Cognizant Autonomous Sensor Technology : Sensors as Robots

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Introduction

- One can easily envision future military operations and emerging civilian requirements that will be both complex and stressing and will demand innovative sensors and sensor configurations.
- The goal of our research is to develop a cost effective and extendable approach to providing surveillance for a variety of applications in dynamically changing environments.
- We foresee a new sensor archetype. In this paradigm, sensors and algorithms will be autonomously altered depending on the environment.
- Intelligent sensor platforms working in concert will increase information flow, minimize ambiguities, and dynamically change multiple sensors' operations based upon a changing threat environment.
- Concomitant with the current emphasis on more flexible defense structures, Sensors as Robots will allow the appropriate incremental application of remote sensing assets by matching resources to the situation at hand.

Objective

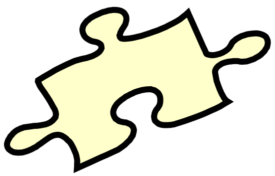
- To develop a futuristic ISR concept utilizing the innovative integration of cutting edge technologies such as: *knowledge-based signal processing, robotics, wireless networking, waveform diversity, the Semantic Web, advanced architectures and supporting software languages*.
- Sensors as Robots is projected as an autonomous constellation of air, space, and ground vehicles that would offer a robust paradigm to build toward future deployments.
- Sensors as Robots may eventually lead to an operational capability that will replace airborne assets in the operational world

Motivation

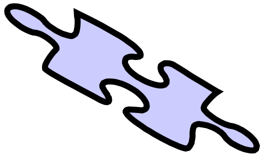
- Governments worldwide are undertaking major alterations in capabilities, from forces designed during the Cold War to those adapted to 21st century adversaries including terrorism.
- This change has been driven by a changing threat as well as technology innovations, especially information and sensor technology.
- As the military services attempt to increase the agility and versatility of their forces, they also see a need to seamlessly and automatically increase the capabilities of intelligence, surveillance and reconnaissance (ISR) to support the new weapon systems and operating methods against these new threats.

Motivation
(continued)

- UAV Based Sensor Systems Will Ultimately Replace Conventional Airborne Radars
- Other Sensor Suites Will Also Succumb To The Revolution
  - High Cost Of Staffing
    - Advances in Signal Processing And Computing Will Make Automation More Affordable



  - Inevitable Advances in Technology e.g.
    - Wireless Will Change The Way Engineers Build Sensors and Communications Systems
    - Semantic Web



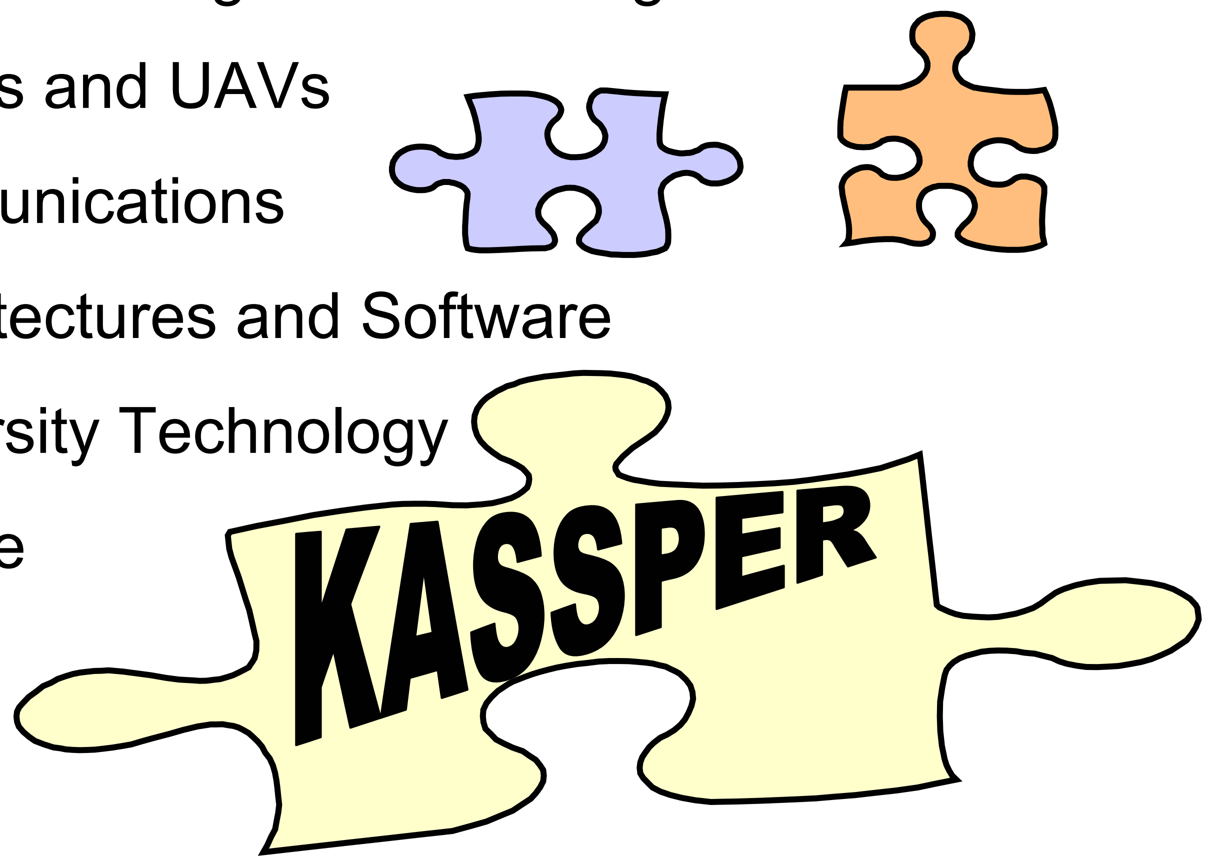
- A defense strategy built around the concept of shifting to a “capabilities-based” approach to defense, one that focuses more on how an adversary might fight than who the adversary might be and where a war might occur QDR 9/30/01

