RDT&E BUDGET ITEM JUSTIFICATION SHEET (R-2 Exhibit)					DATE February 2004		
APPROPRIATION/BUDGET ACTIVITY RDT&E, Defense-wide BA2 Applied Research			R-1 ITEM NOMENCLATURE Computing Systems and Communications Technology PE 0602301E, R-1 #12				
COST (In Millions)	FY 2003	FY2004	FY2005	FY 2006	FY 2007	FY 2008	FY 2009
Total Program Element (PE) Cost	390.607	334.696	342.614	408.070	470.866	503.595	535.638
Intelligent Systems and Software ST-11	41.373	43.492	43.735	49.775	74.761	76.022	67.041
High Performance and Global Scale Systems ST-19	121.391	72.188	50.236	75.000	75.000	75.000	100.000
Information Assurance and Survivability ST-24	31.773	46.117	52.513	65.474	63.283	77.855	99.968
Asymmetric Threat ST-28	79.163	0.000	0.000	0.000	0.000	0.000	0.000
Language Translation ST-29	42.848	57.201	44.972	35.767	35.945	36.196	40.826
Learning and Reasoning ST-30	15.198	60.503	91.173	112.535	120.761	131.858	124.399
Communications, Interaction and Cognitive Networks ST-31	24.180	34.140	32.433	36.069	59.833	58.570	50.512
Computing Foundations ST-32	8.282	17.583	27.552	33.450	41.283	48.094	52.892
Knowledge Representation and Reasoning ST-33	26.399	3.472	0.000	0.000	0.000	0.000	0.000

(U) Mission Description:

(U) The Computing Systems and Communications Technology program element is directed toward the application of advanced, innovative computing systems and communications technologies. Cognitive Information Processing Technology will be 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.

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(U) The Intelligent Systems and Software project develops new technology for software creation, processing and database management. It promises significantly improved software for systems that produce, store, and analyze information about battlespace operations. Efforts will develop fundamentally new techniques for: (1) transforming signals into descriptions of battlespace entities; (2) exchanging information about entities among different systems at both the syntactic and semantic levels; and (3) managing that information exchange as situations and resources change over time.

(U) The High Performance and Global Scale Systems project develops the computing, networking, and associated software technology base underlying the solutions to computational and information-intensive applications for future defense and federal needs. These technologies will lead to successive generations of more secure, higher performance, and more cost-effective microsystems, associated software technologies, advanced mobile information technology and prototype experimental applications critical to defense operations.

(U) The Information Assurance and Survivability project is developing the technology required to make emerging information system capabilities (such as wireless and mobile code/mobile systems) inherently secure, and to protect DoD's mission-critical systems against attack upon or through the supporting information infrastructure. These technologies will enable our critical systems to provide continuous correct operation even when they are attacked, and will lead to generations of stronger protection, higher performance, and more cost-effective security and survivability solutions scalable to several thousand sites.

(U) The Language Translation project will develop and apply new software database management and human computer interaction technologies to provide fundamentally new capabilities of critical importance for a wide range of national security needs. This will enable advanced information technology to (a) automatically exploit large volumes of speech and text in multiple languages; (b) revolutionize human-computer interaction via using spoken and written English and foreign languages; (c) more effectively accomplish computing and decision-making tasks in stressful, time sensitive situations; and (d) become active, autonomous agents/assistants to the warfighter by collecting, filtering, synthesizing and presenting information in a timely and relevant form.

(U) The Learning and Reasoning project will develop technologies that enable systems to learn and draw on their accumulated experience by applying knowledge gained through such experience to improve performance. These technologies will lead to systems demonstrating increased self-reliance, self-adaptive reconfiguration, intelligent negotiation, cooperative behavior, and survivability with reduced human intervention. Cognitive systems will comprise three primary types of processes: reactive, deliberative and reflective. Each of these will be improved through experiential learning.

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(U) The Communications, Interaction and Cognitive Networks project will dramatically improve warfighter effectiveness by: (1) developing revolutionary methods for users to interact with and direct cognitive systems (and the physical sensors and effectors they control) and (2) enabling large-scale collections of cognitive systems to interact with one another in support of user objectives. Specifically, this project will develop technologies for creating systems capable of instruction, guidance, and persuasion using all forms of natural communication; technologies enabling systems to detect and assess the user's cognitive state and adapt to optimize understanding and effectiveness of the user; and high-level languages for rapid but precise specification of complex behavior in response to mission demands, such as configuration of sensor networks.

(U) The Computing Foundations project will develop novel system-level solutions through the intelligent integration of cognitive capabilities built on robust software and hardware infrastructure. Systems with humanlike capability will integrate the cognitive capabilities of reasoning, learning, explaining, ability to be advised, self-awareness and coping robustly with surprise. These aspects of intelligence will be combined in innovative and powerful ways using new cognitive architectures. Overall this element seeks to make fundamental scientific and mathematical improvements in our understanding of and ability to create information and computing systems.

(U) The Knowledge Representation and Reasoning project is central to the creation of a new class of computational systems – Cognitive Computing Systems. These novel computer-based systems will reason, learn, and respond intelligently to things that have not been previously programmed or encountered. This will be accomplished by creating unique and powerful new abilities for computers to perceive and understand the world, and to reason intelligently with the results of this kind of perception. This program will develop novel and effective technologies for representing knowledge of the world in computer-processable form. This project focuses on two groundbreaking research areas that will develop core cognitive capabilities essential to a cognitive information processing system.

(U) **Program Change Summary:** *(In Millions)*	**FY 2003**	**FY 2004**	**FY2005**
Previous President's Budget	409.256	404.859	479.119
Current President's Budget	390.607	334.696	342.614
Total Adjustments	-18.649	-70.163	-136.505

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	FY 2003	FY 2004
Congressional program reductions	0.000	-76.590
Congressional increases	0.000	6.500
Reprogrammings	0.110	-0.073
SBIR/STTR transfer	-18.759	0.000

(U) Change Summary Explanation:

FY 2003	Decrease reflects SBIR transfer and below threshold reprogrammings.
FY 2004	Decrease reflects congressional program reduction to terminate Information Awareness Office activities in Project ST-28, offset by congressional adds for Through-Wall Radar Imaging, Secure Group Communications and the Counterterrorism Information Initiative.
FY 2005	Decrease reflects termination of Project ST-28 in response to congressional action and repricing of cognitive computing programs in Projects ST-31 and ST-32.

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COST (In Millions)	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008	FY 2009
Intelligent Systems and Software ST-11	41.373	43.492	43.735	49.775	74.761	76.022	67.041

(U) **Mission Description:**

(U) This project develops new technology for software creation, processing and database management to significantly improve software for systems that produce, store, and analyze information about battlespace operations. It develops fundamentally new techniques for : (1) transforming signals into descriptions of battlespace entities; (2) exchanging information about entities among different systems at both the syntactic and semantic levels; and (3) managing that information exchange as situations and resources change over time. First, they accelerate the design of complex Command, Control, Communications and Computation Intelligence, Surveillance and Reconnaissance (C^4ISR) systems. By formalizing descriptions of semantics, performance, and resource levels, they save programming time. By developing design tools to use those formalisms to assemble systems, they save developers time. Second, they enable field integration of legacy systems by providing general-purpose tools. These tools use the formalisms to search for, browse, display, and combine services available to a command center.

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

	FY 2003	FY 2004	FY 2005
Advanced Human-Computer Interaction for Robust Sensor Exploitation	0.000	0.000	3.000

(U) The Advanced Human-Computer Interaction for Robust Sensor Exploitation program will develop new interactive mechanisms for analysts and commanders to interact with sensed data. The objective is to facilitate rapid manipulation, correlation, presentation and planning. The program develops new visualization concepts including immersive interactive visualization, interactive temporal data mining, acoustic, haptic and gesture interfaces, and configurable presentation concepts. They will allow "game-like" interactivity with sensor databases, providing rapid feedback to permit what-if exploration of target hypotheses. This program enables more comprehensive utilization of multiple data sources and data feeds. This in turn accelerates certain critical functions: (1) locating challenging targets; (2) processing situational awareness data; (3) interpreting context and intent; and (4) mining historic data for trends. The program particularly enables retrospective, multi-source analysis to understand the historical context of unanticipated events.

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(U) Program Plans:
- Acquire a diverse set of all-source (radar, optical, acoustic, SIGINT) data from observations of training exercises.
- Register and align the data to a common reference frame, and store in a laboratory repository.
- Install prototype tools in the laboratory.
- Evaluate prototypes for novelty, effectiveness, and compatibility.
- Select the most promising tools for further development.
- Assess performance of upgraded tools in terms of coverage rate, error rate, and confidence.

	FY 2003	FY 2004	FY 2005
Advanced Target Identification and Classification	0.000	0.000	4.500

(U) The Advanced Target Identification and Classification (ATIC) program will develop new sensor exploitation aids to enable detection of targets in high-volume sensor feeds with minimal human support. ATIC supports very large target decks (thousands of target types) with high identification performance and very low false alarm rates. It is developing a calculus of variation to account for target variability within a target deck. The program supports appropriate interactions with humans-in-the-loop. ATIC features robust bounds on target classification performance and techniques for on-the-fly training or recognition systems. It promises improved speed and accuracy of target detection, recognition and identification in high volume sensor imagery. The program will dramatically reduce sensor-to-shooter timelines, allowing dynamic target engagement of relocatable and moving targets, and will enable future autonomous hunter-killer weapon concepts. Manpower burdens and requirements for human analysis of sensor data will be reduced, allowing humans to focus on the most critical or ambiguous target calls. Increased targeting flexibility and wide-area robust situational awareness that more fully describes the capabilities of surface targets will be realized.

(U) Program Plans:
- Develop statistical models of target variability, including shape, surface material, and emissions.
- Extend high-fidelity signature generation software (both optical and radio frequency) to evaluate sensitivities of signatures to target variations.
- Identify stable features that distinguish among target type but are insensitive to expected target variations.

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- Define a test set of regular and irregular military vehicles.
- Collect data from sample vehicles using a variety of standoff sensors (radar, optical) in a variety of environments.
- Verify that the selected features provide robust target characterization.

	FY 2003	FY 2004	FY 2005
Software for Situational Analysis	14.037	7.292	0.000

(U) Two complementary programs are budgeted in the Software for Situation Analysis thrust: Rapid Knowledge Formation, and High Precision Knowledge Formation.

- The Rapid Knowledge Formation (RKF) program enables subject matter experts who are not Artificial Intelligence (AI) experts to build, share, and reuse large knowledge bases. RKF is developing technologies for evaluation in challenge problem experiments in tactical ground combat. Technology hurdles include: direct knowledge entry by non-AI experts; coordinating entry of possibly overlapping and inconsistent knowledge by geographically distributed individuals; and achieving a knowledge entry rate by people untrained in AI at twice the rate of today's AI expert. Knowledge entry R&D is focused on techniques for natural language user input into statements of logic. Knowledge coordination focuses on generating new axioms. (Axiom creation techniques include reasoning by analogy, reasoning by example, and techniques for combining sets of axioms.) An especially taxing problem is combining axiom sets developed by different sources, into larger, consistent modules. RKF requires creation of large knowledge bases because it aims to solve complex problems. The problems include: detection and identification of evasive and concealed targets; offensive and defensive information operations; and Weapons of Mass Destruction (WMD) capability assessments of terrorist organizations. RKF is delivering a number of sets of knowledge engineering and development tools. These tools will be provided to DoD and government organizations for incorporation in their intelligence and warfare analysis systems.

- The High Precision Knowledge Formation (HPKF) initiative develops tools to build rich, complex, highly specialized knowledge bases needed to support precision tactical operations. Ground warfare tactics exhibit great variety and complexity. They are highly dependent upon complex relationships between natural and man-made elements of the battlefield. HPKF develops tools to construct, maintain, and update knowledge about terrain features, mobility factors, sensor characteristics, weapons effects, and engagement tactics. It encompasses

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combat situations ranging from desert warfare through infantry operations in jungle to urban combat. It enables automated forces and planning systems to achieve precision engagement of hostile ground forces, both mechanized and dismounted.

(U) Program Plans:

- Rapid Knowledge Formation.
  - -- Assess multi-user (25-50 individual) system design.
  - -- Conduct Predictive Battlespace Awareness (PBA) challenge problems.
  - -- Develop proof-of-concept knowledge bases in coordination with end users.

- High Precision Knowledge Formation (HPKF).
  - -- Evaluate ability of a 1 mega-axiom knowledge base to support high-fidelity problem solving methods for situation awareness and tactical command and control.
  - -- Define tactical air/ground combat challenge problem.
  - -- Select external decision aids, and prototype export/import of knowledge with those aids.

	FY 2003	FY 2004	FY 2005
DARPA Agent Markup Language (DAML)	21.360	10.500	10.545

(U) The DARPA Agent Markup Language (DAML) program develops military software tools for use on Intelink and other emerging Command and Control Link systems. The program's focus is on developing technologies to enhance interoperability and to extend the reach of the World Wide Web to programs, sensors, and other data sources. It enables agent-based programs to share information through these mechanisms. DAML develops software language that ties the information about a web resource to machine-readable semantics (ontology) that describes both data content and service providers. Planned DAML demonstrations include both the intelligence community (Intelink) and the control of tactical military operations in operational environments. This effort provides new technologies for intelligent integration of information across a variety of heterogeneous military sources and systems in real time. The related DARPA Intelligent Software Toolkit (DIST) initiative provides a set of tools to transform existing intelligence and command/control software. DIST, which enables existing software to operate in network-centric computing environments, uses DAML ontologies and service descriptions. Without these automated tools, the cost of bringing older software systems into network-centric computing environments would be prohibitive. The tools correlate application-specific ontologies to

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shared database schema, construct translators from application data structures to database schema, and build mediators that convert product streams from publishers to subscribers. The plan is to prototype and evaluate the tools within existing CISR support systems. Systems selected for the prototyping will be those featuring high data-rate signal processing, sensor exploitation, and engagement planning applications.

