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DARPATECH 2000 SYMPOSIUM

DARPA

TRANSFORMATION THROUGH TECHNOLOGY INNOVATION

Wyndham Anatole Hotel Dallas, Texas

SEPTEMBER 6-8, 2000

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Microsystems Technology Office (MTO)

DARPA Tech 2000

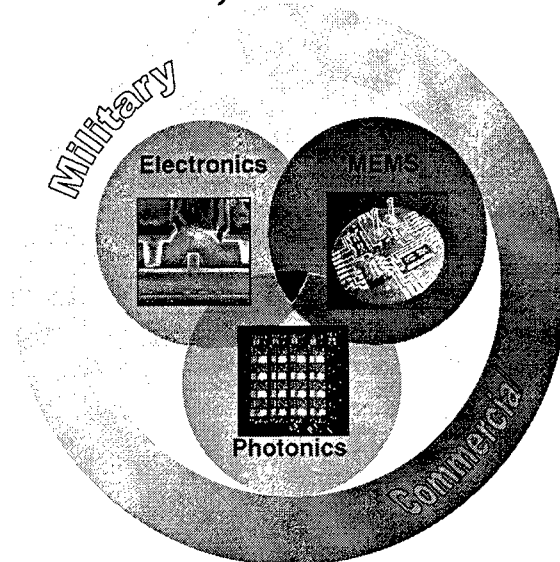
Dr. Robert Leheny, Director



Microsystems Technology Office

DARPA TECH 0005

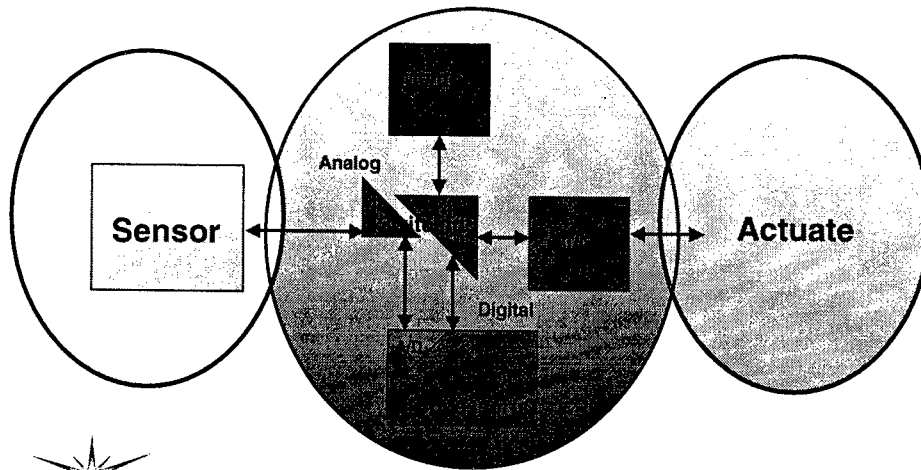
Driving a New Chip Scale Revolution in Electronics, Photonics & MEMS



Microsystems Technology Office

DARPA TECH 0005

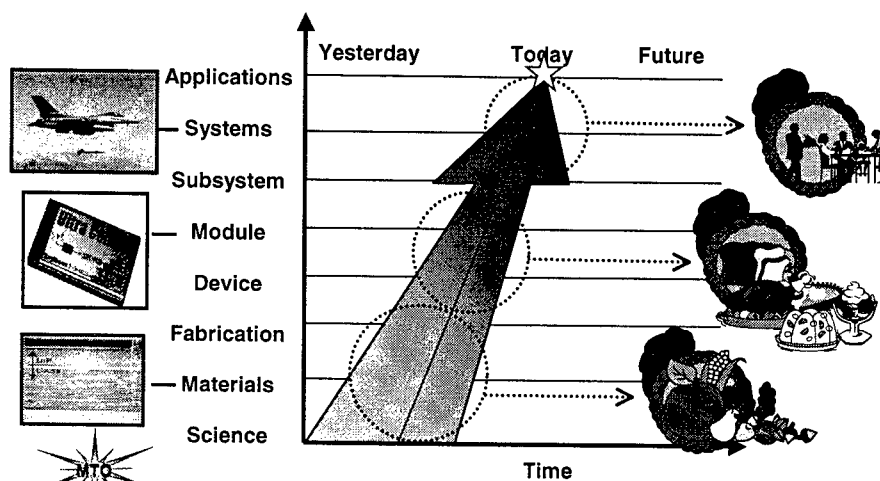
Platform Scale Information Systems



Microsystems Technology Office

DARPA/TECH 0009

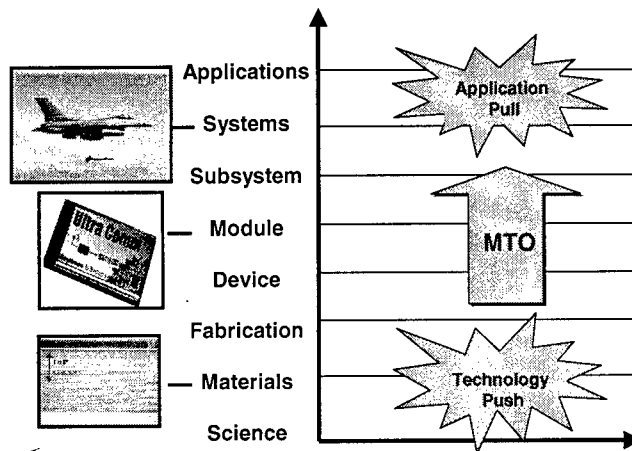
Flow of Technology Innovation



Microsystems Technology Office

DARPA/TECH 0009

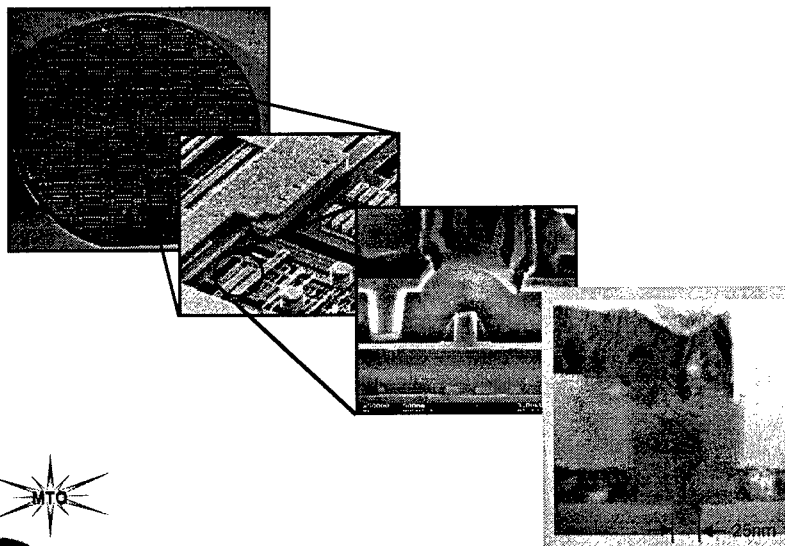
Flow of Technology Innovation



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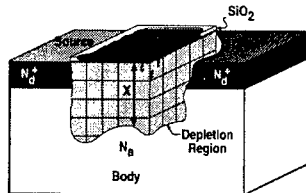
Advanced Micro Electronics Technology



Microsystems Technology Office

DARPA TECH 0009

Beyond Silicon-CMOS: The Limits of Scaling



Random Dopants

Physical Challenges to Continued Scaling:

- Contact Resistance
- Statistical Variation in Channel
- Atomic Oxide Thickness
- Approaching Molecular Scale Devices



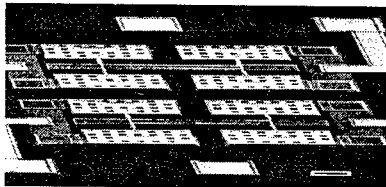
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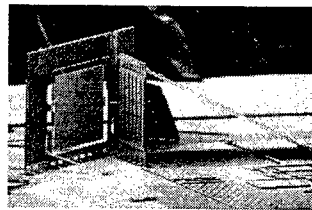
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Micro Electro Mechanical Systems

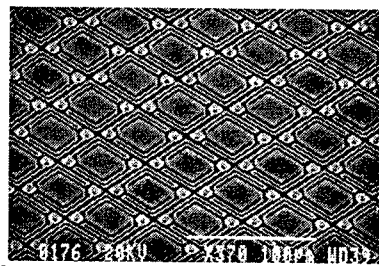
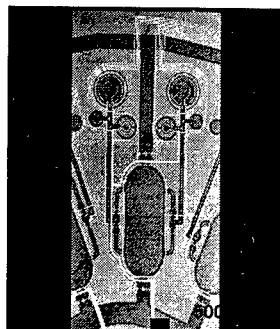
Magnetometers



Laser Deflection



MicroFluidic Pump



High Sensitivity Microbolometers

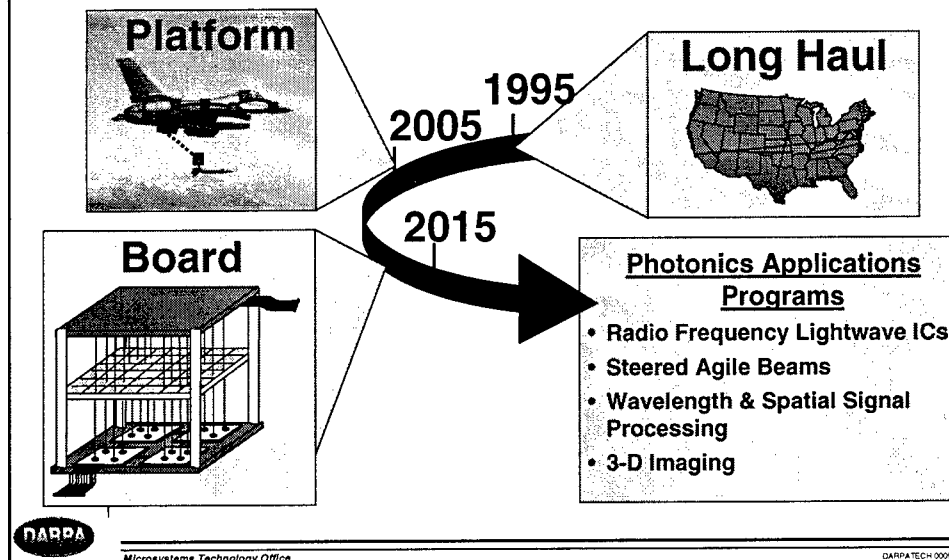


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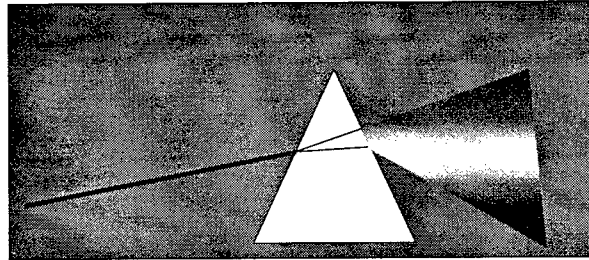
Photonics in Military Information Systems



Outline of MTO Presentations

Office Overview	R. Leheny
Photonics Overview	E. Towe
From Microelectronics to Nanoelectronics	C. Marrian
MEMS & Micro Power Generation	W. Tang
Bio-Fluidic Chips (Bio-Flips)	A. Lee
Design of Integrated Mixed Technology Microsystems	A. Krishnan
Gallium Nitride and Related Wide Bandgap Materials and Devices	E. Martinez





Photonics Overview

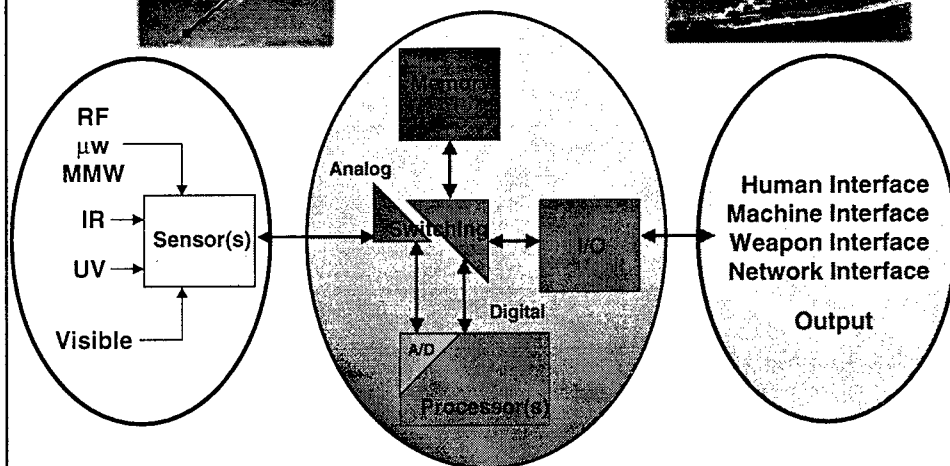
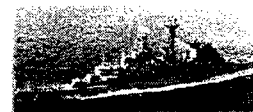
Elias Towe

DARPA/MTO

DARPA Tech 2000

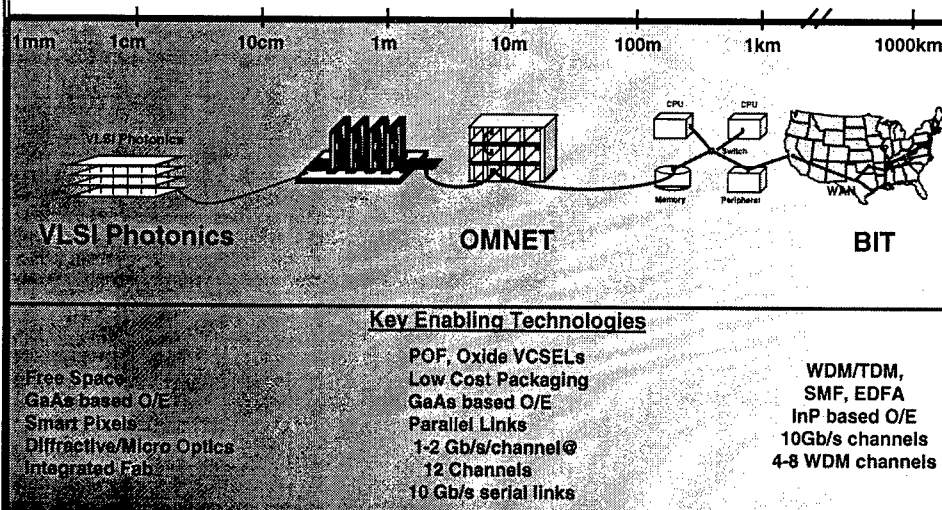


Military Platform Information System Functions





Recent DARPA Thrusts Digital Data Communications



MTO - Photonics Programs



- Sensing
 - IR Sensitive Materials; GaN Sensors; Photonic WASSP
- Communication
 - RF Photonics; Steered Agile Beams (STAB)
- Processing
 - VLSI Photonics; Photonic A/D Converter



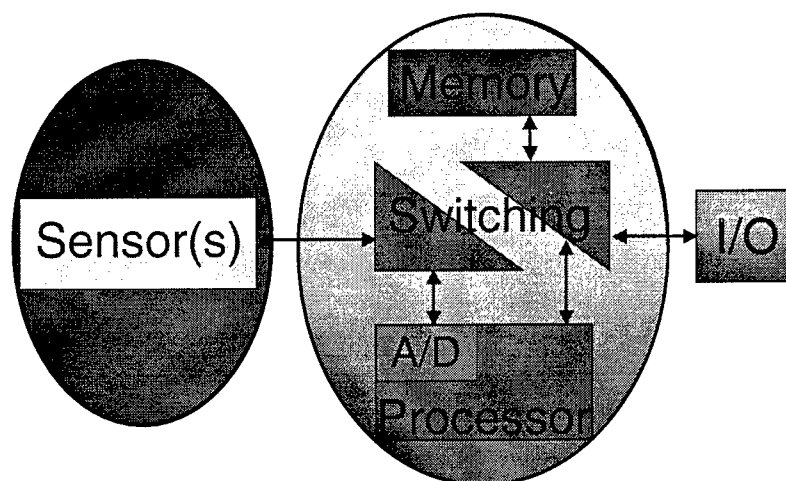
MTO - Photonics Program Managers



- Sensing
 - R. Balcerak, E. Martinez, E. Towe
- Communication
 - D. Honey
- Processing
 - D. Honey, J. Murphy, E. Towe

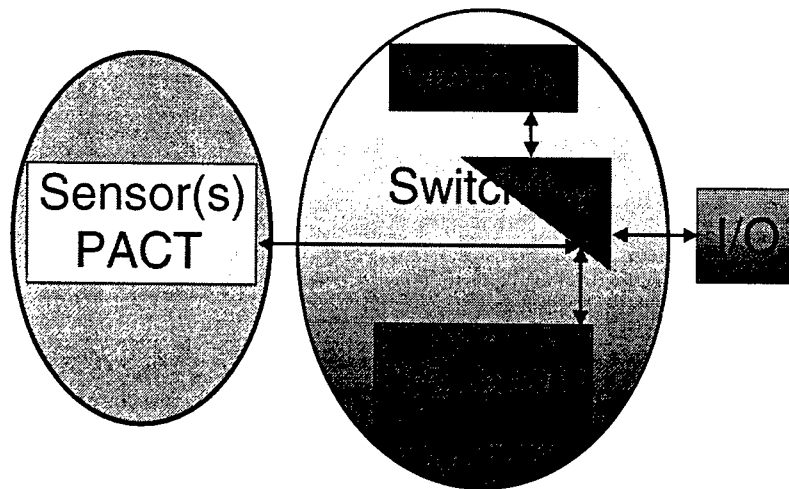


General Architecture

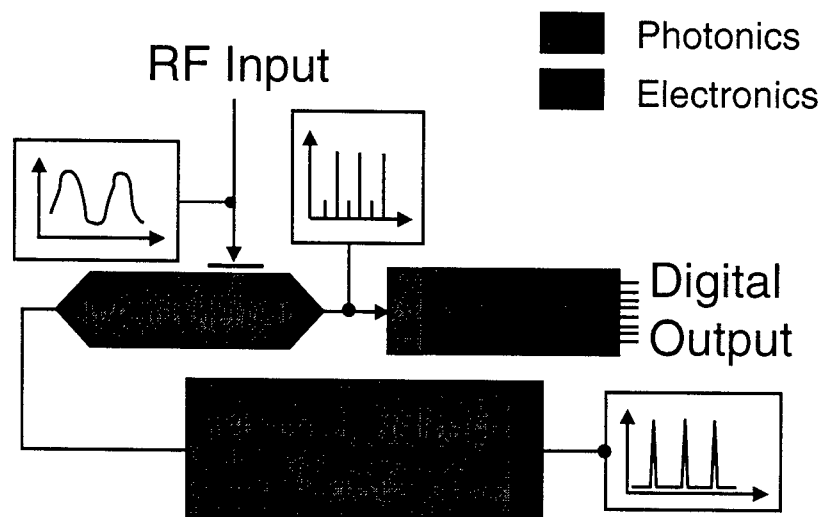




Photonic A/D Converter

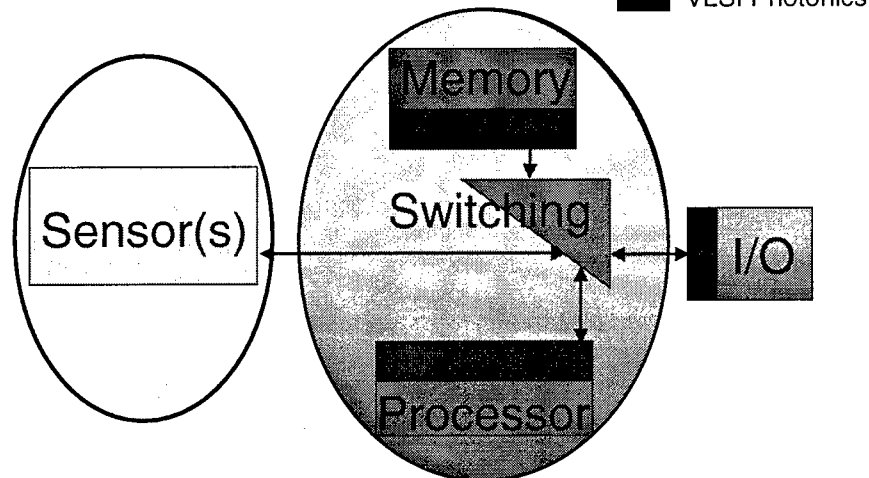


Photonic A/D Converter

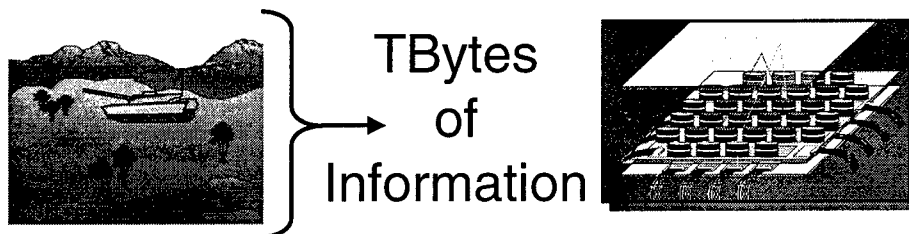




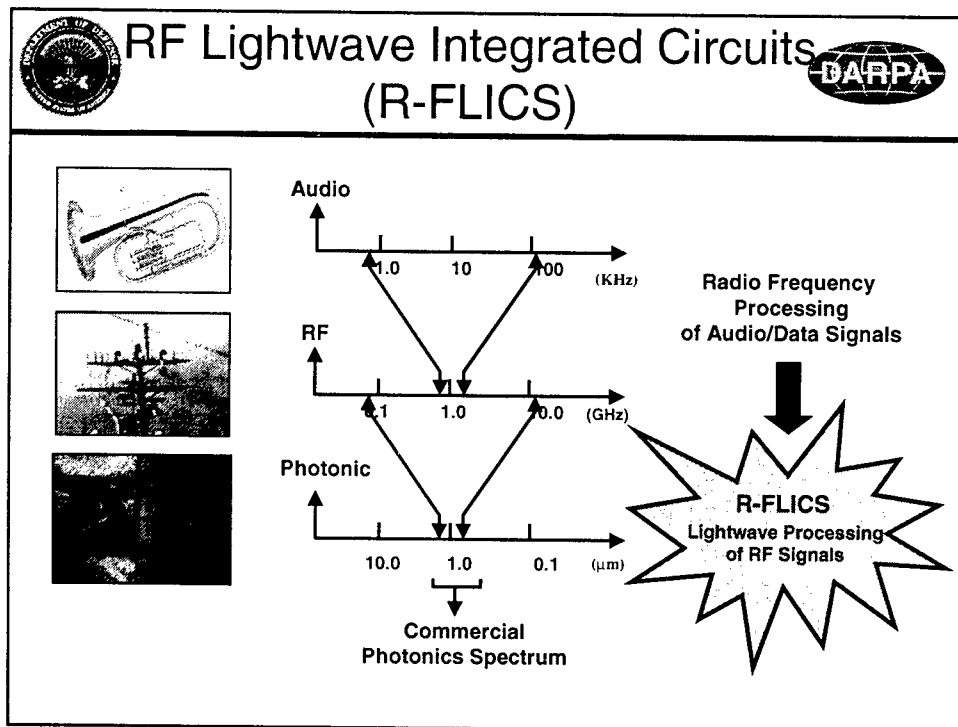
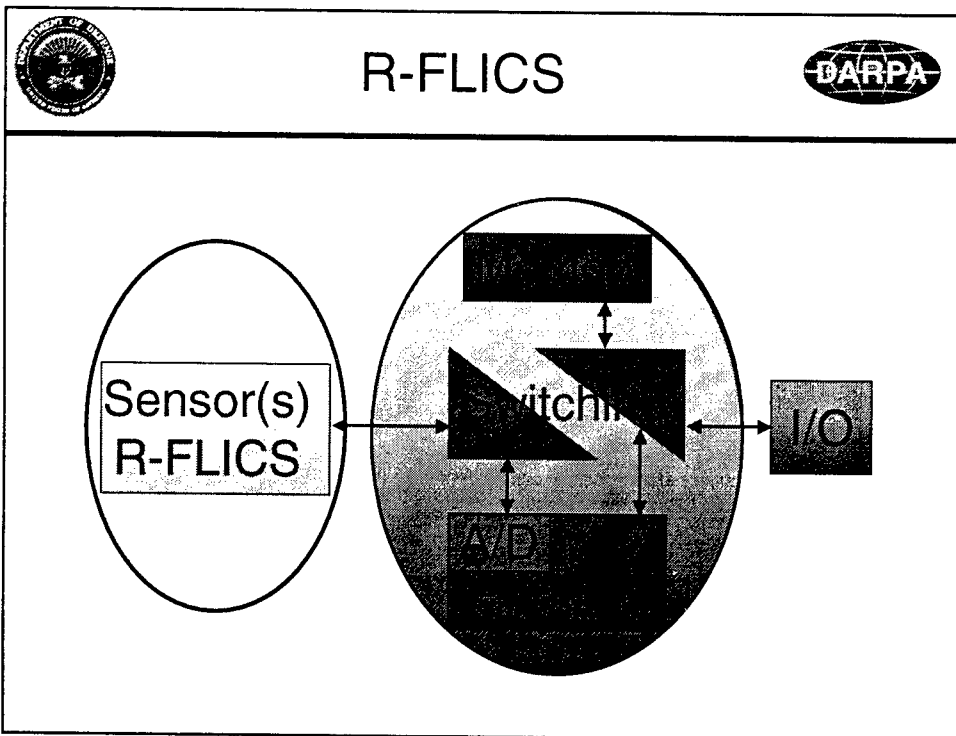
VLSI Photonics