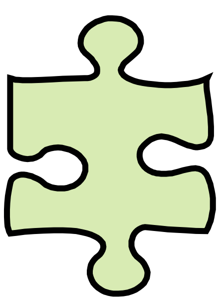
Motivation
(continued)

- Limitations to current ISR systems
  - Sensors and systems have been built given a fixed set of requirements and therefore are often inflexible
  - Algorithms in general are often derived under narrow or ideal assumptions
  - Software is often costly to change or port to new processors
    - Fielded software is computer platform dependent
  - Sensors systems are stove piped
    - Don’t easily communicate with other systems or sensors except for handoff
  - Single mode operation
    - Simultaneous multimode operation is required yet currently unavailable
- Conflicts with today’s military transformation

Motivation
(continued)

- Critical Technologies to be Leveraged
  - Sensor Systems and Signal Processing
  - Robotic Systems and UAVs
  - Wireless Communications
  - Computer Architectures and Software
  - Waveform Diversity Technology
  - Knowledge Base





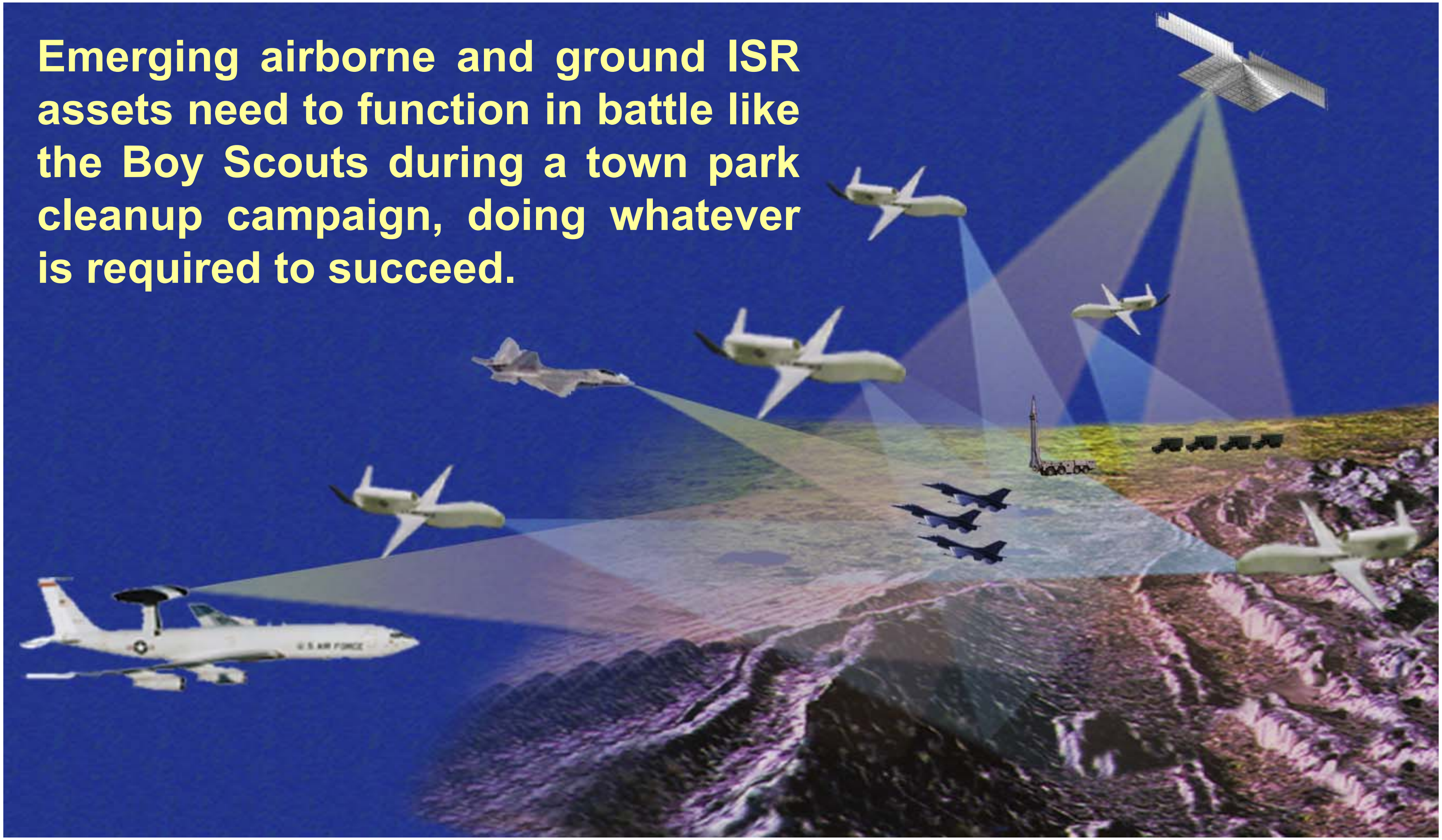
The Boy Scout Troop Analogy

- A Boy Scout troop is charged with cleaning the town park. Initially, each boy is assigned a specific task and timeline.
- Soon into the exercise, and as a result of some minor and perhaps major situational changes, the original individual marching orders are modified, or perhaps even ignored, on the fly.
- In any event, however, each member of the troop does his part to accomplish the goal of cleaning the park. In the end, the mission is successfully completed.
- Independent entities (the Scouts) have operated in an autonomous manner using cognitive reasoning in responding to real-time changes in the environment, to accomplish a pre-assigned mission.
- The individual Scouts, by sensing the behavior and activities of their colleagues in response to the changing environment, and by communicating the necessary data and information, achieved a collective response that resulted in a "successful" operation. <u>This "system" worked as a result of the autonomous and intelligent interaction between the individual "subsystems".</u>
- <u>We need to capture the essence of this autonomous and intelligent interaction in Sensors as Robots in order to succeed.</u>