(U) Program Plans:

- Perform experimental analysis on and deploy Intelink DAML Briefing and Search Tools on an operational Intelink node.
- Demonstrate and prototype DAML tools for web applications for the Military and National Intelligence Community.
- Conduct experimental analysis of DAML applications.
- Deploy DAML tools on joint and component command and control interoperability systems of major commands such as Joint Forces Command.
- Prototype DAML tools as support to enhance the use of agents for coalition warfare command and control.
- Prototype suite of additional tools to encapsulate legacy software to support DAML ontologies, logics, and service descriptions.
- Build example mediators to convert data among DAML ontologies, referencing external knowledge bases as necessary.

	FY 2003	FY 2004	FY 2005
Taskable Agent Software Kit (TASK)	5.976	5.490	0.000

(U) The Taskable Agent Software Kit (TASK) program develops tools for construction and analysis of advanced multi-agent systems. Target systems are those that realize a global objective through local decisions based on embedded models of the mission, the environment, and interaction with other agents. These tools provide a common engineering foundation for developing high-confidence, agent-based computing solutions to a spectrum of military problems that require robust, scalable, decentralized approaches in dynamically changing environments. Many agent-based systems are currently being built to support militarily relevant applications such as information retrieval and logistics, however, development methods are ad hoc. Developers understand little about how to engineer desirable global behaviors from local, autonomous actions and decisions or about how to mitigate and contain potentially undesirable behaviors, particularly in highly dynamic and uncertain environments. TASK explores methods derived from Control Theory, Decision Theory, and Operations Research for correctly modeling and building agent-based systems. TASK experiments are designed to reveal the qualitative aspects of environments that favor the use of agent-based systems rather than centralized approaches.

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(U) Program Plans:

- Publish initial design and analysis techniques in two focus domains: (a) control and analysis of autonomous vehicles in dynamic environments; and (b) decentralized, competitive resource allocation for logistics.
- Establish a consolidated, open experimental framework based on cooperative autonomous vehicles.
- Employ it for integration and evaluation of agent control, coordination, learning, and adaptation algorithms and analysis techniques.
- Demonstrate and evaluate agent design and analysis techniques on a series of challenge problems characterized by: increasing mission complexity (search to surveillance to targeting); increasing scale (10s to 100s of vehicles); and increasing environment uncertainty (dynamic target behavior to vehicle failures to malicious vehicle behavior).
- Deploy a prototype suite of integrated agent-creation tools with predictable behaviors based on mathematical techniques for modeling and analyzing agent behavior.

	FY 2003	FY 2004	FY 2005
Automatic Target Recognition Technology	0.000	8.000	8.690

(U) The Automatic Target Recognition Technology program develops new sensor exploitation aids to detect targets in high volume sensor data with minimal human support. It supports very large sets of targets (1000's of target types) with high identification performance and very low false alarm rates. It develops modeling methods to account for target variability related to partial damage, design difference, or equipment carried on the vehicle's exterior. The program supports interaction with humans, who supply operational context, guide hypothesis development, and adapt models. The program develops techniques for in-the-field training of models, signatures, and scoring parameters. This allows it to identify vehicle-specific signatures, and develop new target fingerprinting techniques. The program develops new methods to assist humans in achieving precise identification of ad hoc, poorly defined targets. It enables a dramatic reduction in sensor-to-shooter timelines, supporting dynamic target engagement.

(U) Program Plans:

- Obtain a regular supply of data from field and developmental sensors, covering many target types in many environmental settings.
- Obtain or estimate ground truth for those data to provide a foundation for periodic performance assessments.
- Extend existing performance analyses to provide bounds on detection, identification, and fingerprinting performance for 1000's of vehicle types.

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- Develop model generation, model update, detection, recognition, identification, and fingerprinting algorithms based on a range of technical approaches.
- Periodically assess technologies on the field data. Compute statistically significant estimates of performance to compare against the performance analyses.

	FY 2003	FY 2004	FY 2005
Information Dissemination and Management	0.000	6.210	8.000

(U) The Information Dissemination and Management program develops technology to allocate information resources (transmission, storage, and processing) for optimal utilization of data across multiple missions. Program techniques adjust information flows to fit available bandwidth/time for bulk data. Target imagery is adjusted by altering quality, data rate, and time of transmission; streaming data, such as video and ground moving target indications (GMTI), is adjusted by altering quality and rate. Command data, such as waypoints and events, is adjusted by altering time of transmission. The program explores approaches to the reallocation of resources dynamically as tasks arise and network topology and capabilities change. Reallocation is achieved through the use of intermediate storage or intermediate processes (e.g. registration). The program provides real-time sensor-to-shooter resource management to support dynamic operations, including targeting, force protection, and battlespace awareness. Most importantly, it provides information for commanders and weapons when communications resources are oversubscribed during battle conditions. It will provide commanders with the means to respond in real-time to changes in resources due to outages or battle damage.

(U) Program Plans:

- With service partners, identify and obtain a suitable testbed, with supporting data links, databases, application servers, and users.
- Define a class of information architectures that establishes insertion constraints for information management technology.
- Develop and extend real-time resource allocation technology to manage network assets in response to time-varying demands.
- Develop human interfaces to allow controllers to specify information needs, both present and anticipated.
- Insert information management algorithms into the testbed, and stimulate them with increasing levels of subscription.

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	FY 2003	FY 2004	FY 2005
Rapid Software Composition for Embedded Systems	0.000	6.000	7.000

(U) The Rapid Software Composition for Embedded Systems program develops technology to permit rapid assembly of heterogeneous C^4ISR components for execution on complex, highly parallel real time embedded architectures. It explores techniques for rapid parallel code development and optimization, and leverages advanced architectures for development, exploration, and rapid deployment of C^4ISR components. The program delivers tools and software libraries that allow C^4ISR systems to be rapidly assembled from discrete, pre-tested components. It will assist developers in assembling and tailoring C^4ISR systems for mission-specific tasks. In addition, the technology facilitates mapping C^4ISR system components onto advanced run-time architectures. This will enable high performance operations in limited footprint environments (airborne, tactical vehicle, afloat). The tools created will support rapid development and optimization of new C^4ISR capabilities using spiral development processes without loss of performance.

(U) Program Plans:

- Identify a set of challenge applications across the spectrum of C^4ISR missions.
- Assemble a library of kernel algorithm components.
- Map the kernel components onto representative hardware architectures.
- Develop input/output/state descriptions of each kernel component, as mapped to each architecture.
- Construct tools to assemble kernel components into systems, including data flows and process/processor assignments.
- Build predictive models of systems assembled from kernel components.
- Verify run-time feasibility and achievement of desired performance.
- Validate the tools and models within the challenge applications.

	FY 2003	FY 2004	FY 2005
Semantic Information Fusion	0.000	0.000	2.000

(U) The Semantic Information Fusion program develops tools to correlate fragments of target location, identity, and behavior information into a composite description of a situation. The program will focus on incorporating data on human activities obtained from human sources, whether

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openly or surreptitiously. Information represented in linguistic terms will combine with physics-based models of visibility, mobility, and access to reconstruct past events, and infer current situations. This effort enables combining human-derived information with products prepared for automated systems. It will permit context-sensitive determination of the sensitivity of inferred information, and invocation of protection mechanisms, at the time of inference.

(U) Program Plans:

- Obtain streams of text information produced by tactical commanders in training operations.
- Employ state-of-the-art entity, date, and relationship extractors to construct symbolic representations of message contents.
- Identify external foundation and contextual knowledge required to correlate material on one entity appearing in different sources.
- Develop symbolic correlation techniques to automatically suggest associations.
- Employ supervised training approaches to improve scoring functions and hypothesis management logic.
- Assess the performance of the technologies on sequestered test data from a variety of sources.

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

- Not Applicable.

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COST (In Millions)	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008	FY 2009
High Performance and Global Scale Systems ST-19	121.391	72.188	50.236	75.000	75.000	75.000	100.000

(U) **Mission Description:**

(U) This project develops the computing, networking, and associated software technology base underlying the solutions to computational and information-intensive applications for future defense and federal needs. These technologies will lead to successive generations of more secure, higher performance, and more cost-effective microsystems, associated software technologies, advanced mobile information technology and prototype experimental applications critical to defense operations. The project is comprised of five primary components - - Responsive Computing Architectures, Network Embedded Technology, Autonomous Systems Control, Mixed Initiative Control of Automa-Teams, and Networking.

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

	FY 2003	FY 2004	FY 2005
Responsive Computing Architectures	59.425	55.712	50.236

(U) The Responsive Computing Architectures component is bringing needed flexibility to DoD systems. It is developing integrated computing subsystems that will respond in real-time to dramatic changes in mission application requirements and operating constraints based on the mission-of-the-day. The current projects are focused on energy/power management, quality of service, and algorithm/application computing diversity and scalable computing efficiency. This technology has direct and significant impact for military systems such as the Land Warrior/Objective Force, ground and airborne autonomous devices, distributed sensors, space sensors, and intelligence collection ground systems. The Responsive Computing Architecture component is comprised of Power Aware Computing and Communications and High Productivity Computing Systems.

- The Power Aware Computing and Communications (PAC/C) program is developing an integrated software/hardware power management technology suite comprised of novel techniques that may be applied to all levels of a system from the chip to the system level. Embedded

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military computing systems such as future Land Warrior systems, autonomous devices, distributed sensors, and space sensors have extreme dynamic computational and energy requirements. PAC/C will enable embedded computing systems to reduce energy requirements by ten to one hundred-fold for energy constrained military applications ranging from hand-held computing devices to unmanned aerial vehicles.

- The High Productivity Computing Systems (HPCS) program will provide DoD with significant technology and capability advancements for the national security and industrial communities by filling a high-end tera to petascale computing gap between today's late 1980's based technology High Performance Computing systems and the promise of quantum computing. This program is targeting high end computing, medium to long term, national security missions where U.S. superiority and security is threatened, according to two recent DoD studies. The proposed technology development plan is part of a three-phase program that will extend up to the end of this decade. The three phases are concept study, research and development, and full-scale development. HPCS will address a number of critical technology barriers over the next decade: (1) processor/bandwidth performance efficiency; (2) software availability/reliability of large scale computing systems; (3) integral hardware, software, application robustness; (4) intrusion resistance; (5) run-time software brittleness; (6) time-to-solution; and (7) cost of developing, operating, and maintaining DoD national security applications. As an example, performance (efficiency) for critical national security applications will be improved by 10-to-40 fold. Early identification of high-end computing application computing requirements, metrics, and performance prediction tools will be used throughout the program to assess both technical and schedule progress.

(U) Program Plans:

– Power Aware Computing and Communications.
  -- Demonstrate 10X power/energy aware reduction techniques across five power aware levels: 1) mission, 2) subsystem/algorithm, 3) software/compilation, 4) operating systems, 5) architecture/devices into the power aware simulator library.
  -- Conduct preliminary PAC/C energy simulation/modeling framework concept demonstration.
  -- Provide a beta release of the PAC/C energy aware simulator and modeling framework for the PAC/C subscale developers to evaluate.
  -- Finalize selection of the power aware technologies to be incorporated and demonstrated for each of the planned power aware subscale demonstration projects which include the following application areas: distributed sensors, space processing, Land Warrior/Objective Force, and communications.
  -- Continue the development of the final subscale demonstration projects and provide interim and final demonstrations.

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– High Productivity Computing Systems.
  -- Established and implemented the cognitive relaxed computer dialog architecture to support the warfighter in natural language interface with the computer.
  -- Perform an industry concept and critical technology assessment review for viable HPCS systems for potential implementation in the (2007 - 2009) timeframe.
  -- Release alpha "value-based" productivity metrics and benchmarks to guide future program research and development activities.
  -- Address large system brittleness by exploring hardware and software reliability/fault tolerance capabilities, active application software bug tolerance, and intrusion identification and resistance.
  -- Explore balanced "productive" system architectures balancing processors, memory, interconnects, software, and programming environments.
  -- Downselect viable system solutions and critical technologies to be prototyped; demonstrated and evaluated prior to full-scale implementation.
  -- Implement basic and applied software research in the revitalization of high-end computing.

	FY 2003	FY 2004	FY 2005
Network Embedded Technology	33.187	16.476	0.000

(U) The Network Embedded Technology component develops software technology for distributed, real-time, and embedded applications, ranging from tens of computing nodes to over a million. Each program is driven by carefully selected Open Experimental Platforms to facilitate the continuous evaluation of progress and end-user influence. By using major theoretical breakthroughs during the past decade in hybrid systems, statistical physics, finite-size scaling, generative programming, and distributed control, the programs have a solid foundation to achieve the ultimate goal of revolutionizing how software-intensive embedded platforms are built for the DoD. The Network Embedded Technology component is comprised of Networked Embedded Systems Technology and Program Composition for Embedded Systems.

- The Networked Embedded Systems Technology (NEST) program provides robust coordination and synthesis services for networked systems that are subject to extremely tight timing, power, and resource constraints. It supports applications that include micro-electromechanical systems-based fine-grain distributed control applications, sensor networks, and "smart" structures for active acoustic and structural damping. These applications require up to 100,000 simple computing nodes arrayed in a network, serving a common

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purpose. NEST produces reusable software libraries, tools and reference applications that dramatically simplify the development tasks in these environments.

- The Programmable Composition of Embedded Software (PCES) program is developing technology to support faster and more reliable development of tactical software – that is, distributed real-time and embedded software for tactical applications, and in particular for the time-critical targeting domain. This technology is enabling programmers to safely and productively integrate so-called "cross-cutting" aspects, such as concurrency, synchronization, security, and memory management, with core functionality that implements the interaction of tactical software with the diverse and evolving suite of sensors and actuators that constitute the sensor-to-decisionmaker-to-shooter chain. The reusable code-base, tools and reference applications delivered by PCES more effectively exploit human effort to produce high-quality software that has the adaptability, robustness, and efficiency required by time-critical targeting systems.

