| RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit) | DATE February 2005 |
|---|---|
| APPROPRIATION/BUDGET ACTIVITY<br>RDT&E, Defense-wide<br>BA2 Applied Research | R-1 ITEM NOMENCLATURE<br>Cognitive Computing Systems<br>PE 0602304E, R-1 # 13 |

| COST (In Millions) | FY 2004 | FY 2005 | FY 2006 | FY 2007 | FY 2008 | FY 2009 | FY 2010 | FY 2011 |
|---|---|---|---|---|---|---|---|---|
| Total Program Element (PE) Cost | 0.000 | 149.782 | 200.799 | 241.006 | 263.375 | 274.243 | 301.243 | 309.243 |
| Cognitive Systems Computing Foundations COG-01 | 0.000 | 27.552 | 33.678 | 37.710 | 41.284 | 41.751 | 56.751 | 56.751 |
| Learning, Reasoning, and Integrated Cognitive Systems COG-02 | 0.000 | 81.797 | 113.931 | 141.780 | 160.865 | 170.741 | 180.741 | 190.741 |
| Collective Cognitive Systems and Interfaces COG-03 | 0.000 | 40.433 | 53.190 | 61.516 | 61.226 | 61.751 | 63.751 | 61.751 |

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

(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. This program element and the projects funded within it were created in accordance with congressional intent in the FY 2005 DoD appropriations bill with prior year funding budgeted in PE 0602301E, Projects ST-30, ST-31, and ST-32.

(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.

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

(U) The Collective Cognitive Systems and Interfaces project will dramatically improve warfighter and commander effectiveness 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 | FY2006 | FY2007 |
|---|---|---|---|
| Previous President's Budget | 151.158 | 182.054 | 221.877 |
| Current Budget | 149.782 | 200.799 | 241.006 |
| Total Adjustments | -1.376 | 18.745 | 19.129 |

Please note that this program element has been newly created from projects previously funded in PE 0602301E. The *previous President's Budget* amount reflects projects ST-30, ST-31 and ST-32 funded under that PE.

| | |
|---|---|
| Congressional program reductions | -1.376 |
| Congressional increases | 0.000 |
| Reprogrammings | 0.000 |
| SBIR/STTR transfer | 0.000 |

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| APPROPRIATION/BUDGET ACTIVITY<br>RDT&E, Defense-wide<br>BA2 Applied Research | R-1 ITEM NOMENCLATURE<br>Cognitive Computing Systems<br>PE 0602304E, R-1 # 13 |

**(U) Change Summary Explanation:**

| | |
|---|---|
| FY 2005 | The decrease reflects congressional undistributed reductions. |
| FY 2006 - 2007 | The increase reflects expansion of learning programs in project COG-02 and collaborative cognition efforts in project COG-03. |

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| APPROPRIATION/BUDGET ACTIVITY<br>RDT&E, Defense-wide<br>BA2 Applied Research | R-1 ITEM NOMENCLATURE<br>Cognitive Computing Systems<br>PE 0602304E, Project COG-01 |

| COST (In Millions) | FY 2004 | FY 2005 | FY 2006 | FY 2007 | FY 2008 | FY 2009 | FY 2010 | FY 2011 |
|---|---|---|---|---|---|---|---|---|
| Cognitive Systems Foundations COG-01 | 0.000 | 27.552 | 33.678 | 37.710 | 41.284 | 41.751 | 56.751 | 56.751 |

**(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, mix 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 novel forms of computation developed in Cognitive Systems will revolutionize future military systems. Next-generation 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. The Cognitive Systems Foundations project will develop the necessary foundational software methods and hardware architectures to facilitate the learning and inference 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 new 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. This program element and project were created in accordance with congressional intent in the FY 2005 DoD appropriations bill. Prior year funding was budgeted in PE 0602301E, Project ST-32 and is noted as a memo entry in each of the following programs.

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**(U) Program Accomplishments/Planned Programs:**

| | FY 2004 | FY 2005 | FY 2006 | FY 2007 |
|---|---|---|---|---|
| Architectures for Cognitive Information Processing | (8.808) | 11.628 | 12.678 | 15.715 |

(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:

- Select innovative computer architecture(s) and in-context applications for cognitive architecture implementations, demonstration 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.

