cognitive learning system that facilitates real-time selection and composition of protocols.
-- Demonstrate an adaptive cognitive prototype in an urban environment using mobile, airborne, and stationary nodes.

– Local Area Network droid (LANdroid)

FY 2008 Plans:

-- Develop control algorithms for LANdroids so they can self-configure (forming the initial network), self-optimize (making small movements to improve the network), and self-heal (move to cover gaps in the network caused by nodes being destroyed or powering down).
-- Develop small robotic LANdroid platforms that meet basic requirements for size and capability.
-- Evaluate a 10-node LANdroid network.

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FY 2009 Plans:
-- Develop control algorithms for LANdroids that enable them to tether the network to warfighters so the network moves as the warfighters move.
-- Develop intelligent power management algorithms for LANdroids so they make intelligent decisions about whether or not to move based on current conditions and expected power expenditures (by moving) and savings (by being in a better location).
-- Develop network load balancing protocols for LANdroids that dovetail with the power management algorithms to enable the network to last as long as possible.
-- Harden the LANdroid robotic platform and reduce its weight.
-- Evaluate algorithms using a 15-node LANdroid network that spans two floors of an indoor building.

– Brood of Spectrum Supremacy (BOSS)
FY 2007 Accomplishments:
-- Developed 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.
-- Validated algorithms for network understanding tasks.
FY 2008 Plans:
-- Refine capabilities of Software Communications Architecture (SCA)-compliant platforms, while working within the software-defined radio trade space.
-- Validate implementations for network understanding tasks using SCA-compliant platforms.
FY 2009 Plans:
-- Implement BOSS capabilities on handheld/wearable software-defined radio platforms.
-- Test and evaluate BOSS handheld radios in “real-world” scenarios.

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	FY 2007	FY 2008	FY 2009
Integrated Collective Systems	7.200	15.433	14.607

(U) The Integrated Collective Systems technology program addresses information integration, one of the most critical and challenging problems facing the DoD and continually tops the list of critical defense needs. The current 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. The problem has been raised by numerous DoD and service studies as well as by Combatant Commanders themselves. The Integrated Collective Systems program 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. 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. The Integrated Collective Systems program consists of two efforts: Digital Network Archive (DNA) and Data Integration and Exploitation SystEm that Learns (DIESEL).

- 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 Digital Network Archive (DNA) effort 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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- Today's warfighters are overwhelmed with information, but have difficulty finding and integrating the right fragments of data they need from the vast array of disparate data sources available. Military systems including command and control, intelligence, information assurance, special operations, maintenance and logistics are plagued by non-integrated, heterogeneous, legacy information systems. The Data Integration and Exploitation SystEm that Learns (DIESEL) effort will develop a new suite of information integration techniques for the warfighter. The fundamental problem is that information systems are, necessarily, developed independently using different software conventions, data types, semantic models and assumptions about their use. All of these "stovepipe" systems come together at many levels of command, where they must interoperate and share data. A new suite of intelligent information integration tools are needed – ones that could *learn* to automatically ingest and understand new information systems as they occur and learn to semi-automatically map/integrate those new systems into the existing information environment. Recent developments in web services, DAML, and the Semantic Web have created the right infrastructure on which to develop this information integration technology. The ultimate utility of better information integration is better and faster decisions; the result of warfighters having the right information they need at the right time.

(U) Program Plans:

– Digital Network Archive (DNA)

FY 2007 Accomplishments:

-- Created web interfaces to a digital object repository enabling networked access.
-- Completed initial design work for implementing identity management, security, and privacy controls.
-- Launched a trial system demonstrating utilization of persistent digital object identification across multiple protocols and application platforms.

FY 2008 Plans:

-- Extend the digital repository architecture to enable ubiquitous access from multiple devices while providing secure, effective, document sharing.
-- Develop a prototype repository system with military applicability that can accommodate thousands of users and further facilitate an open, extensible, and vendor-independent architecture.
-- Research and develop technologies to address issues of access control, security, indexing and search, metadata creation and maintenance, and version tracking.

FY 2009 Plans:

-- Continue to develop a variety of innovative services for the repository architecture and prototype subsystems to address such issues as access control, security, indexing and search, metadata creation and maintenance, and version tracking.

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-- Bring on line multiple, interoperating, digital repositories demonstrating the feasibility, and advantages of the digital repository architecture.
-- Demonstrate controlled, secure access across administrative domains, and its potential for integrating diverse, distributed information bases.

– Data Integration and Exploitation SystEm that Learns (DIESEL)
FY 2008 Plans:
-- Incorporate scientific, technical, and military domain knowledge in emerging web-service, semantic, and knowledge-base information integration infrastructure technologies including XML, DAML, and OWL.
-- Demonstrate preliminary ideas for learning-based entity resolution, data source modeling, and schema mapping technologies.
-- Demonstrate “best effort integration” methods.
-- Review commercial technical baseline.
-- Describe military needs and representative challenge problems.
-- Develop multimedia database techniques to store the raw content and associated metadata to enable search, correlation, and analysis.
-- 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.
FY 2009 Plans:
-- Develop learning-based semantic integration techniques including brokering techniques to dynamically discover and compose information services “on the fly” to fit the user’s mission, situation, preferences, available data, and context in general.
-- Develop techniques for representing and composing services that use task learning to discover, represent and access new information sources.
-- Develop tools to easily add new components and services including machine learning techniques to induce schema ontology mappings.
-- Develop machine learning-based techniques to semi-automatically ingest, understand, and “wrap” legacy information sources.
-- Develop data discovery techniques to automatically search multimedia databases, semi-structured collections of data, and unstructured text collections for correlations and actionable intelligence.
-- Create new multimedia analysis algorithms with an emphasis on using context to determine feature attributes.

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	FY 2007	FY 2008	FY 2009
Improved Warfighter Information Processing (IWIP)	1.147	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 program developed the means, devices and infrastructure 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.

(U) Program Plans:
FY 2007 Accomplishments:
- Deployed to Commander Navy Europe/Commander Sixth Fleet (CNE-C6F) Navy Europe Plans and Operations Command Center (NEPOCC) and Theater Maritime Fusion Center (TMFC).

(U) Other Program Funding Summary Cost:

- Not Applicable.