Desired System Attributes

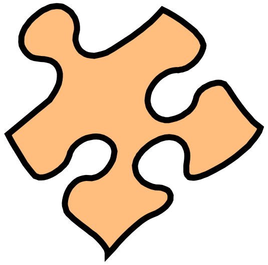
- Dynamic sensors and systems – algorithms that can autonomously adapt to the environment and control the sensor platform.
- Multi-mission multi-mode systems, e.g.
  - Radar systems that use the same returns to perform detection, discrimination, etc.
  - Radar systems that dynamically change waveform parameters for multiple purposes – waveform diversity
- Sensors and systems that communicate and share data/instructions in real-time
- Intelligent sensor systems within and between platforms
  - Intelligent integration of multiple data sources provides information
  - Needed to achieve dynamic goals
  - Avoid electromagnetic fratricide

Futuristic Scenario



Philosophical Foundation

- Detect & exploit observable phenomena
  - "Long, *mid & near*" range
    - *Mimic integrated use of the five senses plus memory and intelligence*
    - *Exploit our understanding of human, animal & insect behavior*
    - *Build upon the success of the ISR triad*
  - Improve sensor signal & data processing
    - Knowledge base & "a priori" information
    - Multiple processing paradigms
    - Sensor fusion



- Autonomous maneuvering of UAV sensors
  - Motion, displacement & "right" placement
    - Use all appropriate sensor & control data
- This research initiative will strive to meet future UAV sensor requirements to perform multi-level autonomous functions dynamically, in the real world and will do so by leveraging, and in some cases, stimulating advances in an array of technological regimes.

Quadrennial Defense Review

- Report dated 9/30/01
  - "The new defense strategy is built around the concept of shifting to a "capabilities-based" approach to defense."
  - "A capabilities-based model - one that focuses more on how an adversary might fight than who the adversary might be and where a war might occur - broadens the strategic perspective.

An Intelligent Sensor Configuration

- A potentially powerful solution for the exchange of information between heterogeneous sensors is for each sensor to publish information based upon an accepted and understood format, i.e. an ontology.
- In this proposed configuration, each sensor must have its own functional signal and data processing capability and the ability to address fusion of sensors, and communication between them.
- The intelligent network will be able to coordinate the communications between the sensors onboard and off platform sensor systems as well. There are approaches that can be exploited to build this system by using fiber optic or wire links onboard the platform. Radio frequency (RF) links using Bluetooth or 802.11 "like" technologies can be utilized for linking these sensors onboard the platform.

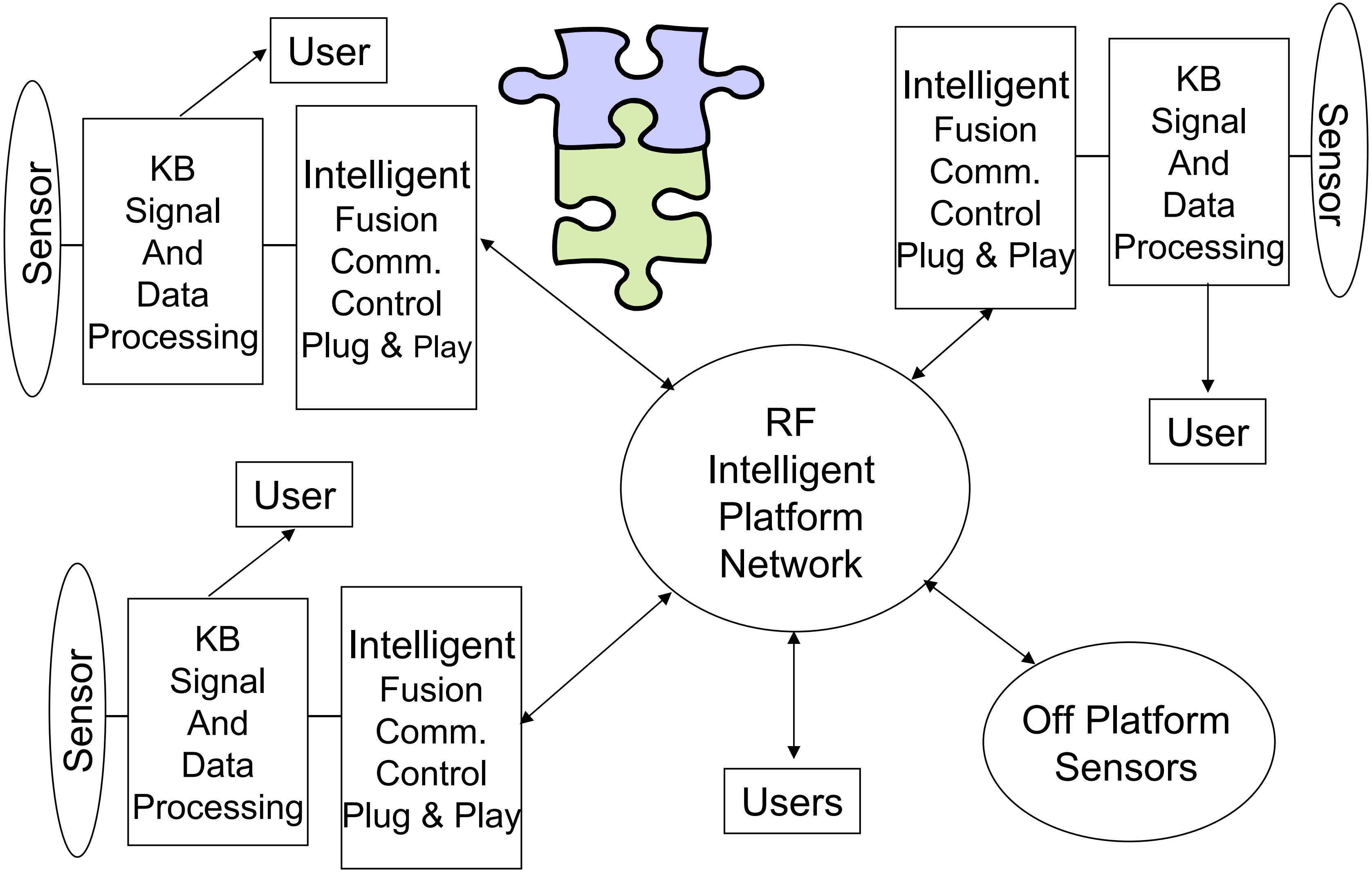
Report for Congress (RL31425)