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| APPROPRIATION/BUDGET ACTIVITY<br>RDT&E, Defense-wide<br>BA2 Applied Research | R-1 ITEM NOMENCLATURE<br>Cognitive Computing Systems<br>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.

| | FY 2004 | FY 2005 | FY 2006 | FY 2007 |
|---|---|---|---|---|
| Self-Regenerative Systems | (7.423) | 9.821 | 12.000 | 12.300 |

(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. SRS technology 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. Beyond graceful degradation capabilities provided by fault- and intrusion-tolerance mechanisms developed in prior DARPA programs, 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. They will also maintain robustness and trustworthiness attributes even with growth and evolution in functionality and performance.

(U) Program Plans:
- 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.
- Demonstrate scalable data redundancy for network-centric military applications and infrastructure services, and develop techniques for natural robustness via biological metaphors to counter vulnerabilities of monoculture in military information systems.
- Develop techniques for natural robustness via biological metaphors to counter vulnerabilities of software monocultures in military information systems.
- Develop strategies to preempt insider attacks, including infer military system operator goals, enable anomaly detection, combine and correlate information from system layers and use direct user challenges.

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| | FY 2004 | FY 2005 | FY 2006 | FY 2007 |
|---|---|---|---|---|
| Security-Aware Systems | (4.163) | 6.103 | 9.000 | 9.695 |

(U) Today's military software systems are brittle in the face of changing requirements, and vulnerable to skilled attackers who develop creative and unpredictable strategies. Security-aware systems will avoid brittleness and vulnerability by reasoning about their own security attributes, capabilities and functions with respect to specific mission needs. Security-aware systems will also dynamically adapt to provide desired levels of service while minimizing risk and providing coherent explanations of the relative safety of service level alternatives. In addition, these systems will bolster the reliability and security of critical open source software systems by reducing vulnerabilities and logic errors, and providing state-of-the-art software analysis techniques augmented with cognitive decision-making techniques.

(U) The Application Communities (AC) program will leverage the research conducted under DARPA's information assurance programs to create a new generation of self-defending software that automatically responds to threats and provides a comprehensive picture of security properties and current status, displayed at multiple levels of abstraction and formality. This capability will bring intelligent security adaptation to DoD systems and make security properties and status more apparent to decision-makers, thus increasing the speed and confidence with which military systems can be securely and dynamically reconfigured, particularly under stressful conditions. AC technology will enable collections of similar systems to collaboratively generate a shared awareness of security vulnerabilities, vulnerability mitigation strategies, and early warnings of attack. AC will revolutionize the security of general-purpose information systems and reduce the threat from stealth attacks where attackers take control of systems undetected. In addition, this program will develop quantitative information assurance measurement techniques to enable military system integrators to construct networks and information systems with a high degree of confidence that the systems are protected against cyber-attacks (by the assurance properties of available components). The technology will greatly enhance the reliability and security of C4ISR systems.

(U) Program Plans:
- Demonstrate automated techniques for reasoning about and understanding the security-relevant interactions between software components of military systems.
- Develop techniques to summarize security policy and status so that the descriptions produced by AC can be understood while at the same time not omitting critical details.

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| APPROPRIATION/BUDGET ACTIVITY<br>RDT&E, Defense-wide<br>BA2 Applied Research | R-1 ITEM NOMENCLATURE<br>Cognitive Computing Systems<br>PE 0602304E, Project COG-01 | |

- Augment current techniques to construct a framework for developing high-assurance behavioral specifications (including security policies). Formulate a unified knowledge base to represent the properties and capabilities of disparate security mechanisms.
- Develop techniques to collaboratively diagnose and respond to problems (e.g., attacks or failures that threaten a mission) in groups of military systems.
- Develop static and dynamic source code analysis techniques (e.g., data- and control-flow-based techniques, model-checking, strong typing) to relate software module structures and runtime state with the representation of security properties/configurations.
- Demonstrate self-explanation techniques in which systems explain their critical security properties and status in a manner that is understandable to a variety of managing software components and human operators.
- Develop test and validation regimes to assess the protection mechanisms of security products and certify protection to quantifiable levels based on a scientific rationale.
- Develop measures to quantitatively characterize various dimensions of security (availability, integrity, confidentiality, authentication, and non-repudiation), fault tolerance, and intrusion tolerance and demonstrate the theory's relevance by applying it to a realistic exemplar system.
- Demonstrate cognitive security analysis of complex multi-component software systems.
- Create an extensible knowledge base of embedded system design flaws.