VLSI Photonics

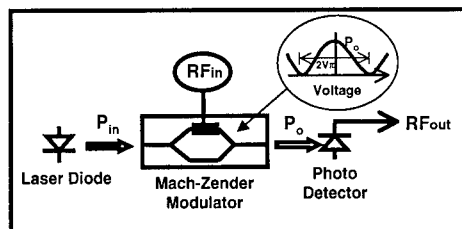
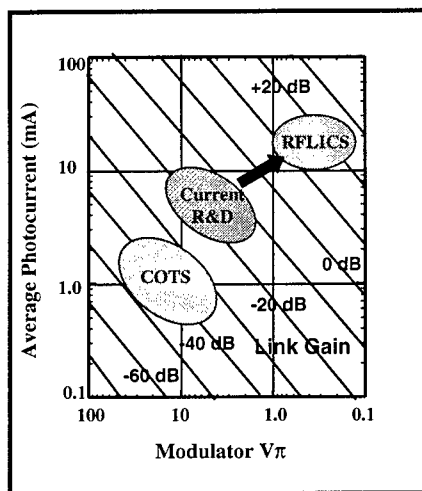


Chip-to-Chip Optical Interconnect





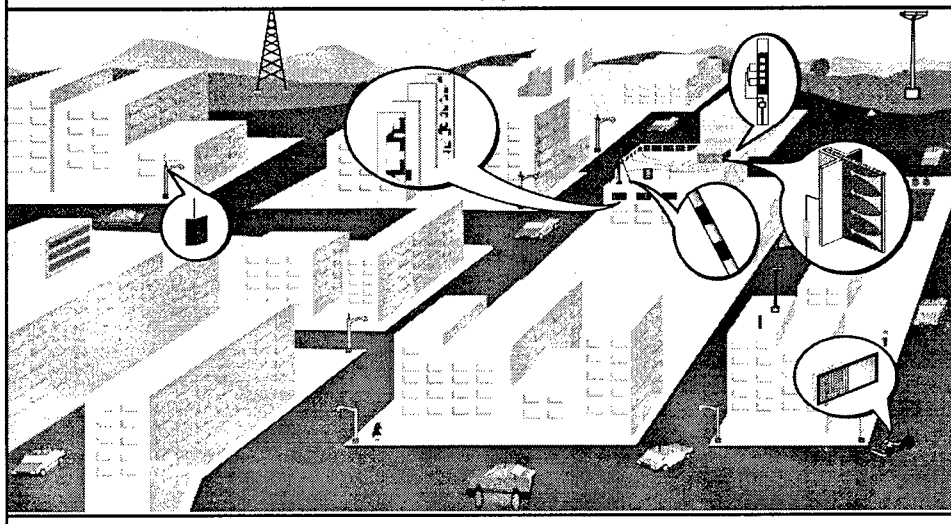
RF - Photonic Link Performance



R-FLICS Application Example

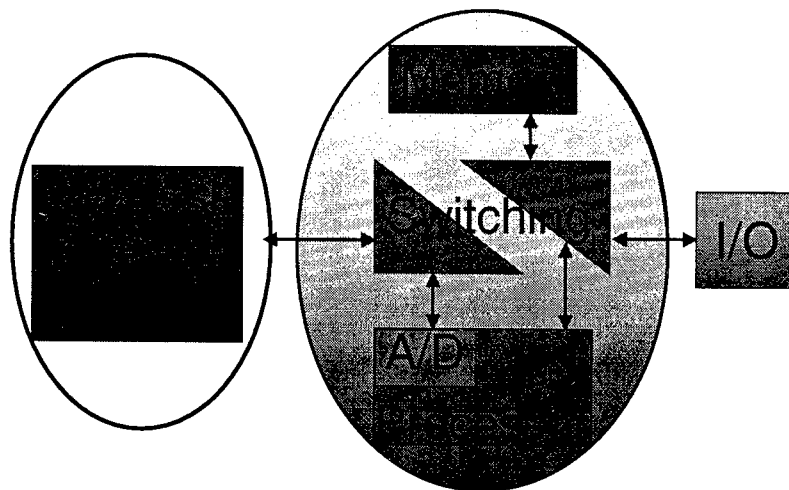


Urban Wireless Copy and Geolocation

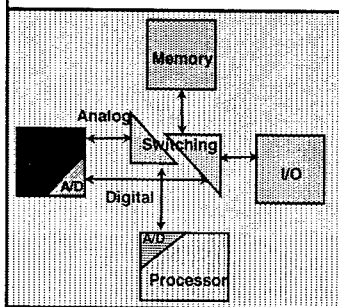




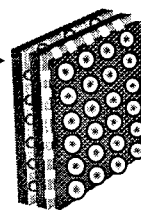
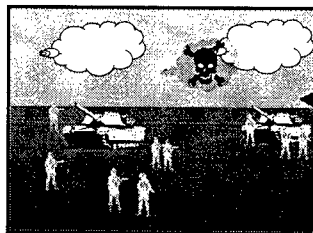
MTO Sensor Programs



Photonic WASSP



Photonic WASSP ■





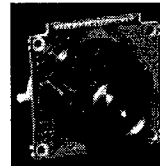
Advanced Uncooled IR Sensors



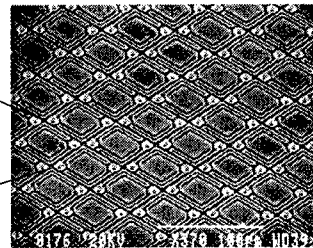
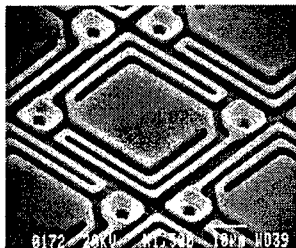
Missile Seeker



Target Acq.



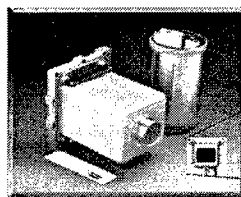
Micro Sensor



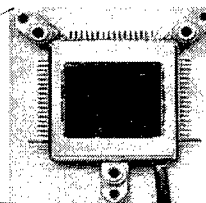
High Sensitivity Microbolometers



Why Uncooled IR Sensors?



Cryogenic Sensor

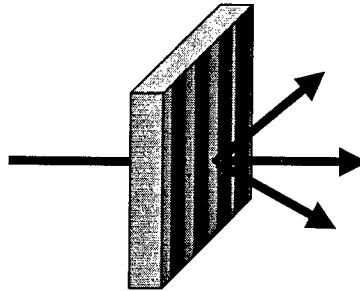
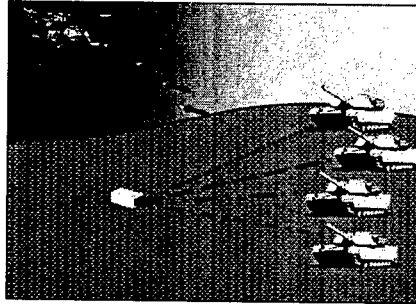


Uncooled Flat Pack

- 20 x Power reduction
- 10 to 100 x reduction in size
- 10 x Cost reduction



Steered Agile Beams



Multiple Target Engagements



Summary



- Use of photonics in analog and digital military/commercial systems in sensing, communications, and some limited signal processing
- Photonics can offer unique performance characteristics that purely electronic systems cannot
- Today, it is evident that significant benefits exist if we compute with electrons but communicate with photons

From Microelectronics to Nanoelectronics

Christie Marrian
DARPA MTO
DARPATech 2000

cmarrian@darpa.mil

DARPATech 2000

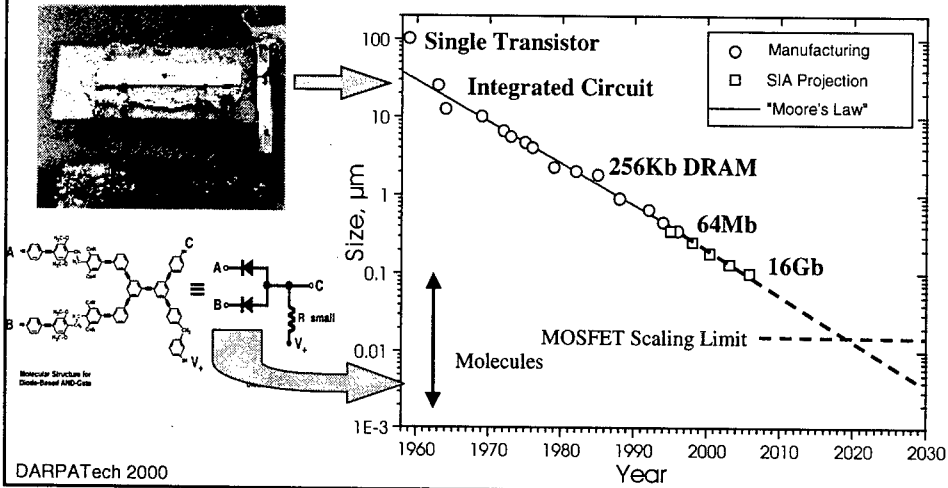
Overview

- Microelectronics is becoming Nanoelectronics
 - 18 nm transistors
- Challenges and Opportunities
 - Terabit circuits
 - Patterning
 - The molecular electronics approach
 - Designer materials
 - Integrated nanostructures

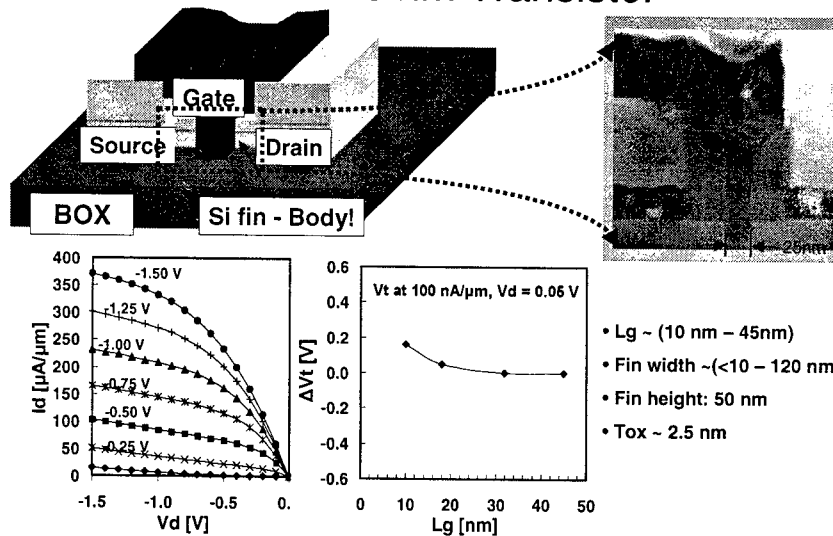
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Microsystems Length Scales

- Si scaling limits: one switch per ~100,000,000 atoms
- Molecules are multifunctional: one operation in ~100 atoms
 - Logic Element, Memory, Sensor



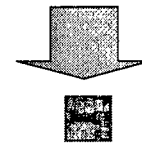
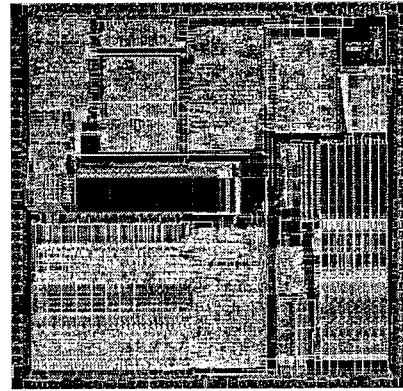
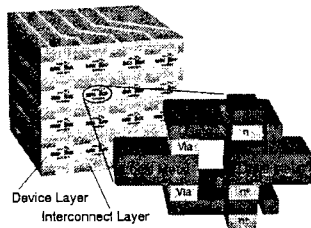
The 18 nm Transistor



Deep Scaling - World's Shortest Gate Length FET (18 nm)
With Useful Electrical Characteristics (IEDM 1999)

The Challenge of the 20 nm Transistor Circuit

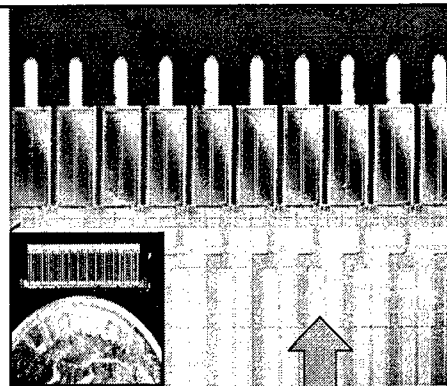
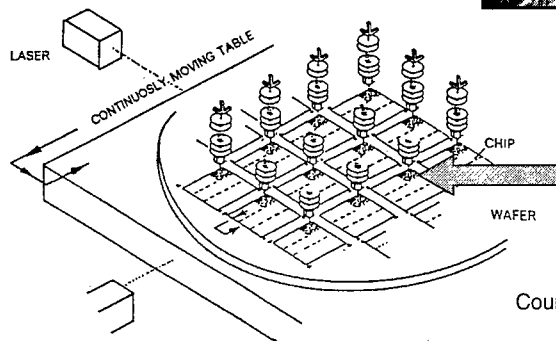
- $>10^{10}$ transistors per chip
 - Patterning
 - System design



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Maskless Patterning

- Low volume (~1000 wafers per mask) dominated by mask cost
- Eliminate mask!

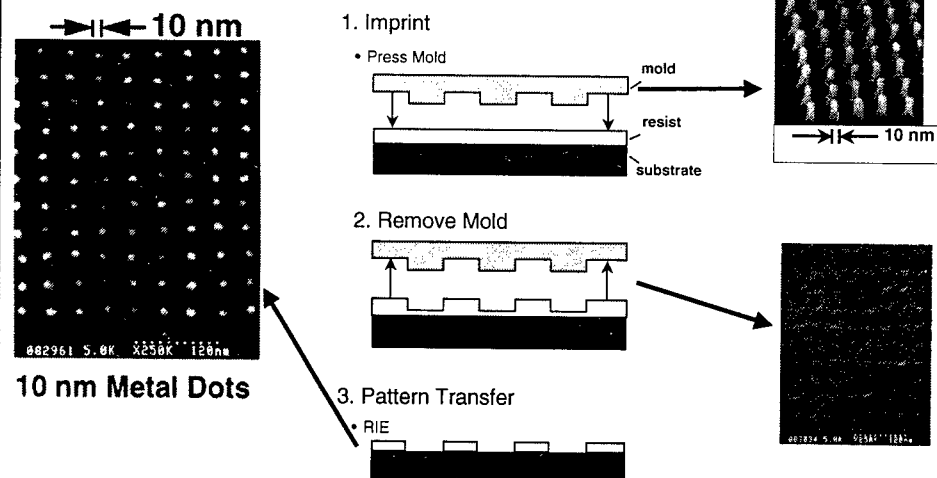


Multiple probes

Multiple electron columns

Courtesy of Stanford University and ETEC

Nanoimprinting (Chou, Princeton Univ.)



- Phenomenal resolution over large area
 - <10nm over several cm²

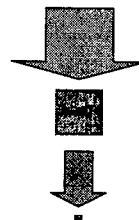
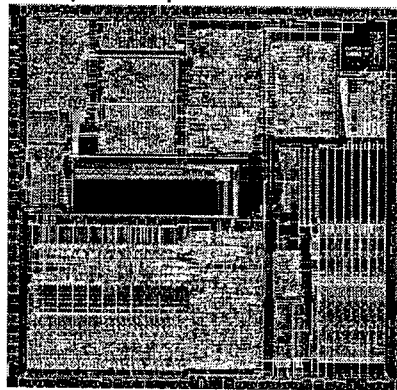
- Wide range of 'printing actions'
 - Patterns of self-assembling 'ink'

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Moletronics (Molecular Electronics)

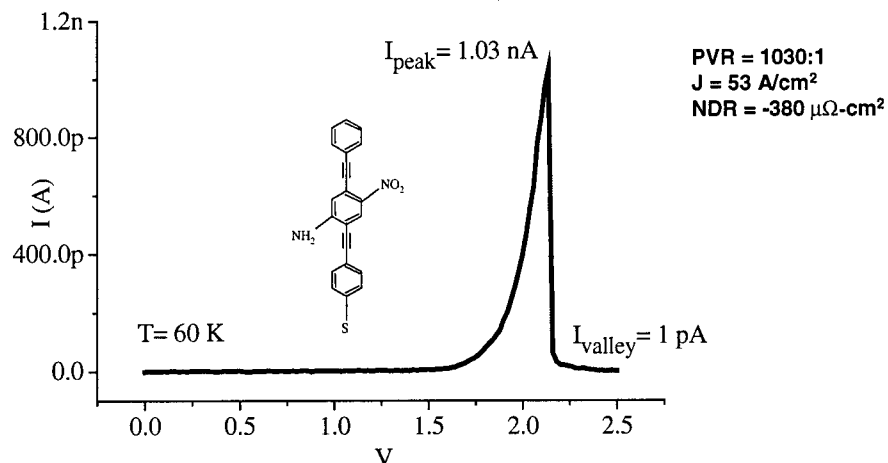
The roadmap to 10¹¹ devices per chip

- Molecular based switches
- Assembly rather than fabrication
 - Defect tolerance
- Scalability



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Electrical Properties of Molecular Diodes



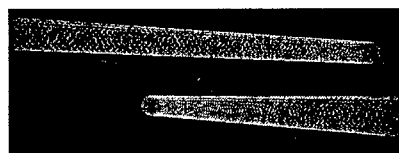
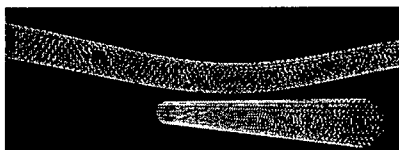
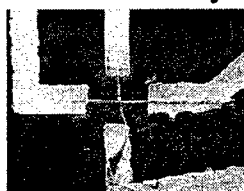
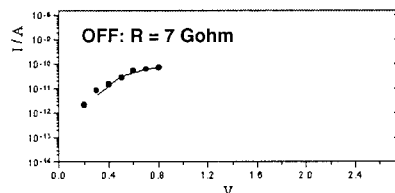
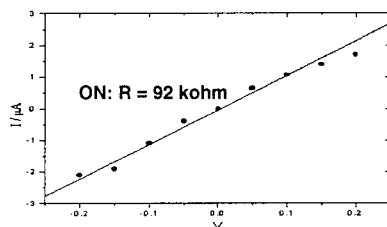
- <30nm diameter active device
 $>10^{10} \text{ bits/cm}^2$
- Room temperature
- Reversible

Yale University, Rice University
 DARPATech 2000

Control of electronic properties by chemistry

Carbon Nanotubes: <10 nm² memory bit

- Large on-to-off ratios ($10^5:1$)
- Low power: CMOS ~ 1 nW/device,
 Cross bar < 1 pW/device

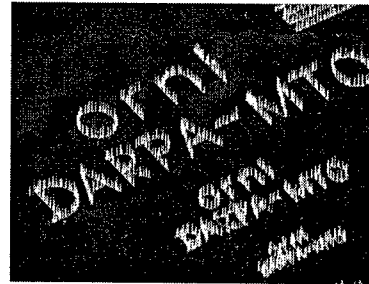


Room temperature reversible memory

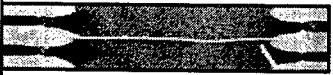
Harvard University, Stanford University

Hierarchical Assembly: An alternative to slicing and dicing

- Let thermodynamics do the hard work
 - Molecules and nanowires into nano-arrays
 - Carbon nanotubes
 - Molecular self-assembly
 - Nano-arrays into micro-modules
 - Field driven alignment
 - Input and output
 - Fluidic assembly



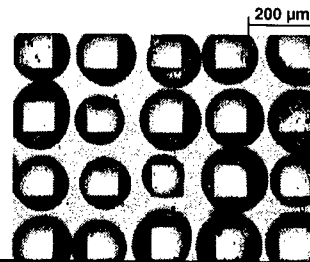
Chained 200 nm Au wires



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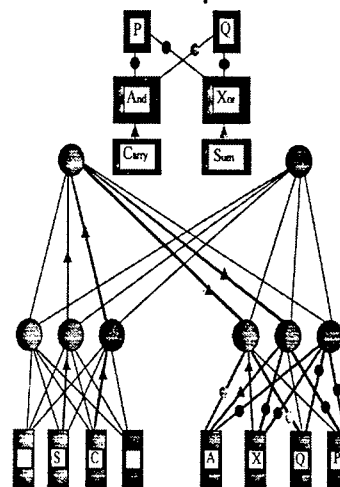
E-field Assembly,
Penn State

Fluidic assembly of
arrays of spheres, HRL



Scalability

- Scaled CMOS $\Rightarrow$ Gigascale systems on a chip
- Moletronics has the potential of tera (not terror) scale integration
 - 10^{12} devices
- Need systems architectures to be scalable to these levels
 - Defect tolerance
 - Programmability
 - Access times
- Hard challenges but enormous **pay-off**

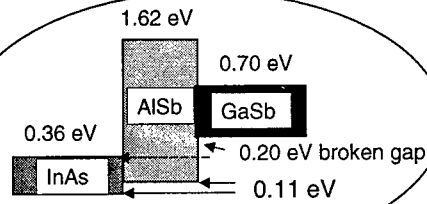
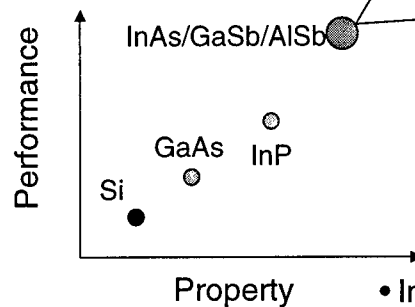


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UCLA/HP: Fat Tree Architecture

Nanoelectronics: New Materials

- Increased speed
- Decreased power
- Lower noise figure



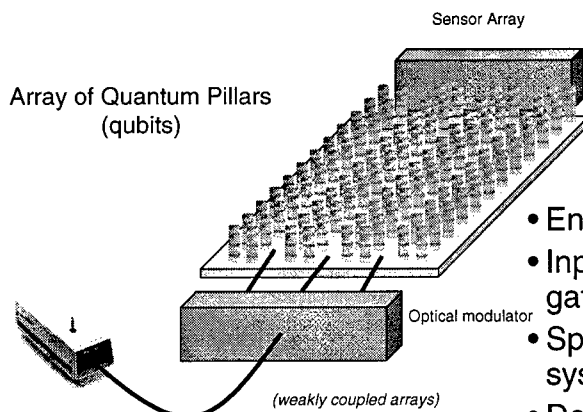
Lower consumed power
>100GHz operation

- Increasing mobility
- Decreasing bandgap
- Increasing lattice constant
- Decreasing effective mass

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Nanoelectronics: New Challenges

Scalable Quantum Computing



- Ensemble of devices/qubits
- Input signal acts as a logic gate
- Spectroscopy to read system output
- Does not require connectivity or coupling between adjacent devices

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The Future

- Incredible opportunities and challenges exist
 - Multi-functional electronics systems combining the best attributes of inorganic and organic materials
- We aren't done yet!

MEMS & Micro Power Generation (MPG)

DARPA Tech 2000

William C. Tang, Ph. D.

Program Manager

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<http://www.darpa.mil/MTO/MEMS>

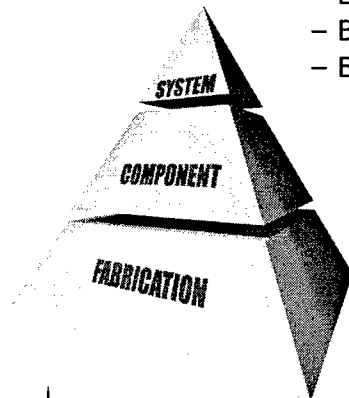


Microsystems Technology Office

Micro Electro Mechanical Systems – A Core Technology

MEMS is a core technology that:

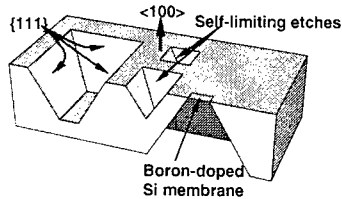
- Leverages IC fabrication technology
- Builds ultra-miniaturized components
- Enables radical new system applications



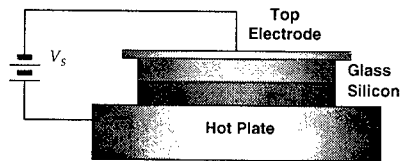
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[WT MEMS & MPG Rev 2.ppt] Slide 2

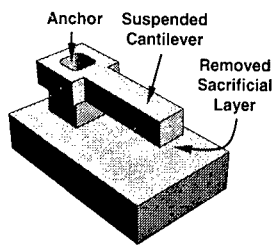
MEMS Fabrication Technologies



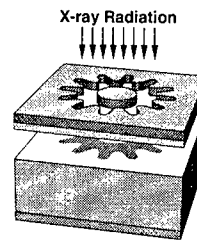
Anisotropic bulk etching



$200^{\circ}\text{C} < T < 500^{\circ}\text{C}$
 $200\text{ V} < V_s < 1000\text{ V}$
Anodic wafer bonding



Surface micromachining



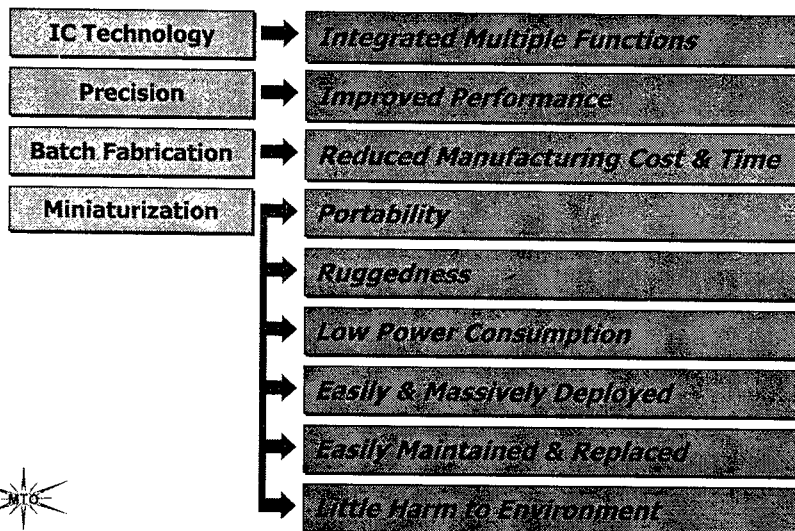
LIGA



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[WT MEMS & MPG Rev 2 ppt] Slide 3

Advantages of MEMS

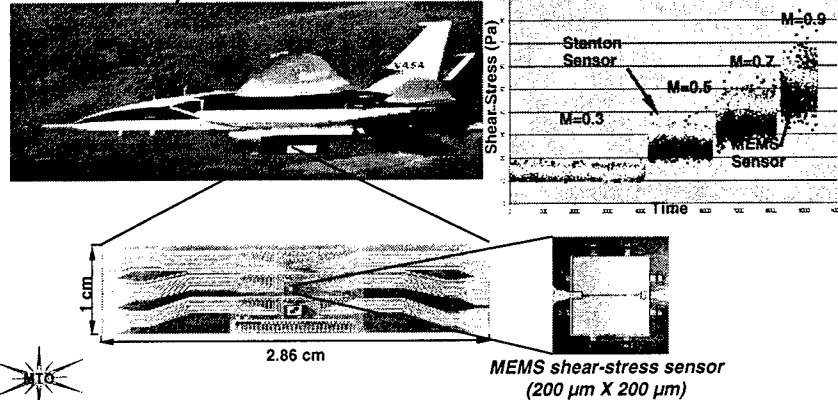


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[WT MEMS & MPG Rev 2 ppt] Slide 4

Shear Stress Sensor for Jet Fighter (Caltech)

- Demonstrated 10X more bandwidth over state-of-the-art sensors in F-15 flight test (co-funded by NASA)



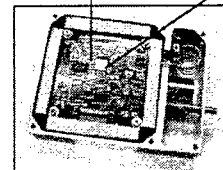
Microsystems Technology Office

[WT MEMS & MPG Rev 2 ppt] Slide 5

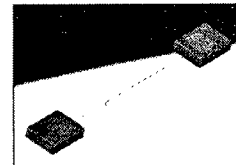
Pico Satellites (Aerospace Corp., et al.)