(U) Program Plans:

– Network Embedded Systems Technology.
  -- Develop formal modeling and verification techniques for coordination-services and for integrating them.
  -- Develop low-cost, Open Experimental Platforms for network embedded software technology.
  -- Conduct baseline demonstrations of NEST technology in a variety of environmental monitoring and tracking applications.
  -- Demonstrate real-time synthesis of schedules (e.g., for actuator firing sequences) and services (e.g., for localization, route planning) using phase transition-aware constraint solvers.
  -- Develop customizable and adaptable solutions for coordination-services for network embedded software technology applications.
  -- Develop tools for the automatic composition and verification of application-specific coordination service packages.
  -- Demonstrate the synthesis of an optimized coordination service package on the experimental platform.
  -- Demonstrate the application design process and evaluate performance of a deployed thousand-node sensor system capable of self-initializing, detecting, tracking and assisting in the pursuit of smart evaders.

– Program Composition for Embedded Software (PCES).
  -- Develop scalable techniques for validation of tactical embedded software by computerized analysis of models of the system.
  -- Develop language representation and compilation techniques for fine-grained and coarse-grained; aspect-oriented programming of tactical embedded systems.
  -- Develop a mechanism whereby quality-controlling functionality can be packaged in a portable and reusable form, and that is suitable for automated integration by the analysis and composition tools.

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-- Develop model-driven tools and representations for generating military system software that supports *flexible binding*, meaning that the allocation of resources to software functions may take place at any time after system design, up to and including during deployed system operation.
-- Develop quality-of-service enabled services for persistence, fault tolerance, and high-bandwidth sensor data transmission, such as those services that are required by the highly dynamic nature of modern air-to-ground warfare.
-- Develop catalogs of patterns and pattern languages that formalize the successful techniques associated with developing tactical embedded systems middleware and applications.

	FY 2003	FY 2004	FY 2005
Autonomous Systems Control	6.001	0.000	0.000

(U) The Autonomous Negotiation Teams program developed the software technology to resolve time-critical constraints in logistics and mission planning. The technology has enabled designers to build systems that operate effectively in highly decentralized environments, making maximum use of local information, providing solutions that are both good enough and soon enough.

(U) Program Accomplishments:
- Autonomous Negotiation Teams.
  -- Demonstrated ability to identify autonomous negotiating teams needed for cooperative flight scheduling and maintenance planning.
  -- Demonstrated prototype implementation and evaluation of negotiation in real-time mission planning for Harrier aircraft mission planning and maintenance operations.
  -- Demonstrated ability for hierarchical coalition formation in real-time and avoidance of conflict by changing plans.
  -- Demonstrated ability to negotiate tasks in a real-time, multiple target tracking problem with requirements of 0.25 ft error, 90 percent probability of disambiguation, and 500-millisecond response time.
  -- Demonstrated an integrated utility for the selection of negotiation strategies to meet goals of convergence, optimality, timeliness and stability in changing environments.
  -- Demonstrated dynamic re-synthesis of the application under time constraints, using distributed constraint solvers.

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	FY 2003	FY 2004	FY 2005
Mixed Initiative Control of Automa-Teams (MICA)	16.678	0.000	0.000

(U) The Mixed Initiative Control of Automa-teams (MICA) program is developing algorithms, software, and modeling and simulation capabilities to perform multi-level planning, assessment and control of distributed, autonomous combat forces. MICA provides a commander with the operational and mission planning tools to select optimal team composition, to perform dynamic tasking and re-tasking of teams, and to generate cooperative routes for autonomous unmanned air vehicles (UAVs) in stressful operational missions, especially suppression of enemy air defenses. The program focuses on collaborative strategies and tactics for these teams under the supervision of a single human operator, with adjustable autonomy determining the degree of human authority desired or required during task execution. Through the exploitation of control science metrics for stability, performance and robustness, these teams of cooperative, autonomous vehicles such as unmanned combat air vehicles will accommodate uncertainty in both the operating environment and in the feedback information, as well as address the presence of an intelligent adversary and fixed and mobile threats in the battlespace. The program is funded in PE 0602702E, Project TT-13, in FY 2004.

(U) Program Accomplishments:

- Developed algorithms and software to assign autonomous combat vehicles to task-oriented teams.
- Developed algorithms and software to assign mission-derived subtasks to each combat vehicle in a team.
- Developed algorithms and software to generate event schedules and collaborative routes for each combat vehicle in a team.
- Defined algorithms and software supporting dialog between human commanders/operators and semi-autonomous entities to communicate recommended courses of action, appropriate feedback information, and decision tuning parameters.
- Deployed an open experimental simulation environment, driven by UAV suppression of mobile air defense elements and incorporating multiple UAV teams and multiple command levels.

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	FY 2003	FY 2004	FY 2005
Networking	6.100	0.000	0.000

(U) The Networking program developed new paradigms in networking technologies to meet future defense and national security needs. The program created highly robust and rapidly configurable networking capabilities essential for both secure national infrastructure and ad-hoc military networks through key innovations in software and hardware technologies. The results are applicable to wired, wireless and mixed networks. The Networking component was comprised of Active Networks and Ultra High-Performance Networking.

- The Active Networks program investigated the use of smart packet processing to enable new strategies in rapid network service introduction and enhancement.

- The Ultra High-Performance Networking program advanced transparent all-optical networking and gigabit wireless techniques to dramatically enhance bandwidths available to end-applications.

(U) Program Accomplishments:

– Active Networks.
  -- Developed and demonstrated: 1) Intrusion Detection and Response (IDR) prototype; 2) Active Network Operating System focused on policy-free security architecture and availability; and 3) the capability to operate within a mobile computing environment.
  -- Developed active network techniques for distributed network management, resource control, and distributed network service deployment, configuration, and management.

– Ultra High-Performance Networking.
  -- Demonstrated correlation of multi-gigabit per second transfer of radar signal streams from multiple sources.
  -- Demonstrated 16-32 video blanket media streams and client side browsers for display of these streams.
  -- Designed precision (1cm) network based geo-location system scalable to 100 nodes in an indoor setting.
  -- Demonstrated hybrid optical/radio frequency self-healing link with proactive switching at 600 Mbps.

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

- Not Applicable.

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COST (In Millions)	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008	FY 2009
Information Assurance and Survivability ST-24	31.773	46.117	52.513	65.474	63.283	77.855	99.968

(U) **Mission Description:**

(U) This project is developing the technology required to make emerging information system capabilities (such as wireless and mobile code/mobile systems) inherently secure, and to protect DoD's mission-critical systems against attack upon or through the supporting information infrastructure. These technologies will enable our critical systems to provide continuous correct operation even when they are attacked. The technologies will also lead to generations of stronger protection, higher performance, and more cost-effective security and survivability solutions scalable to several thousand sites. Technologies developed under this project will be exploited by all the projects within this program element, and by the Command and Control Information Systems (Project CCC-01, PE 0603760E), Information Integration Systems (Project CCC-02, PE 0603760E), Joint Warfare System (Project NET-01, PE 0603764E), Maritime Systems (NET-02, PE 0603764E), and other programs that satisfy defense requirements for secure, survivable, and network centric systems.

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

	FY 2003	FY 2004	FY 2005
Fault Tolerant Networks	13.557	4.191	2.000

(U) The Fault Tolerant Networks (FTN) program will develop technologies to provide continuous and correct network operation even when attacks are successful. These technologies will reduce the amount of damage sustained during an attack, allowing networks to maintain an acceptable, minimum level of functionality. Technologies for strengthening networks will be developed by introducing fault tolerance capabilities against possible attacks at the network level, emphasizing integrity and availability; and technologies for mitigating potential vulnerabilities associated with denial of service attacks. The most promising of these technologies will be tested in operationally relevant experiments with U.S. warfighters in DARPA's Partners in Experimentation program, which is also budgeted in this project.

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(U) Program Plans:

- Developed epidemic protocols for reliably communicating between peers in ad-hoc networks and adaptive multi-path forwarding protocols for tolerating and adapting to faults in wide-area networks. Explored the relationship between these approaches and developed a unified model for multi-path communication.
- Demonstrated attack profiling and filtering algorithms that discard a high percentage of DDoS traffic and a low percentage of non-DDoS traffic.
- Extend an overlay network prototype to integrate boundary security, enforcing overlay separation and preventing leakage of traffic onto the base network.
- Demonstrate statistical measures that are both efficient and effective at detecting traffic that contributes to a Distributed Denial of Service (DDoS) attack that originates multiple network "hops" back from the attack target.
- Implement and evaluate distributed queuing in prototype router hardware while continuing fundamental studies of distributed queuing algorithms, with a focus on algorithms that support reservation-oriented traffic.
- Develop tools for measuring and communicating the structure of network topologies in both wide-area and mobile environments and for measuring underlying latencies, service times, and characteristics that constrain the best possible network availability solutions.

	FY 2003	FY 2004	FY 2005
Dynamic Coalitions	9.942	2.009	2.000

(U) The Dynamic Coalitions program is developing technologies to support the secure creation of dynamic coalitions including the necessary technologies for policy management, group communications, supporting security infrastructure services, data sharing, and joint collaboration spaces. These areas are critical for future warfighting scenarios as outlined by Joint Vision 2020, which states that future military operations will be increasingly conducted jointly, both with multiple branches of the U.S. Armed Forces and with allied and coalition forces, requiring increased levels of interoperability. Further, this effort will build upon recent advancements in wireless networking technologies by investigating technologies to migrate coalition information assurance tools from servers to gateway radios thus placing the functionality directly at the interface, and localizing coalition policy to gateways. The most promising technologies developed under this program will be tested in operationally relevant experiments with U.S. warfighters in DARPA's Partners in Experimentation program, which is also budgeted in this project.

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(U) Program Plans:

- Developed a new formalism for application level policies to accommodate new aspects of policy that do not manifest at the network layer such as access control mechanisms.
- Developed specific technology to enable multi-level network management and multi-level message passing.
- Completed the implementation of the surrogate trust negotiation architecture for supporting trust negotiation in a wireless environment.
- Complete the design and implementation of architecture for scalable trust negotiation that incorporates reusable tickets or tokens so that repetitive, heavyweight trust negotiations are not required for access to every protected resource within a security domain.
- Develop adaptors to a policy engine for a set of real networking monitoring and control technologies including: network management tools; commercial firewalls; and application specific entities such as web servers.
- Develop low-cost IP-Sec devices that could be deployed to every coalition desktop or tactical work station, providing a low-cost classified coalition networking solution.

	FY 2003	FY 2004	FY 2005
Partners in Experimentation	4.043	7.844	5.843

(U) The Partners in Experimentation program will conduct security technology experimentation with operational military and coalition partners. Operational experimentation will provide valuable feedback to the security technology research and development process which will demonstrate to operational personnel the benefits of advanced technology, and accelerate technology transition.

(U) Program Plans:

- Demonstrate secure group communication capability for informal trust relationships.
- Demonstrate multi-application cross-domain information sharing capability.
- Provide the capability for cross-domain information sharing for an interoperability demonstration.
- Demonstrated network monitoring and Distributed Denial of Service (DDoS) countermeasures.
- Demonstrated identity-based encryption techniques to secure email in a multi-organization collaborative environment.

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- Construct and demonstrate a trusted patch management system as well as an Information Assurance Vulnerability Assessment (IAVA) compliance checking capability.
- Evaluate performance and scalability of lab proven anomaly detection techniques for intrusion detection in real world high volume environments.

	FY 2003	FY 2004	FY 2005
Next Generation Optical Networks	0.000	8.671	7.521

(U) The Next Generation Optical Networks program will revolutionize the operation, performance, security, and survivability of the United States' critical inter-networking system by leveraging technology developed in DARPA photonics component and secure networking programs. These goals will be accomplished through a transformation in fundamental networking concepts that form the foundation upon which future internetworking hardware, architecture, protocols and applications will be built. Key technical enablers that will be developed in this thrust include: the elimination of data flow bottlenecks through the creation of optical network hardware that minimizes the occurrence of optical-to-electrical-to-optical conversions, network management tools that guarantee optimization of high density optical channels such as those provided by wavelength division multiplexing, the creation of a new class of protocols that permit the cross-layer communications needed to support quality-of-service requirements of high priority national defense applications, and novel concepts in intelligent and cognitive switched based networks. Integration of terrestrial fiber optic lines with free-space optical and RF wireless transport systems, and establishment of a CONUS wide testbed with mobile overseas nodes will enable development, experimentation, and validation of new hardware, software, and network architecture concepts. This effort will deliver the high-performance internetworking capabilities needed for development of applications such as distributed and network based command and control, intelligence analysis, predictive logistics management, simulation and scenario enhanced decision-making support for real-time combat operations, and assured operation of critical U.S. networking functions when faced with severe physical layer attack. These network-based functions will support the real-time, fast-reaction operations of senior leadership, major commands and field units.

(U) The Millimeter Wave Networks project is to develop new technology to make upper millimeter wave (MMW) region affordable for proliferated use in an operational environment. Current approaches to Low Probability of Exploitation systems are inherently constrained by the inherent requirement to radiate energy and create high levels of signal to noise ratio in order to communicate increasing amounts of information. This project leverages the unique characteristics of the 60GHz band, which attenuates radio signals very rapidly due to absorption, to develop

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network devices that can transmit the reasonably high levels of power required for high data rates, and still be undetectable at a distance from the network. Existing systems are vulnerable to intelligent jamming by high power sources at relatively long ranges. Oxygen absorption limits the ability of distant jamming systems to create interference level signals within the network area. The program will also develop and exploit new concepts for the development of RF components to reduce cost and size. These concepts have been developing through other DARPA technology programs, and include quasi-optical, special combining, resonant tunnel device, and related technologies. The program will develop network components that can be operated anywhere in the world with a highly controllable detection radius. These technologies will also be applicable to unmanned, space and aircraft based uses.