"…the subject matter for most military analysts is far more fluid than during the cold war, rendering standard databases and analytical models for explaining behavior obsolete. Indications and Warning, the analysis which warns of impeding attack on the United States or its vital interests, depends on the ability to predict enemy activity, based on enemy plans, doctrine, and observed exercises and training. Many of today's potential adversaries offer little in the way of traditionally observable activity."

Component Building Blocks

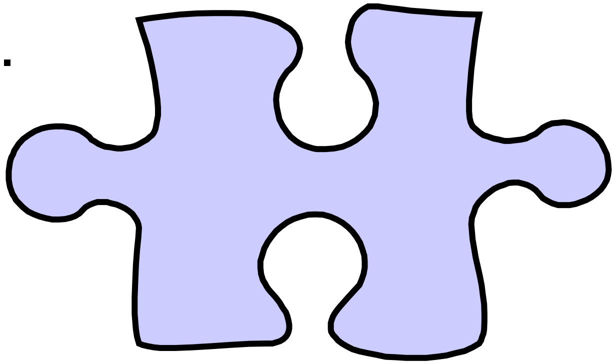
- **In order to be successful, the Sensors as Robots must leverage, and in some cases, stimulate advances in an array of technological regimes. These include:**
- **<u>Sensor systems and signal processing</u>**
- **<u>Language/model development for numerical and non-numerical signal processing</u>**
- **<u>Artificial intelligence (AI) for signals analysis</u>**
- **<u>Computer architectures and software development</u>**
- **<u>Waveform diversity for multi-mission/multi-mode operation</u>**
- **<u>Embedded communication models and procedures</u>**
- **<u>Robotic Power, Propulsion, and Navigation</u>**

An Intelligent Sensor System



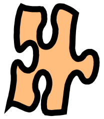
Sensor Systems and Signal Processing

- Develop knowledge-aided sensor signal processing techniques to maximize the use of prior knowledge in radar signal & data processing for improvements in detection, track, identification & handoff.
- We are exploiting current on-going, related activities: US Air Force Research Lab Signal Processing Evaluation, Analysis, and Research (SPEAR) facility for the evaluation of signal processing algorithms… funded under AFRL 6.2 and DARPA KASSPER program.



Language/Model Development for Numerical and Non-Numerical Processing

- Efforts and activities will be required to provide the capability to easily define the signal, data, and logic (algorithmic or heuristic) based sensor-processing functions.



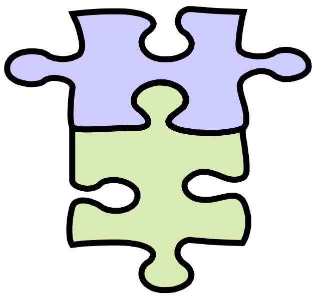
- Requirements will include the capability to exercise this language on conventional processors for emulation and evaluation of single and multiple sensor sub-subsystems where their respective information for all sensors' use is fused.
- Research and development activity will be required to develop the capability to store and access multiple dynamic and stable data and information sources as well as the ability to model the processing within and between multiple sensors and communications systems.

Artificial Intelligence (AI)

- This Component Building Block will be critical to the Sensors as Robots and will leverage, for example, the work of the World Wide Web Consortium (W3C) and activities such as the Defense Advanced Research Project Agency’s (DARPA) Agent Markup Language (DAML) program, which will lead to the next generation Internet or the Semantic Web.
- The next generation Web is being designed in a manner similar to a large knowledge base such that one can define ontologies for different domains of interest (e.g., radar or sensors). The concept of ontology is exactly what is needed to achieve a system of sensors that operate in a collaborative fashion and eventually, to have sensor platforms operate autonomously as a robotic system.
- The construction of ontologies is a present-day activity. They can easily be found on the Web and can be used to build and share information within the community and domain of interest. The Sensors As Robots program will leverage the object oriented feature of inheritance and reference the resource descriptive framework (RDF) (i.e. an instantiation of an ontology) of those ontologies that already exist and then add those additional facts and rules required for one’s own needs.
- Ultimately, it will be possible to develop the AI algorithms and processing rules within various sensor types such as radar, electro-optical, acoustic, infrared and perform multiple tasks such as imaging, detection, tracking, target identification and to develop ontologies for multiple sensor types and communication systems so that they can exchange data and information in a coherent and timely fashion.

Sensors Ontologies

- Numerous ontologies on the Web
- Some ontologies are built in XML
- Most ontologies reference other accepted ontologies such as W3C, DAML, DublinCore, etc.
- Tools are being made available that read and inference over OWL based ontologies
  - Note the W3C has recently (18 Aug 2003) proposed OWL as a standard
- Why ontologies? – Spelling, meaning, inference rules and syntax are precisely defined so that any ontology-aware software can accept new sensor systems without reprogramming.