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

- Not Applicable.

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| APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research | R-1 ITEM NOMENCLATURE Cognitive Computing Systems PE 0602304E, Project COG-02 |
|---|---|

| COST (In Millions) | FY 2004 | FY 2005 | FY 2006 | FY 2007 | FY 2008 | FY 2009 | FY 2010 | FY 2011 |
|---|---|---|---|---|---|---|---|---|
| Learning, Reasoning and Integrated Cognitive Systems COG-02 | 0.000 | 81.797 | 113.931 | 141.780 | 160.865 | 170.741 | 180.741 | 190.741 |

**(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 degradation or failure and mission success, 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 Learning, Reasoning and Integrated Cognitive Systems 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 human 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. This program element and project were created in accordance with congressional intent in the FY 2005 DoD appropriations bill. Prior year funding was budgeted in PE 0602301E, Project ST-30 and is noted as a memo entry in each program below.

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**(U) Program Accomplishments/Planned Programs:**

| | FY 2004 | FY 2005 | FY 2006 | FY 2007 |
|---|---|---|---|---|
| Integrated Cognitive Systems | (31.046) | 45.409 | 57.192 | 63.063 |

(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 thrust comprises the Personalized Assistant that Learns (PAL) and Cognitive Command, Control, Communication, Computers, Intelligence, Surveillance, and Reconnaissance (Cognitive C4ISR) programs.

- 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

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<tr><td>APPROPRIATION/BUDGET ACTIVITY<br>RDT&E, Defense-wide<br>BA2 Applied Research</td><td colspan="2">R-1 ITEM NOMENCLATURE<br>Cognitive Computing Systems<br>PE 0602304E, Project COG-02</td></tr>
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intermediate preferences and constraints on system behavior, to specific direction and contingency actions. The end-user will be able to engage in a natural dialogue with the system, and the advice will be translated to an executable form.

- The Cognitive Command, Control, Communication, Computers, Intelligence, Surveillance, and Reconnaissance (Cognitive C4ISR) program will develop embedded learning and real-time reasoning elements along with multimodal dialog-based interfaces to enable a new generation of cognitive C4ISR. These technologies will support effective decision-making in the face of the increased pressures, ambiguity, deception and surprise of today's military operations. The embedded learning element will provide faster response times by allowing a system to retain and apply what it has learned in the past. Real-time reasoning allows the system to apply what has been learned to new scenarios in an intelligent and thorough way. The multimodal dialogue technology transition to the military will emphasize adaptable and scalable architectures and automatic dialogue that addresses human stress adaptation, prosody and system reliability. The Cognitive C4ISR transition efforts will assist commanders by providing critical information in a timely manner, with alternative courses or action, to enable more effective decision-making.

(U) Program Plans:

- Personalized Assistant that Learns.
  - Developed baseline architecture for a complete PAL system.
  - Developed an initial knowledge base representing a PAL system's task domain.
  - Developed initial technology for a PAL system to interact with its user and enable the system to perceive activities over time and develop an understanding of user preferences and basic operational procedures.
  - Develop mixed-initiative technology that enables a PAL system to ask appropriate questions at appropriate times when confidence in an inference is below threshold.
  - Develop and demonstrate core machine learning, knowledge base and flexible planning technologies to enable development of a cognitive planning agent.
  - Develop and demonstrate 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 the ability for an integrated cognitive system to examine its own behavior and learn from that experience.

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- -- Develop test problems, define metrics, and conduct formal experiments to evaluate progress in integrated cognitive systems technology R&D.
- -- Develop compelling scenarios to drive advisable technology research through a series of increasingly difficult challenge problems.
- -- 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.