(U) Program Plans:

- Create an all-optical hardware design and fabrication with regeneration capability and optical wavelength switching.
- Conduct network data flow/bottleneck analysis, 10 Gb/s to end user.
- Develop switch architecture design for zero apparent jitter real-time applications.
- Develop national testbed hardware specification, local area to wide area network integration, with data-format independence.
- Protocol development for physical layer-to-application layer connectivity.
- Demonstrate the ability to manage frequency and enforce low probability of detection limits.
- Validate that photonics-based modem and RF sources are orders of magnitude simpler than conventional RF.
- Demonstrate that the upper millimeter wave region offers increased RF power scaling due to low combining loss which can allow almost unbounded bandwidth.

	FY 2003	FY 2004	FY 2005
Dynamic Quarantine of Worms (formerly known as the Malicious Code Analysis)	2.231	13.543	14.807

(U) The goal of the Dynamic Quarantine of Worms is to develop dynamic quarantine defenses for U.S. military networks against large-scale malicious code attacks such as computer-based worms. The ever-growing sophistication of the malicious code threat has surpassed the ability of commercial industry to address this problem. As the U.S. military pushes forward with network-centric warfare, terrorists and other nation-states are likely to develop and employ malicious code to impede our ability to fight efficiently and effectively. This program will develop the capability to automatically detect and respond to worm-based attacks against military networks, provide advanced warning to other DoD enterprise networks,

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study and determine the worm's propagation and epidemiology, and provide off-line rapid response forensic analysis of malicious code to identify its capabilities, modalities, and future behavior. (Further, the program will develop defenses against cyber attacks on mobile ad hoc network (MANET) systems that can to sense failures and attacks and auto-recover in real-time. Technical approaches include the automatic and dynamic quarantine response and forensics analysis of malicious code that will employ static and dynamic code analysis for program understanding. Defense Against Cyber Attacks on MANETs project under this program will develop the means to monitor and control the trustworthiness of distributed tactical applications used in network centric warfare operations. This program will develop technology to ensure network centric warfare systems are able to fulfill their mission in spite of cyber attacks such as computer worms unleashed on MANETs and runtime failures.

(U) Program Plans:

- Develop automatic detection and quarantine mechanisms.
- Provide real-time and off-line analysis capabilities.
- Develop network appliance and host-based detection/response network interface devices.
- Verify integrated system capabilities.

	FY 2003	FY 2004	FY 2005
Trustworthy Systems	0.000	9.859	9.908

(U) The goal of the Trustworthy Systems program is to address information assurance of tactical systems in complementary strategies, including to build trustworthy information processors (TIP), as the basis for running trustworthy systems. The Trusted Information Processors (TIP) Project under this program will develop the ability to design systems that can be provably verified as trustworthy despite complexity of millions of transistors and millions of lines of code. TIP will develop prototypes in partnership with other government agencies responsible for follow-on development of such capabilities, as well research publication and demonstration prototypes that lend themselves to commercial production that dramatically offsets military acquisition costs. Other aspects of ensuring trustworthiness in network centric warfighting architectures such as validating users, adapting mission goals, and reconfiguring nodes and platforms for optimal mission execution as a result of changes that may occur in the trustworthiness of the network will be explored.

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(U) Program Plans:

- Explore processors capable of fully encrypting the entire state of computation at each step.
- Design and fabricate an integrated circuit chip that can be verified to have everything in the design, without malicious inclusions.
- Design and produce a microprocessor system that keeps all state information outside the arithmetic logic unit cryptographically signed at all times.
- Design a processor with each component fully validated via formal mathematical proofs to faithfully execute high level instructions.
- Produce a malice tolerant architecture capable of consistently producing correct results, even if most components are compromised.
- Produce a computer verified proof that the malice tolerant architecture will consistently produce correct results under worst cases.
- Develop fundamental principles and approaches to trustworthy control and emergent survivable behavior.
- Identify dynamic indicators of system unreliability and insecurity.
- Develop approaches for real-time trustworthy monitoring and control.
- Develop trustworthy co-processors for adaptive control and dynamic provisioning of computational resources.

	FY 2003	FY 2004	FY 2005
DARPA Future Information Assurance Initiatives	0.000	0.000	3.737

(U) DARPA has been at the forefront of advancing the state of the art for information assurance technologies. Many of today's commercial practices have their roots in previous DARPA investments. As the DoD continues to be reliant upon commercial networks it is paramount that DARPA continue to look forward and investigate promising technologies. The 21st century transformation of the U.S. military will be more dependent on information technology for C^4ISR and combat functions than perhaps any other aspect of the military. To a large extent, future combat systems will be more dependent on information than armor to accomplish missions successfully. The Department's vision for the future includes near-perfect knowledge of the battlespace and the ability to fight wars with information technology that enables remote C^4ISR operations. Sophisticated computing capabilities like those available in current desktop workstation and server systems are moving to mobile wireless embedded systems that communicate over low bandwidth self-organizing tactical networks often with low-powered devices. Concurrent with the advanced computing capability will be security and other trustworthiness challenges in the systems on which the future U.S. military will be heavily dependent during battle. With the increased U.S. military dependence on information technology, the ability to maintain battlefield superiority requires control of our information systems against increasingly sophisticated adversaries employing computer network attack. With

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foreign production of information technology increasing, and adversaries seeking to use the asymmetric leverage of cyber warfare as the Achilles' heel of current and future U.S. military systems, the U.S. military must have the ability to withstand, operate through, and counter increasingly lethal cyber attacks. The DARPA Future Information Assurance Initiatives will identify promising technologies to continue to push the state of the art. Distinct programs within this project will be created for promising technologies as they are identified for further focused development.

(U) Program Plans:

- Develop mechanisms to improve end-to-end Transmission Control Protocol and Internet Protocol (TCP/IP) wide-area network performance between the Continental United States (CONUS) operating base and forward deployed tactical units.
- Develop the ability of individual hosts (end-points) to learn essential characteristics about the network path between themselves and their transmission partners.
- Develop an operating system with higher assurance, higher performance, and higher functionality than current A1 systems.
- Develop computing languages, compilers, and systems capable of producing executable code verified to be correct and bug free.
- Protection of Signaling Networks: Develop the ability to protect the core signaling and control of converged networks running voice over IP (VOIP), 3G wireless, and voice, and data networks in the backbone telecommunications switching fabric.
- Identify hosts securely and authoritatively on the network with a follow-on goal of allowing these hosts to query the network to discover the network's operating attributes.
- Develop a family of distributed, autonomous firewalls that work together as required to deal with asymmetric traffic on wide area networks.
- Develop a wireless protocol that securely provides location, authentication, and communications in a practical manner.

	FY 2003	FY 2004	FY 2005
Control Plane	0.000	0.000	3.597

(U) The Control Plane Program will improve end-to-end network performance between the Continental United States (CONUS) operating base and forward deployed tactical units. Control Plane seeks to develop the ability for individual hosts (end-points) to learn essential characteristics about the network path between themselves and other hosts, allowing the hosts to shape any transmission to pass through the network with the minimal network load. Additionally, when multiple network paths are available, a host will be able to either choose the path that

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best meets its requirements or simultaneously transmit over multiple paths. This technology will support the Defense Department's Global Information Grid concept of operations.

(U) Program Plans:

- Develop mechanisms to improve end-to-end Transmission Control Protocol and Internet Protocol (TCP/IP) wide-area network performance between the Continental United States (CONUS) operating base and forward deployed tactical units.
- Develop the ability of individual hosts (end-points) to learn essential characteristics about the network path between themselves and their transmission partners.
- Develop the ability of hosts to learn about more than one possible path, choose the one which suits their needs best, and use it.
- Develop the ability of a host to simultaneously use multiple network paths for the same data transmission with the same partner, increasing communications speed and reliability.

	FY 2003	FY 2004	FY 2005
CyberPanel	2.000	0.000	0.000

(U) The Cyber Panel Program developed capabilities to help defend mission-critical information systems by monitoring them for signs of cyber attack, and allowing operators to manage the operation of system security and survivability features to avert or counter developing attack situations. Intrusion assessment technologies were developed to detect security threats through correlation and analysis of observed/reported activities. Autonomic response capabilities were developed to react in milliseconds to block or withstand many classes of known and unknown attacks. Monitoring and response components were developed that allow warfighters to observe the performance, health and threat state of mission critical information systems, project the likely impact of reported cyber attacks on system operation, assess possible defensive actions, and carry them out.

(U) Program Plans:

- Investigated methods for augmenting passive intrusion detection sensors with capabilities to actively probe for additional attack information.
- Explored techniques for improving the effectiveness of auto-response defenses with limited intelligence about attack models.

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- Conducted experiments to determine the usability of general-purpose anomaly detection algorithms to monitor a large, complex military software system.
- Combined selected Cyber Panel technologies into an integrated demonstration prototype incorporating cyber attack detection, correlation, assessment, and response capabilities.

	FY 2003	FY 2004	FY 2005
Asymmetric Firewalls	0.000	0.000	3.100

(U) The Asymmetric Firewalls program develops devices that can act as firewalls for wide-area networks. Asymmetric flows are traffic flows (groups of data packets) between a sender and receiver where the outbound packets and the inbound packets do not follow the same route. Forty to sixty percent of all traffic on the Internet (and on military networks) flows asymmetrically. There is currently no technology capable of providing firewalls on wide area networks because current firewalls must be able to monitor all traffic in both directions to work correctly.

(U) Program Plans:

- Develop protocol analyzers for simultaneous decoding of packet, session, flow, and application layer data.
- Develop high-speed distributed cueing system for use by distributed and independent firewalls.
- Develop software asymmetric firewalls for small networks.
- Develop high speed asymmetric firewalls for networks.

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

- Not Applicable.

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COST (In Millions)	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008	FY 2009
Language Translation ST-29	42.848	57.201	51.972	35.767	35.945	36.196	40.826

(U) Mission Description:

(U) This project will develop and test powerful new Human Language Technology (HLT) that will provide critical new capabilities for a wide range of national security needs. This technology will enable systems to (a) automatically exploit large volumes of speech and text in multiple languages; (b) revolutionize human-computer interaction via spoken and written English and foreign languages; (c) perform computing and decision-making tasks in stressful, time sensitive situations; and (d) become active, autonomous agents/assistants to analysts, operators and warfighters by collating, filtering, synthesizing and presenting information in timely and relevant forms.

(U) Program Accomplishments/Planned Programs:

	FY 2003	FY 2004	FY 2005
Situation Presentation and Interaction	8.232	10.869	6.400

(U) There are two programs involving *human-machine* communication:

- The Compact Aids for Speech Translation program, formerly the Babylon program, is providing the tactical warfighter with real-time, face-to-face speech translation during combat and humanitarian operations in foreign territories. The program addresses domain-specific translation accuracy and response time. Early prototypes of the technology relying on simple dictionaries and phrases have been deployed on a test basis to Afghanistan. Future versions will offer more sophisticated, flexible and fluid translation and paraphrasing capability that will be more robust and conducive to normal human conversations.

- The Symphony program is an applied follow-on effort to the Communicator Program, emphasizing technology transition to the military, adaptability, and scalability of the Communicator Galaxy Architecture for automatic dialogue in support of C2 (Command and Control)

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applications. Technologies to be emphasized include human stress adaptation, prosody, and system reliability in military environments. The program will centerpiece six technology insertion projects supporting all services.

(U) Program plans:

– Compact Aids for Speech Translation.
  -- Established baseline hardware design for handheld translation technology.
  -- Developed and evaluated initial DARPA 1+1 Way prototypes which provide limited two-way translation.
  -- Conducted multi-lingual data collection in Pashto, Dari, Farsi, Arabic, and Mandarin for contingency operations.
  -- Distributed multilingual corpus to R&D community.
  -- Upgrade DARPA one-way technology to limited two-way translation.
  -- Obtain initial software decision approvals for full-featured DARPA two-way translation.
  -- Produce prototype handheld devices for field evaluations and acceptance.
  -- Perform initial coordination with U.S. Army PM Soldier for software integration into land warrior Block III (version 3.0).
  -- Integrate speech recognition engines into natural language parsers and translators.
  -- Receive feedback from evaluators on DARPA two-way technology (deliver patches and fixes); units remain in operational use.
  -- Deliver upgraded handhelds (capable of supporting two-way technology) to software developers.
  -- Deliver alpha versions of DARPA two-way software for initial user testing.
  -- Select set of foreign languages for final development.
  -- Populate language digital resource repository at Defense Language Institute.

– Symphony.
  -- Develop FA-18 aircraft maintenance mentor prototype to enhance flight mechanic methods.
  -- Develop the Battlefield Casualty Reporting System, a dialogue driven process to allow casualty reporting and sworn statements to be collected, automated validation and direct reporting to Decision Authority notification officials.
  -- Develop a ship based command and control system to allow officers and crew to query ship system status from any location on the ship, set an alarm for a future change in status, or launch agents to monitor particular sub systems.

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-- Create a complete dialogue based interface for information management systems to support system navigation and analytical processes; augment search parameters and dialogue based mentoring to assist the novice analyst or enhance the experienced analyst.
-- Conduct a vehicle navigation effort that focuses on the on-the-move environment attacking dialogue base capability in tactical vehicle noise, for the purposes of navigation, command and control and logistical support.
-- Initiate evaluation of dialog technologies for the Institute of Justice for use in multilingual detention facilities.