- ◆ Pico satellites
 - Weight & Size: 250 gm, 2.5 x 7.5 x 10 cm
 - A platform for testing MEMS devices and microsystems for space applications
- ◆ Potentials
 - Cooperative constellations
 - Sparse aperture antennas
 - Inspect and service missions
 - Launch-on-demand, robust communications, and surveillance space systems
- ◆ First demonstration:
 - Launched 26 Jan 2000
 - RF communication established 7 Feb 2000
 - Operated MEMS RF switches in space

MEMS RF Switch (Rockwell)



Pico Sat (Aerospace Corp)



Microsystems Technology Office

[WT MEMS & MPG Rev 2 ppt] Slide 6

Wireless Integrated Network Sensors (UCLA, et al.)

- Demonstrated embedded processor, radio links, multihop network, and seismic/acoustic sensing
- Condition-based maintenance, battlefield awareness, health monitoring, environmental monitoring, etc.



Army NTC / Aberdeen PG



USS Rushmore

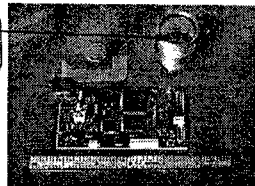
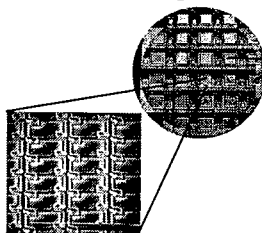


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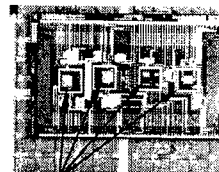
[WT MEMS & MPG Rev 2.ppt] Slide 7

Product-Neutral Vacuum Packaging (Raytheon, et al.)

- Low-cost, mass-produced, high reliability
- Meets IR MEMS, RF MEMS, Inertial MEMS requirements
- Demonstrated <10 mTorr for 31 months, survived 10,000-g shock



Wafer-level vacuum-packaged 120x160 α -Si microbolometer arrays



Microshell vacuum-packaged accelerometers, gyroscopes, & resonators

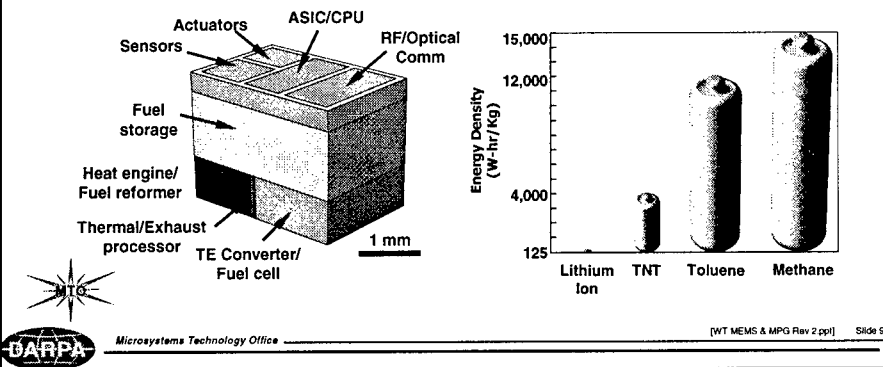


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[WT MEMS & MPG Rev 2.ppt] Slide 8

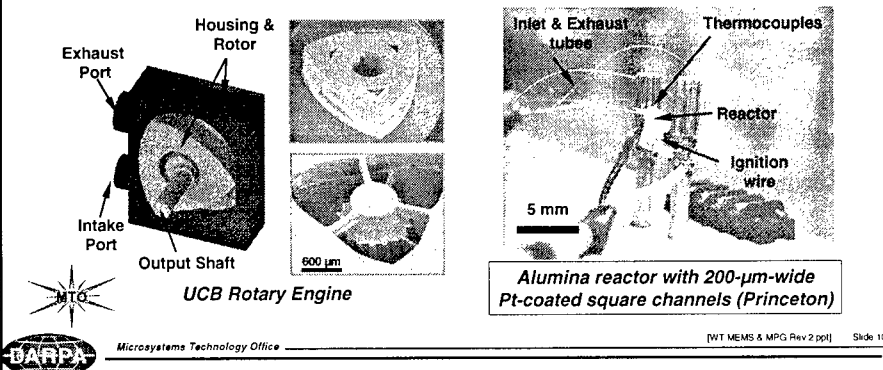
Micro Power Generation (MPG)

- Generate power at the micro scale to enable stand-alone micro sensors and micro actuators with wireless communication to realize new systems and strategies for weapons systems, processes, and battlefield environments.



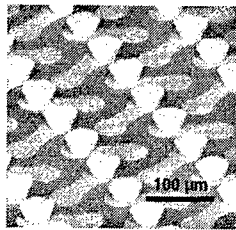
Microcombustion (UC Berkeley, Princeton, et al.)

- Demonstrated fabrication techniques of high-temp materials (SiC at UCB, alumina at Princeton).
- Demonstrated self-sustained combustion in 1 mm³ chamber (H₂/Air, Princeton).

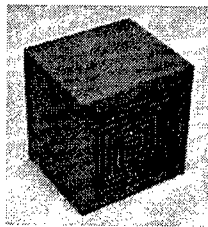


Thermoelectric Conversion (USC, et al.)

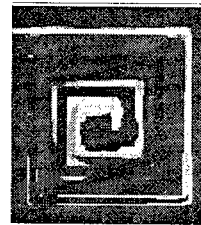
- Demonstrated counterflow Swiss-roll combustor
- Pursuing fabrication compatibility with thermoelectric elements (Bi_2Te_3)



USC/JPL
micro TE elements



USC macro
Swiss-roll combustor



Simulation of
combustion

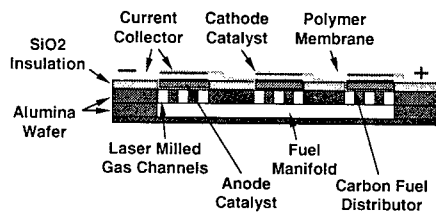


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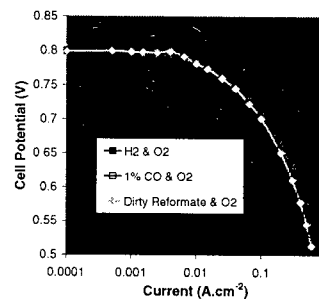
[WT MEMS & MPG Rev 2 ppt] Slide 11

Micro Fuel Cells (CWRU, et al.)

- Demonstrated fabrication of micro fuel cells with built-in super capacitor & PdH layer as H_2 source
- Demonstrated high-temperature ($>130^\circ\text{C}$) fuel cell operation in the presence of CO



CWRU micro fuel cell with palladium hydride



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[WT MEMS & MPG Rev 2 ppt] Slide 12

The Future of MEMS at DARPA

- ◆ Continue existing commitment
 - Maturing projects
 - New thrust: Micro Power Generation
- ◆ Emphasize transition
 - Into DoD systems
 - Into industry
- ◆ Establish new programs
 - Programs enabled by MEMS



Bio-Fluidic Chips (BioFlips)

Abraham 'Abe' Lee, Program Manager

DARPA Tech 2000

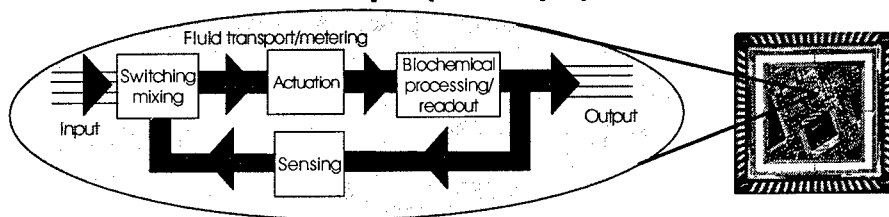
September 6, 2000



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DHO Review 000119L

Bio-Fluidic Chips (BioFlips)



- ♦ **Goal of Program:** Demonstrate integrated biofluidic microprocessor technologies capable of providing on-chip reconfiguration and self-calibration via feedback control

The prototypes developed in this program will demonstrate biological fluid assay capability which will form the basis for the future goal of real-time, unobtrusive monitor and control of health parameters of the warfighter.



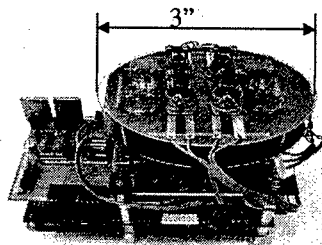
Microsystems Technology Office

DHO Review 000119L

Bioflips - A Paradigm Shift from MicroFlumes

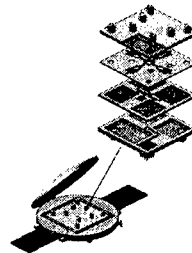
Microflumes

- ◆ Discrete microfluidic components
- ◆ Passive, fixed assays
- ◆ CBD, non-disposable



Bioflips

- ◆ Total integration platforms
- ◆ Active, reconfigurable assays
- ◆ Medical, disposable



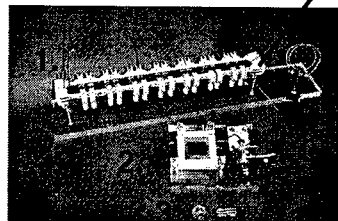
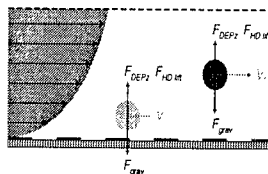
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DMO Review 00013PL

The Microfluidic Molecular Systems Program (MicroFlumes)



- Agent attacks cell and disrupts dielectric properties
- Agent binding alters surface dielectric properties



UTMDACC/
LLNL/Lynntech



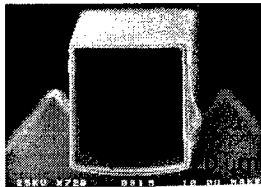
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DMO Review 00013PL

"Versatility" of Microfluidics

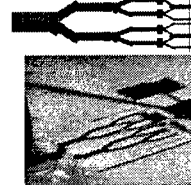
♦ Miniaturized channels and reservoirs

- Increase speed of reaction
- Reduce cost of reagents
- Reduce power consumption
- High surface to volume ratio/low Reynolds number
- Precise mixing/dosage and heating



♦ Integration

- Reduce cost of manufacture
- Minimize dead space, void volume
- Minimize sample carryover
- Multiplex capability: increased number of parameters monitored per assay

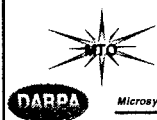


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DARPA Report 0001176

Integration Tasks and Technical Challenges

Technical Tasks	Challenges
1. Substrate processing for integrated fluidic transport and local flow control	Incompatible fabrication processes to integrate pumps, valves, channels, mixers, fluid sensors on single chips
2. Integrated fabrication of specific ligand receptors on passive and active surfaces	Incompatible fabrication conditions (temperature, sealing, patterning), surface conditioning and storage
3. Heterogeneous integration of disposable plastics with optical source/detector and electronics	Alignment, interconnection, optical components (e.g., lens), assembly
4. Integration of sample collection/delivery interface and sample storage	Sealing from contamination and pressure leakage, fabrication of protruding needles, z-direction flow control
5. Prototype integration and demo	Integration of fluidic and electronic interconnects; power consumption

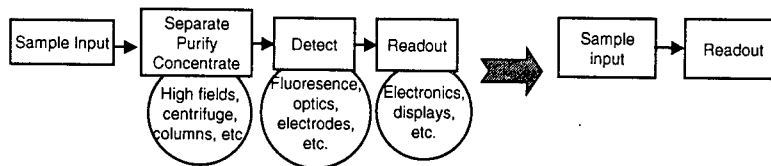


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DARPA Report 0001176

Technical Approach: Sample-to-Readout Multi-functional Micromachining Platforms

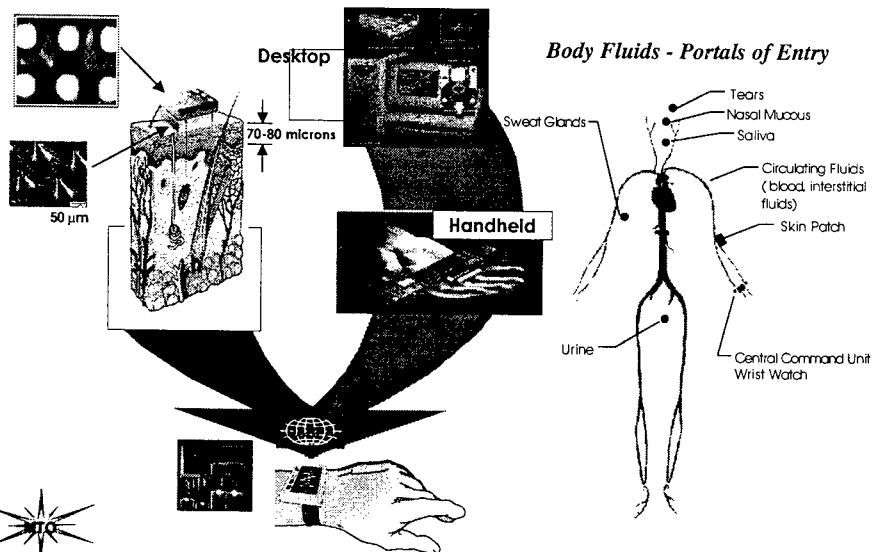
Enable the chip designer to design an integrated system meeting specific application specifications (analogous to CMOS for integrated circuits).



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DTIC Number 0001 134

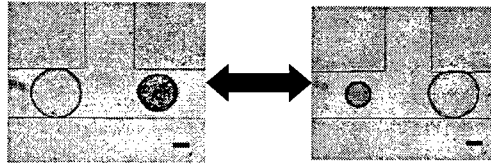
Bioflips Enables Ubiquitous Sampling, Analysis, and Synthesis of Biofluidics



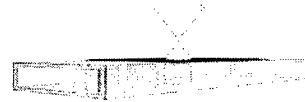
Microsystems Technology Office

DTIC Number 0001 134

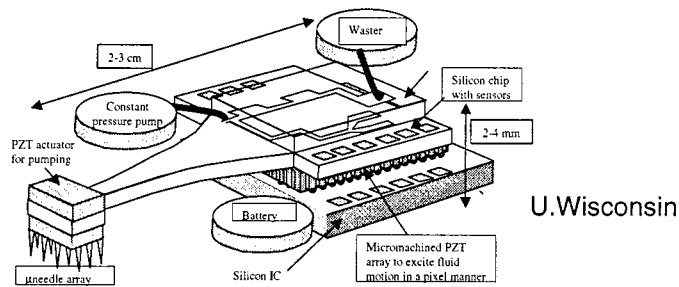
Two BioFlips Examples



U.Wisconsin/UIUC



In situ polymerized/patterned/functionalized components



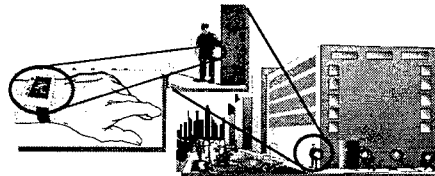
U.Wisconsin

Piezoelectric micromachining platform for BioFlips



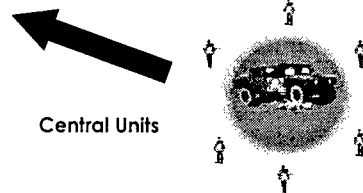
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DTIC Ref ID: A601134



Distributed

Wrist-Mounted BioFlips



Central Units

It should be possible to detect a presymptomatic infection within the first hour by a cytokine profile

Commercial Applications

- ◆ Quick assessment of contaminated water and food sources
- ◆ On-demand chemical and drug synthesis
- ◆ Antidote delivery, swallowable and implantable chips
- ◆ Out patient care for high risk and chronically-ill patients

DoD Application

- ◆ Distributed, covert deployment of bio-detectors
- ◆ Rapid indication of CBW incident
- ◆ Indication of extent of problem and overall effect
- ◆ Battlefield triage information for medic
- ◆ Human responses during testing
- ◆ Performance enhancement drug delivery



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DTIC Ref ID: A601134

Design of Integrated Mixed Technology Microsystems

Anantha Krishnan

**Microsystems Technology Office
DARPA Tech
September 2000**



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DTRC Review 000613PL

Technology Trends

- **SYSTEM COMPLEXITY IS INCREASING !!**
- **DESIGN AND PROTOTYPING COSTS
ARE INCREASING AT A GREATER RATE
(TRIAL & ERROR APPROACH) !!**
- **INTUITION AND 'EXPERIENCE' ARE JUST
NOT GOING TO CUT IT !!**

**NEED CAD TOOLS TO SIMULATE AND PREDICT
SYSTEM PERFORMANCE BEFORE PHYSICAL
PROTOTYPING IS DONE !!**



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DTRC Review 000613PL

Design Approach

Today, mixed technology
"systems" are developed
from the "bottom up" using
many different components

SYSTEM



SUB-SYSTEM



COMPONENT

Ad-hoc Design, Research
Codes, Single User Tools



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DTIC Review 000613PL

Design Approach

Future mixed technology
systems must
be designed from the "top
down" using a consistent set
of requirements

SYSTEM



SUB-SYSTEM



COMPONENT

Methodology, Design Rules
and Checks, Multi-User Tools



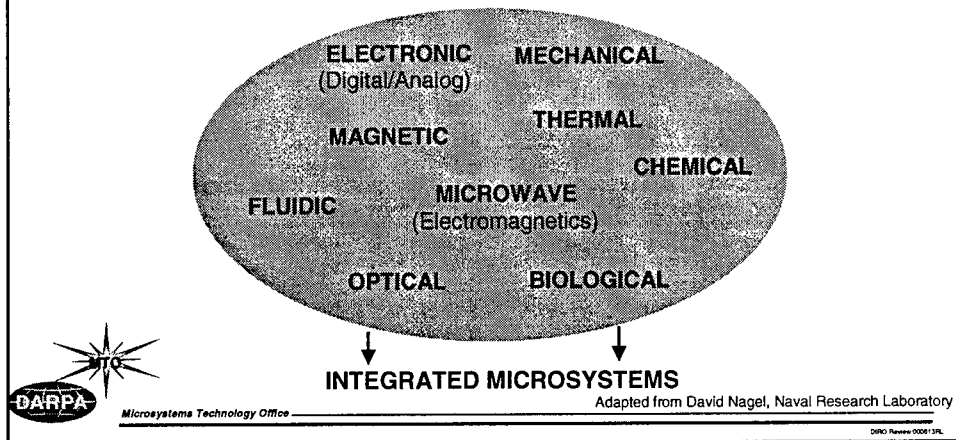
Goal is to provide VLSI-like Design Tools for
Integrated Mixed Technology Systems

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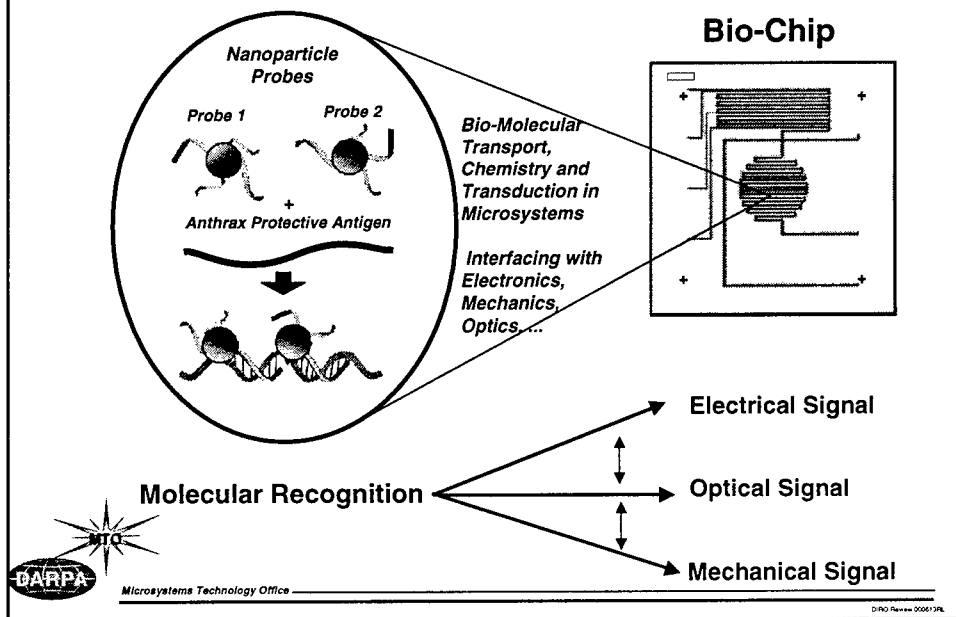
DTIC Review 000613PL

Integrated Microsystems

- Microsystem technology is much more complex due to interaction of mixed technologies - electronics, mechanics, optics, fluidics, chemistry, biology, ...
- But same analogy holds: Microsystem-EDA essential for growth of integrated system technology !