– Cognitive C4ISR.
- -- Develop technologies to enable a system to draw inferences from mission-defined rules of operation for situational awareness from which a course of action may be suggested.
- -- Develop a common architecture and integration technologies that will examine and characterize the influences and interactions among the organization structure, its staff, tasks and technology.

| | FY 2004 | FY 2005 | FY 2006 | FY 2007 |
|---|---|---|---|---|
| Foundational Learning Technology | (11.112) | 26.224 | 38.830 | 55.282 |

(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 comprises Real-World Learning, Bio-Inspired Cognition, and Learning Locomotion and Navigation.

- The Real-World Learning thrust 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 the ability to transfer knowledge and skills learned for specific situations to novel, unanticipated situations and perform appropriately and effectively the first

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time a 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 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. Cognitive systems 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. Real-World Learning will enable systems to execute unanticipated tasks with minimal direction and will provide a much-needed military capability for coping with dangerous and unpredictable situations.

- The Bio-Inspired Cognition thrust (formerly Neuromorphic Learning Technology) 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/sensor 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.

- The Learning Locomotion and Navigation thrust will develop learning and reasoning technologies that specifically address concerns in robotic systems. The resulting robotic systems will learn automatically 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, 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. This thrust comprises two components: Learning Applied to Ground Robots (navigation) and Learning Locomotion.

(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 generation of specific and novel situations to use for evaluating 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; to adapt to a wide variety of naturally-occurring situations; and to 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.
  - -- 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 and skills acquired for one purpose to other purposes, and demonstrate the ability to propose novel problem solution methods when specified resources are unavailable.
  - -- 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.
  - -- Create methods for using domain knowledge to guide and direct learning algorithms.
  - -- 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.

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- 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 two test batteries for testing and evaluating cognitive architectures: a "cognitive decathlon" for assessing specific skills associated with cognition (e.g., visual perception, memory); and a set of challenge problems, each of which will require a complex range of cognitive functions in order to be successfully negotiated.
  - Using these batteries, compare the performance of biomorphic learning technologies against those of traditional artificial intelligence.

- 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.

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| | FY 2004 | FY 2005 | FY 2006 | FY 2007 |
|---|---|---|---|---|
| Knowledge-Based Technology | (5.647) | 10.164 | 17.909 | 23.435 |

(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-Base 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 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 some new ways for knowledge to be transferred efficiently to a knowledge base including 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 store knowledge about the choices the warfighter has made in the past, so when faced with a similar task, the system would select a performance method by referring back to previous decisions. Although not appropriate for all cognitive systems tasks, this action-

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centric technique should be effective for simple tasks, such as information gathering to support mission planning or intelligence analysis. Most cognitive research is predicated on explicit representation (i.e., having models of the world) and reasoning about the way to achieve a specific goal or meet specific need. While this approach is effective, encoding the knowledge and reasoning procedures is labor intensive and expensive. This program will develop a new technique that eliminates the material investment required by traditional approaches. This approach will replace deep reasoning and deep semantics with implicit reasoning and semantics derived from actual warfighter performance and experience.

(U) Program Plans:

- Knowledge-Based Systems.
  - Develop 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. 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.
  - Explore novel methods for acquiring new knowledge that are less onerous than traditional methods requiring hand-coding by experts including direct input through processing natural language text.

- 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 the performer and store these operations along with the implicit semantic knowledge in a repository for future automation.

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**(U) Other Program Funding Summary Cost:**

- Not Applicable.

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| COST (In Millions) | FY 2004 | FY 2005 | FY 2006 | FY 2007 | FY 2008 | FY 2009 | FY 2010 | FY 2011 |
|---|---|---|---|---|---|---|---|---|
| Collective Cognitive Systems and Interfaces COG-03 | 0.000 | 40.433 | 53.190 | 61.516 | 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, which 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 to take advantage of the power of collective cognitive agents.

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(U) The suite of programs conducted under project will significantly advance the military's ability to address and deal with complex situations in operational environments. This program element and project were created in accordance with congressional intent in the FY 2005 DoD appropriations bill. Prior year funding was budgeted in PE 0602301E, Project ST-31 and is noted as a memo entry in each program below.