	FY 2003	FY 2004	FY 2005
Automated Speech and Text Exploitation in Multiple Languages	34.141	46.332	45.572

(U) There are three programs involving *human-human* communication:

- Translingual Information Detection, Extraction and Summarization (TIDES) is revolutionizing the way time-critical intelligence is obtained from speech and text by developing technology to enable English-speaking operators and analysts to exploit the huge amounts of foreign speech and text available electronically or in captured documents, but currently unexploitable due to vast volumes and insufficient foreign language skills. TIDES is creating powerful new capabilities for Detection (finding or discovering needed information), Extraction (pulling out key information), Summarization (substantially shortening what a user must read), and Translation (converting foreign language material to English). This will dramatically increase the quantity, quality, and timeliness of analysis and reporting, thereby providing vital information to senior decision makers and enabling commanders to carry out critical missions swiftly, safely and effectively.

- Effective, Affordable, Reusable Speech-To-Text (EARS) is creating powerful new automatic speech-to-text transcription technology whose output is substantially richer and much more accurate than previously possible. EARS will provide passive listening technology for critical languages and media for a wide range of national security applications. It will enable effective automated transcription from broadcasts, telephone conversations, and multiparty speech.

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- Global Autonomous Language Exploitation (GALE) will develop techniques for discovering critical intelligence by autonomously exploiting enormous volumes of streaming speech and text from around the world (in many languages). GALE will enable machines to analyze, refine, combine, and package information from broadcasts, conversations, newswire, and internet sources; discover trends and deviations; discern operator/analyst interest (from their tasking, actions and reports); and issue critical alerts, reports, and pointers whenever appropriate (without overwhelming the analysts), delivering information in actionable form without requiring the operators or analysts to request it. GALE will build off the successes of both TIDES and EARS.

(U) Program Plans:

– Translingual Information Detection, Extraction and Summarization (TIDES).
  -- Demonstrate capability to detect and track events described in English, Arabic, and Chinese news sources.
  -- Demonstrate capability to extract key information (about people, places, organizations, and relationships) from English, Arabic, and Chinese.
  -- Demonstrate capability to translate Arabic and Chinese documents into readable English.
  -- Develop methods to convert document images to translated text.
  -- Develop methods for porting TIDES technology to new languages.
  -- Define architecture for a unified text and audio processing (TAP) system that integrates various TIDES technologies.
  -- Transition successful components to operational customers.

– Effective Affordable Reusable Speech-To-Text (EARS).
  -- Develop automatic techniques to produce rich, readable transcripts of broadcasts and telephone conversations in English, Chinese, and Arabic.
  -- Develop automatic techniques to produce rich, readable, searchable transcripts of multiparty speech from command centers, teleconferences, and meetings.
  -- Substantially improve the word-error-rate performance of automatic transcription from approximately 50% down to 5-10%.
  -- Create automatic metadata extraction algorithms to enrich the resulting transcripts and to make them more readable.
  – Create, demonstrate, and evaluate prototype systems.

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– Global Autonomous Language Exploitation (GALE).
  -- Initiate multifaceted effort to develop techniques for discovering critical intelligence autonomously, exploiting huge volumes of streaming speech and text in multiple languages.

	FY 2003	FY 2004	FY 2005
Center for Critical Languages	0.475	0.000	0.000

(U) Provided funding to assist in the development of a Center for Critical Languages.

(U) Other Program Funding Summary Cost:

- Not Applicable.

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COST (In Millions)	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008	FY 2009
Learning and Reasoning ST-30	15.198	60.503	84.173	112.535	120.761	131.858	124.399

(U) Mission Description:

(U) In the real-time environment of military operations, networks and systems that can learn, reason, draw on their experience, automatically adapt to maintain their critical functionality, effectively assist their military user, and improve their responses over time, will be crucial to operational success. These technologies 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 sleek, dynamic expeditionary force, it is critical for systems to be more self-sufficient.

(U) The Learning and Reasoning project will develop core technologies that enable computing systems to learn, reason, and draw on their accumulated experience by applying knowledge gained through such experience and then respond intelligently to things that have not been previously programmed or encountered. These technologies will lead to systems demonstrating increased self-reliance, self-adaptive reconfiguration, intelligent negotiation, cooperative behavior, and survivability with reduced human intervention. This will be accomplished by creating unique and powerful new abilities for computers to learn about and understand the world, and to reason intelligently with the results of learning. Cognitive systems will typically comprise three primary types of processes: reactive, deliberative and reflective. Each of these will be improved through learning and reasoning. Reactive processes respond quickly and directly to known stimuli. Deliberative processes embody what is usually known as "thinking." Reflective (higher-order) processes allow a system to "step back" and evaluate the environment and their own capabilities to decide the next appropriate course of action. Capabilities developed in this project include novel representations for knowledge, skill learning, reasoning (deductive, abductive, planning, strategic inference, and hybrid approaches), pattern detection, and language learning, all of which will extend fundamental computing capabilities for dealing with real-world information complexity and uncertainty.

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(U) Program Accomplishments/Planned Programs:

	FY 2003	FY 2004	FY 2005
Integrated Cognitive Systems	12.198	31.046	40.146

(U) The Integrated Cognitive Systems technology thrust will build upon prior DARPA programs that developed improved human-computer interaction capabilities and highly-responsive computing systems to develop technology for a new class of integrated, highly functional cognitive systems. These systems will act purposefully to assist military commanders and decision-makers. Embedded learning will provide faster response times and more effective responses by retaining what has been learned in the past and applying this knowledge to new scenarios, and most importantly, will allow the performance of a cognitive system to improve over time. The Integrated Cognitive Systems thrust comprises Personalized Assistant that Learns (PAL), Dismounted Soldier Complement Enhancing Reporting and Navigation (DISCERN), and Cognitive Command, Control, Communication, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR).

- The Personalized Assistant that Learns (PAL) program will develop integrated cognitive systems that will act as personalized executive-style assistants to military commanders and decision-makers. It is only through the exploration of full, integrated systems that we can ultimately validate the effectiveness of component technologies developed to support machine reasoning and learning. Initially the program will strive to create assistant programs that will display basic competencies, including interaction with people and other assistant programs in a normal operational environment; sending and receiving information in a natural manner; relating information and activities in various different media; interacting with the assistant's user and inferring preferences and how to do useful procedures; and accepting coaching and guidance expressed naturally in language. Such systems will push the limits of technology for formal reasoning and learning, all integrated in a unified multitasking, mixed-initiative architecture. The program will demonstrate cognitive systems that make use of basic knowledge and past experience to help the system understand and seek input, resulting in systems that do purposeful perception (i.e., sensor information will be acquired, filtered and processed to serve specific, high-level goals). Methods for processing raw data will be learned in a way that optimizes performance of the entire system.

- The Dismounted Soldier Complement Enhancing Reporting and Navigation (DISCERN) program will develop episodic memory mechanisms to augment the individual warfighter's ability to accurately recall and communicate experienced events to reduce the operational impact of the "fog of war." The warfighter's understanding of what is happening depends critically on knowing what has

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already happened. To facilitate situational awareness, the military has developed extensive standardized reporting mechanisms and procedures to support the capture of information and its communication to where it is needed. The warfighter is called upon to recall and report, in a timely and accurate manner, salient events that are experienced. However, the noise, smoke, and confusion of the battlefield, and the physiological and psychological stresses of combat, make this task very difficult. Furthermore, sleep deprivation reduces the warfighter's recall effectiveness even when physically removed from the battlefield. Foundational episodic memory technologies will be developed and applied to support and enhance after-action report generation, information sharing between dismounted squad members, information sharing across multiple shifts of command center staff, and the interaction of trainees and instructors in training situations. Lives depend on the decisions made by warfighters, from the theater commander down to the squad member on patrol. This effort will maximize the sensor and information resources available to the network-centric warfighter to improve not only the individual's cognitive ability but also the effectiveness of the collective force.

- The Cognitive Command, Control, Communication, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) program will develop specific embedded learning and real-time reasoning elements to enable a new generation of C4ISR. The embedded learning will provide faster response times by retaining what it has learned in the past and real-time reasoning allows the system to apply what has been learned to new scenarios. The resulting knowledge will assist the commander by providing critical information in a timely manner with alternative courses of action for more effective decision-making. The Cognitive C4ISR program will provide flexibility and adaptability technologies as part of the solution to time-critical decision-making in the face of increased ambiguity, deception, and surprise within the engagement timeline.

(U) Program Plans:

– Personalized Assistant that Learns.
  -- Develop baseline architecture for a complete PAL system..
  -- Develop initial knowledge base representing a PAL system's knowledge of its task domain.
  -- Demonstrate continuous teaming capability over a protracted period of time.
  -- Develop technology for a PAL system to interact with its user and perceive activities over time and develop understanding of 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.

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-- Develop core machine learning, knowledge base and flexible planning technologies to enable development of a cognitive planning agent.
-- Develop core physical awareness, cyber-awareness, multimodal dialogue, machine learning, and representation and reasoning technologies to support a cognitive assistant for executive functions.
-- Develop test problems, define metrics, and conduct formal experiments to evaluate progress in cognitive systems technology R&D.

– Dismounted Soldier Complement Enhancing Reporting and Navigation.
-- Abstract input data streams into sequences of events and states, which are aggregated into threads and episodes to produce a timeline that constitutes an "episodic memory."
-- Develop an ontology-based data structure that indexes data for rapid retrieval and continually evolves as the data is processed to generate multiple layers of representation at increasing levels of abstraction through inference and reasoning.
-- Demonstrate the capability to present critical situational awareness elements such as "who", "what", "where", and "when" to the soldier in a hands-free manner, reducing the reporting burden and increasing the recall and reporting content quality.
-- Demonstrate the effective sharing of information in dismounted warfighting, command center, and training environments.

– 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 maybe 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.
-- Develop a unified cooperative system to provide a means for integrating dissimilar C4ISR systems.

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	FY 2003	FY 2004	FY 2005
Foundational Learning Technology	2.000	9.139	14.500

(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 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 to adapt in real time to the naturally changing environment without programmer intervention. The application of this technology will result in military systems that are more robust, self-sufficient, and minimize platform-specific customization. The Foundational Learning Technology thrust comprises Real-World Learning, the Neuromorphic Learning Technology and the Learning Locomotion and Navigation programs.

- The Real-World Learning program will explore the integration and application of advanced machine learning techniques to enable cognitive computing systems that learn from experience and adapt to changing situations. The program will determine which types of learning (e.g., learning by example, learning by analogy, statistical learning from training data, explanation-based learning, etc.) are most effective when applied to challenging problems of importance to the military. Moreover, this technology program will drive the design and implementation of new hybrid learning technologies that allow cognitive systems to learn in a wider variety of situations; among other things, these new methods will combine statistical learning techniques with knowledge-based techniques that take into account background knowledge and *a priori* experience. This technology will also enable a new generation of flexible machines capable of pattern recognition and adaptive behavior that respond to dynamic interaction in parallel. Developing technologies that allow enduring systems to learn continuously over long periods of time is a goal of this program.

- The Neuromorphic Learning Technology program will combine principles from computational neuroscience with traditional Artificial Intelligence-based symbol processing and knowledge representation to enable a new class of intelligent systems with generalized neuromorphic learning and self-organizing capabilities. Subsystem development and integration will be based on adaptive, self-organizing models. Such incremental adaptation will allow systems to grow and change with their environments, even to adapt around failed components. System design will be based on a general set of organizing principles, rather than in developing individual rules and

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processes. Unlike rule-based systems, these networks will self-organize into a functional system, developing the rules themselves. These systems will leverage the statistics of large numbers of simple computing elements to enable incremental learning, high-speed parallel evaluation, and fault tolerance.

- An outgrowth of Autonomous Software for Intelligent Control previously funded on Project ST-33, the Learning Locomotion and Navigation program will develop learning and reasoning technologies specifically for robotic systems. These enhanced robotic systems will automatically learn to interpret sensor data and apply this knowledge to the control of their actuators for improved locomotive and navigational autonomy in complex environments with changing terrain and heterogeneous obstacles. Approaches in reinforcement learning and technologies for learning from example will be explored. These learning technologies in locomotion and navigation will open new horizons in unmanned military operations, surveillance and reconnaissance, and will dramatically advance the state of autonomous vehicles, especially for tasks requiring higher-level computation, such as perception-based navigation.

(U) Program Plans:

– Real-World Learning.
  -- Select several critical problems and scenarios to challenge machine learning technology in ways that will determine the essential value of individual techniques.
  -- Classify a broad variety of problems into classes that are best addressed by different types of learning technologies and determine the most powerful and comprehensive sets of techniques that complement one another.
  -- Design and develop hybrid learning systems that allow cognitive systems to adapt to a wide variety of naturally-occurring situations and perform better over time against challenges similar to those challenges to which they have been exposed in the past.
  -- Develop algorithms that generalize based on information gathered and learned to operate successfully in similar, but not identical situations.

– Neuromorphic Learning Technology.
  -- Investigate the role of parallel architectures, algorithms, and general principles inspired by neuroscience in hybrid learning and adaptive systems, rigorously comparing neuromorphic approaches to more traditional AI approaches and others developed under this program.

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-- Develop dynamic adaptation technologies for probabilistic action selection to create complex mappings of integrated input data to enable self-organization of necessary data representations.

– Learning Locomotion and Navigation.
-- 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.
-- 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.

	FY 2003	FY 2004	FY 2005
Knowledge-Based Systems	0.000	12.241	17.500

(U) The Knowledge-Based Systems program, formerly budgeted in Project ST-33, will develop enabling technologies, methodologies, ontologies, and specific 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 program will develop technologies for codifying, linking, integrating, accessing, and using complex and cross-disciplinary knowledge at widely varying scales. This capability at a strategic level will provide DoD decision-makers with rapid as-needed access to decision-relevant background knowledge from a broad spectrum of distributed sources. The knowledge will be expressed in formal knowledge representation languages that will allow computers to reason about the knowledge, consider its implications, imagine possible future scenarios, and query the warfighter for clarification of various aspects of the information. The significant challenges are centered on the fact that critical knowledge involves temporal information, complex belief structures, and uncertainty, and current representation technology is not adequate to capture such information. This program will also develop the 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 replanning. By formalizing situation model representations, automated support will be provided to commanders and analysts for prediction of unforeseen events and determination of the relevance of isolated or partial events to the evolving situation. To achieve these objectives, this program will formalize situation representation and develop analogical and case-based reasoning, functional representation languages and situation markup languages

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technologies. This effort would then provide the warfighter with intelligent automated assistance to help him plan and accomplish his daily activities and, over time, learn how he accomplishes these tasks and provide increasingly valuable automated assistance.