Waveform Diversity

- Encompasses both the adaptation of waveforms in order to compensate for the environment and multi-user interference, as well as receiver structures that employ *a priori* and estimated knowledge to separate desired information from multiple users and jamming.
- Effort will be needed to investigate waveform diversity techniques that enhance the performance of multiple sensor types.
- Research efforts to develop algorithms and procedures to alleviate fratricide issues related to dynamic frequency assignment in and between moving and fixed platforms must be undertaken.
- Development of communication protocols and techniques to maintain communications while dynamically changing waveform parameters will be needed.
- Current on-going, related activities: Tri-Service Working Group developing plans, programs, and experiments to rapidly advance this area.

Communication Models and Procedures

- Develop fault tolerant techniques for the multiple sensors and communication devices to communicate within a platform will be required.
- Similarly, fault tolerant methodologies for multiple platforms to communicate by leveraging different commercial protocols such as Bluetooth, 802.11, and mobile IP are needed.
- These technologies will be the bond that connects supporting technologies such as operations planning, mission planning, reasoning, decision making and distributed real-time computing and control.
- The development of wideband communications technologies to be used between platforms to transmit and receive large amounts of data such as data cubes and their proper ontological header data, in real time will be essential.

Communication Models and Procedures (continued)

- Multimedia Intelligent Network of Unattended Mobile Agents (Minuteman). The project is part of a program on Intelligent Autonomous Agent Systems for the Office of Naval Research.
- A portable, rapidly deployable airborne network that will allow robotic agents to communicate.
- (Minuteman) will provide local communications for the increasing array of unmanned air vehicles (UAVs) and unmanned ground vehicles (UGVs). This agile, dynamic "Internet in the sky" will support the demanding communications requirements of unmanned missions.

Software Development

- Leverage languages such as MATLAB and the results of language/model development efforts to create a library of algorithms will be needed.
- Efforts to develop techniques and tools to automatically map these language characterizations to different computer architectures (and their languages, Java, VSIP, C++) must be initiated.
- On-going activities to develop methods to minimize the cost to maintain and upgrade software on fielded systems will be watched closely and used as needed

Computer Architectures

- Research efforts to develop fault tolerant computer architectures that can process signal, data, and logic/control of a real time sensor system are needed.
- Effort to develop architectures able to accommodate both numerical and non-numerical processing and be able to store and retrieve large amounts of data describing such entities as ground truth, map data, intelligence data, battle damage assessments will be required.
- Programs to acquire architectures able to process multiple tasks in parallel with the same sensor data (e.g. tracking and imaging), and be able to spawn off multiple task instantiations of each with different algorithms for comparisons in real time as the environment changes must be started.
- Architectures able to receive data, information, and control from multiple on board and off board sources such as communications links and other sensors will be essential.

Robotic Power, Propulsion, and Navigation

- Micro Air Vehicle (MAV) Advanced Concept Technology
- The primary goal is to further develop and integrate MAV technologies into militarily useful and affordable backpackable systems suitable for dismounted soldier, marine, and special forces missions. It will focus on the development of MAVs to accomplish unique military missions, particularly with regard to flight operations in restricted environments. The system will provide the small unit with militarily useful, real-time combat information of difficult to observe and/or distant areas or objects. The system will also be employable in a variety of warfighting environments. For example, it will be beneficial in complex topologies (i.e., mountainous terrain with caves), heavily forested areas/dense foliage/triple canopy jungle, confined spaces (often internal to buildings) and high concentrations of civilians (where it may be critical to determine the neutral or hostile intent of a crowd).
- The initial MAV technology development program focused on the technologies and components required to enable flight at small scales, including flight control, power and propulsion, navigation and communications.

Robotic Power, Propulsion, and Navigation (continued)

- Detecting Hidden Targets With 'Smart' Robotic Sensors.
- A vision of futuristic robotic aircraft and land vehicles that can sense and close in on targets hidden in trees, caves or bunkers.
- Researchers at Duke, Georgia Institute of Technology, Stanford University and the University of Michigan will each take on different parts of developing the enabling mathematical underpinnings of this technology.

Robotic Power, Propulsion, and Navigation (continued)

- Autonomous Navigation and Sensing Experimental Research
- A collaborative demonstration effort between BAE Systems Australia and the University of Sydney's Australian Centre for Field Robotics (ACFR).
- The primary objective is to demonstrate decentralized, multiple UAV tactical-picture compilation of ground targets.
- The processing, sharing and fusing of the ground picture is to be carried out without a central processing facility. This approach to data fusion takes decentralised networks attractive from a reliability, scalability and flexibility perspective.

Robotic Power, Propulsion, and Navigation (continued)

- Swarming UAVs will affect behavior of future drones.
- Bird flocks, insect colonies and schools of fish have one common quality. They consist of large numbers of individual entities that are comparatively unintelligent, but able to execute relatively complex functions efficiently as a group, much to the amazement of scientists. This occurs even though the movements and interactions of each individual entity are random.
- The USAF is exploring ways to mimic this approach. The idea is to leverage off [living organisms] to see how much simpler we can make things and still do something militarily useful.

Robotic Power, Propulsion, and Navigation (continued)

- <u>TACTICAL MOBILE ROBOTS</u>
- Concept: Penetrate denied areas and project operational influence in ways that humans cannot by using reliable semi-autonomous robotic platforms.
- Integrate sensors, locomotion, power, communications, and sufficient smarts on a compact, man-portable platform to provide a semi-autonomous system capable of penetrating into denied areas and serving as an extension of the human soldier.
- Users: Special-operations forces, Early-entry forces, Marine Corps
- Goals: Mature enabling technologies for machine perception and mobility, demonstrate autonomous fault recovery, conduct operational demonstrations with integrated systems.