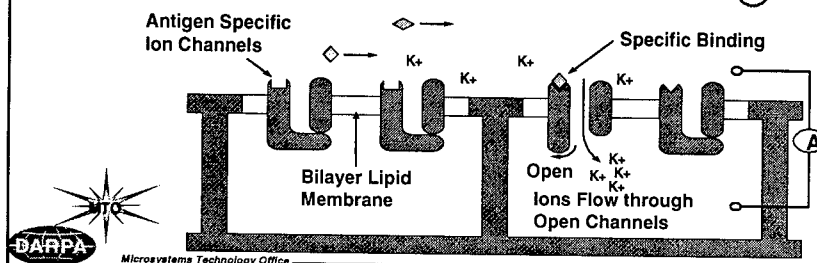
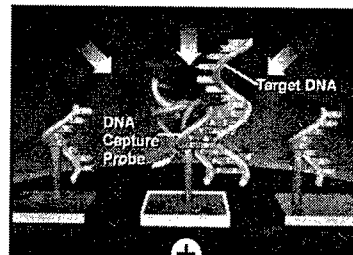
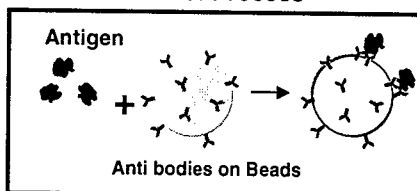
Biological/Chemical Sensor Systems



Molecular Recognition

Development of models for bio-molecular interactions in microsystems

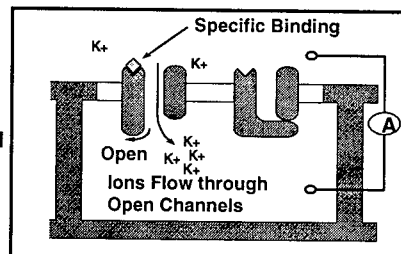
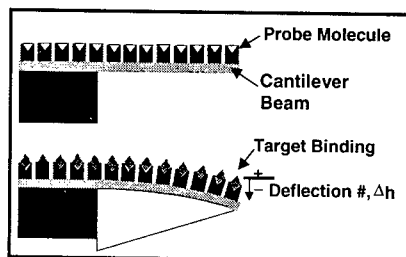
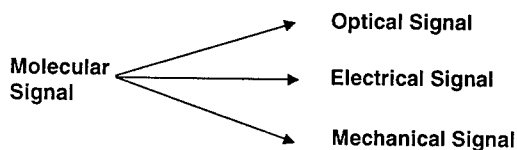
Time Scale of Process



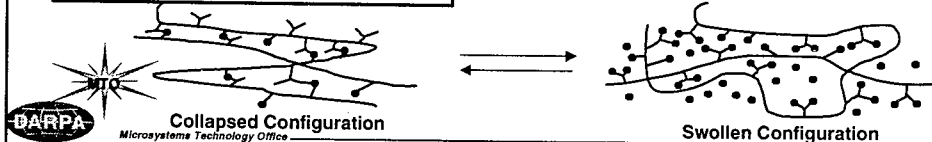
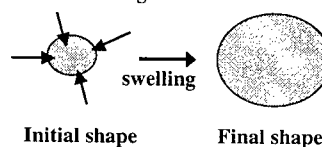
DTIC Review 0008 13/L

Signal Transduction

Development of models for the transduction process



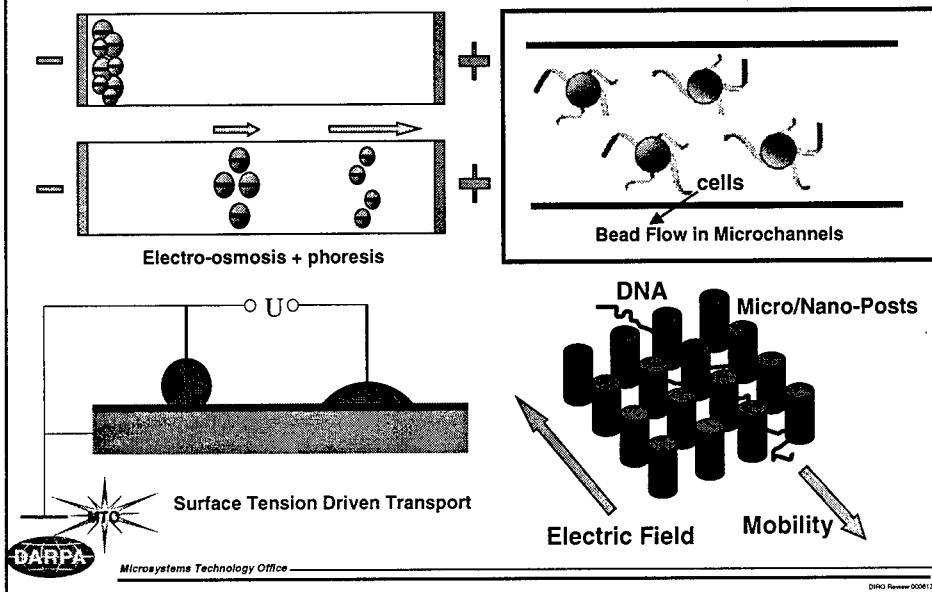
Solvent mixing



DTIC Review 0008 13/L

Microfluidics

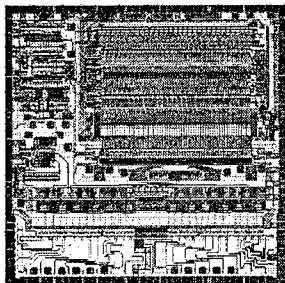
♦ Models for Bio-Molecular and Fluidic Transport



Electronic and Photonic Systems

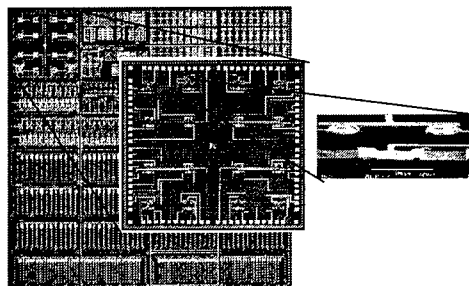
Mixed Signal (Analog-Digital) Systems

Advanced Digital Receiver Chip
(A-D and D-A Converters)



Mixed Electronic/Photonic Systems

Integrated VCSEL-Detector Arrays

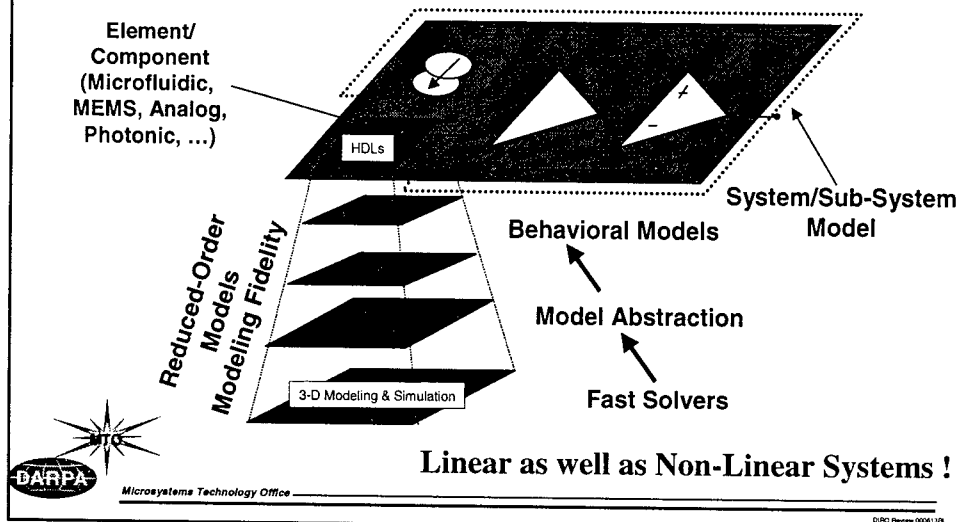


**Lack of Automated Design Methodologies;
More of an ad-hoc approach**



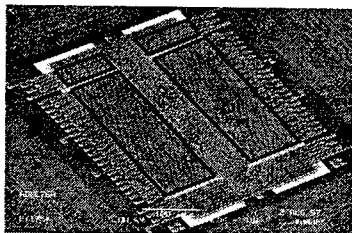
Integrated System Analysis

- ♦ Development of reduced models and integrated system models for mixed technology microsystems

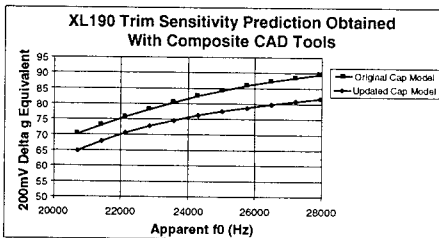


Demonstration of Mixed Technology Design – Example 1

- ♦ Reworking the (Analog Devices) 50g Sensor into a 190g device

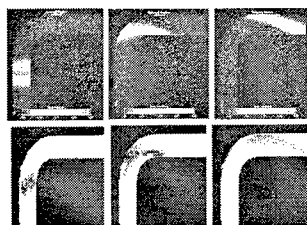


Full 3D simulation improved trim yield by 20% because of better sensitivity prediction.

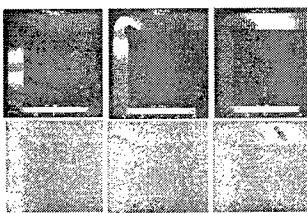


- Accurate calculation of the trim factors for this particular device was only possible using the 3D electromechanical (Composite CAD) tools
- The trim factors are essential in order to trim the device accurately. Without the simulations, AD would not have a product.

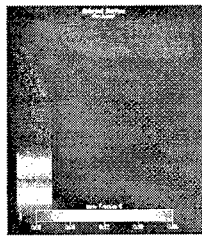
Demonstration of Mixed Technology Design – Example 2



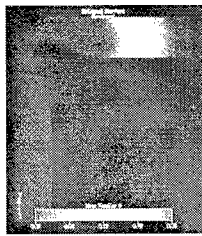
Simulation



Summary



Stanford
Microfluidics
Laboratory



Experiment

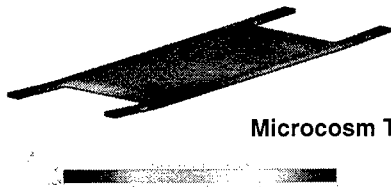


- **Simulation enabled development of a new design that minimizes dispersion in a miniaturized electro-osmosis process !!**

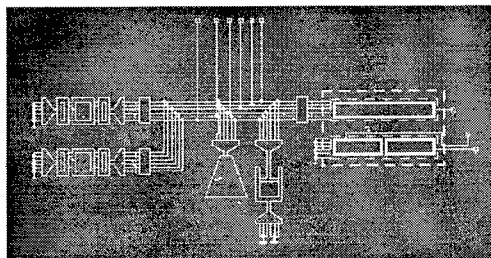
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DIPO Review 00061376

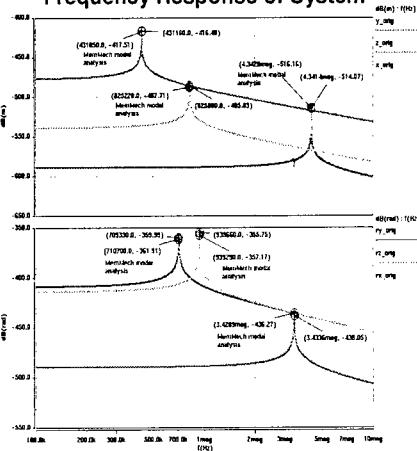
Demonstration of Mixed Technology Design – Example 3



Microcosm Tech.



Frequency Response of System



- Model reduction enabled orders of magnitude reduction in simulation cost without sacrificing model accuracy

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On the Order of the Day

Focus Areas

- ◆ Quantitative models (scaling relationships and phenomenological models) for microfluidic devices, MEMS, photonic components, etc.
- ◆ Model abstraction/reduction and integration at the microsystem scale - **Integrated System Analysis**

Capability to design microsystems with a high level of multi-disciplinary integration – Enabling technology for exponential growth !!



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DUO Review 000413PL

Gallium Nitride & Related Wide Bandgap Materials and Devices

Dr. Edgar J. Martinez
Program Manager

DARPA Tech 2000



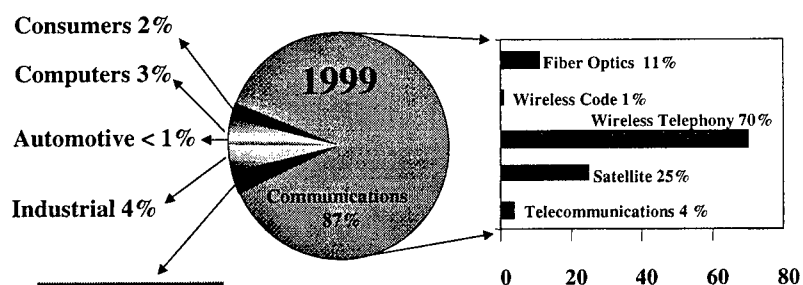
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000008

GaAs IC Markets

1999 Market \$11 Billion

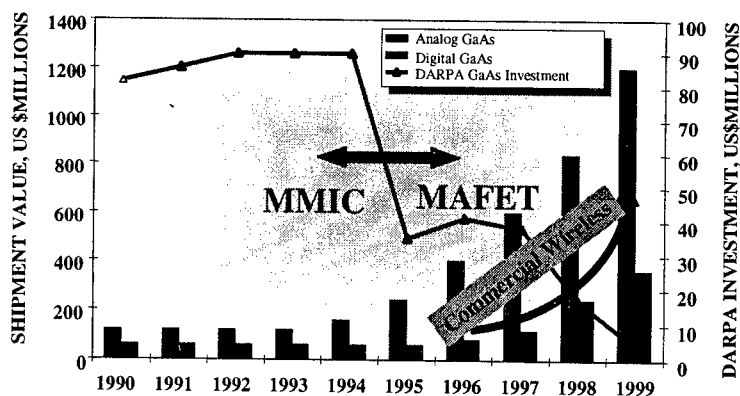
2005 Market \$20 Billion



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000009

GaAs IC Market 1990-1999



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Unmet Challenges in RF Analog Front Ends

- ❖ Power Density > 1 W/mm
- ❖ Multi-octave Bandwidth
- ❖ High Efficiency > 50%
- ❖ Linearity
- ❖ Low Noise Figures
- ❖ Low Phase Noise



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Electronic Properties of Semiconductor Materials

	Si (----)	GaAs (AlGaAs/ InGaAs)	InP (InAlAs/ InGaAs)	4H SiC (----)	GaN (AlGaN/ GaN)
Bandgap (eV)	1.1	1.42	1.35	3.26	3.49
Electron mobility (cm ² /Vs)	1500	8500	10000	700	900
Saturated (peak) electron velocity (x10 ⁷ cm/s)	1	2.1	2.3	2	2.7
2DEG sheet electron density (cm ⁻²)	NA	<4 x 10 ¹²	<4 x 10 ¹²	NA	20x10 ¹²
Critical breakdown field (MV/cm)	0.3	0.4	0.5	2	3.3
Thermal conductivity (W/cm-K)	1.5	0.5	0.7	4.5	>1.7
Relative dielectric constant (ϵ_r)	11.8	12.8	12.5	10	9.0



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III-N Material Challenges

- ❖ Substrates difficult to produce
- ❖ High temperature material growth process
- ❖ Defect rampant
- ❖ Low hole mobility
- ❖ Deep donors and acceptors

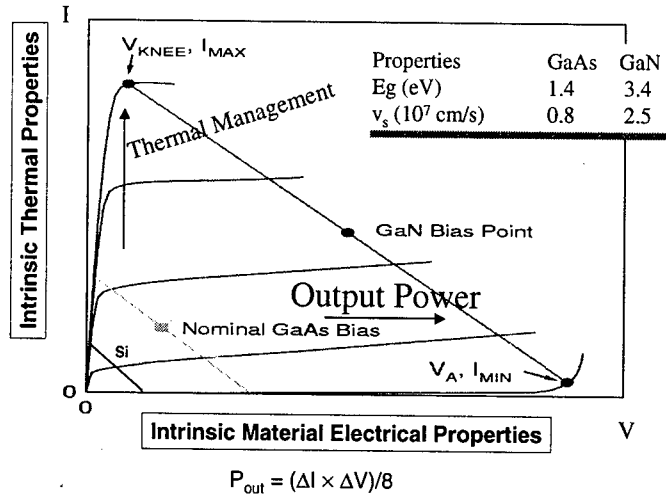


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Limitations of Today's Solid-State Devices

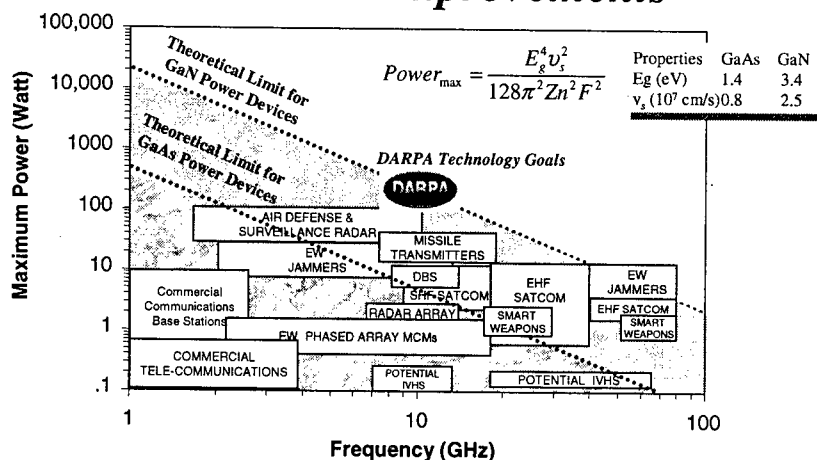
FET Microwave Output Power



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Current Technology Limitations and Potential Improvements

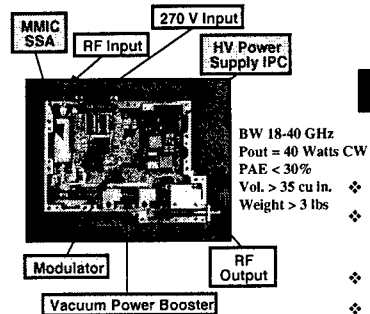


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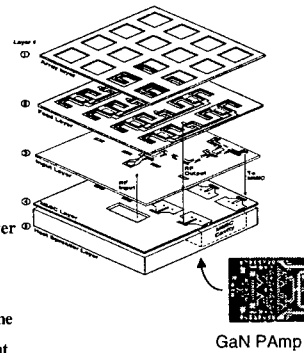
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GaN - A Disruptive Technology

State-of-the-art Microwave Power Module



Future RF Single Power Chip in an Advanced Package



- ❖ 10X to 100X output power
- ❖ Multi-octave bandwidth operation
- ❖ >35X reduction in volume
- ❖ >50X reduction in weight



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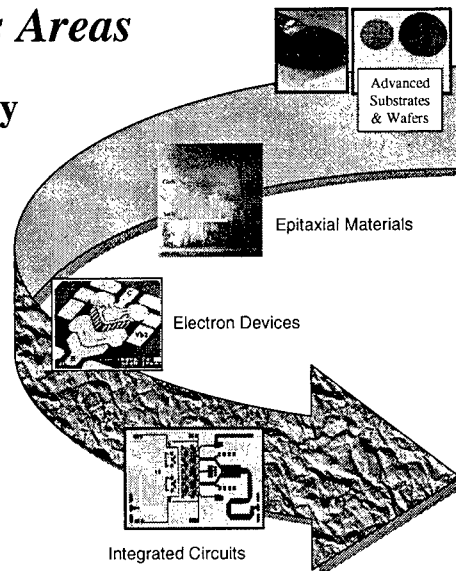
WBG Compound Semiconductors Focus Areas

❖ Material Technology

- Bulk Crystal
- Epitaxial Materials

❖ Device Technology

❖ Thermal Control & Packages



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Technical Strategy

**Comprehensive Effort
is Required for
Development of Robust
Technology**

**System
Performance**

**MMIC
Performance**

**Packaging &
Thermal Management**

Device Performance

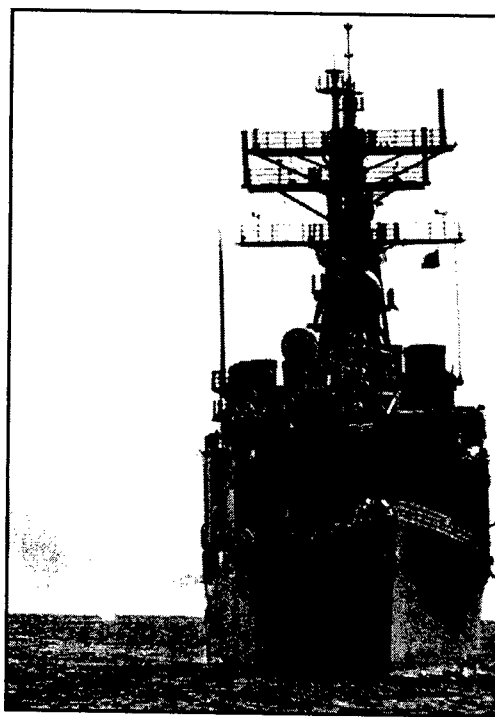
**Material Properties
& Parameters**

- Apply Knowledge & Experience from GaAs MMIC Community
- Leverage from Emerging GaN Commercial Developments - Economies of Scale

PARDA

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Military Applications

Multifunction RF Systems

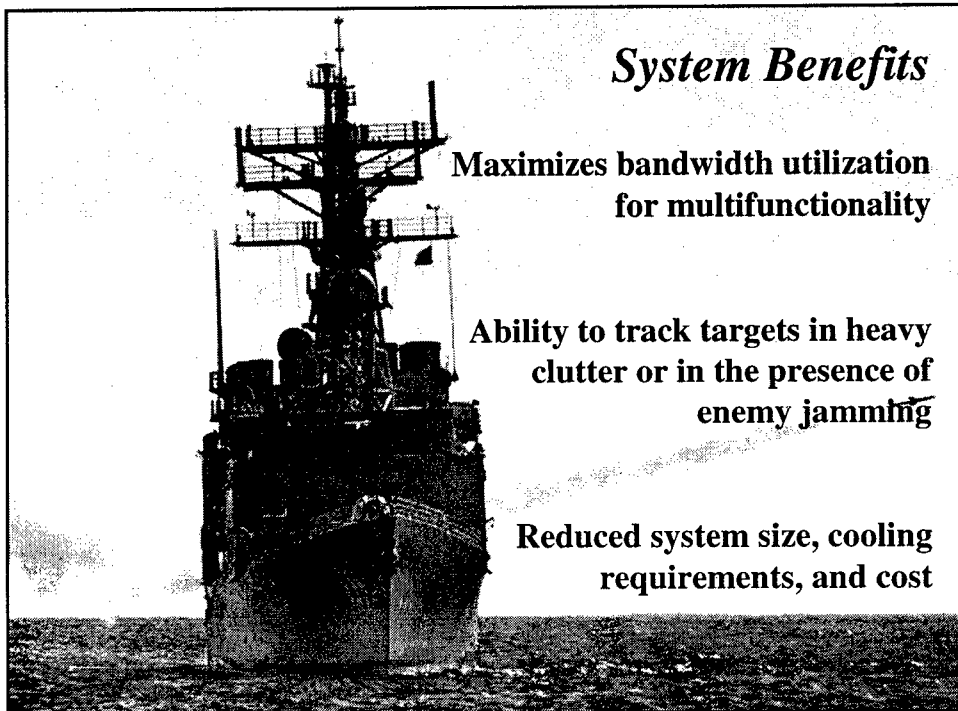
Radar

Electronic Surveillance

High Speed Communications

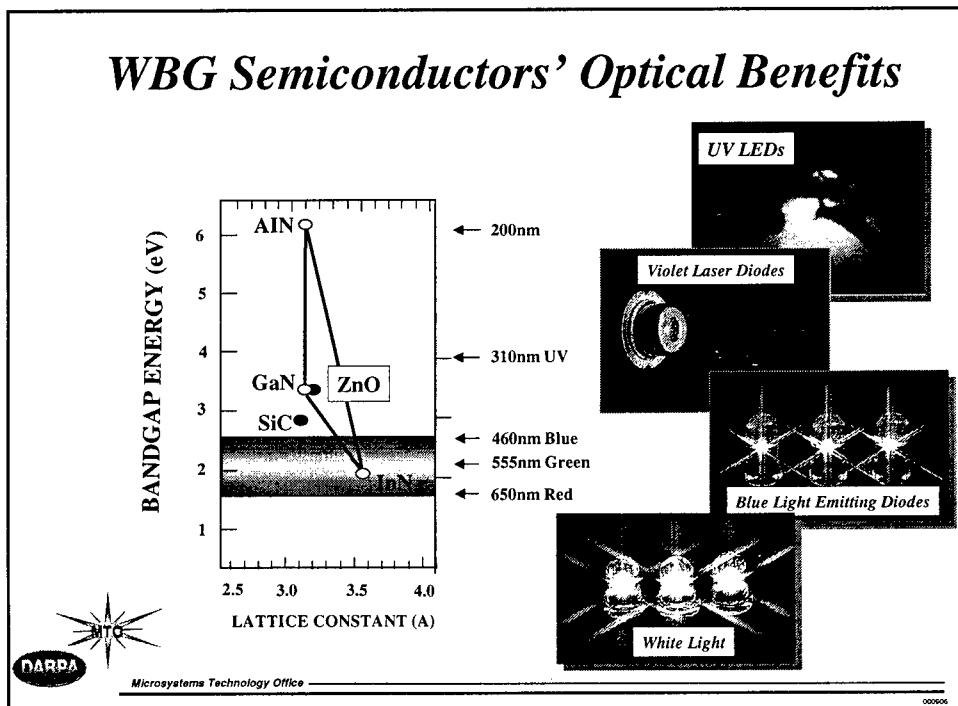
Electronic Warfare

Smart Weapons

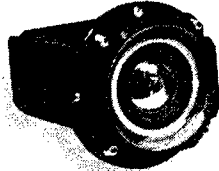


System Benefits

- Maximizes bandwidth utilization for multifunctionality**
- Ability to track targets in heavy clutter or in the presence of enemy jamming**
- Reduced system size, cooling requirements, and cost**



UV Solar Blind Detectors & Current and Future Missile Warning Systems



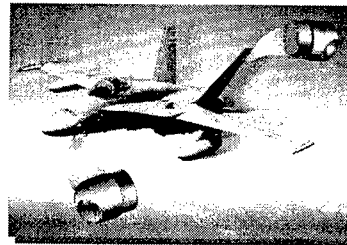
AN/AAR-47 Ultraviolet
Helos Transports



AN/AAR-57
Ultraviolet
Helos Transports
Tactical



- Ground vehicle self protection
- Airborne missile threat warning
 - AAA/MG detection and estimation
 - UV search and track
- Biological agent detection
- Engine monitoring
- Combustion control



Today's Technology
Bulky, Fragile and Expensive

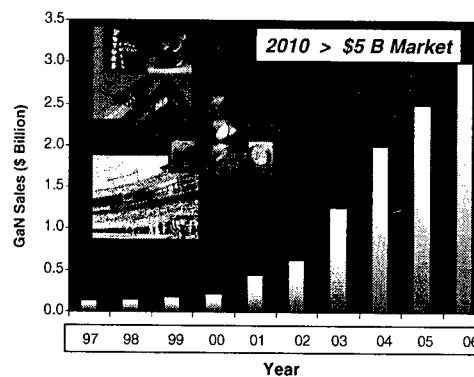


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Commercial Opportunities for GaN

- ❖ Traffic lights
- ❖ Illumination
- ❖ Automotive
- ❖ Medicine
- ❖ Outdoor displays
- ❖ Mass data storage
- ❖ Wireless communications



Data Source: Strategies Unlimited 1997



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Summary

- ❖ GaN enabling technology for many military applications
- ❖ Many material and device challenges
- ❖ Technical strategy requires comprehensive development efforts with many industry and academia partnerships
- ❖ Significant system benefits anticipated
- ❖ Commercial interest will not meet military needs



*is in the process of creating new
opportunities with WBG semiconductors*



Tactical Technology Office Programs

DARPA Tech 2000

Dr. David Whelan

Director

dwhelan@darpa.mil

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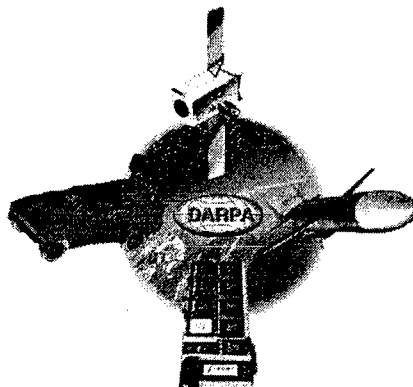


Tactical Technology Office

Global Surveillance



**Land
Systems**



**Aerospace
Systems**

Embedded Processing & Control

©2000 DARPA



Global Surveillance



Objectives:

Birth-to-Death Track
Moving Target ID

Enabling Technologies:

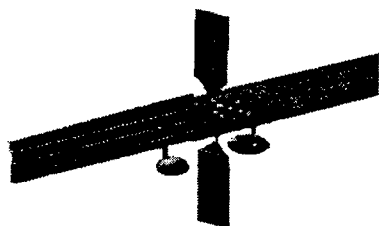
Space-Time Adaptive Processing
Thinned ESA Antennas
Low Power Processors
Geographic Data Bases

Challenge:

"Eyeball-on-Target" from Space

New Efforts:

Coherent Communications,
Imaging and Targeting

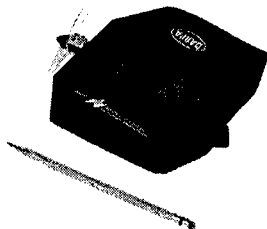
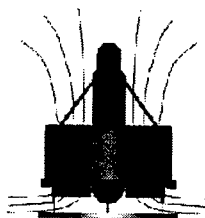


*Agile Space-Based Radar
Validates Birth to Death Tracking
of Ground Targets*

000000 Whulin Diagrams



Micro Air Vehicles



Technical Challenges:

- Increase endurance/payload
- High wind operation
- Perch/stare
- Operate under canopies

Accomplishments:

- Successful flight tests
- Full motion video
- Miniature IMU

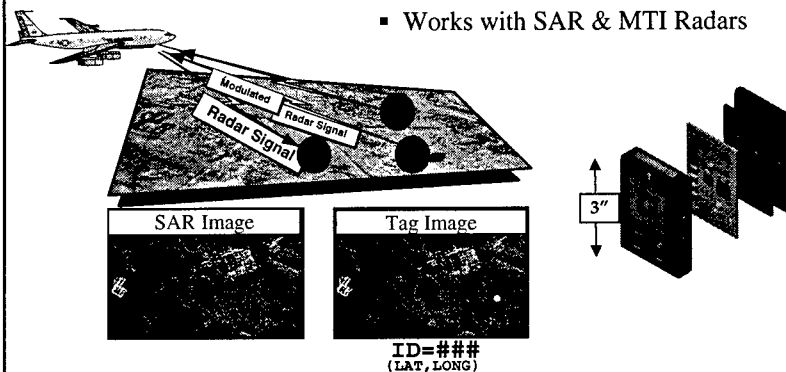
000000 Whulin Diagrams



Digital RF Tags Program



- C³ Information Embedded in Radar Signal Modulation
- High Bandwidth Communications Capability
- Works with SAR & MTI Radars



600906 Whelan Dargatzis



Aerospace Systems

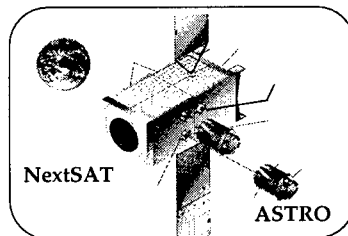


Objectives: Prompt Precision SEAD
Space Force

Challenge: Tactical Maneuvering Satellites

Enabling Technologies:
Autonomous Control
Active Aerodynamics
Flow Manipulation
High Strength Materials for Airfoils

New Efforts:
**Supersonic Miniature Air-
Launched Interceptor**
UCAV-N



Orbital Express

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Unmanned Combat Air Vehicle

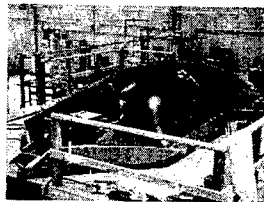
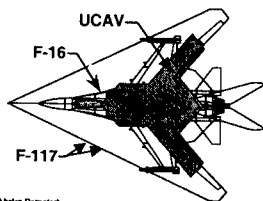


A Revolution in Air Power:

- 4:1 vehicles per operator
- Dynamic mission replanning
- 20% of current O&S costs
- Affordable stealth to the next level
- AT3 & onboard SAR targeting
- Flexible transporter
- Self-deployment
- 1/3 of JSF cost

Program Status:

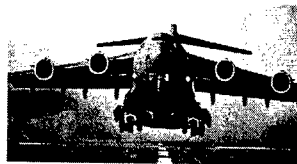
- Initial demonstrations successful
- Toolkit under construction
 - System Integration Laboratory online
 - MCS software build in work
 - Air vehicles & containers being built
- T-33 Surrogate UCAV flies this summer
- First UCAV flies next Spring



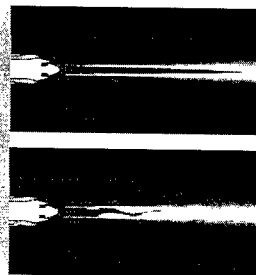
©2004 DARPA



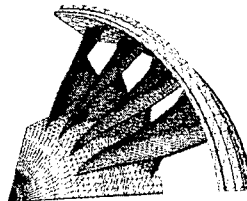
Micro Adaptive Flow Control



C-17 Active Control of Exhaust



Advanced CFD Codes



Aspirated Compressor Blades

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DARPA

Hummingbird A160



- **Demo Advanced Rotorcraft Technology**

- Advanced hingeless rotor design
- Reduced acoustic signature

- **Significant Increase in VTOL Range & Endurance**

- 3000 nautical mile range with surveillance payload
- 30-48 hours endurance

High Capability Surveillance Payloads

- SAR/MTI Radar
- EO/IR Search/Designator
- FOPEN Radar
- ELINT

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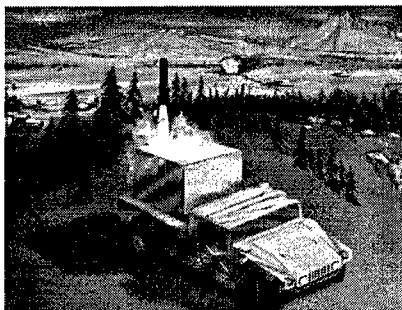
DARPA

Land Systems



Objectives:
Faster Deployment
Reduced Logistics

Enabling Technologies:
Unmanned Vehicles
Networked Remote Fires



Net Fires

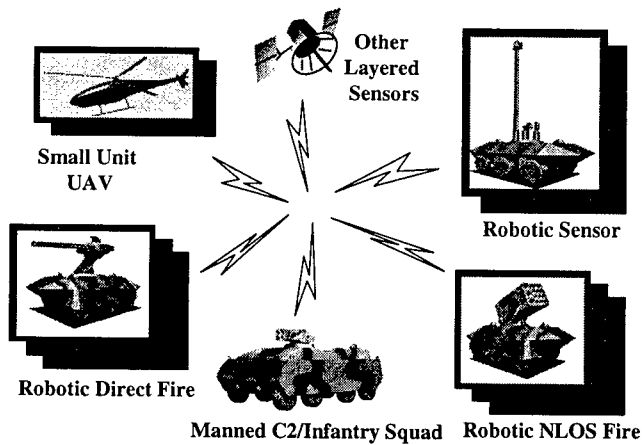
Challenge:
Distributed Functions

New Efforts:
Future Combat System

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Future Combat Systems Network Centric Force



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Embedded Processing and Control



Objectives:

Multi-Sensor Organic Processing/Fusion
Real-Time Response

Enabling Technologies:

Bit Systolic Processing
Wideband Space-Time Adaptive Processing

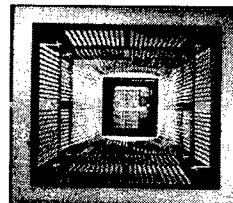
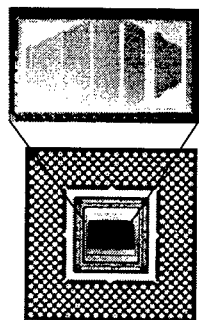
Challenge:

Mission Specific Processors
(Throughput/Power)

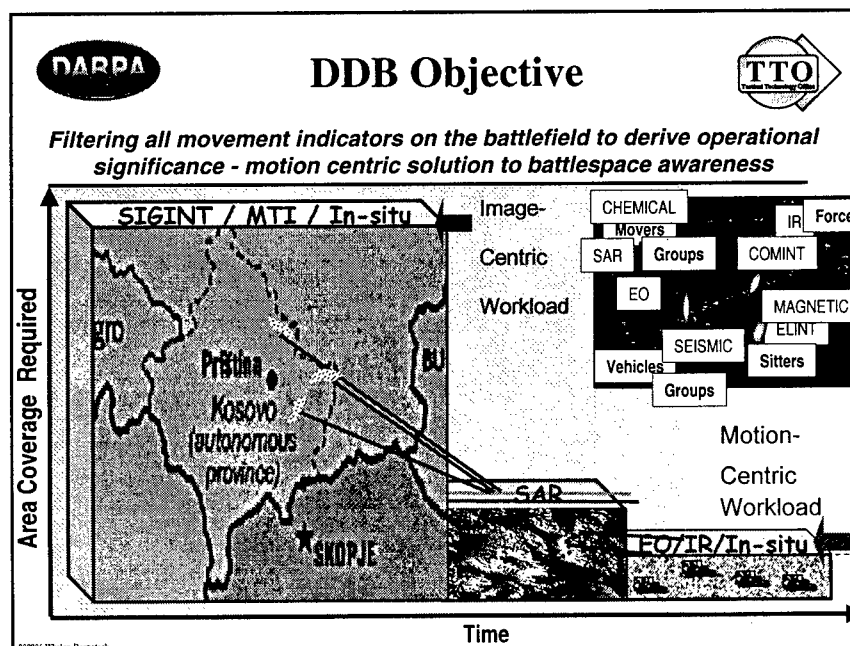
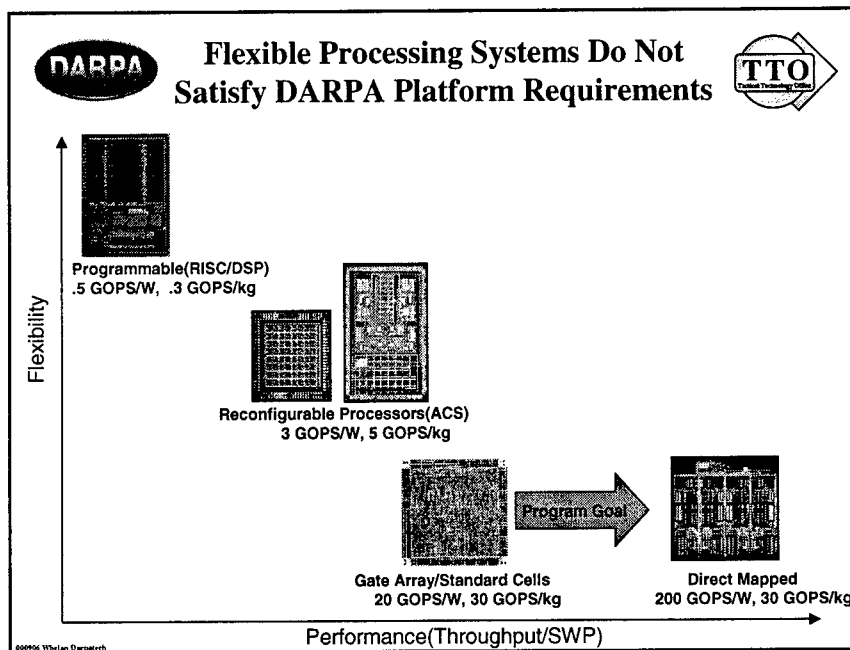
New Efforts:

Mission Specific Processors

MITLL Polyphase Filter



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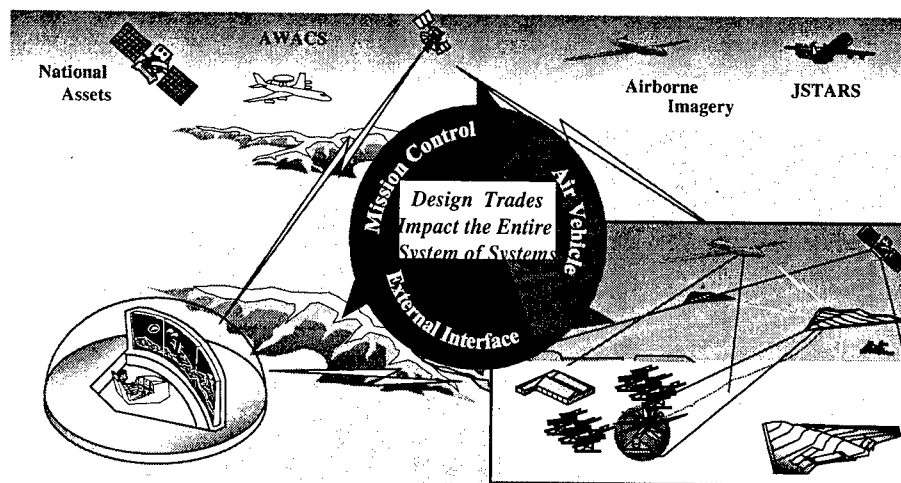
Video



Football thrown past crowd in background



System Concept



07/21/97



System Themes

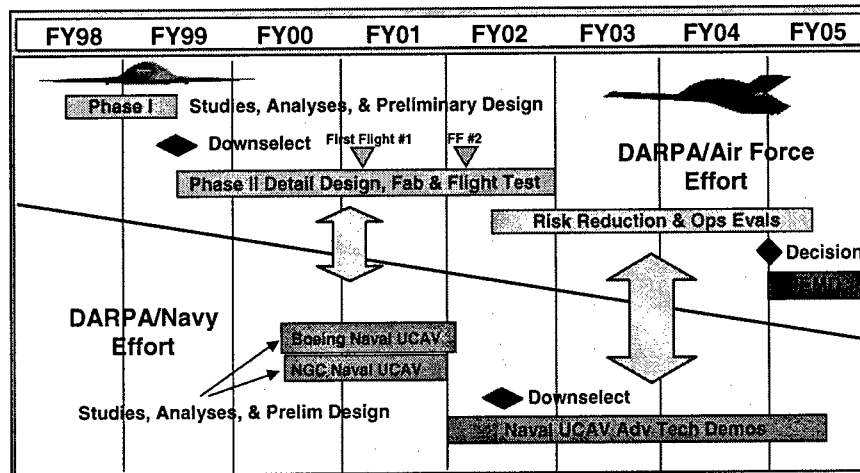


- **Network Centric Warfare**
- **Revolutionary Mission Control System Potential**
 - Operators at the center of information
 - Intelligent decision aids
 - Teams control swarms
- **Revolutionary Air Vehicle Potential**
 - End-node of a lethal system
 - High degree of on-board intelligence
 - Product of latest design/manufacturing tools
 - Tailored yet robust capabilities
 - Minimal maintenance/high sortie rate
- **All Technologies Buy Their Way onto the System**
- **Lowest Mission Cost per Target Kill**

07/21/97



UCAV & UCAV-N Acquisition Plan



07/21/97



Program Philosophy



- Partnership to Demonstrate Technical Feasibility
- Exploit Design Freedom
- Think Out of the Box
- Mission Focus but Not a Point Solution
- Exploit UCAV ATD
- Focus on Naval Unique Environment/Issues
- Advanced Technology NOT an Acquisition Program
- Seamless Path to EMD Decision
- Provide Focus for S&T

07/21/97

Goal & Objectives



Demonstrate the technical feasibility for a UCAV system to effectively and affordably prosecute persistent, sea-based 21st century SEAD/Strike/Surveillance missions within the emerging global command and control architecture.

▪ Develop

- A low life-cycle cost, mission effective sea-based design for a SEAD/Strike/Surveillance unmanned air vehicle
- A reconfigurable control system for multi-vehicle operations in Naval environments
- Robust/secure command, control & communications, including line-of-sight and over-the-horizon

▪ Evaluate

- Human computer function allocation, dynamic mission planning & management approaches
- Off-board/on-board sensor integration, weapon targeting & loadouts

▪ Demonstrate

- Naval operations including ship launch and recovery, deck handling and storage, maintenance and training, and interoperability with other Naval aviation systems and operations
- Human-in-the-loop, detection, identification, location, real-time targeting, weapons authorization, weapons delivery and target damage indication

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Program Approach UOS Focuses SMP



Analyze High Payoff Missions

Naval UCAV Operational System (UOS-N)

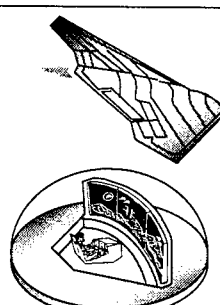
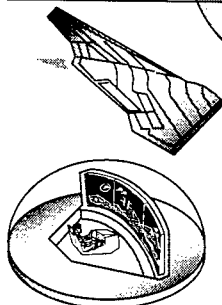
- Effective & affordable weapon system for post 2010 missions
- Product of multi-dimensional / optimized trade studies
- Designed to identify the critical technologies, processes & System Attributes (TPSAs)

System Maturation Plan (SMP)

- Complete roadmap of TPSA risk reduction activities including cost and schedule to achieve UOS-N vision
- Naval UCAV Demonstrator System (UDS-N) is fundamental component of the SMP
 - Maintains direct legacy to UOS-N
 - Focused by UOS to address critical TPSAs, explore CONOPS design space & validate UOS key assumptions

Technologies Processes & System Attributes (TPSAs)

- Shipboard Integration
- Command / Control / Communications (C³)
- Targeting / Weapons Delivery
- Supportability/Health Mgmt
- Human-Systems Interaction
- Signature
- Air Vehicle



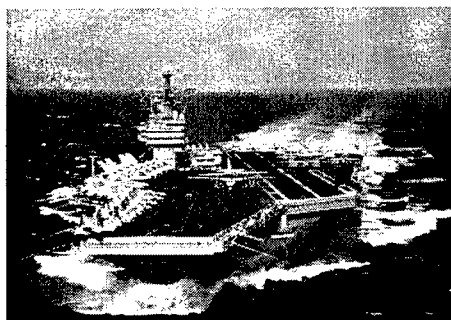
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UCAV-N Technical Challenges



- Focus on Naval unique technology and integration issues
- Leverage DARPA / USAF UCAV Program



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■ Ship Suitable UCAV Design

- Size, weight, costs for ship design
- Speed, stability and control of LO design
- Cat/Trap vs. alternatives (e.g. V/STOL)
- Maritime environment issues
- Safety

■ Mission Control Integration

- Autonomous launch & recovery
- Integrated deck operations
- Shipboard interfaces
- Integration With Navy C4ISR assets
- EM/EMC environment

■ Naval CONOPS

- SEAD / Deep Strike / Surveillance

■ Affordable Naval Operations & Support

- Storage transport
- Training
- Rapid turnaround, maintenance



Phase I Products



- Trade Study Results
- Alternative CONOPS Analysis
- UCAV-N Operational System Design (UOS-N)
- UOS-N Effectiveness & Affordability Analysis
- System Maturation Assessment (SMA)
- UCAV Demonstration System (UDS-N) Requirements

Naval Focus

Goal is to Demonstrate That Proceeding into Phase II is Justified and can be Accomplished within Cost & Schedule

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Program Approach Organization



■ Phase II

- Wide range of options
 - Full scale advanced technology demo like UCAV ATD
 - Conduct Naval unique aspects of SMP
 - Anywhere in-between
- Continue to refine effectiveness/affordability projections
- Provide best value to the government
- Additional information available with MS 2 feedback

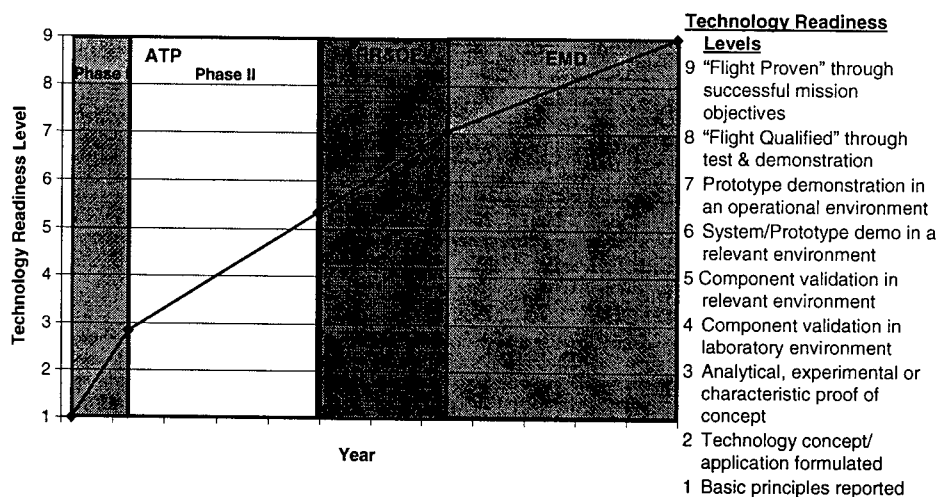
■ RR&OE

- Focus shifts to operational utility & military value
- Completes seamless path to EMD

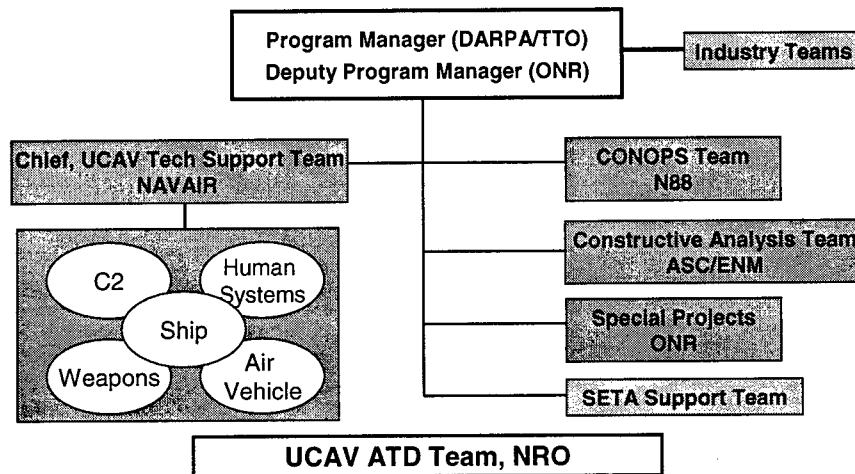
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Program Approach Technology Readiness Level Perspective



07/21/97



07/21/97



- Naval UCAV program
 - Meets high priority Naval needs
 - Technology and program opportunities exist
 - Potential revolutionary payoffs
- Phase I underway
 - Boeing and Northrop Grumman selected
- Phase II
 - Funding identified
 - Execution contingent on successful Phase I outcome
 - Draft solicitation out to industry for comment

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Future Combat Systems DARPATech 2000



Marion H. Van Fosson, LTC, USA
PM Future Combat Systems
(703) 696-7499
mvanfosson@darpa.mil



What is the FCS Program?



- The Future Combat Systems (FCS) Program is a collaborative program between the Defense Advanced Research Projects Agency (DARPA) and the US Army to provide for the evaluation and competitive demonstration of the Future Combat Systems.
- The FCS Program will:
 - Define and validate FCS design/operational concepts using modeling and simulation and surrogate exercises
 - Develop key enabling technologies for distributed lighter forces
 - Fabricate and test a multi-mission FCS Demonstrator suitable for EMD and production



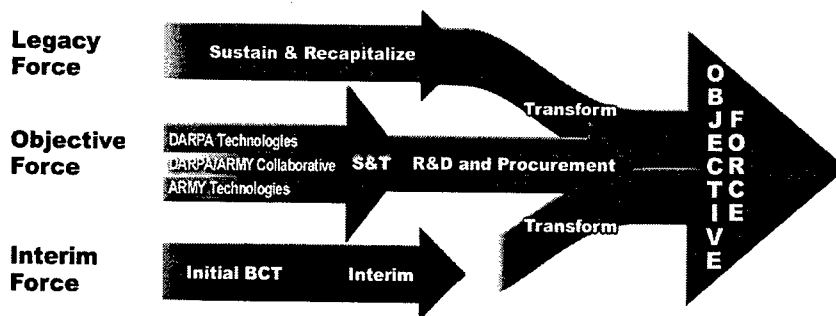
FCS Program Structure



- Structured to support the vision of the Objective Force.
- Contains the key elements representing the user, the technologist, and the developer.
- Built around a core team to execute the program.
- Supported by directly related DARPA risk reduction initiatives, Army S&T and a TRADOC TSM.
- Structured to share information and encourage Team innovation.