(U) Program Plans:

- Develop knowledge module authoring tools.
- 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.

	FY 2003	FY 2004	FY 2005
Advisable Systems	0.000	8.077	12.027

(U) The goal of the Advisable Systems program is to design and build systems that warfighters can control in natural and flexible ways – not via menus or by programming them, but by exchanging advice and instructions with them. "Advice" will span a spectrum ranging from high-level policy and goals to intermediate preferences and constraints on system behavior to specific direction and contingency actions. The warfighter will be able to express this advice in natural English and engage in a dialogue to clarify/elaborate the general advice. Based on this dialogue, the system will incorporate the advice into an executable plan and start behaving as if it were originally programmed for that function. As Advisable Systems mature, this behavior will increase in complexity from configuration of existing capabilities to the automated acquisition or generation of new capabilities. Advisable Systems will furthermore continuously engage in natural dialogues with warfighters as they encounter unforeseen circumstances or conflicts in priorities and standing orders, eventually becoming fully autonomous in their functioning as commanded. Although progress in this area will require initial focus on selected mission domains to constrain the dialogue, tools will be developed for adapting the technology to other domains. While natural language interfaces are an essential enabler for Advisable Systems, this project will not support

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speech recognition research *per se* (except where important conceptual gaps exist that would bear on successful expression of advice and explanations), but rather the development of dialogue management systems that allow systems to glean and clarify warfighter intent. Advisable systems will allow commanders and other decision-makers more natural and more productive access to and control over a wide range of software capabilities in a variety of mission-critical areas, including command and control, intelligence and logistics. (This project was previously listed in ST-33).

(U) Program Plans:

- Select two or three key mission domains and compelling scenarios to drive advisable systems research with a series of increasingly difficult challenge problems. Metrics for assessment include "programming" speed and length of dialogue necessary, correctness of resulting system behavior, and performance of the advisable system versus a hand-programmed one.
- Develop domain-specific intermediate languages for expressing guidance/advice with precise operational and declarative semantics and tools for translating these languages into either executable plans or parameterized configurations of existing software modules.
- Develop a dialogue system with domain-specific semantics for eliciting natural language advice from the warfighter. This dialogue system will translate warfighter guidance into the precise intermediate languages described above for both implementation and verification of purpose and intent.
- Develop protocols and tools for applying policy preferences and constraints and mediating conflicts among them.

	FY 2003	FY 2004	FY 2005
Adaptive Networking	1.000	0.000	0.000

(U) The Adaptive Networking program assessed the feasibility of information and communication networks that possess significant degrees of self-reliance and responsibility for their own behavior and survival. This research effort is focused on the capabilities of self-diagnosis, automatic adaptation to changing and hostile environments, reconfiguration in response to changes in environment, intelligent negotiation for tasks and resources, and robustness under attack. (This program moves to ST-31 in FY04).

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(U) Program Plans:
- Identified and characterized the major components of an adaptive/cognitive network and software functionality for large-scale redesign.
- Initiated a detailed architectural plan to implement adaptive, self-diagnostic and reconfiguration network capabilities.

(U) Other Program Funding Summary Cost:

- Not Applicable.

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COST (In Millions)	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008	FY 2009
Communications, Interaction and Cognitive Networks ST-31	24.180	34.140	32.433	36.069	59.833	58.570	50.512

(U) **Mission Description:**

(U) The Communications, Interaction and Cognitive Networks project will dramatically improve warfighter and commander effectiveness by developing revolutionary methods for users to interact with and direct cognitive systems (and the physical sensors and effectors they control) and for large-scale collections of cognitive systems to interact with one another in support of user objectives. Specifically, this project will develop technologies to enable systems to detect and assess the user's cognitive state and adapt to optimize understanding and effectiveness of the user; and high-level languages for rapid but precise specification of complex behavior in response to mission demands, such as configuration of sensor networks. 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 affecting the external world. A remarkable and unique aspect of natural perceptual systems is their ability to take an inordinate amount of raw sensor data, such as visual flow and rich auditory input, filter and integrate that data, and almost instantaneously unify the resultant data into meaningful elements. The human brain is able to create from this information perceptual units that parcel the world into objects and discrete entities that are then recognized, remembered, and used in problem solving. Looking closely at these innate perception abilities will yield insights into how to build totally novel computational systems that identify important, low-frequency events in a noisy environment. This kind of approach should lead to dramatic improvements in the abilities of computers to process and analyze huge amounts of data to form a high-level understanding within their environment. This project will significantly advance the military's ability to address information overload in the operational environment.

(U) Robust interaction among cognitive systems, legacy systems, and operators will require incorporation of advanced models and control of the network infrastructure that connects them to ensure adequate provisioning of quality-of-service under dynamic loads to meet mission requirements. These technologies, taken together, will greatly increase operator effectiveness by allowing the operator to focus on high-level mission objectives rather than low-level interactions with the system while at the same time ensuring that he maintains essential understanding of how (and how well) the system is implementing and responding to that high-level direction.

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

	FY 2003	FY 2004	FY 2005
Improved Warfighter Information Processing	16.012	19.706	12.763

(U) The Improved Warfighter Information Processing (IWIP) technology thrust will develop technologies to enhance the warfighter's and the commander's information management capacities and improve decision-making performance. This research area seeks to significantly expand the operators' capabilities in a real-time operational environment by enhancing intellectual performance in the way that weapons, vehicles and sensors extend operators' physical capabilities today. In addition, this thrust will 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. The hypothesis of this emerging area is that recent impressive 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, advance 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 (Augmented Cognition) program will develop the means, devices, and infrastructure necessary to assess the warfighter's or commander's status in real time and then enhance operational effectiveness via adaptive strategies in order to greatly improve the information throughput in the computational interface. This program will develop the technology to integrate new digital devices that support memory, attention, and context recovery and link that support with the operator's status to directly improve overall performance in complex and operationally stressful conditions. The program will culminate in the development of closed-loop computational systems in which the computer system adapts to the state of the warfighter or decision-maker to significantly improve performance. The program will enhance operational effectiveness through at least these specific improvements to operator efficiency: 1) increasing the amount of information that operators can handle; 2) reducing manpower requirements (e.g., one person doing the job of three); and 3) improving attention management during stressful operations. This 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 deliver content more effectively to the operator. The effort will design and build adaptive

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multimodal interfaces that improve the ability of the warrior to communicate on the battlefield and the commander to operate in a command center, and exploit all of the digital information currently available only in a static command environment.

- The Context-Based Computing for Command and Control (CBC^3) program will demonstrate dramatic improvements in command decision-making based on the development of "context-based computing" to maintain situational awareness in real time. CBC^3 will also seek to find ways to capture in real time the context (situation assessment including information about places, people, time, functional activities, etc.) that is critical for supporting the decision maker in a meaningful way. The long-term impact of this work will be to provide users with vastly expanded expressive power, interface flexibility and transparency, more timely access to key 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.
  -- Design closed-loop computational interfaces to mitigate specific information-processing bottlenecks that serve as roadblocks to high performance and information flow; elaborate interfaces into full-fledged "decision-interactive spaces" to illustrate the full power of decision-focused computing for command and control.
  -- Develop intelligent interruption strategies to effectively increase limited working memory capacities in command and control environments.
  -- Develop adaptive attention management methods to improve focus during complex operational tasks facing the dismounted soldier.
  -- Develop cued memory retrieval strategies to enhance situational awareness and context recovery in information-rich unmanned-vehicle control stations.
  -- Develop modality switching strategies (i.e., audio, visual) to adapt information delivery interfaces in mobile command and control settings.
  -- Integrate sensor technologies into a suite of warfighter status "gauges" that will permit the assessment and enhancement of warfighter performance for order-of-magnitude improvement in operator efficiency.
  -- Demonstrate and evaluate methods for using multimodal query of digital memory to enhance performance; create capabilities for a command center to interpret multimodal input streams; and interpret what is going on within it.

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-- 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, testing their performance and usability advantages within multimodal systems developed in the program; these will include protocols for the proactive manipulation and presentation of information.

– Context-Based Computing for Command and Control.
-- Identify decision-making bottlenecks, impediments, and opportunities in the context of on-going military and non-military operations.
-- Identify critical information exchanges between command centers at different echelons and define operational metrics for decision-making.

	FY 2003	FY 2004	FY 2005
Collaborative Cognition	0.000	3.780	8.670

(U) The Collaborative Cognition technology thrust will enable the design and implementation of collaborative software agents in dynamic multi-agent environments (which include both software agents and people). The resulting technology will allow software agents to cope with limited and/or noisy sensor information; limited communication capabilities; changing and unforeseen environments and other agents; and limited *a priori* knowledge of each other's capabilities. An outgrowth of previous DARPA work such as Control of Agent-Based Systems (CoABS), the technology can quickly and efficiently explore the application of innovative cognitive and behavior modeling approaches to intelligent software agent systems. The Collaborative Cognition technology thrust comprises Collaborative Cognition Systems and Coordination Decision-Support Assistants.

- 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. In particular, the software will be adept at controlling agent programs under previously unseen or unknown conditions. This work will

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explore revolutionary concepts for applying distributed agent technology, first to modeling and simulation systems, with the long-range goal of applying this technology to operational environments, delivering a leap ahead in the capability of intelligent systems.

- The Coordination Decision-Support Assistants (COORDINATORs) program will develop a new class of cognitive systems that learn and reason about performance in order to provide dynamic activity coordination and decision support to the warfighter. The program seeks to dramatically improve the coordination of warfighter activity in dynamic operational environments including task selection and scheduling. The COORDINATORs program will enhance system performance, improve response times, increase adaptability and flexibility, add a level of reliable autonomy and decrease the number of assets required to perform tasks or solve problems. COORDINATORs, through real-time reasoning that adapts and changes in response to the environment, will enable commanders to focus on the "hard problems" and offload certain mechanizable coordination decision tasks to automated systems as necessary and appropriate.

(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 and 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.

– Coordination Decision-Support Assistants.
  -- Develop algorithms that allow distributed, real-time coordination and scheduling (avoiding centralized bottlenecks and single points of failure); extend those algorithms to plan courses of action in an adaptive and flexible manner.
  -- Develop distributed coordination and autonomous control to coordinate activities.
  -- Develop machine learning algorithms to enable the coordination systems to learn concepts of operation and commander preferences for coordination decision-making.

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	FY 2003	FY 2004	FY 2005
Self-Aware Collective Systems	0.000	3.336	7.000

(U) The Self-Aware Collective Systems technology thrust will enable heterogeneous teams of individuals (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. Self-Aware Collective Systems offer a powerful set of concepts intended to empower warfighters to take full advantage of all available information and to bring to bear all available assets in a rapid and flexible manner. The technology will improve information sharing and situational awareness in heterogeneous environments by robustly and dynamically networking teams of agents and warfighters cooperating on a specific task. The Self-Aware Systems thrust is comprised of two programs: Self-Aware Peer-to-Peer Systems and Collective Cognitive Information Processing for Improved Asset Performance.

(U) The Self-Aware 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 support battlespace awareness by enabling the self-formation of large *ad hoc* networks of sensors and computational elements within the severely resource-constrained environment (power, bandwidth, stealth) of military operations while enabling networks to survive component failure, network intrusion, and the subversion of elements. This self-aware network of sensors and communication element 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. Therefore as elements fail or are subverted, the Self-Aware Peer-to-Peer Systems will control the graceful degradation of any of its parts. This technology will support a variety of networks of manned and unmanned systems.

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(U) The Collective Cognitive Information Processing for Improved Asset Performance program will develop learning and reasoning algorithms that can identify and classify emergent problems and opportunities for proactive maintenance of equipment and use of sensors in a dynamic operational environment. In a way that is unachievable from the local perspective of an individual element in the collection, these new self-aware distributed systems will be able to reflect globally on their overall operation (including understanding trends), and make decisions based on the collective disposition of assets connected by sensors (e.g., vehicles or other equipment). One consequence of this new approach would be significantly increased reliability and readiness of military equipment because information from all equipment is seen and correlated globally, rather than just locally on individual vehicles. This technology will enable commanders to optimize the mix of resources required for a particular task, allowing fewer resources to accomplish extended military operations.

(U) Program Plans:

- Self-Aware Peer-to-Peer Systems.
  - -- Define and develop cognitive representations and distributed agent technologies, information fusion algorithms, diagnostic and prognostic algorithms, network control language, and network benchmarks.
  - -- Integrate image recognition, adaptive 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-aware, self-forming networks allowing for distributed control; allow the overall collective to 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.

- Collective Cognitive Information Processing for Improved Asset Performance.
  - -- Identify and classify emergent behavior of equipment performance and utilization in a dynamic operational environment; use historical data collected in an operational setting.
  - -- Create technology for forming a dynamic knowledge base to hold and process information from a distributed collection of vehicles or other assets.

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-- Apply learning through observation, monitoring and data collection, and integrate operator input to augment data sets and modules to provide critical health and status of equipment.
-- Develop computational mechanisms for producing recommendations for specific proactive maintenance or sensing actions based on reasoning over information collected on a real-time basis from a distributed set of platforms.