Robotic Power, Propulsion, and Navigation (continued)

- **Biologically Inspired Multifunctional Dynamic Robots (BIODYNOTICS)**
  - **BIODYNOTICS will explore the following areas:**
- **1. Dynamic Mobility—biologically inspired appendages to demonstrate multifunctional, dynamic, energy efficient and autonomous locomotion to enable revolutionary mobility capabilities such as running over multiple terrains, climbing (trees, cliffs, cave walls), jumping and leaping, and manipulating the world with an appendage in tasks such as grasping and digging. The successful exploitation of biological appendages will also enable transitions between environments (e.g., a leg on land used to swim, a flyer perching or landing with legs, a swimmer emerging from the water and running on land).**
- **2. Behavior—biological inspirations in animal behavior that will enable the ability to autonomously recognize and navigate in operational environments to perform critical simple and complex capabilities (navigation, terrain following, grazing incidence landings, target location and tracking, plume tracing, and cooperative tasks such as hive and swarm behavior). This activity may incorporate principles derived from biological behaviors of both single and social groups.**
- **3. Integration—the integration of locomotion and behavior to achieve specific demonstrations using multifunctional dynamic biorobotic platforms, culminating in a Phase I platform demonstration with clearly defined metrics across a number of defined capabilities.**

Robotic Power, Propulsion, and Navigation (continued)

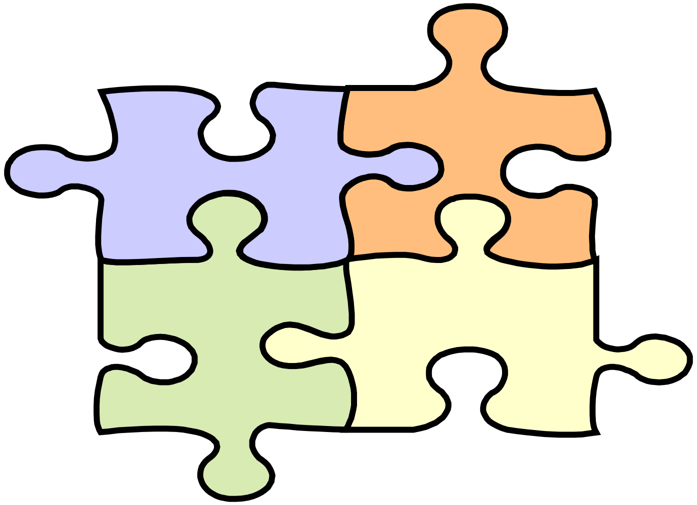
The goal of the Controlled Biological and Biomimetic Systems Program is to understand and exploit the basic strategies that an organism uses to optimize fitness. These strategies include unique locomotory, navigation, sensory fusion, and target recognition strategies that capture the innate ability of biological organisms to collect necessary information about their environment. Application areas of interest include developing new animal or animat sentinels that could report on the presence of desired information about the environment such as the presence of toxins or human survivors in search and rescue missions.

Robotic Power, Propulsion, and Navigation (continued)

- INTEGRATED SENSING & PROCESSING
- The Integrated Sensing and Processing (ISP) Program aims to open the next paradigm for application of mathematics to the design and (co)operation of DoD sensor/exploitation systems and networks of such systems, as required to meet computational and performance challenges posed by next-generation surveillance, reconnaissance, and strike scenarios. The program is developing mathematical tools enabling the design and global optimization of systems that interactively combine traditionally independent functions of sensing, signal processing, communication, and exploitation. Successful ISP methodologies will result in replacement of traditional sensor designs with sensor system architectures comprising fully interdependent networks of functional elements, each of which may span the roles and functions of multiple distinct subsystems in current generation sensor systems.

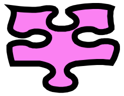
And There's More

- Other technological initiatives such as wireless networking, detection and classification algorithms for multi-modal inverse problems, etc. will be closely monitored as well, and where appropriate, leveraged into the overall program.



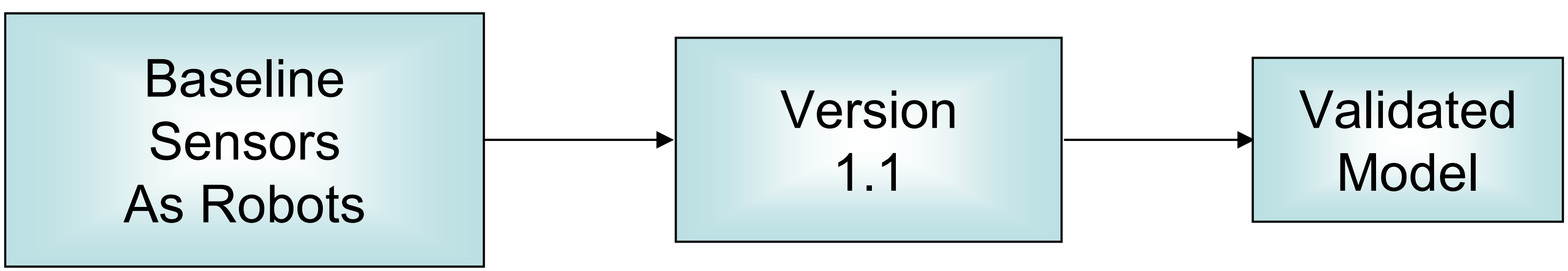
Initial Direction

- The development of the Sensors as Robots concept will proceed using a top down systems level methodology in which advances in the COMPONENT BUILDING BLOCKS are utilized and integrated.
- For example we would incorporate embedded AI and software advancements, leverage Semantic Web technologies (i.e. XML, ontologies,…), employ intelligent sensor and platform management algorithms, capitalize on ultra wideband, optical, and wireless advancements (e.g. mobile IP, 802.11, Bluetooth), and use human engineering interface control for intelligent sensor systems.