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

| | FY 2004 | FY 2005 | FY 2006 | FY 2007 |
|---|---|---|---|---|
| Improved Warfighter Information Processing | (21.206) | 12.763 | 12.112 | 0.000 |

(U) The Improved Warfighter Information Processing (IWIP) technology thrust will develop technologies to enhance the warfighter's and commander's information management capacities and improve decision-making performance. This thrust will develop technologies to enable systems to detect and assess the user's cognitive state (e.g., level of attention, memory retention, and decision-making capabilities) and adapt to optimize the user's understanding and productivity. The work will significantly expand the warfighters' capabilities in a real-time operational environment by enhancing information throughput and retention, and executive function efficiency. This thrust will also help create context-based computational systems that will understand, predict and participate in goal-directed collaboration to maintain situational awareness and assist the warfighter in the decision-making process. Recent progress in neural science, computation and miniaturization can now be leveraged to enable new concepts of warfare. The technologies developed under this thrust will revolutionize the way 21st Century warriors and commanders interact with computer-based systems, implement advanced systems design methodologies, and fundamentally re-engineer military decision-making processes. The IWIP thrust comprises two programs: Improving Warfighter Information Intake under Stress and Context-Based Computing for Command and Control.

- 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

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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 will also pursue 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 an MOA with the U. S. Army Soldier and Biological Chemical Command and the Naval Air Systems Command for transition of this program.

- The Context-Based Computing for Command and Control ($CBC^3$) program will demonstrate dramatic improvements in command decision-making and situational awareness, in real time, based on the development of "context-based computing." $CBC^3$ will also capture, in real time, the context (situation assessment including information about places, people, time, functional activities, etc.) critical for supporting the decision-maker. Software tools and agent services will be provided to support the rapid creation of interoperability capabilities for information exchange in heterogeneous environments. The long-term impact of this work will be to provide users with vastly expanded expressive power, interface flexibility and transparency, timely access to relevant information, and greater overall utility and robustness of interaction with next-generation military digital systems.

(U) Program Plans:

– Improving Warfighter Information Intake under Stress.
  -- 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.
  -- 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.

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- -- Quantify and characterize 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.
- -- 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 proactive information manipulation and presentation.

– Context-Based Computing for Command and Control.
- -- Identify decision-making bottlenecks, impediments, and information exchanges in specific command and control settings in the context of on-going military and non-military operations; define operational metrics for decision-making.
- -- Develop techniques for capturing the context of military command and control center operations to enable intelligent information management.
- -- Elaborate interfaces into full-fledged "decision-interactive spaces" to illustrate the full power of decision-focused computing for command and control.
- -- Allow for the flexible adaptation of policy and protocol in information exchange and the issuing of orders; allow for interoperability across disparate security domains.
- -- Integrate interoperable agent-based technologies into existing military operations to provide secure and easy-to-use solutions.

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| | FY 2004 | FY 2005 | FY 2006 | FY 2007 |
|---|---|---|---|---|
| Collaborative Cognition | (7.780) | 15.232 | 20.204 | 26.383 |

(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 in dynamic environments that 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 and prediction tools, and other aids to human decision-making. The technology developed 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 three programs: Collaborative Cognition Systems, Coordination Decision-Support Assistants (COORDINATORs), and Advanced Soldier Sensor Information System and Technology (ASSIST).

- The Collaborative Cognition Systems program will develop software for controlling agent computer programs capable of interacting with both friendly and adversarial software agents, and operating in multiple domains and/or varying scenarios within the same domain. The application of learning and reasoning technology in an explicitly collaborative setting will allow systems to modify themselves based on experience and information exchanged among multiple team members; this will enable adept control of agent programs under previously unseen or unknown conditions. This work will also explore revolutionary concepts for applying distributed agent technology to modeling and simulation systems. The long-term goal is to apply this technology to operational environments, thereby significantly advancing deployed system capabilities.

- 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 and conflict situation by keeping track of 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 with far fewer

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personnel required in the re-planning coordination 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 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 Iraqi 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:

– Collaborative Cognition Systems.
  - -- Develop a strategic control language to specify the behaviors of individual software agents and teams of agents regardless of their low-level implementations.
  - -- Develop plug-and-play modules for cognitive processes and primitive behaviors to increase the intelligence of software agents in simulation and autonomous systems.
  - -- Create an ability for software agents to monitor, assess and explain the situation in the environment to support autonomous and collaborative behavior with other agents and warfighters-in-the-loop.