	FY 2003	FY 2004	FY 2005
Cognitive Networking	0.000	1.472	4.000

(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 systems 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 explore the possibility of a virtual "application-private network", whose on-demand protocols are based on specific application requirements and current network conditions. It will also attempt to create a "cognitive radio" capability, which uses cognitive information processing to optimize communication based on current conditions, past experience and high-level user guidance.

(U) The Adaptive Networking program will assess the feasibility of information and communication networks that possess significant degrees of self-reliance and responsibility for their own behavior and survival. This research effort will focus on the capabilities of self-diagnosis, automatic adaptation to changing and hostile environments, reconfiguration in response to changes in the environment, intelligent negotiation for tasks and resources and robustness under attack. Key research challenges for the program are the development of formal models and representations that enable collective learning and reasoning in the distributed setting; development of a decentralized, scalable overlay architecture; and accurate responses to the changing issues that arise in complex trust and administrative environments. This program will dramatically increase information assurance through the reduction of human error in network management. These technologies will enable the military to achieve smaller, more agile rapid-deployment forces through self-configuring, self-managing networks. (This project was previously listed in ST-30.)

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(U) Program Plans:
- Identify and characterize the major components of an adaptive/cognitive network and software functionality for large-scale redesign.
- Develop a detailed architectural plan to implement adaptive, self-diagnostic and reconfiguration network capabilities.
- Design and develop a broad collection of specific cognitive network protocols and network management software for automatic statistical diagnosis and control.
- Design and implement an experimental cognitive physical network infrastructure.

	FY 2003	FY 2004	FY 2005
Network Modeling and Simulation	8.168	5.846	0.000

(U) The Network Modeling and Simulation (NMS) program develops software to enable the autonomous prediction, design and control of complex networks over a broad range of time scales, network sizes, composition and performance. New models and simulators will enable reliable and rapid planning, design, analysis and configuration of military and emergency networks with minimal manual intervention.

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

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

- Not Applicable.

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COST (In Millions)	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008	FY 2009
Computing Foundations ST-32	8.282	17.583	27.552	33.450	41.283	48.094	52.892

(U) **Mission Description:**

(U) The Computing Foundations (formerly Cognitive Systems Foundations) project will develop novel system-level solutions through the intelligent integration of cognitive agent capabilities built on robust software and hardware infrastructure. To handle increasingly complex jobs, next-generation computer systems will need to integrate the cognitive capabilities of reasoning, learning, explaining, and self-awareness, and be able to be advised and cope robustly with surprise. These aspects of intelligence will be combined in innovative ways with powerful new conventional computing architectures. Overall this element seeks to make fundamental scientific and mathematical improvements in our understanding of and ability to create information and computing systems. The next generation of systems, with cognitive capabilities, may also form teams to achieve goals in a coordinated manner, exceeding the performance of individual systems or humans working alone. Current fragile commercial systems will require enhancements or radical changes to support this revolutionary objective. The new computing foundations will extend beyond today's standard Von Neumann computing model.

(U) 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 their means drives the need for systems that are able to dynamically adapt, collect and assimilate large quantities of data, and remain robust under a large set of potential failure conditions and threats. Computing Foundations will enable next-generation systems to be more responsible for their own monitoring and protection, as well as for restoring themselves to full capability after an attack or failure.

(U) In addition, the plan is to develop, evaluate, prototype and demonstrate a set of promising concepts in the context of full-scale test-beds in realistic scenarios and environments. The next transformational revolution for military force development will be the seamless integration of autonomous physical devices, computation software agents, and humans. Transition goals are military next-generation network-centric systems and platform-specific information collection and processing systems in space, air, sea and land.

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

	FY 2003	FY 2004	FY 2005
Self-Regenerative Systems	3.653	5.778	10.500

(U) The Self-Regenerative Systems (SRS) program will conceive, design, develop, implement, demonstrate and validate architectures, tools, and techniques for fielding systems capable of adapting to novel threats, unanticipated workloads and evolving system configurations. Employing innovative techniques like diversity and scalable redundancy as well as higher-level cognitive functions such as reasoning, reflection, and learning, SRS technologies will allow future information systems to be dramatically more robust, survivable, and trustworthy than today's systems. 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. Also, they will maintain their robustness and trustworthiness attributes even as they undergo growth and evolution in functionality and performance over time.

(U) Program Plans:

- Identify novel attacks and generalize and learn from specific attack events to form a defense against a general set of cyber-attacks and failures.
- Develop technologies to diagnose and assess damage, repair and recover from damage caused by accidental faults, software aging, or malicious activities and, generally, heal the system automatically.
- Develop information systems that can assess dynamic security risks and predictively adapt their security posture to anticipated threat conditions, and adaptively balance performance and functionality with security.
- 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.

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	FY 2003	FY 2004	FY 2005
Architectures for Cognitive Information Processing	3.336	6.280	10.552

(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 fundamentals, framework and development environments that will provide the basis for and enable innovative and truly efficient cognitive processing. Current intelligent processing implementations depend on the use of existing numerically-based architectures and/or standard software architectures, and therefore are implemented via algorithms and processing architectures that are potentially ill-suited to cognitive tasks. To realize the impact and promise of cognitive processing, approaches, algorithms, and architectures that are attuned to cognitive processing fundamentals and that efficiently implement unique cognitive structures need to be established. 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 to support efficient implementations. In order to focus and establish context for the ACIP program, ACIP will pursue focused in-context DoD mission areas for the development of ACIP concepts. ACIP will develop implementations that will span the areas of perception, reasoning and representation, learning, and communication and interaction to enable new classes of cognitive information processing applications that move us dramatically forward toward the overall goal of creating computer systems that truly know what they are doing.

(U) Program Plans:

- Establish a Cognitive Information Framework that will provide common cognitive development environments, tools and evaluation methods for cognitive algorithm and architecture developments, providing an enduring cognitive basis for a broad set of domains and applications.
- Establish proof-of-concept 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 also uses deliberation to plan and solve problems.
- Establish and demonstrate a first-generation framework supporting cognitive approach implementation, algorithm development and architectural evaluation.

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

	FY 2003	FY 2004	FY 2005
Security-Aware Systems (formerly Visibly-Controllable Computing)	1.293	5.525	6.500

(U) Today's mechanistic military software systems are brittle in the face of changing requirements, and vulnerable to skilled attackers who bring creativity and unpredictability to their strategies. Prior work in system security has focused on flexible design and removing, or compensating for vulnerabilities. These approaches, however, cannot be perfectly realized and risk to military systems remains high. The goal of a security-aware system is to minimize unavoidable cyber risk to military missions by having a system itself smoothly adapt to changing resources, building blocks, security requirements, mission goals and threats. A security-aware system will reason about its own security attributes, capabilities and the utility of its functions with respect to a mission context. A security-aware system will dynamically adapt to provide desired levels of service while minimizing risk and providing coherent explanations of the relative safety of service level alternatives.

(U) The Security-Aware Critical Software (SACS) program, formerly Visibly-Controllable Computing, will leverage the research conducted under Cyber Panel and other DARPA programs to create a new generation of software that provides a comprehensive picture of security properties and current status, and will present this information at multiple levels of abstraction and formality. SACS will eliminate confusing and information-free error messages in favor of useful explanations. This capability will make security properties and status transparent to decision-makers, which will increase the speed and confidence with which military systems can be securely and dynamically reconfigured, particularly under stressful conditions. SACS will revolutionize the security of general-purpose information systems and reduce the threat from stealth attacks in which attackers take control of systems without being detected. 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 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.

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- Develop techniques to summarize security policy and status so that the descriptions produced by SACS can be understood while at the same time not omitting critical details.
- 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 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 understanable to a variety of managing software components and human operators.
- Develop testing and validating protection mechanisms of security products to certify protection to quantifiable levels based on a scientific rationale.
- Develop measures of merit and metrics to quantitatively characterize various dimensions of security (availability, integrity, confidentiality, authentication, and non-repudiation), fault tolerance, and intrusion tolerance and show the relevance of the theory by applying it to a realistic exemplar system.

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

- Not Applicable.

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COST (In Millions)	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008	FY 2009
Knowledge Representation and Reasoning ST-33	26.399	3.472	0.000	0.000	0.000	0.000	0.000

(U) **Mission Description:**

(U) The Knowledge Representation and Reasoning project is exploring technology central to the creation of a new class of computational systems – Cognitive Computing Systems that will reason, learn, and respond intelligently within the dynamic environment of military operations. The real power of information processing emanates from higher-level capabilities that use abstraction, mental simulation and planning, hypothetical reasoning, powerful language understanding and generation capabilities and self-awareness. This program will develop novel and effective technologies for representing knowledge of the world and accompanying methods of reasoning (including deductive, abductive, planning, strategic, analogical, and hybrid) methods. The Knowledge Representation and Reasoning project comprises Autonomous Software for Intelligent Control, Knowledge-Based Systems and Advisable Systems.

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

	FY 2003	FY 2004	FY 2005
Autonomous Software for Intelligent Control	16.437	3.472	0.000

(U) The Autonomous Software for Intelligent Control effort will program a variety of autonomous mobile robots to independently perform military tasks in a diverse spectrum of complex, dynamic environments. The goal is to advance real-world performance in the tasks of perception-based autonomous vehicle navigation and effective natural interaction of robots with humans. Representations of tasks, goals, plans, common-sense knowledge, and perceived environmental features, including soldier interaction, are core to this effort. Several alternative approaches are being pursued to augment pre-programmed activities and responses with powerful learning-derived competencies for perception and control analogous to those of natural systems. This software will enable autonomous systems to effectively reason about real-world situations in order to appropriately modify their behaviors. Integrated perception, including fusion of data from multiple sensor and multiple processing modalities of the same data will reduce operator intervention and achieve semi-autonomous operation. The resulting highly capable robots will have the ability

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to learn new tasks and adapt quickly to changing environments (with minimal programming effort) essential for applications in the battlespace of the future.

(U) Program Plans:

- Demonstrate adaptive generation of complex behaviors; multi-sensor-enabled, outdoor navigation; and methods for directing perceptual attention.
- Develop and demonstrate an integrated robust on-road driving system capable of operating in a natural environment with congestion.
- Demonstrate a trainable, perception-based, autonomous navigation capability for robots in urban environments.
- Integrate perceptual, behavioral, and natural interactive capabilities onto a humanoid robotic platform, and measure the relative performance of supervised and autonomous behavior modes.
- Develop distributed perception-based autonomous navigation behaviors for unmanned surface vessels (USVs) and share information between multiple USVs, to achieve cooperative target tracking, interception, and self-defense.
- Demonstrate cognitively compatible teams of semi-autonomous, semi-independent robots, with adjustable interaction modes.
- Develop infrastructure and tools to seamlessly integrate communications, control, and perception capabilities to implement a networked team of air and ground unmanned vehicles for reconnaissance and area patrol.

	FY 2003	FY 2004	FY 2005
Knowledge-Based Systems	5.842	0.000	0.000

(U) The Knowledge-Based Systems program will develop enabling technologies, methodologies, ontologies, and specific 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 program will develop technologies for codifying, linking, integrating, accessing, and using complex and cross-disciplinary knowledge at widely varying scales. This capability at a strategic level will provide DoD decision-makers with rapid as-needed access to decision-relevant background knowledge from a broad spectrum of distributed sources. The knowledge will be expressed in formal knowledge representation languages that will allow computers to reason about the knowledge, consider its implications, imagine possible future scenarios, and query with warfighter for clarification of various aspects of the

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information. The significant challenges are centered on the fact that critical knowledge involves temporal information, complex belief structures, and uncertainty, and current representation technology is not adequate to capture such information. This program will also develop the 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 replanning. By formalizing situation model representations, automated support will be provided to commanders and analysts for prediction of unforeseen events and determination of the relevance of isolated or partial events to the evolving situation. To achieve these objectives, this program will formalize situation representation and develop analogical and case-based reasoning, functional representation languages and situation markup languages technologies. This effort would then provide the warfighter with intelligent automated assistance to help him plan and accomplish his daily activities and, over time, learn how he accomplishes these tasks and provide increasingly valuable automated assistance. (This program moves to project ST-30 in FY04).

(U) Program Plans:

- Identify methods and protocols for using interoperable knowledge modules resident on distributed knowledge servers.
- Explore integrated knowledge representation and learning technology that enables effective representation of essential forms of knowledge.
- Initiate development of knowledge module authoring tools.

	FY 2003	FY 2004	FY 2005
Advisable Systems	4.120	0.000	0.000

(U) The goal of the Advisable Systems program is to design and build systems that warfighters can control in natural and flexible ways – not via menus or by programming them, but by exchanging advice and instructions with them. "Advice" will span a spectrum ranging from high-level policy and goals to intermediate preferences and constraints on system behavior to specific direction and contingency actions. The warfighter will be able to express this advice in natural English and engage in a dialogue to clarify/elaborate the general advice. Based on this dialogue, the system will incorporate the advice into an executable plan and start behaving as if it were originally programmed for that function. As Advisable Systems mature, this behavior will increase in complexity from configuration of existing capabilities to the automated acquisition or generation of new capabilities. Advisable Systems will furthermore continuously engage in natural dialogues with warfighters as they encounter unforeseen

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circumstances or conflicts in priorities and standing orders, eventually becoming fully autonomous in their functioning as commanded. Although progress in this area will require initial focus on selected mission domains to constrain the dialogue, tools will be developed for adapting the technology to other domains. While natural language interfaces are an essential enabler for Advisable Systems, this project will not support speech recognition research *per se* (except where important conceptual gaps exist that would bear on successful expression of advice and explanations), but rather the development of dialogue management systems that allow systems to glean and clarify warfighter intent. Advisable systems will allow commanders and other decision-makers more natural and more productive access to and control over a wide range of software capabilities in a variety of mission-critical areas, including command and control, intelligence and logistics. (This program moves to project ST-30 in FY04).