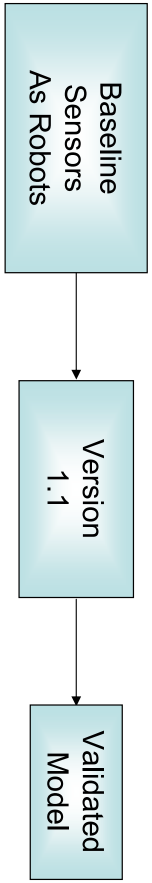
Initial Direction
(continued)

- The system strategy that will be employed is basically a three-phase approach:
- (1) development of a baseline Sensors As Robots prototype utilizing state-of-the art Component Building Blocks (Version 1.0)
- (2) Periodic Upgrade and integration of advancements in Component Building Blocks (Version 1.1, Version 1.2, etc.);
- (3) Release of an approved version to the appropriate sponsor for implementation. This phased approach will be iterated in a spiral fashion as knowledge, technologies, and approaches mature.



Initial Direction
(Continued)

- An objective of the approach is to accelerate and facilitate application of mature advanced technologies to assist in the development of a cognitive autonomous sensor system.
- At this point, the process by which a candidate system moves from the initial phase to a validated model is very flexible but might typically be described as follows:
- The baseline implementation will be represented by a collection of technology programs that are combined and integrated into a demonstration carried out in the laboratory.
- This means identifying significant operational shortfalls, matching them up with technology programs ready to focus on important applications, and responding to a user-sponsor who believes that application is important to his mission.
- The result of a phase 1 effort will be a system comprised of the most mature technology building blocks available and will be labeled Version 1.0. It will, however, be just a starting point. Version 1.0 will embody a rudimentary autonomous system; however, it will serve as a demonstration platform as we build towards a more sophisticated system.
- As technology advances are achieved in the Component Building Blocks, judicious selection and integration of these advances will be inserted during phase 2 and the model upgraded to Version 1.1, 1.2, etc. During this phase, each version will meet certain criteria with respect to interoperability, functional performance, robustness, etc. At some stage, when a certain level of specified performance is achieved, the Sensors as Robots model is released as Version 2.0.
- In this manner, and as the methodology is refined, the Sensors as Robots program will provide a mechanism for achieving a cognitive, autonomous sensor system.



Why now?

- Requirements demand innovative sensors
- Modern platforms enable autonomous operation
- Numerous research & development investigations increase confidence
- Maturing technologies will lead to success

Summary

- In future scenarios, unattended air and ground based sensors will be called upon to accomplish difficult tasks in dynamic environments.
- For example, we foresee military applications in the vein of the surveillance of hostile urban battlefield situations as well as monitoring functions inherent to peacekeeping activities; civilian applications such as crop production assessment/management and traffic assessment/management; industrial applications that include factory smoke emissions monitoring, production assembly assessment and management, facility management, and inventory shipment and tracking.
- However, existing UAVs and mobile robotic systems can only accomplish straightforward or repetitive tasks which are not scenario level functions and they generally do not operate in concert with other systems. More will be needed in the future.
- Propelled by the twin factors of transformation in military affairs and the dramatic increase in technological innovation, we believe that the environment is right for the introduction of a new concept in sensor system technology.
- This concept would embody cognitive, autonomous sensor system operation where the types and numbers of sensors would be matched to the task at hand. Sensors will collaborate with each other by sharing information, sensing the environment, adapting operation as necessary, and will do this by incorporating artificial intelligence, capitalizing on advancements in the Semantic Web, employing intelligent sensor & platform management algorithms, exploiting ultra-wide band communication, optical, & wireless advancements and by utilizing human engineering interface control for intelligent sensor systems.
- The Sensors as Robots initiative is a forward looking initiative that we believe will act as a catalyst and vehicle for stimulating the developments needed to make such future sensor systems possible.

Robots 101

- The modern definition of a robot classifies it as a machine with these parts:
- A program that tells it what to do
- An arm, hand, or other moving part that performs a useful action, like lifting, assembling or moving something
- One or more sensors, so it can tell the difference between what it's working on and everything else
- A decision maker to decide whether to perform the action
- A controller, which is in charge of overall operations.

The Robot Family

Automatons,	Manipulators/Tools	Computers/AI,	Science Fiction
OLD	OLD	NEW	OLD
Clocks,	pantographs	Jacquard loom	
Marionettes		Babbage calculating	

Science Fiction

- Robot is taken from the Czech word for forced labor by Karal Capek in R.U.R (Rossum’s UniversaL Robots) 1921.
- Isaac Asimov published “I, Robot” in 1950
- Forbidden Planet, a science fiction version of Shakespeare’s play The Tempest with the good natured Robbie

Parts & Pieces

- Arms and Hands
  - Revolute joint, prismatic joint, rectangular arm, cylindrical arm, spherical arm, articulated or jointed spherical arm, 6-DOF Arm, tilt/roll platform arm with 2 DOF
  - Muscle power
- Hands
  - Industrial robot hand, typical force-sensing wrist, three-fingered hand; each finger has 3-DOF, external gripper
- Legs and Feet
  - Moving Around. Robotic motion requires legs and feet, or substitutes. A mobile robot also must have a navigation system.

Navigation

- Before the 15th century, dead reckoning was state of the art.
- Today, following electronic signals aids navigation.