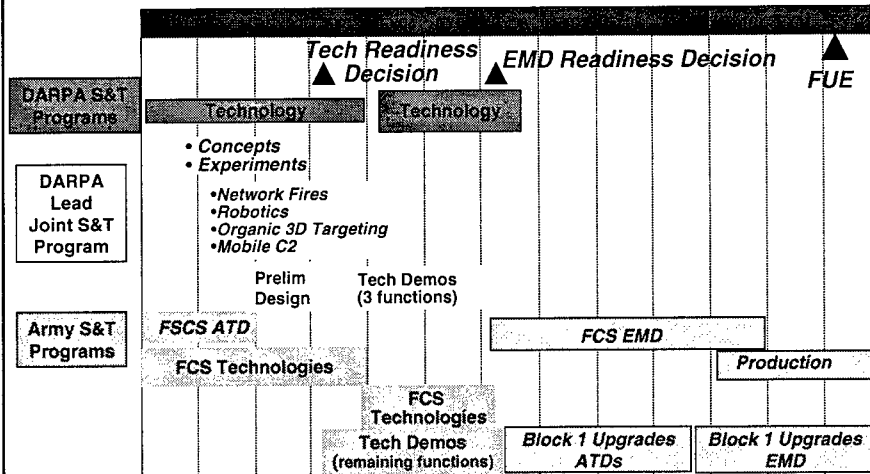
The Army Transformation



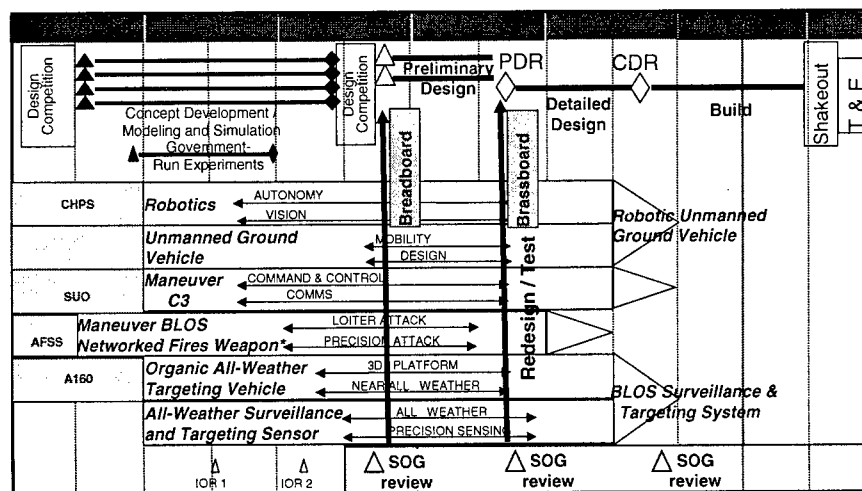
*... Responsive, Deployable, Agile,
Versatile, Lethal, Survivable, Sustainable.*



FCS Way Ahead -- "System" FUE FY12



Total Collaborative Effort to Support FCS

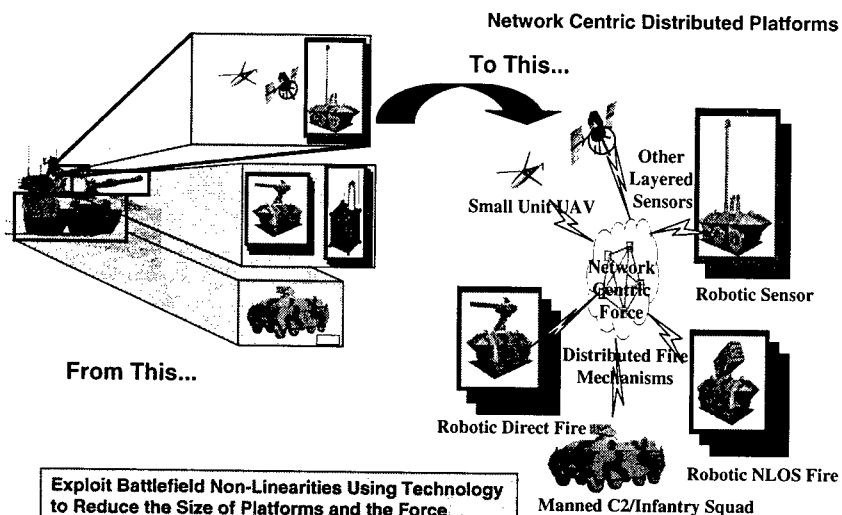




FCS Baseline System Concept



Future Combat Systems



FCS Concept Teams (Six Proposals - Four 845 Agreement Awards)



- The Boeing Team

- The Boeing Company, Seattle, WA
- New Definitions, Inc., Tacoma, WA
- Vector Research, Inc., Ann Arbor, MI
- Whitney, Bradley & Brown, Inc., Vienna, VA
- Signature Research, Inc., Calumet, MI
- National Institute of Standards and Technology (NIST), Gaithersburg, MD
- Rockwell Science Center, Thousand Oaks, CA
- Krauss-Maffei Wegmann (KMW), Germany

- Team Full Spectrum

- SAIC
- United Defense, LP
- ITT Industries
- Northrop Grumman Corp
- Logistics Management Institute (LMI)
- SRI International
- Strategic Perspectives Inc.
- Omnitech Robotics International LLS
- University of Texas Center for Electromechanics
- VRI

- Team Gladiator (Consortium)

- TRW
- Lockheed Martin
- CSC/Nichols Research
- Battelle Institute
- Carnegie Mellon
- IITRI/AB Technologies

- Team FoCuS Vision (Consortium)

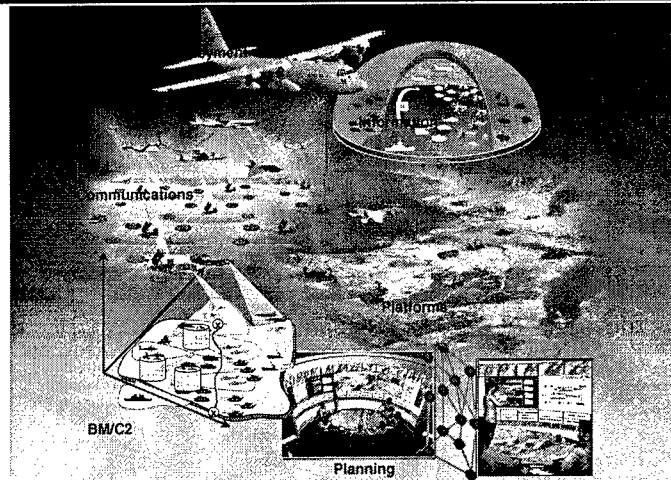
- Team FoCuS vision led by General Dynamics Land Systems Inc., Sterling Heights, Michigan and Raytheon Company, Plano, Texas.

Other participants with GDLS and Raytheon include:

- Aurora Flight Sciences
- Carnegie-Mellon University
- Honeywell
- Maxwell Physics International
- Stanford Research Institute International
- Sensis
- Sensor.com Wireless Integrated Network Sensors
- Whitney Bradley & Brown Inc.
- Los Alamos National Laboratory



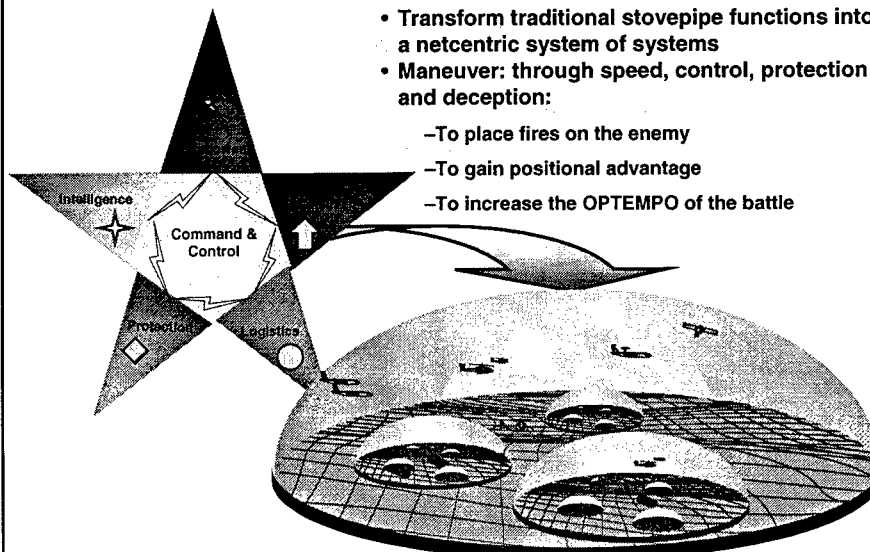
Concept - *Boeing Team*

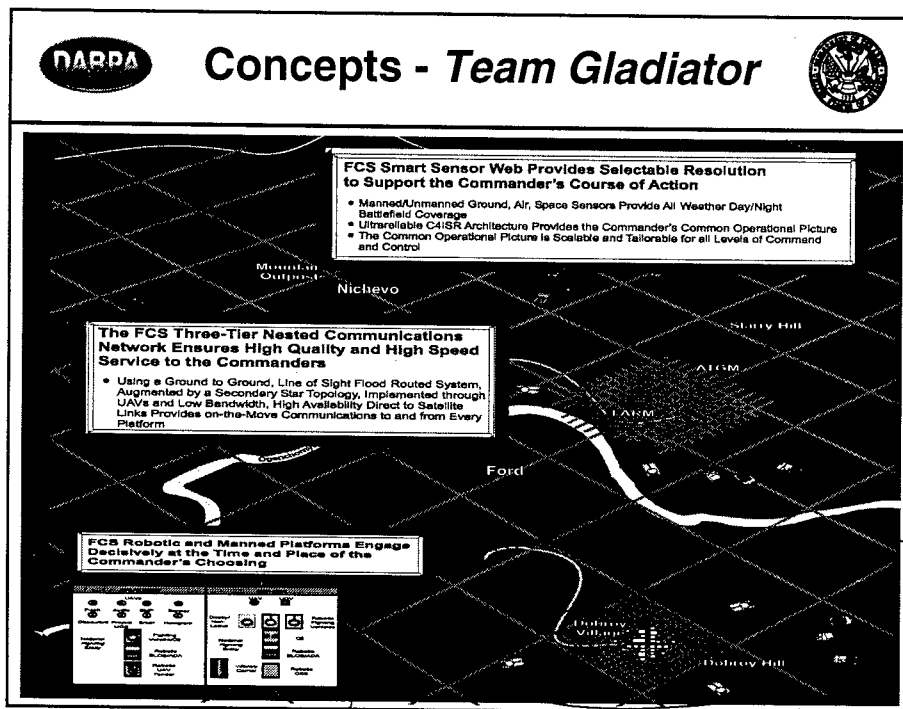
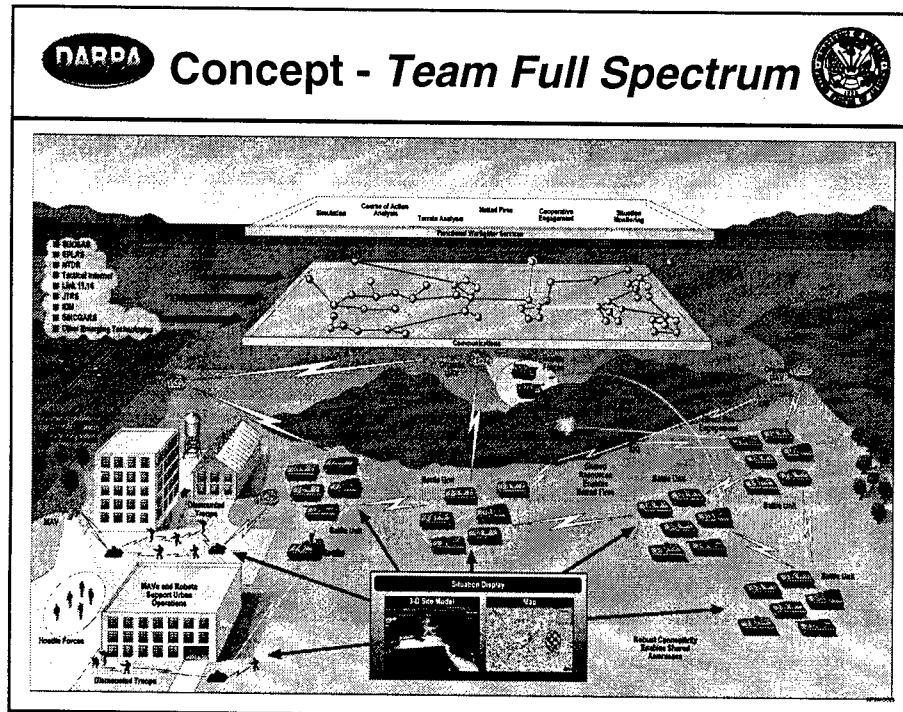


Tailorable multipurpose force comprising an adaptable system of robotic-enhanced platforms brought together by a remoted distributed and non-dedicated architecture.



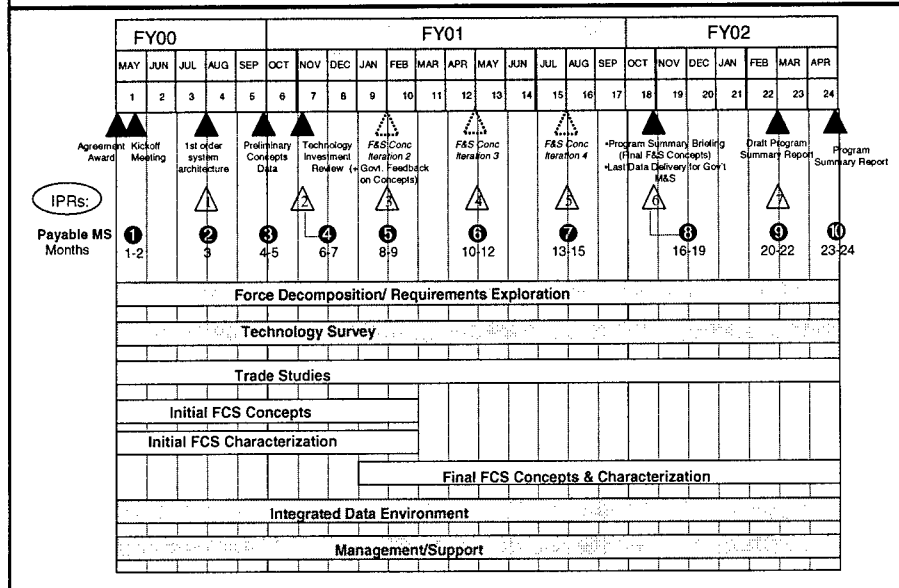
Concept - *Team FoCus Vision*







Milestone/Schedule



Expectations



- Diverse Team backgrounds bring different approaches to defining FCS Force solutions.
- Team taxonomies provide necessary skill and facility mixes to address the needs of the total program.
- Teams, augmented by government expertise and technology, will significantly reduce overall program risk.
- We will understand “what makes a difference” based on government and Team modeling and limited and focused government testing.
- Capability to “reteam” in the next phase will capture the “best of the best.”



Summary



- MOA is signed.
- Concept Team Agreements have been awarded and we are underway.
- Program relationships, organizational structure, and significant cost sharing (including Army, DARPA and Industry teams) are in place. PM will transition with program to promote continuity.
- Industry and Government teams are *solid* and enthusiasm levels are high.
- Program is structured to meet 2012 FUE.

Discoverer II

Space Based Radar Concept



DARPA Tech 2000

Sept 2000
Allan Steinhardt



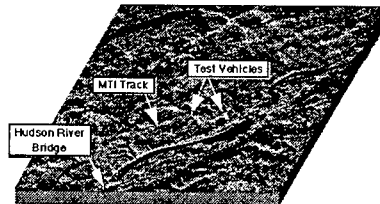
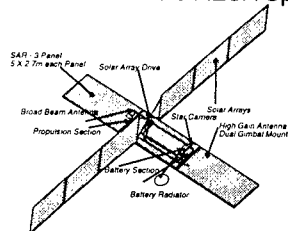
Outline

- ■ **The Discoverer II Concept**
- **New Capabilities**
- **Active Electronic Scanned Antenna**
- **Space Based Information Processing**
- **Mission Utility**



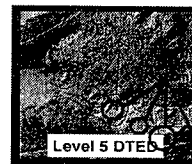
Discoverer II Space Radar Objectives

Affordable AESA Spacecraft



MTI Overlaid on SAR Image

- Feasibility of GMTI from space
- Tracking of ground vehicles
- Dynamically tasked imaging of ground targets
- Collection of terrain elevation data
- Show affordability MTI from space



DARPA



Outline

- The Discoverer II Concept
- ■ **New Capabilities**
- Electronic Scanned Antenna
- Space Based Information Processing
- Mission UtilitY

DARPA



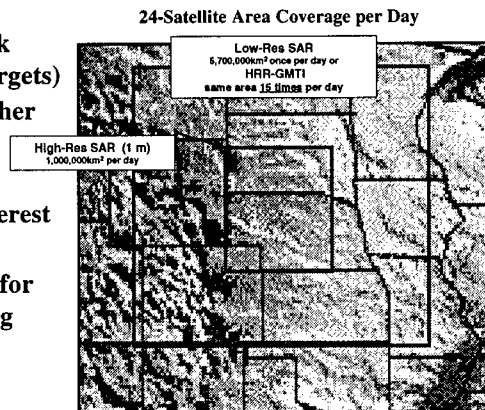


Why Moving Target Indication (MTI)?

- Detect, characterize, and track movers (e.g. critical mobile targets)
- Wide area cueing filter for other modes /ISR assets

Desired Attributes:

- Cover multiple theaters of interest
- "Birth-to-death" tracking
- High range resolution (HRR) for target classification & tracking

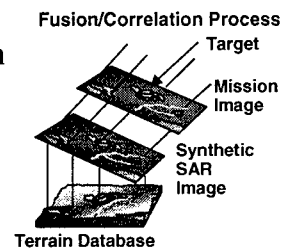


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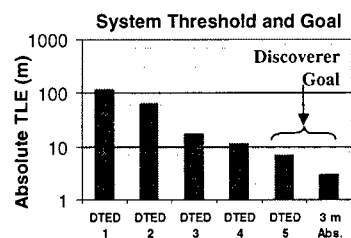


Why Digital Terrain Elevation Data (DTED)?

- Provide common grid for sensor data fusion
 - Day/night, all weather
- Generate accurate feature location data for targeting and other warfighter applications



DTED



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Outline

- The Discoverer II Concept
- New Capabilities
- ■ **Electronic Scanned Antenna**
- Space Based Information Processing
- Mission Utility



Affordable Space Based Radar

Active Electronically Scanned Antenna is a key enabler

- Change look direction without mechanical slew
 - Simplified satellite bus

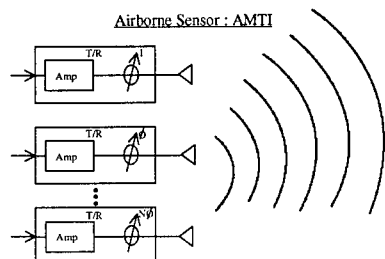


Affordable AESA requires innovation

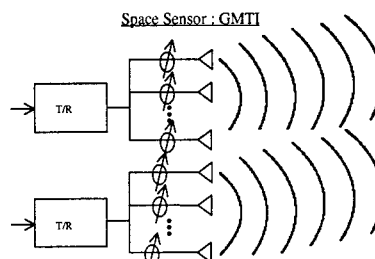
- Array thinning
 - Reduce # modules while retaining scan and beam quality
- Manufacturing
 - Heavy automation & streamlined testing
- Adaptive digital radar and signal processing technology
 - Relaxed radar tolerances



ESA: Space vs. Airborne



- Technical Challenge: Compactness
- Solution: High power, small aperture
 - 1 element/(T/R)



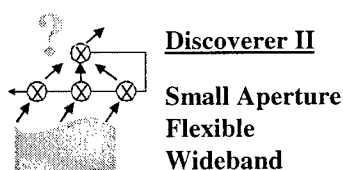
- Technical Challenge: Power drain, long-range, large field of view
- Solution:
 - Thinned arrays, large aperture, electronic agility

Affordable space AESA leads to large, low-power systems: new challenges

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Revolutionary Affordability for Global Surveillance: Satellite Form Factor



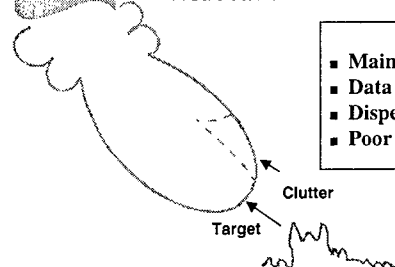
- Light, low-cost, multiple satellite/launch
- Increased range resolution enables mainbeam rejection
- Clutter rejection requires Space-Time Adaptive Processing

Challenges

- Mainbeam interference
- Data adaptive calibration
- Dispersion mitigation
- Poor cross-range resolution

Key Enablers

- Sub-band architecture
- Teraflop-class processing
- Wideband communications
- HRR MHT tracker



Emerging information technologies enable affordable constellation

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Outline

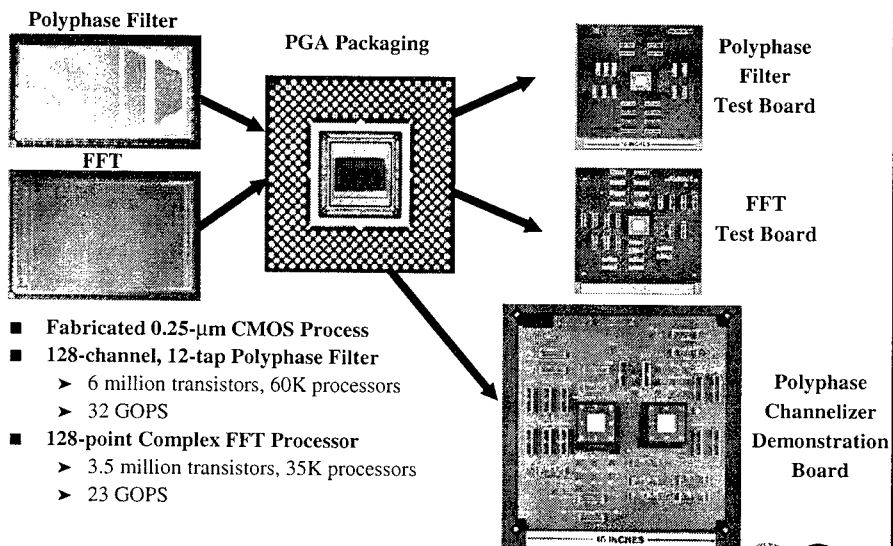
- The Discoverer II Concept
- New Capabilities
- Electronic Scanned Antenna
- ■ **Space Based Information Processing**
- Mission Utility

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Wideband Digital Processing Enables Relaxed Antenna Specifications



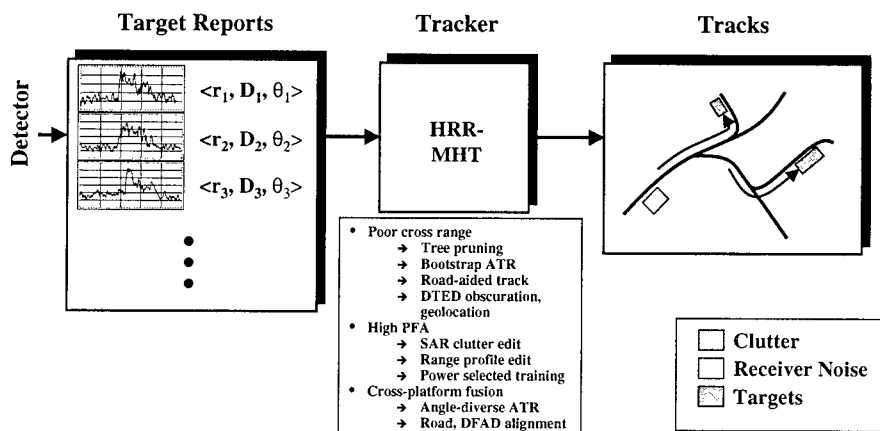
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Discoverer II Signal Processing Flow: Tracker



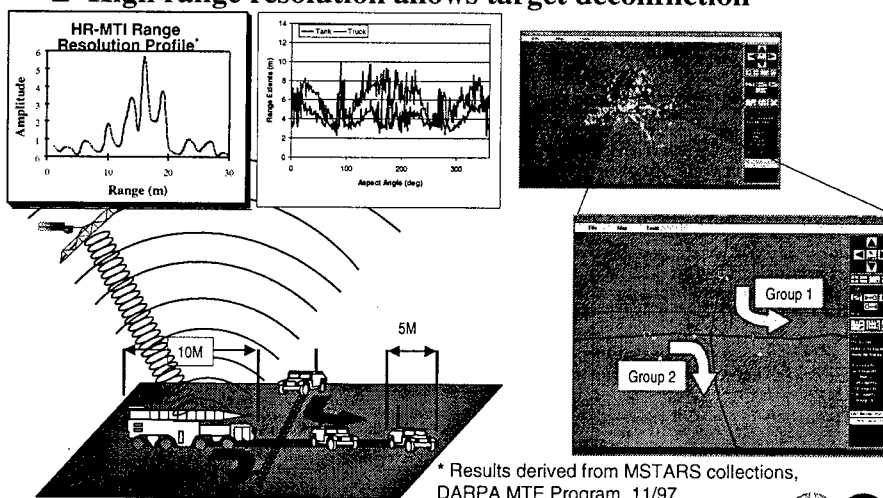
Tracker compensates for platform stand-off/diversity

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Feature-aided Tracking

High range resolution allows target deconfliction



00B055.ppt 8/11/00 14





Outline

- The Discoverer II Concept
- New Capabilities
- Electronic Scanned Antenna
- Space Based Information Processing
- ■ **Mission Utility**

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Prospective Strategic Relocatable Targets/Critical Mobile Targets Applications

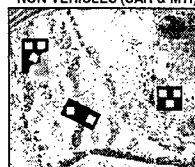
1 IDENTIFY SCUD
OPERATIONAL AREAS
(IPB)



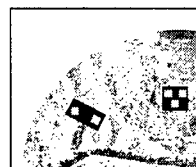
2 DE-LIMIT AREAS OF
UNCERTAINTY
(DTED)



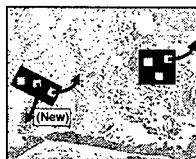
3 IDENTIFY ALL
PROSPECTIVE TARGETS.
FILTER OUT
NON-VEHICLES (SAR & MTI)



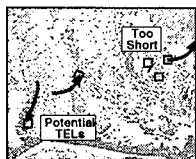
4 EXPLOIT SBIRS CUE
(IF AVAILABLE)



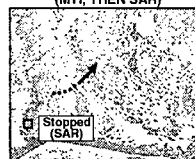
5 IDENTIFY TRACK MOVERS
(MTI)



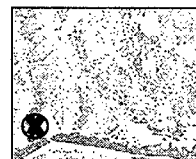
6 CLASSIFY MOVERS
(HRR-MTI WITH SAR)