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- 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 can self-direct option generation when the human units are occupied or uninterruptible.
  - Develop a meta-cognition technology that reasons about resource allocation (i.e., where a given COORDINATOR should spend its processing time), so that 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 that COORDINATORs follow correct information exchange protocols and ensure that decisions and recommendations stay within the scope of authorization.

- Advanced Soldier Sensor Information System and Technology (ASSIST).
  - Demonstrate 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 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.

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| | FY 2004 | FY 2005 | FY 2006 | FY 2007 |
|---|---|---|---|---|
| Self-Sufficient Collective Systems (formerly "Self-Aware Collective Systems") | (1.949) | 2.338 | 4.781 | 9.422 |

(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 a specific task. 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.

(U) The Cognitive Collectives for Autonomic Situation Awareness thrust will create software technologies that enable future warfighters to form a collective unit and share information automatically. This will provide the warfighters with a broad tactical battlespace awareness. The selection, generation, sharing and display of information will be handled by cognitive software systems coupled with each warfighter. The network of individual systems will form a collective. Each system will monitor the sensors attached to its 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.

(U) Program Plans:

- Cognitive Collectives for Autonomic Situation Awareness.
  - 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.

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| | FY 2004 | FY 2005 | FY 2006 | FY 2007 |
|---|---|---|---|---|
| Cognitive Networking | (9.072) | 10.100 | 16.093 | 25.711 |

(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 communication based on current conditions, past experience and high-level user guidance. The Cognitive Networking thrust comprises three programs: Universal Adaptive Controller for Mission-Aware Ad-Hoc Networks, Self-Sustaining Peer-to-Peer Systems, and Situation-Aware Protocols in Edge Network Technologies.

(U) An outgrowth of the Adaptive Networking program, the Universal Adaptive Controller for Mission-Aware Ad-Hoc Networks (UNMAN) program will develop an adaptive configuration management capability that dramatically reduces life-threatening communication failures in complex communication networks. In order to develop this new capability, the initial focus is on the tactical mobile ad-hoc networks (MANETs). As are other critical networks, MANETs are composed of interdependent nodes based on interdependent system layers. Each node exposes dozens to hundreds of configurable parameters that must be continuously adapted due to variable tactical factors such as mission profile, phase, force structure, enemy activity, and environmental conditions. The complexity of this high-dimensional, adaptive, constrained, distributed network configuration problem is overwhelming to human operators and designers. Furthermore, today's commercial trends are not aimed at supporting the DoD's extreme deployments. This program will take on the ambitious goal of addressing the integrated management of all network layers simultaneously. Key technical challenges include mission understanding and mapping mission requirements to goals for each of the network's agents in order to optimize instantaneous resource allocation. These challenges are particularly difficult in a distributed setting with partial and uncertain information, high communications overhead, and high probability of failure. To address this problem, the UNMAN program will develop new mission-aware, adaptive, distributed, active learning and reasoning technologies that will provide a robust and effective configuration capability for MANETs.

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(U) The Self-Sustaining Peer-to-Peer Systems program, an outgrowth of the DARPA Networking program, will develop resilient, scalable sensor/computation/communication networks with decentralized control. This technology will enable continuous monitoring of critical areas and targets in remote or inaccessible areas through the development of self-forming, large *ad hoc* networks of sensors and computational elements. Networks will operate within severely resource-constrained environments (power, bandwidth, stealth) of military operations, while enabling critical networks to survive component failure, network intrusion and the subversion of elements. This self-sustaining network of sensors and communication elements will provide a lifeline to the warfighter in the support of effective operations while automating the burdensome and distracting tasks of network deployment, configuration and management. High-level languages will be developed to map the warfighter's mission plans, including geographical constraints and direct control of individual sensors, into network control actions. The cognitive network technology will provide on-demand sensing, imaging and tracking with a prediction/planning capability to estimate the state and trustworthiness of network elements, communication links, and assets connected by sensors. Thus, as elements fail or are subverted, the Self-Sustaining Peer-to-Peer Systems will control the graceful degradation of any of its parts. The program will develop network technology for terabit data streaming and processing, on-demand networking and methods for mobile, data-centric ad-hoc networks. This technology will support a variety of networks of manned and unmanned systems.