Sensors

- Robots can have sensors that imitate four of our senses. Taste is often excluded from the mix.
- Vision
  - Visual cortex for final image analysis
- Touch, Force and Torque Sensors and the somatosensory cortex. Strain gauges.
- Sensing sound, odor, and heat

Putting it Together in the Real World

- The brain works on several problems at the same time – parallel processing
- The brain also works on several levels at once, a hierarchy.

Teaching Robots to be Robots

- Fixed stop robots – like a train that stops only at its station, never in between. Robots of this type are used for pick-and-place operation.
- Servo-controlled robots. A servomechanism is a device that knows where a joint or arm is, in relation to its possible range. This lets the controller compare where the arm should be, and how fast it is [should be] moving, with its real position and speed.
- Point-to-point control *versus* Continuous path control

Teaching Methods

- There are two ways to teach a robot. A human teacher can move the arm through the motion, recording each start and stop position with a control box called a teach pendant. This is called lead through programming. Other robots can be programmed using a computer language specially designed to describe motions and angles.   The latest teaching method is graphics-based programming. It combined record-and-playback with programming.

From Master-Slave to Androids

- Intelligent teleoperated system has some computerized control at the slave or remote end.
- Supervised autonomy, the robot's computer performs almost all of the decision making as well as calculations, but a human can still take control of either operations or decision making.
- Fully autonomous robot is completely free of human control.

Why Aren’t There More Robots At Work

- Two problem are holding robots back:

  Robots are not accurate enough.

  They need greater intelligence.

Intelligence

- If the human brain is a computer, it is far more complex than any built in a factory or laboratory. Combining and rearranging symbols is just part of the brain's work. It also has a way of storing information so that even the smallest clue of language or image can bring a whole idea, story, picture, or series of events into the person's mind. This is called associative memory.
- A normal person can understand the structure of living things.
- Any person can make a plan to solve a problem, then carry it out, adjusting along the way.
- Each normal person is aware.

Mind and Memory

- Today many scientist believe that the term mind means how the brain works, and memory is how it stores information.
- Memories are formed and kept in many parts of the cortex, the “smart” part of the brain. They are coordinated in hippocampus
- Learning
  - The brain doesn’t store bike riding or other knowledge all by itself. A person can apply the knowledge learned about bike riding to other situations… This type of learning is called generalization.

Knowledge-Based Systems

- Expert systems or knowledge-based systems are computer programs that follow the same plan. Each one contains:
  - A body of knowledge
  - A method of getting information about a specific problem to be solved
  - A set of rules or another method to make use of the information
  - A set of instructions for making decisions that solve the problem

Reasoning

- There are two major kinds of reasoning.
- One kind takes past experience and makes easy-to-use logical or practical rules from it. This is called shallow or heuristic reasoning.
- The other kind analyzes knowledge, experience, or a problem to find out its basic structure – what is called deep reasoning. Both kinds are used in expert systems.

Shallow Reasoning

- Shallow reasoning is put in the form of rules … IF-THEN
- One can work through a series of connected rules (a chain) until one reaches a conclusion or solves the problem – what is called forward chaining. Or the person can form a possible answer (a hypothesis) and work backward through the series of rules to see if the facts support it (backward chaining).
- The military uses expert systems. Those for combat systems are called battle management.

Deep Reasoning

- **In real life, someone who has used heuristic reasoning to get through a tough situation may go back over it in his or her mind.**
- **This will allow the person to figure out what worked and what did not. The person may compare the situation to previous ones and see what they had in common.**
- **Such comparisons may let the person determine how the situation might have been handled better. It may also provide expertise for successfully dealing with similar situations in the future.**
- **This is referred to as deep reasoning.**

Uncertainty

- Some expert systems have been designed to handle a degree of uncertainty

Talking to Intelligent Systems

- Natural language
- To understand language, one must understand its structure (syntax) and its meaning (semantics). In addition to basic understanding, one must be able to summarize what he or she hears, or take a short statement and expand it. A person must be able to turn a statement into a question, or use one word in place of another.
- A computer that uses natural language will need those abilities too, although using a natural language with a computer is much harder than with another person.

Computers for AI

- The computers people use have slowed the development of intelligent systems. Even most supercomputers- … process problems one at a time…
- Parallel processing
- AI Languages
- Brain like computers – neural networks

Are There Intelligent Robots?

- Tele-operations and sensors must be improved.
- They will have to transmit more realistic information to their human operators or overseers – what is called tele-presence.

Artificially Intelligent Robots

- An intelligent robot needs a plan to follow as it works.
- The plan should include goals along the way.
- It should also be able to deal with failures and – most of all – the unexpected.
- The robot also has to learn from its experiences. And it has to be aware of what it knows and doesn't know.

Intelligent Teaching and Learning

- How does one teach a robot to give a sheep a haircut?
- It's hard enough to teach a robot to do assembly line work.
- Teaching one to work in the outside world is even more complicated.
- Shearing a sheep is like giving the animal a skinhead haircut, only all over its body.
- A human shearer has to hang onto a squirming animal, then use electronic clippers to quickly take off all the wool, without injuring…

“There’s More Than One Way To Skin A Sheep”

- Some Australian robotics scientists took on the job of teaching a robot to shear a sheep this way.
- First they used computer graphics to design a generic 3-D sheep.
- Then they gave it the measurements and shape of a specific animal.
- They added the shape change caused by breathing and other natural movements.
- An expert sheep shearer’s hand and body movements were added in.
- Then when everything worked on the computer, the scientist programmed the shearing motion into a robotic arm and clipper hand.
- It took the scientist several years to put the whole system together.

Introspection

- The final AI skill an intelligent robot needs is introspection, the ability to examine its own method of reasoning.
- This lets the robot tell the difference between what it knows and what it doesn't know.
- Introspection will let an autonomous robot react faster and better in a changing environment, enabling it to decide whether to act on its best knowledge or wait until it has more or better information.