7 IDENTIFY HIDE POINTS
CONFIRM TARGETS
CUE & COMMIT SHOOTERS
(MTI, THEN SAR)



8 BDA
(SAR & MTI)

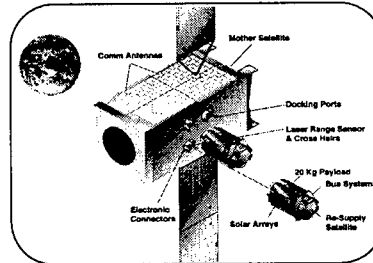


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ORBITAL EXPRESS

A Comprehensive Architecture for the 21st Century



Sam B. Wilson, III

Tactical Technology Office

Defense Advanced Research Projects Agency

**swilson@darpa.mil
(703) 696-2310**



DoD Space Architecture Limits



☆ Operational

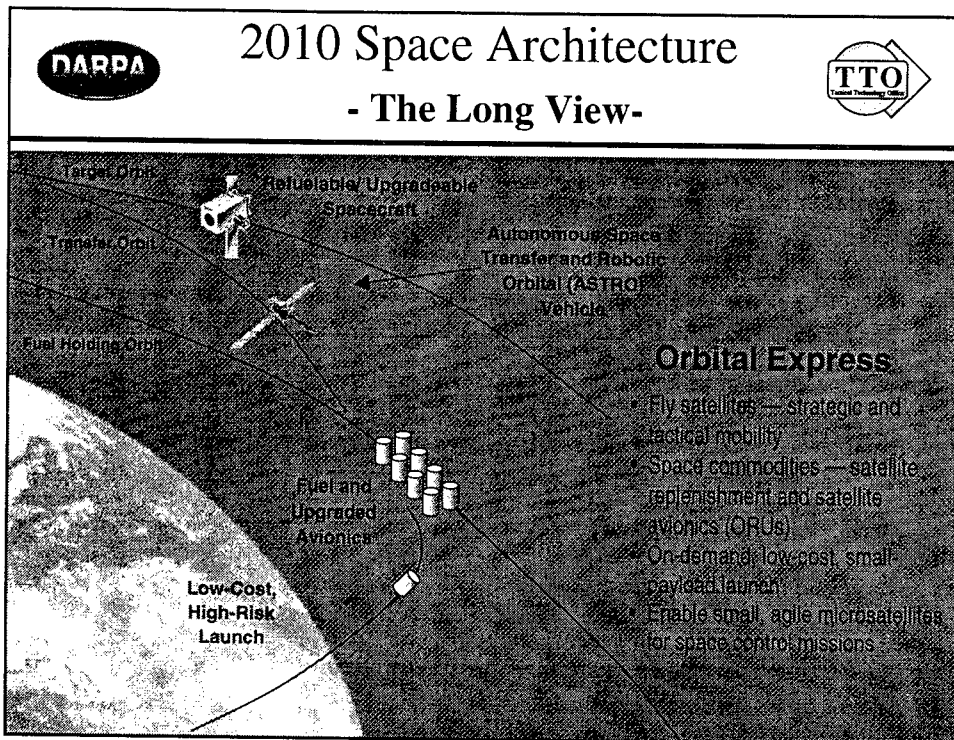
- ⇒ System availability concerns force risk intolerance
- ⇒ Predictable orbits allow scheduling by adversaries
- ⇒ Orbital infrastructure does not account for vulnerability
- ⇒ Limited ability to tactically optimize orbital configuration
- ⇒ Finite fuel restricts utility

☆ Costs

- ⇒ Complex, highly redundant, cross-strapped designs
- ⇒ Manned servicing is cost prohibitive —\$2M+ /orbital-hr
- ⇒ High fuel fraction costs for "maneuverable" satellites

☆ Technology

- ⇒ On-orbit technology at least 10-15 years old
- ⇒ Unmanned satellite servicing requires development





Orbital Express

Military & Intelligence Advantage



☆ **Enable new and enhanced capabilities**

- ⇒ **Adjustable satellite coverage / optimization**
 - ➔ Optimize “thin” constellations to provide regional focus (greater coverage)
 - ➔ Operate at different altitudes as needed
 - ➔ Formation “flying”
- ⇒ **Random ΔV: Counter adversary activity scheduling (D+D)**
- ⇒ **Enable space control options**
 - ➔ Protection: evasive and unpredictable maneuvers
 - ➔ Situational awareness: highly agile surveillance system
- ⇒ **Leverage long-lived hardware — reduce cost, increase capability**
 - ➔ Extend lifetimes

☆ **Enable a revolution in space affairs**

- ⇒ **Extensible design + space commodities**
 - ⇒ *Commercial competitive advantage for US industry*

4



History of On-Orbit Servicing



- ☆ 1999 (MIT/LL, JPL, NRL, Draper): Substantial cost saving + significant operational utility
- ☆ 1999 (Leisman & Wallen): Up to \$2B savings for upgrading GPS constellation vs. replacement
- ☆ 1998 (NRL): 28% cost savings + greatly increased sensor availability attributable to spacecraft modular architecture design
- ☆ 1987-1989 (SDIO / BMDO): 9% - 50% savings with on-orbit support
- ☆ 1979 (Classified): "Significant" cost savings to a specific constellation attributable to on-orbit refueling
- ☆ 1974 (TRW): 22% savings due to in-space servicing of DSP satellites

Numerous studies have shown refueling / upgrading produces significant life-cycle cost savings

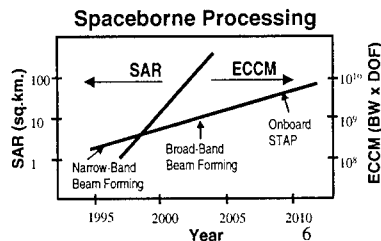
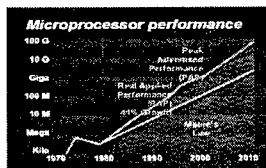
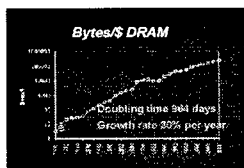
5



P3I Satellite Architectures Extend "Moore's Law" To Space



- ☆ Accommodate differing rates of technology advance
 - ⇒ Orbital Replacement Units (ORU) to improve system performance over time
 - ⇒ "Plug-and-Play" architectures can be made highly adaptable
 - ⇒ Exploit long-lived components (bus, sensors, solar panels)
- ☆ Enable new capabilities
 - ⇒ "Tightly coupled" systems—cross cueing/ tasking of new systems
 - ⇒ Adapt to counter-measure threats
- ☆ Less initial risk reduction required on upgradable avionics
- ☆ Reduction in satellite systems' cost





Planned System Upgrade Standard Procedure for Aircraft



☆ F-16 Multinational Staged Improvement Program (MSIP)

⇒ Plan progressive upgrades

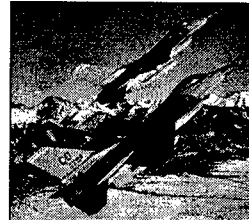
- Airframe life is long - technology evolving slowly
- Avionics technology progressing quickly - short obsolescence cycle

⇒ Retrofit upgrades to earlier F-16s

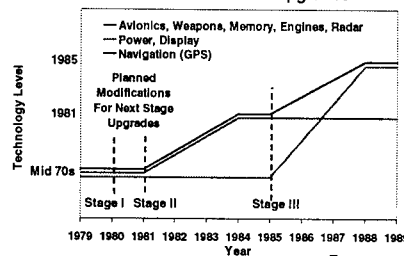
- Early airframes configured to accept future upgrades

⇒ Upgrade

- Processing speed, bandwidth and memory
- Defense capability, displays, weapons and warning systems
- Communications and navigation (GPS)



F-16 MSIP Planned Upgrades



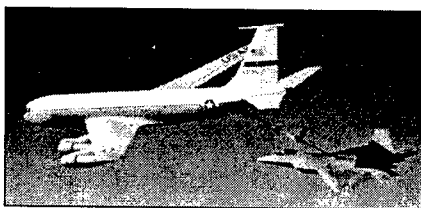
☆ Advantages

- ⇒ Increase service life and capability
- ⇒ Reduce cost and time to retrofit

7



In-Flight Refueling - A Revolution in Military Aircraft Capabilities

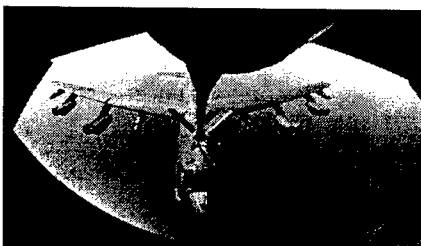


☆ Revolutionize aircraft missions

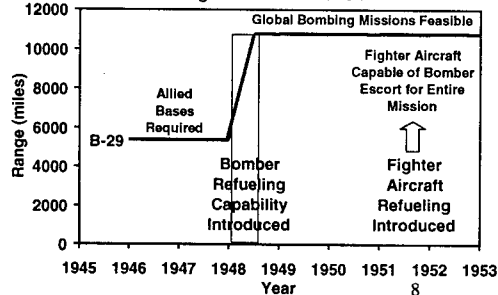
⇒ Extend range and duration

- Global missions feasible
- Fighter escorts sustainable

☆ Reduce cost and time compared to base refueling



In-Flight Refuel Revolution



8

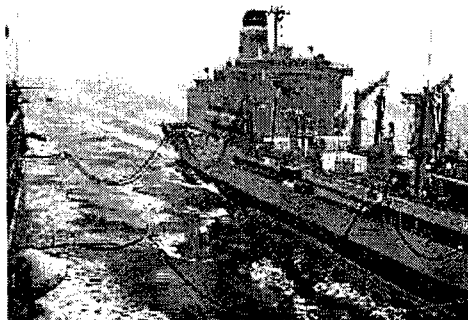


New Capability In Space: “Orbital Replenishment”



Navy's underway replenishment (UNREP) capability provides:

- ⇒ Force multiplier
- ⇒ Flexibility
- ⇒ Enhanced on-station time
- ⇒ All commodities for extended operations: food, fuel, ammo, repair parts
- ⇒ About 1 shuttle craft (fast replenishment ship) per 10 combatants (CVBG)



Man-in-loop required for:

- ⇒ Station keeping
- ⇒ Dexterous manipulation
- ⇒ Anomaly detection / crisis resolution

ORBREP versus UNREP:

- ⇒ Same force multiplier and flexibility benefits
- ⇒ Man-in-loop required only for anomaly detection / crisis resolution
- ⇒ Nominally one servicing spacecraft per orbital plane

9



New Refuelable & Upgradable Satellite Design/Architecture



☆ Design, Build, Add an Extensible Satellite

☆ Preplanned Product Improvement (P³I) Satellite Design

⇒ Standards Based “Dockable” Interfaces

- Thermal
- Signal
- Power
- Inertial

⇒ “Plug and stay” ORUs for Avionics P3I

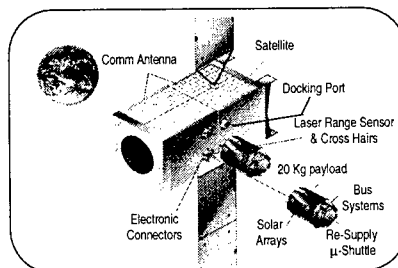
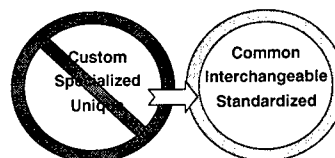
- Electronics
- Power systems
- Stabilization
- RF elements

⇒ Extensible Avionics

⇒ Refuel Spacecraft Features

⇒ Expendables Replenishment

- Fuel, batteries, cryogenics



10



ASTRO Servicer

Autonomous Space Transporter and Robotic Orbiter



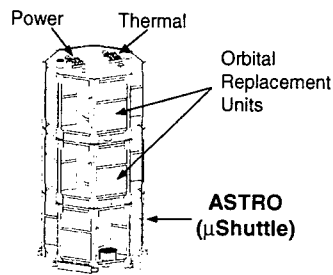
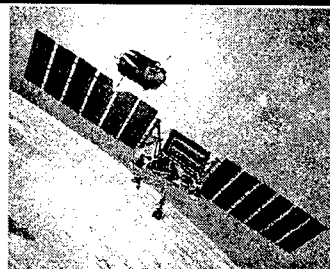
☆ Design, Build, and Demo a Servicer for In situ Refueling and Modular Upgrade

☆ Servicer Functions:

- ⇒ Avionics/fuel canister capture, transport
- ⇒ Autonomous satellite rendezvous & docking
- ⇒ Fuel/Orbital Replacement Unit delivery
- ⇒ Inspection
- ⇒ Host platform for MicroSatellites

☆ Technical Challenges & Opportunities:

- ⇒ Autonomous rendezvous/precision docking
- ⇒ Soft capture mechanism
- ⇒ Electrical/photonic/thermal interfaces
- ⇒ Propulsion & attitude systems



11



Enabling a Robust MicroSatellite Capability/Architecture



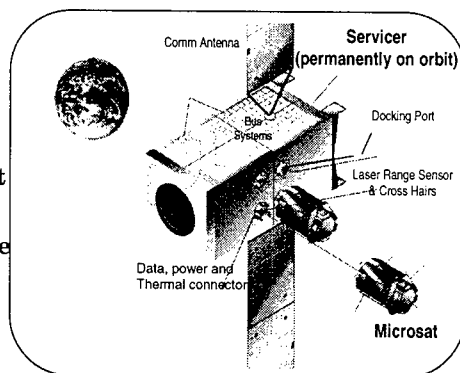
☆ A space logistics vehicle (e.g. the Orbital Express ASTRO vehicle) can provide bus functions to MicroSatellites

- ⇒ Maneuverability / orbit raising
- ⇒ Power
- ⇒ Communications
- ⇒ Attitude control

☆ Risk is mitigated by using proven on-orbit bus systems

☆ More MicroSatellite mass can therefore be devoted to payload

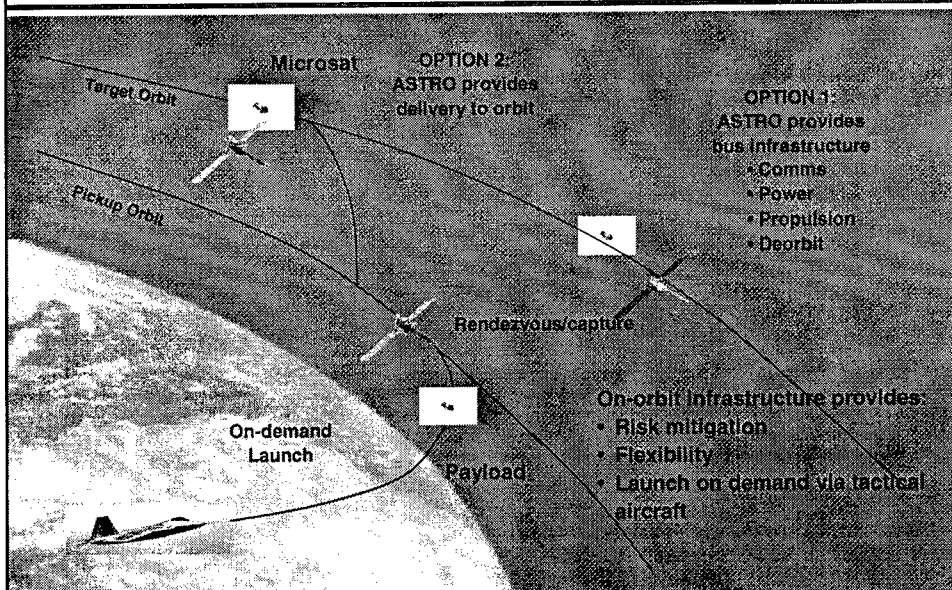
☆ Use of low-cost, on-demand launch opportunities (F-15 /F-22, secondary payload) for delivering MicroSats to orbit now becomes feasible



12



Orbital Express Enables Robust MicroSatellite Architecture



Why MicroSatellites?



- ☆ Lower weight ↔ lower launch costs
- ☆ Leverage excess capacity on large vehicles through secondary payload capability
- ☆ Expand number of organizations manufacturing spacecraft
- ☆ Cluster operations ↔ graceful degradation, distributed functionality
- ☆ Low observability



What Limits Useful Missions for MicroSatellites?



☆ Mass drivers in satellite design

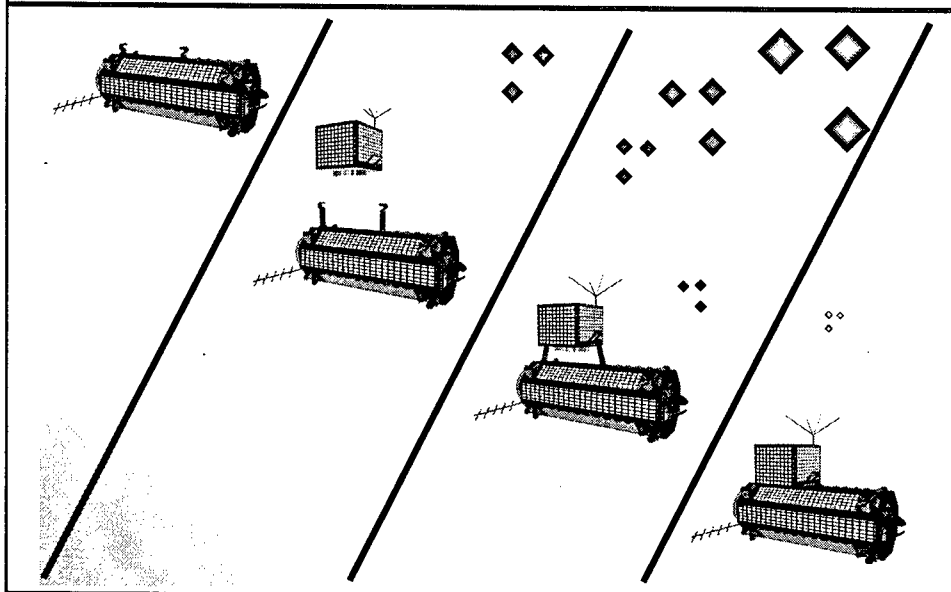
- ⇒ Structure: Must withstand launch acceleration and vibration loads
- ⇒ Solar panels: Must be deployable if mission requires high electrical power (e.g., comms)
- ⇒ Batteries: Required for operability / sustainment during eclipse (almost 50% of time for LEO spacecraft)
- ⇒ Optics: Massive primary elements required to obtain adequate resolution
- ⇒ Radar: Array, transmitter, power storage & handling are large for adequate resolution
- ⇒ Propulsion: Thrusters and fuel (maneuverability, orbit maintenance, deorbit)

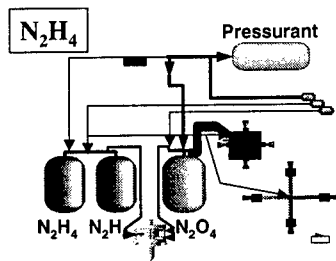
The weight required for bus functions can limit payload weight and capability.

15

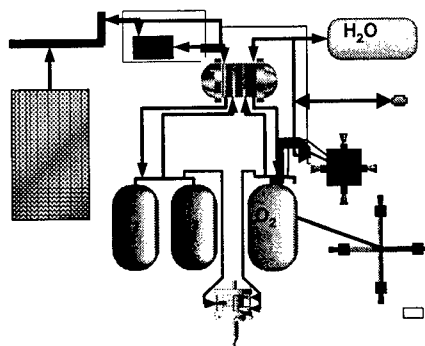


ASTRO MicroSat Docking





Water Rocket



★ Fuel attributes

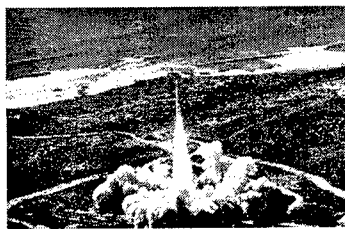
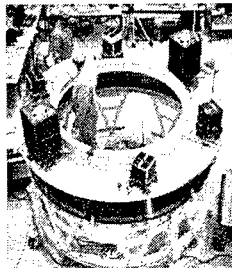
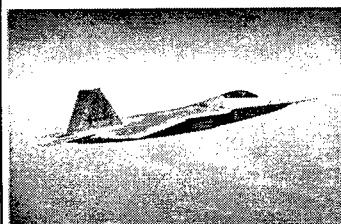
- ⇒ High Isp
- ⇒ Long-term on-orbit storage
- ⇒ Relatively non-hazardous at launch
- ⇒ Multi-mode
- ⇒ Multiple resupply options

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Launch Option

Average Cost

Dedicated	\$ 5,000 - 10,000 / lbW
Piggy Back/Adapter Rings	\$ 1,000 - 2,000 / lb
High Tempo - High Risk/Low Cost	\$?
Gun Launch from Earth	\$?
Aircraft Launch	\$?





Summary



☆A comprehensive on-orbit servicing architecture enables:

- ⇒ Ready availability of fuel, providing the tactical agility required for a wide range of current and emerging missions
- ⇒ Modular replacement function leading to multi-mission capability and life extension
- ⇒ Bus functions and orbit transfer service for MicroSatellite operations
- ⇒ Reduced mission risk through proven on-orbit infrastructure

☆All of these provide opportunities for new and enhanced military applications

☆Life cycle cost reductions will come when infrastructure is in place



Dynamic Database

*Efficiently convert massive quantities of sensor data
into actionable information for tactical commanders*



Mr. Otto Kessler
Program Manager

Tactical Technology Office
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703-696-2280

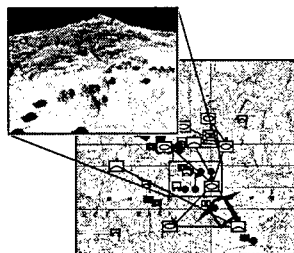
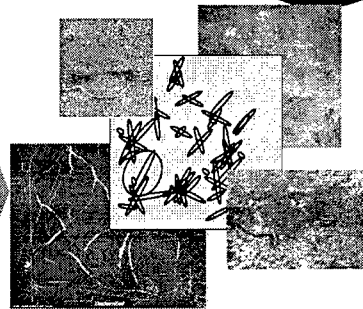


Motivation



■ What the Commanders get . . .

- Large numbers of partially overlapping sensors
- 100s of reports; 1000s of images per minute
- Unregistered, soda straw sensor observations
- Very high false alarm rates
- Signals - based



■ What the commanders want . . .

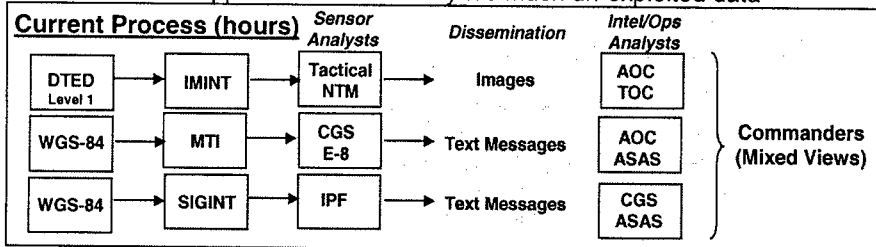
- Timely situation knowledge
- Comprehensive coverage (>1000 targets over ~1000 Km²)
- Accurate target locations with small Circular Error Probabilities
- Low burden, geo-referenced database



The Problem



- Sensor data increasing exponentially
 - FIA, Global Hawk, etc.
- Single source analysts decreasing at high rate
 - No multi-sensor analysts
- Targeting decision cycle delayed by manual processing
- Missed opportunities caused by too much un-exploited data



- Example - Image centric surveillance - Kosovo
 - Pixel by pixel “eyeball change detection”
 - Single sensor at a time (“stovepipe analysis”)
 - Manual exploitation - hours to days for product
 - No automatic multi-sensor geo-registration

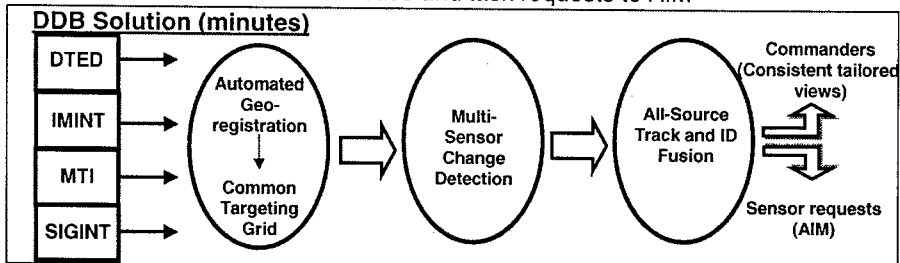
Consequence: Failure to find / identify targets



DDB Solution



- **Common geo-registered database**
 - Common grid tied to wide area terrain data (DTED, CIB, FFD)
 - Multi-sensor observations (SAR, EO, IR, GMTI and SIGINT)
- **Fusion across sensors**
 - Model based evidence accumulation
- **Track targets and features at object level**
 - Wide area coverage, large numbers of targets
- **Dynamic closed loop tasking overcomes missing/ambiguous data**
 - Self evaluation of database and task requests to AIM



Dynamic Multi-sensor ISR Database

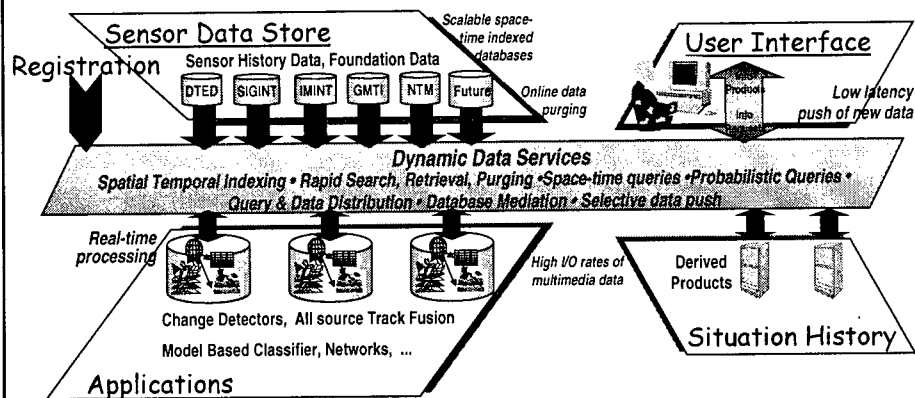


DDB Architecture

Enables Sensor Data Access and Technology Growth

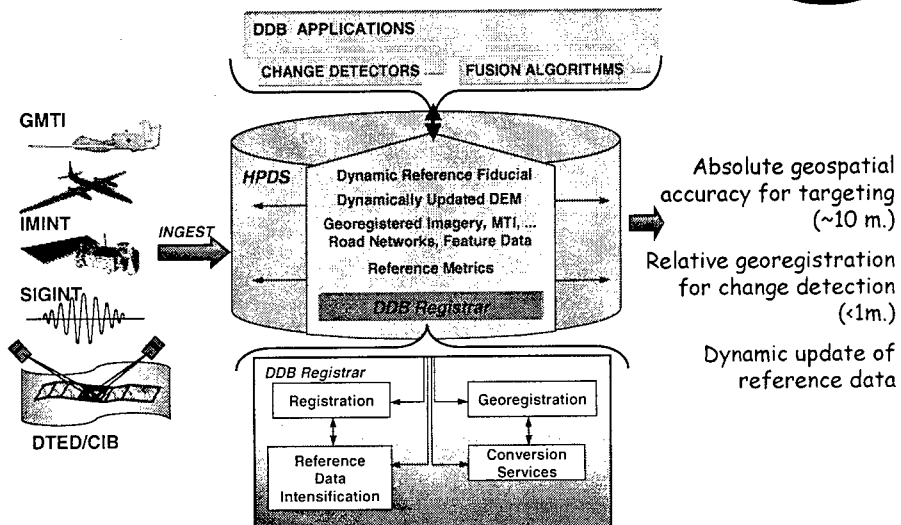
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- Database architecture overcomes limitations of data ownership
- Enhances:
 - Data sharing, interoperability
 - Technological growth - applications and visualization
- Leverages COTS thrusts in “open systems” & “object oriented databases”
 - Explore military needs which exceed likely commercial interests



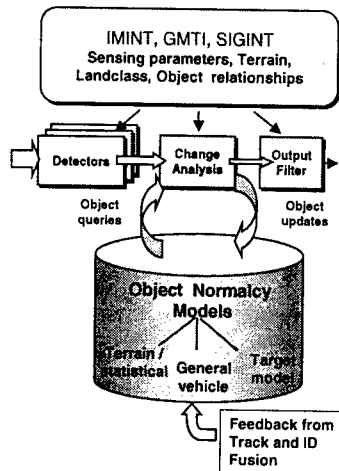
Registration of all Sensors to a Common Targeting Grid

DARPA





Normalcy Models Enable Wide Area Change Detection



Normalcy models provide context for detection thresholds

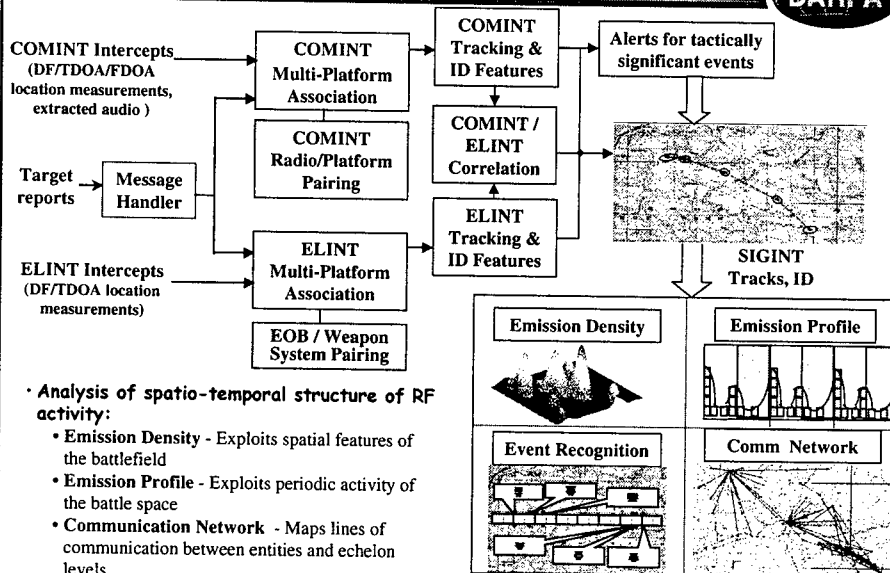
- Is this a region of high clutter?
- Was it there on the last sensing pass?
- Has it changed state or shape?
- Is it emitting as expected?
- Is it moving in a new way, place, or time?