(U) 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 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 and demonstrate 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.

(U) Program Plans:
- Universal Adaptive Controller for Mission-Aware Ad-Hoc Networks.
  - Identify and characterize the major components of an adaptive/cognitive network and software functionality for large-scale redesign.

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- -- Demonstrate the operation of multiple cognitive radios as a team operating as a single unit.
- -- Automatically respond to dynamics associated with mission, capabilities and location.
- -- Design and develop appropriate interfaces between the two architectural components of a cognitive network: the “mission understanding” layer and the “adaptive control” layer.
- -- Develop and demonstrate multi-level learning capabilities that can perform active learning and empirical optimization of resource allocations in mobile ad-hoc networks.
- -- Develop and demonstrate mission understanding and adaptive control capabilities that can drive resource allocation in mobile ad-hoc networks.

– Self-Sustaining Peer-to-Peer Systems.

- -- Define and develop cognitive representations and distributed agent technologies, information fusion, diagnostic and prognostic algorithms, network control language, and network benchmarks.
- -- Integrate image recognition, adaptive radio frequencies (RF) and other sensors, and advanced signal processing for scene analysis and information extraction from sensors allowing operator input to be incorporated as necessary.
- -- Develop a dynamic architecture that defines logic, belief representation, cognitive network protocols, and adaptive target recognition and negotiation techniques.
- -- Develop mathematical models and algorithms to synthesize intelligent, self-sustaining, self-forming networks allowing for distributed control; synthesize global models based on distributed local inputs, and to improve over time using learning technology such as reinforcement learning and Bayes Nets.
- -- Initiate the development/demonstration of robust, secure, self-forming tactical networks.
- -- Develop software models and tools for massive data streaming and processing.
- -- Develop novel 3-D network management software for collaborative information processing and conversion of raw sensor data, detection, classification, tracking and event correlation to support integrated micro-sensor framework for mobile and on demand networks.

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– Situation-Aware Protocols in Edge Network Technologies.
  -- Create 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.
  -- Develop a suite of fundamental protocol components appropriate for these situations.
  -- Develop and implement a selection and composition methodology to exploit situation awareness to construct a functioning network protocol adapted to the situation.

| | FY 2004 | FY 2005 | FY 2006 | FY 2007 |
|---|---|---|---|---|
| Network Modeling and Simulation | (4.249) | 0.000 | 0.000 | 0.000 |

(U) The Network Modeling and Simulation (NMS) program developed software to enable prediction of performance; design; and control of complex networks over a broad range of time scales, network sizes, composition and performance. These models and simulators are enabling reliable and rapid planning, design, analysis, and configuration of military and emergency networks with minimal manual intervention. They have already transitioned to a number of military users, and are currently finding increasing interest in the DoD community.

(U) Program Plans:
– Developed the largest, fastest network simulation to date. Demonstrated a simulation of millions of nodes in near real time. Developed a hybrid simulator integrating fluid and multi-fractal models. Achieved 100x scalability in network size, 50-100x speed in simulation over sequential techniques, for both wired and wireless networks.
– Implemented measurement and simulation based, on-line prediction of core Internet, and border gateway protocol, stability and vulnerability, including that arising from virus propagation.
– Developed a simulator suitable for on-line network analysis and control, and scalable to tens of thousands of nodes.
– Demonstrated on line network controls including quality-of-service provisioning and dynamic reconfiguration.
– Demonstrated 10 to 100 x improvements in time to field new protocols, fault and vulnerability diagnosis, over operator-intensive current techniques.

| RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit) | DATE February 2005 |
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| APPROPRIATION/BUDGET ACTIVITY<br>RDT&E, Defense-wide<br>BA2 Applied Research | R-1 ITEM NOMENCLATURE<br>Cognitive Computing Systems<br>PE 0602304E, Project COG-03 |

- Transitioned simulation software to DoD clients including DISA, DMSO, FCS, Navy, Air-Force, JFCOM and other service agencies, for use in applications including infrastructure protection, rapid battlefield network design, and network management and control.

**(U) Other Program Funding Summary Cost:**

- Not Applicable.