(U) Program Plans:

- Select two or three key mission domains and compelling scenarios to drive advisable systems research with a series of increasingly difficult challenge problems. Metrics for assessment include "programming" speed and length of dialogue necessary, correctness of resulting system behavior, and performance of the advisable system versus a hand-programmed one.
- Explore domain-specific intermediate languages for expressing guidance/advice with precise operational and declarative semantics and tools for translating these languages into either executable plans or parameterized configurations of existing software modules.
- Begin development of a dialogue system with domain-specific semantics for eliciting natural language advice from the warfighter. This diabgue system will translate warfighter guidance into the precise intermediate languages described above for both implementation and verification of purpose and intent.

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

- Not Applicable.

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COST (In Millions)	FY 2003	FY2004	FY2005	FY 2006	FY 2007	FY 2008	FY 2009
Total Program Element (PE) Cost	54.870	13.250	0.000	0.000	0.000	0.000	0.000
Networked Embedded Systems Design AE-01	19.211	5.814	0.000	0.000	0.000	0.000	0.000
Software for Autonomous Systems AE-02	21.775	7.436	0.000	0.000	0.000	0.000	0.000
Software for Embedded Systems AE-03	13.884	0.000	0.000	0.000	0.000	0.000	0.000

(U) Mission Description:

(U) Embedded computing provides the connection between the physical world and computational realm. Embedded computing impacts the superiority of a multitude of DoD systems from avionics to smart weapons. Virtually all new weapon systems from the F-22 aircraft to National Missile Defense and from the Future Combat System to Unmanned Combat Air Vehicles depend on embedded software technology. The level of software complexity in these systems is unparalleled. The goal of the Embedded Software and Pervasive Computing program is to greatly extend the reach and effectiveness of computation from mainframes and desktops into the physical world. These embedded programs pursue the software and systems research to facilitate a new emerging application of computers, and conduct research to greatly increase the autonomy of those systems, to promote the human role from that of operator to supervisor, thereby reducing the mission demand for intensive manpower. Embedded system advancements may revolutionize system and software technology to facilitate the efficacy of the integrated battlefield. This program element will draw to a close at the end of FY 2004. Many of these efforts in Embedded Systems have been funded in PE0602702E, project TT-13, to reorient the research towards specific applications.

(U) The Networked Embedded Systems Design project will extend DoD's ability to build complex embedded software systems, which are the primary source of superiority in modern weapons platforms. Embedded software monitors and controls the physical environment, and lends intelligent behavior to platforms. The design and implementation of embedded software systems require an in-depth approach to information systems. Embedded systems will manage the vast quantities of physical information that can be accessed by sensors and actuators in direct contact with the real world. To enable the design of these tightly integrated physical and information systems, network and software infrastructures must be extended to interact with a wide variety of diverse physical world devices and environments. Designs will accommodate vast increases in the numbers of nodes with real-time data requirements, and must support operating regimes in which network-based nodes must host services on

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behalf of embedded clients. Research on embedded software creation must radically extend the technology to enable the modular composition of software systems subject to physical constraints.

(U) The Software for Autonomous Systems project develops revolutionary control technology to enable predictable, safe, and cooperative operation of free ranging, autonomous systems. DoD needs revolutionary new capabilities for increasing autonomy of weapon systems. Increased autonomy will enable combined manned and unmanned warfare, and the extensive use of robotics technologies empowers future war fighters to accomplish their missions more effectively, reducing the risk of casualties, thereby preserving the U.S. military's most important resource–the warfighter. The project builds on major advancements in computing and software achieved during the past decade, which make the practical application of complex nonlinear, hierarchical control techniques feasible.

(U) The Software for Embedded Systems project developed a new class of software to deal with mobile, distributed sensor networks and the processing of physical world information by embedded devices. The convergence of processing power, vanishing size and decreasing cost of today's microprocessors has created new devices and micro-sensors that enable a new wave of DoD applications. The effort included new algorithms and software allowing distributed micro-sensor networks to rapidly and accurately detect, classify, and track threats and events of interest in the battlefield. This effort also included new technology to make changes in complex software systems predictably, to ensure the safety and reliability of critical military systems, and to make the systems "self-healing."

(U) **Program Change Summary:** *(In Millions)*	**FY 2003**	**FY 2004**	**FY2005**
Previous President's Budget	58.599	13.318	0.000
Current President's Budget	54.870	13.250	0.000
Total Adjustments	-3.729	-0.068	0.000

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Congressional program reductions	0.000	-0.141
Congressional increases	0.000	0.000
Reprogrammings	-1.729	0.073
SBIR/STTR transfer	-2.000	0.000

(U) Change Summary Explanation:

FY 2003	Decrease reflects SBIR transfer and minor repricing.
FY 2004	Decrease reflects congressional undistributed reductions and a below threshold reprogramming.

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COST (In Millions)	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008	FY 2009
Networked Embedded Systems Design AE-01	19.211	5.814	0.000	0.000	0.000	0.000	0.000

(U) **Mission Description:**

(U) This project extends DoD's ability to build complex embedded software systems, which are a major source of superiority in modern weapons platforms. Embedded software monitors and controls the physical environment, and lends intelligent behavior to platforms. The design and implementation of embedded software systems require an in-depth approach to information systems. Embedded systems will manage the vast quantities of information that can be accessed by physical sensors, and provided to physical actuators, in direct contact with the real world. To enable the design of these tightly integrated physical and information systems, tools to develop software for them must be extended to accommodate a wide diversity of physical world devices and environments with increasingly ambitious performance goals. Designs must support vast increases in the numbers of processors with real-time data requirements. This work radically extends software development technology to enable the modular composition of software systems subject to tight physical constraints.

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

	FY 2003	FY 2004	FY 2005
Model Based Integration of Embedded Systems	14.811	5.814	0.000

(U) The Model-Based Integration of Embedded Systems (MoBIES) program is building tools to design and test complex computer-based systems such as avionics, weapons, and communications systems. It simplifies the design of complex embedded systems by focusing on the pre-production environment rather than after-the-fact integration. The approach is to customize the design tools used by applications engineers so that controller design and systems integration can be more fully automated and the errors thereby reduced. The technology will formalize system modeling and programming tools in a common mathematical form. This analysis will allow integrated design of hardware and software from the earliest stages in system development, leading to interoperable tools, automatic systems integration, and simplified test and evaluation. The MoBIES program allows such custom-designed toolsets to be easily tailored to specific applications, resulting in more efficient, verifiable,

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scalable, and re-usable programs for complex weapon and vehicle systems applications. Its objectives are to increase by 100 percent the size of the embedded software programs that existing tools can reliably produce, and decrease by 80 percent the design time necessary to create application-specific tools.

(U) Program Plans:

- Develop methods to integrate different models of computational processes for different applications into a programmable design tool.
- Demonstrate the ability to propagate different physical constraints among design tools.
- Develop hybrid (continuous and discrete) modeling and analysis techniques for embedded systems.
- Develop and demonstrate techniques for the mathematical modeling and formal verification of model-based software generators.
- Demonstrate end-to-end tool integration in avionics, software radio, and vehicle electronics experimental platforms.
- Develop tools for automatically checking safety and reliability properties of automatically generated software.
- Demonstrate the rapid synthesis of embedded systems using customizable frameworks and model-based code generators.
- Develop techniques for integrating different commercial off-the-shelf analysis tools into a single tool environment.
- Develop and demonstrate the use of multiple-view modeling techniques for military avionics, software radio, and combat vehicular electronics applications.

	FY 2003	FY 2004	FY 2005
Adaptive Reflexive Middleware Systems	4.400	0.000	0.000

(U) The Adaptive and Reflective Middleware Systems (ARMS) program has focused on the Total Ship Computing Environment (TSCE) for the DD(X) Future Surface Combatant Family of Ships. The TSCE will be a fully integrated open system computing and information architecture that executes all tasks and mission applications optimized at the platform level, rather than the sub-system level, thus breaking down the traditional C4ISR, Combat Systems, and Ship Control System boundaries. The TSCE is a mission-critical distributed embedded system where 1) different levels of service are possible and desirable under different conditions and costs and 2) the levels of service in one dimension must be coordinated with and/or traded off against the levels of service in other dimensions to achieve the intended overall result, even in the face of battle damage or heavy workloads. The autonomous behavior of TSCE systems requires the middleware components and frameworks to adapt robustly to

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quantifiable changes in environmental conditions. In ARMS, middleware is responsible for coordinating the exchange of information efficiently, predictably, scalably, dependably and securely between remote entities by using advanced Quality of Service (QoS) capabilities of the underlying network and end systems. This program moved to PE 0602702E, Project TT-13 beginning in FY 2004.

(U) Program Plans:

- Develop adaptive protocols, algorithms, patterns, and tools that enforce security policies to enhance and support secure global resource allocation, scheduling, and control.
- Ensure stability and dependability across multi-level feedback loops in the network-centric TSCE.
- Develop meta-programming policies and mechanisms (instead of application-specific point solutions) to customize QoS -enabled middleware services and applications.
- Develop design expertise (pattern languages) to formalize the successful techniques and constraints associated with developing, generating, and validating QoS-enabled middleware frameworks and protocol/service components.
- Develop reflective techniques for synthesizing optimized real-time and embedded middleware.
- Develop languages, algorithms, and tools to configure customizable—yet standards-compliant—TSCE middleware and applications.
- Demonstrate sufficiently mature technologies that can transition, with moderate to low risk, to the DD(X) Surface Combatant Family of Ships and other DoD combat systems.

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

- Not Applicable.

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COST (In Millions)	FY 2003	FY 2004	FY 2005	FY 2006	FY 2007	FY 2008	FY 2009
Software for Autonomous Systems, AE-02	21.775	7.436	0.000	0.000	0.000	0.000	0.000

(U) **Mission Description:**

(U) This project develops revolutionary control technology to enable predictable, safe, and cooperative operation of free-ranging, autonomous systems. Increased autonomy will enable combined manned and unmanned warfare. Extensive use of robotics technologies empowers future warfighters to accomplish their missions more effectively with less risk of casualties, preserving the U.S. military's most important resource. The project builds on major advances in computing and software during the past decade, which has made the practical application of complex nonlinear, hierarchical control techniques feasible.

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

	FY 2003	FY 2004	FY 2005
Common Software for Autonomous Robotics	4.501	0.000	0.000

(U) The Common Software for Autonomous Robotics program developed software technologies for large groups of extremely small and highly resource-constrained micro-robots, enabling the coordinated action of many robots to achieve a collective goal while allowing the warfighter to task and query the ensemble of robots as a group, rather than as individuals. This component addressed four critical areas: 1) coordinated behaviors, including both explicit control strategies that decompose tasks and propagate instructions to individual elements, and implicit control strategies analogous to potential fields; 2) inter-robot communications, including networking protocols that minimize energy consumption and novel alternative communications strategies such as insect-like "pheromone" communications; 3) computational architectures that range from fully distributed processing among the micro-robots themselves to off-loaded processing by a separate "proxy" processing resource; and 4) military personnel-robot interfaces, including both explicit (symbolically grounded) and novel implicit (non-symbolic) user-interface technologies. The technology has enabled distributed "swarm" systems of robots that effectively exploit the scalability of large numbers to robustly perform important military tasks such as area surveillance and mine clearing.

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(U) Program Accomplishments:

- Demonstrated energy-saving protocols with at least 70 percent savings over conventional protocol implementations.
- Integrated developmental network protocols into selected distributed robotic platforms and investigated cooperative approaches to achieve critical situational awareness in the indoor application domain.
- Demonstrated realistic mission scenarios using representative distributed robot platforms in a simulated mission context and in field experiments.
- Developed coordination techniques to support accelerated mobility and reconnaissance for cooperating platforms and developed shared representations to support collaborative communication between humans and robotic systems.
- Developed minimal-resource behavioral algorithms and simulation tools to implement highly scalable distributed approaches to simultaneous localization and mapping, communications, and threat detection.

	FY 2003	FY 2004	FY 2005
Software Enabled Control	17.274	7.436	0.000

(U) The Software Enabled Control program is improving the capabilities of control systems for advanced unmanned and manned aircraft. These control systems enhance the autonomy and reliability of both fixed- and rotary-winged unmanned aerial vehicles, and improve the performance of manned vehicles. The challenges are to mathematically model complex changes in flight conditions and vehicle status, to design fast digital control systems to automate maneuvers, and to automatically detect and recover from faults or damage. These techniques will be implemented on a common, open computing platform using a flexible programmer's interface that facilitates reuse of real-time controllers across multiple vehicles. Advanced control system development will exploit recent successes in hybrid systems research, which combine continuous-time systems with randomly occurring discrete events. Hybrid systems can then adapt to sudden changes such as aerodynamic disturbances, threat conditions, damage or failure, or limits in the flight envelope. The software to implement these controls must manage these events and guarantee stable operation throughout the execution of the mission.

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(U) Program Plans:

- Develop Open Control Platform (OCP) computing services for advanced control of fixed-wing and rotary-wing air vehicles (e.g., flight mode switching, random event handling, stability and optimization, and reliability).
- Develop and implement a system for high-confidence authority management for vehicle control and mission-management levels.
- Develop theoretical frameworks for robust hybrid control.
- Develop software customization, failure reconfiguration, and sensor and actuator resource services for unmanned aerial platforms; integrate with OCP.
- Integrate coordinated hybrid system services into OCP middleware, facilitating multi-vehicle coordinated control.
- Develop guaranteed-safe maneuver libraries and control algorithms for coordinated flight.
- Demonstrate integrated controller with active dynamic models for on-line estimation of external influences such as wind fields and carrier deck motion.
- Implement and verify adaptive real-time control algorithms on model vehicles and in hardware-in-the-loop simulation.
- Demonstrate mission-management and dynamic replanning for multiple aircraft using an F-15 and a T-33 UCAV surrogate in coordinated flight.
- Demonstrate low-level autonomous adaptive flight control using rotary-wing UAVs in complex terrains.

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

- Not Applicable.

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