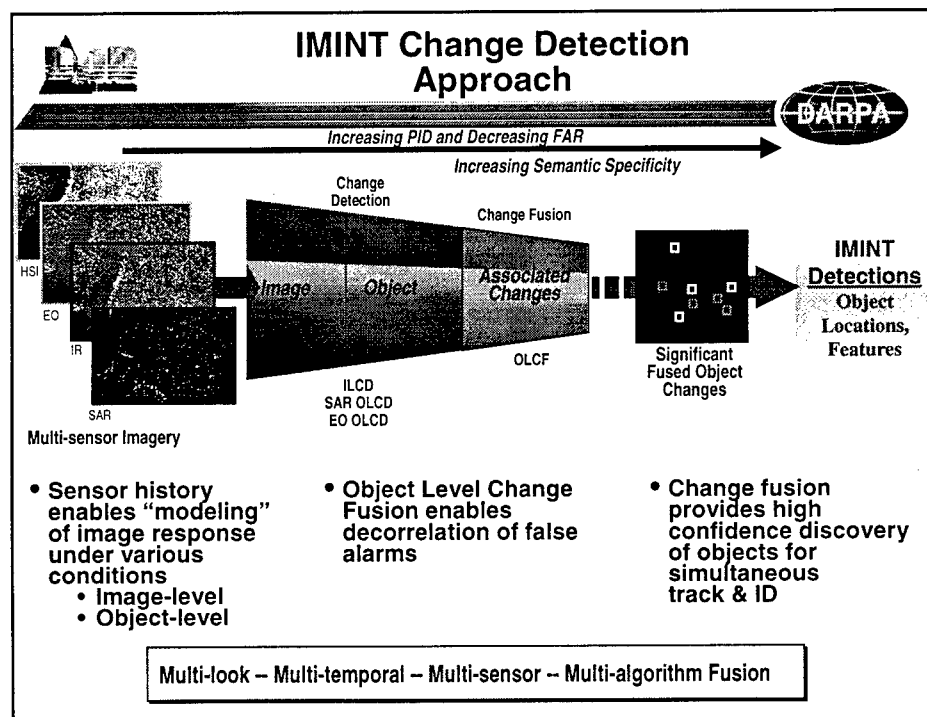
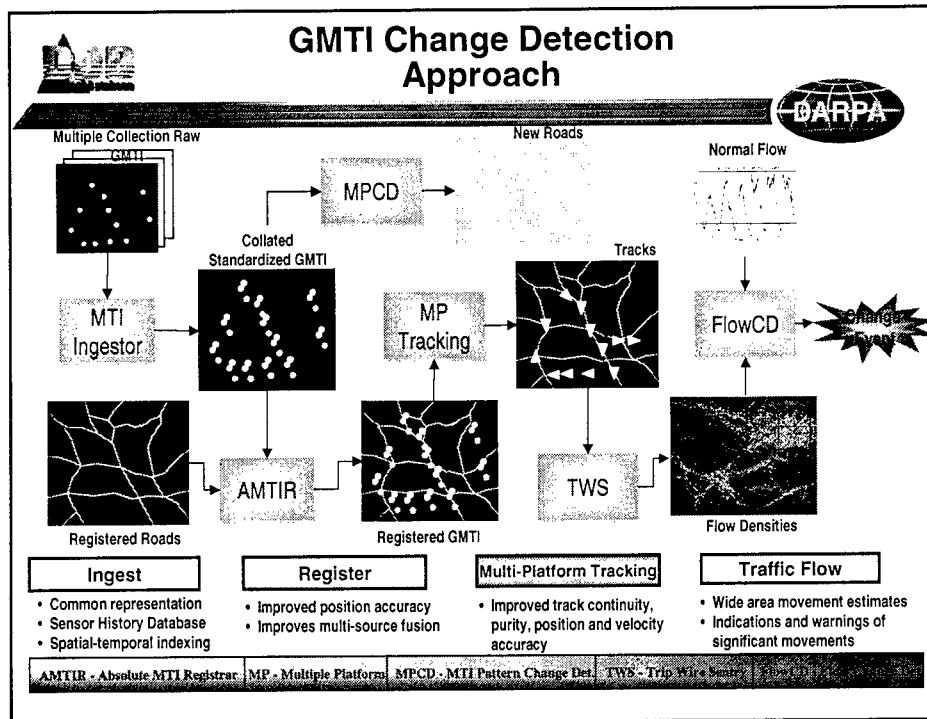
Combined multi-sensor data is required to derive normalcy

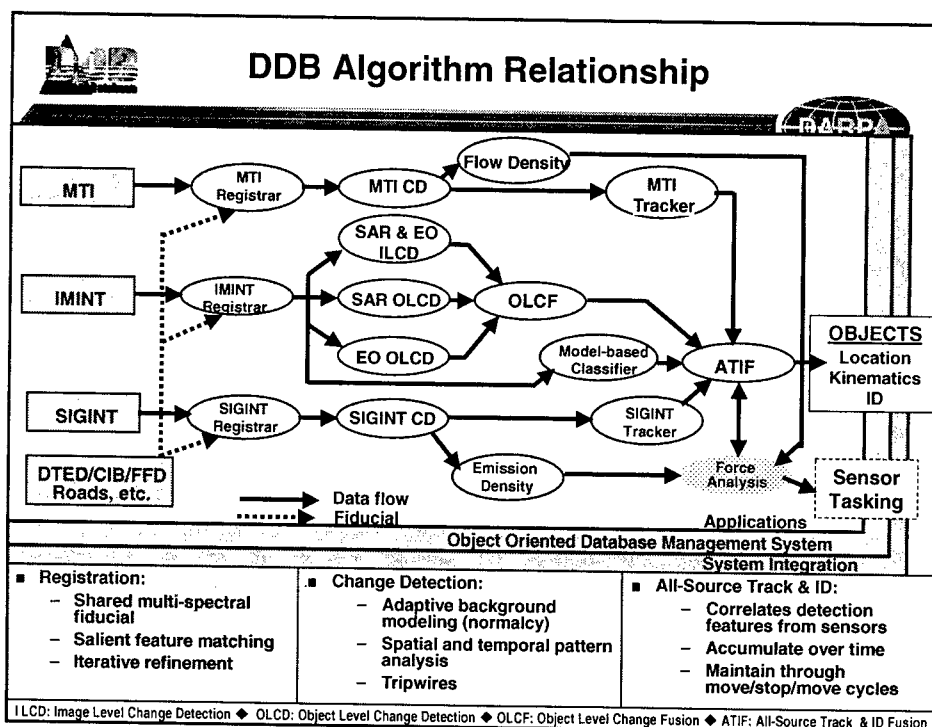
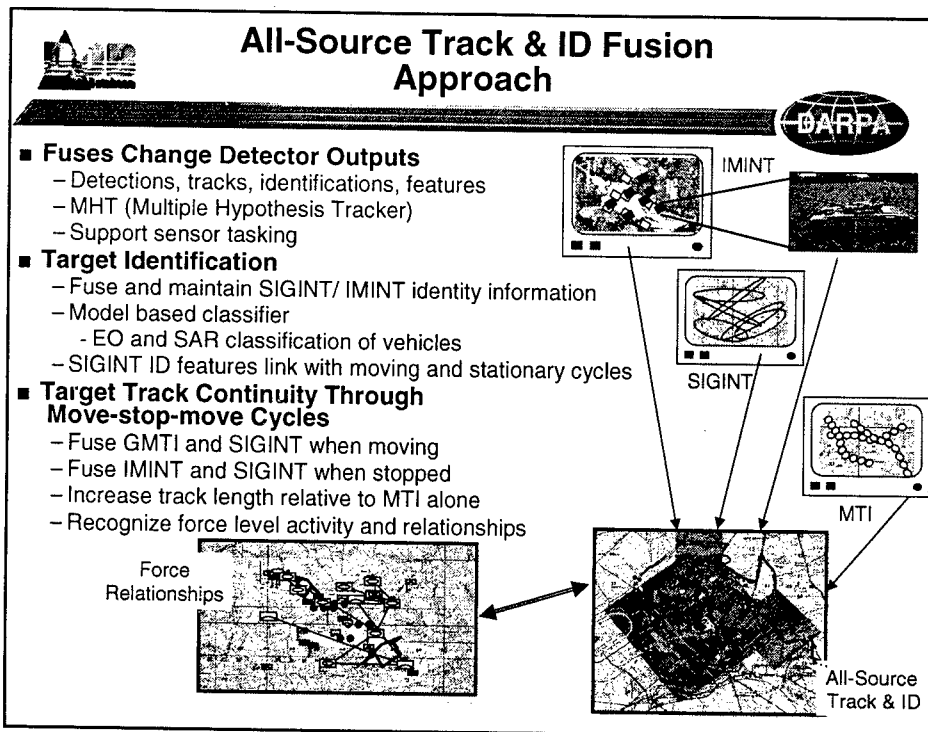
- Spatial, temporal, feature based representation of scene content, background, and behavior.



SIGINT Change Detection Approach

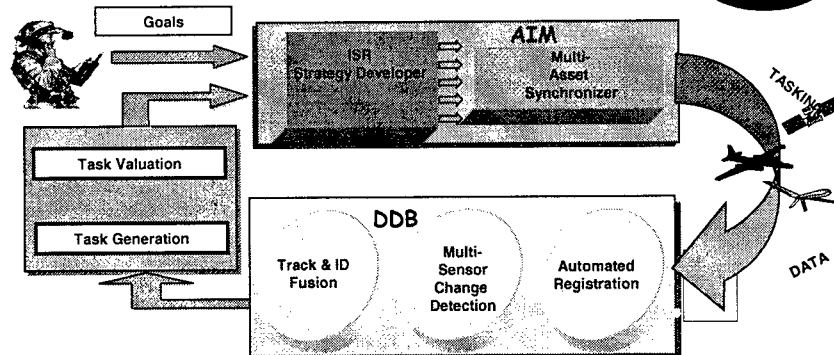








Data Driven Collection Management



■ Goal: Close the Loop Between Collection Management and Situation Estimation

- Now: Manual coupling
 - Forces tasking focus to be on static targets
 - Limits use of uncertainty info in task valuation
- Future: Automate process by developing
 - Task generation from ambiguities in fused product
 - Task valuation based on uncertainty estimate of the current situation

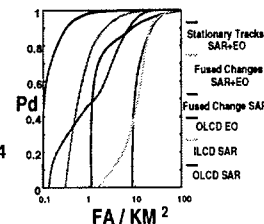


DDB Accomplishments



Demonstrated Benefit of Fusion Gain

- Wide Area Change Detection (WACD)
 - IMINT
 - Statistical normalcy models to recognize change and reject false alarms
 - EO/SAR fusion reduced FAR ~4x in experiments
 - MTI
 - Increased track continuity by 27%
 - Reduced error in position by 37%
 - SIGINT
 - New emitter mapping and profiling capability
 - 50% reduction in emitter location error through multi-platform fusion
- All-source track and ID Fusion (ATIF)
 - Developed new capability to maintain track through move - stop - move cycles
 - Association of mover/sitter tracks extends track continuity ~x4
- Dynamic Data Services
 - Common targeting grid
 - Registered sensor histories over space and time



Foundation technologies to produce a timely, accurate estimate of the ground situation (kinematics, locations and IDs of objects)



Information Technology Office Overview

Dr. Shankar Sastry, Director
Information Technology Office
Defense Advanced Research Projects Agency



DARPA Has Done Great Things for IT

Mission of ITO: Superiority of Armed Forces Through Revolutionary Advances in:

- High Performance Computing and Communications Devices
- Networking and Information Assurance
- Embedded Software
- Seamless User Interfaces for the War Fighter
- Ubiquitous Computing and Communication Resources

The investment by DARPA in Information Technology development has been the primary factor in the creation of an information based economy whose current annual volume is about \$500 B *per year* in the US alone. This number is to be compared with other sectors of the economy such as communications \$1 trillion, transportation \$750 B, and health care \$2.5 trillion.

That's great: what remains to be done? Where do we go from here?



Drivers of IT Research



**Computing, Networking, Security have come a long way,
but they have a long way to go.**

Key drivers:

- wireless and power aware computing devices,
- ubiquitous computing devices,
- embedded computers, (interacting in real time with sensors and actuators),
- wideband optical networks,
- MEMS,
- quantum devices,
- system on a chip: billion transistor chip, photonic interconnects, programmable hardware,
- cognitive neurophysiology,
- bio-informatics.



What Are the Hard Problems??



Wireless:

1. Power/ Energy Aware Computing and Communication (PAC/C): design suites for trading off power/energy consumption. Design environments for integrated design across algorithms, instruction sets, and device clock/frequency characteristics.
2. Distributed Computation with sensors which have to trade off on board computation with communication. Thresholding phenomena in performance improvement of networked sensing systems. (SensIT)
3. Secure Ad-hoc networking protocols for insecure and jammable networks. Game theoretical approaches to information assurance in a hostile environment, physical layer and network layer.



What Are the Hard Problems??



Ubiquitous Computing Devices:

1. Hands off interaction with portable or omnipresent computers. Need for voice / speech / foreign language recognition. (Communicator, TIDES)
2. Operating Systems for small sensors, embedded devices for specialized operation. (Ubiquitous Computing)
3. Ad-hoc networking, content addressable data, queries for intermittently available data stores. (Ubiquitous Computing)
4. Dynamic caching of data, data provisioning systems, aggregation of temporally evolving data. (IM, Ubiquitous Computing)
5. Collaborative and Hierarchical Decision Making Environments. (Ubiquitous Computing)



Hard Problems Continued



Optical Networking

- WDM is nearing maturity, however optical networking protocols for WDM over IP are not ready yet: routing, congestion control, network management. (NGI)
- Security of high speed networks.
- Modeling, estimation and control of traffic at various levels of granularity on WDM networks, ATM networks, WAN and Ad-hoc Wireless Networks is in its infancy. QoS for different streams of traffic. (NMS)

MEMS

- Smart matter: the integration of MEMS actuators and sensors with computation and networks. (seedling, amorphous computation)
- SmartDust: usage of MEMS sensors with wireless, GPS, biochemical sensors and ad-hoc networking to enable distributed detection and tracking of bio-hazards (SensIT)
- Computational infrastructure for distributed, Networked Embedded Systems.



Hard Problems Continued



Computational Models "Beyond Si"

- New paradigms for secure communication and computation.
- Quantum, DNA, smart matter models of computation: Amorphous Computing. Challenge problems: quantum and string theoretic simulations of molecules.
- Integrate adaptively computational elements ASICs, FPGAs, programmable elements using optical interconnects to incorporate security into computational fabric.
- Programmable hardware with verified components for morphing computational elements and power aware applications. (Just-in-Time, DIS)



Hard Problems Continued



Cognitive Neurophysiology:

- Interfacing computer memory to human memory, models of memory and forgetfulness to augment situation awareness. (ISAT Study Area)
- Learning of information search patterns and language acquisition. (TIDES)
- Synthesis of speech, gaze, gesture, and lip reading for noisy, multi-speaker environments.

Computational Biology:

- Hidden Markov models for biological models of gene expression and phenotype expression. Putting biological content into phenomenological models, bio-informatics.
- Architectures for computation, hardware and software with the fault-tolerant and self-organizational character of biological systems.
- Modeling and Control of genetic circuits for applications like suppression of piliation or forced sporulation, multi-grained models of the organism, cell, DNA, gene computational elements.



Hard Problems Continued



Embedded Computers and Software:

- Distributed software each performing time critical tasks needed to coordinate with guarantees of overall QoS. (Quorum)
- Verified software for adaptable, time critical operations with multiple distributed processes for physical systems whose mode changes depending on mission priorities. (SEC)
- Model based design of embedded software for hardware-software codesign. The goal is to have embedded software keep up with Moore's law advances in processor speed. (MoBIES)
- Networked Embedded Systems compositionality and distribution of the subsystems is unknown resulting in large cost overruns and worse inadequate performance in real-time embedded software for distributed sensing and control.



Current ITO Programs



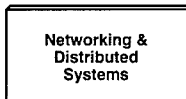
Intelligent Software

- Communicator
- Information Management
- Translingual (TIDES)



Autonomous and Embedded Systems

- Autonomous Negotiation Targets (ANTS)
- Mobile Autonomous Robot Software (MARS)
- Software Enabled Control (SEC)
- Model-Based Integration of Embedded Software (MoBIES)
- Software for Distributed Robotics (SDR)
- Program Composition for Embedded Systems (PCES)



Networking & Distributed Systems

- Active Networks
- Next Generation Internet (NGI)
- Quorum
- Sensor Information Technology (SensIT)
- Network Modeling and Simulation (NMS)



High Performance Computing Components

- Data Intensive Systems
- PAC/C



Information Survivability

- Tolerant Networks
- Dynamic Coalitions

Ubiquitous Computing
Seedlings

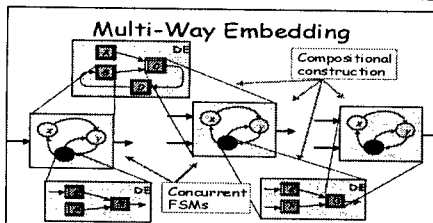
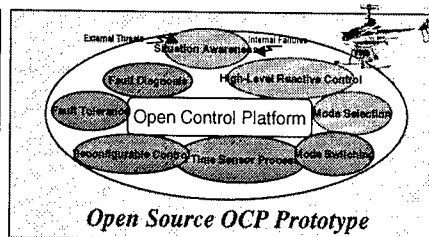
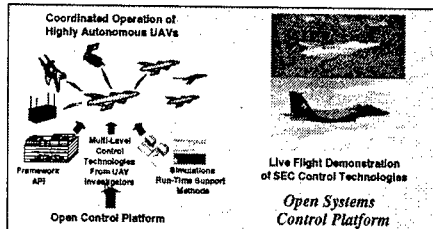


Representative Program Software Enabled Control (SEC)



Technology Goals:

- Control systems that we haven't been able to control before
- Increase automation for extreme maneuvers, tightly coordinated actions
- Middleware for embedded control systems

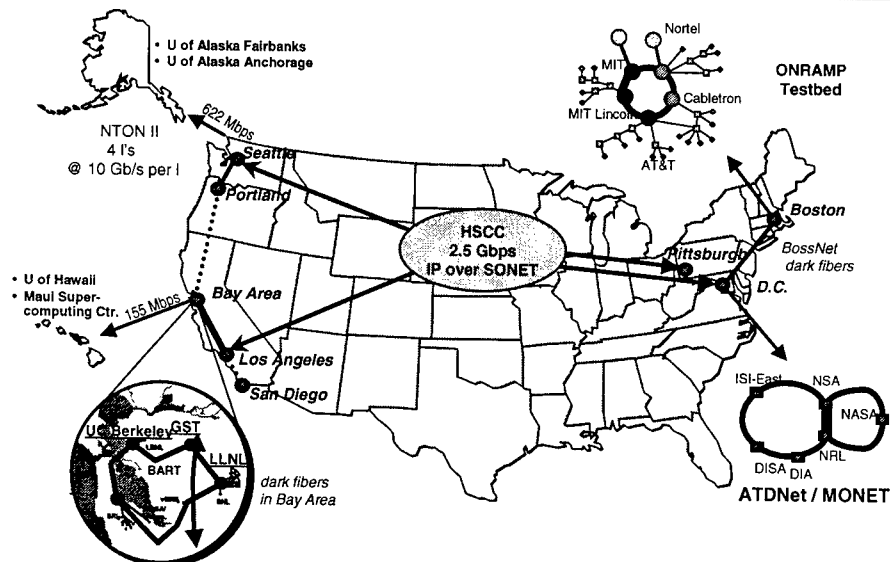


Coordinated Multi-Modal Control:

- Control middleware (reusable)
- Open systems, open source
- Reconfigurable hybrid (discrete and continuous) control loops
- Real-time data services for active (predictive) state models



SuperNet Testbed (www.ngi-supernet.org)





DARPA's NGI Program Components

■ SuperNet Technology

To enable ultra-high bandwidth on demand over national networks guaranteed over the shared infrastructure

- Simplified protocol layering - IP over dynamic optical network
- End-to-end performance
- Testbed

■ Network Monitoring & Management

Create tools that greatly automate planning and management functions enabling networks to grow while limiting the cost and complexity of network management and control

- Adaptive network management and control software
- Large-scale network monitoring/analysis/visualization tools

■ Applications

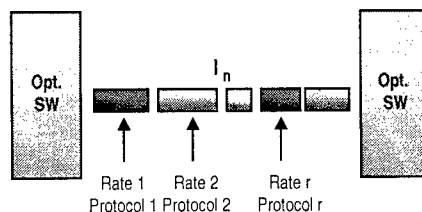
Develop, test, deploy applications requiring gigabit end-to-end throughput



NGI Experiment: Dynamic Optical Switching



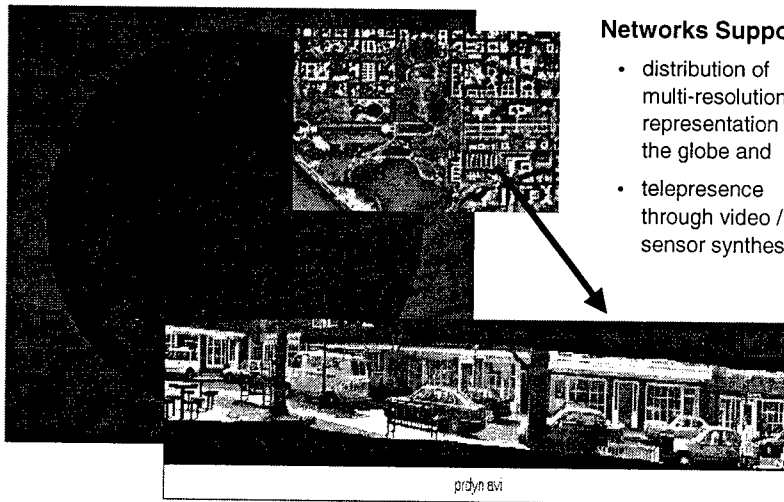
	<u>holding time</u>	<u>switching speed</u>
Reconfigurable Opt. Networking	days, months	50 msec - secs
Optical Flow Switching	>100 msec	~msec
Optical Burst Switching	>10 msec ~ 1 msec	~msec
Optical Packet Switching	> msec	~ nsec
All-Optical Switching	> nsec	~ psec



Goal: Bit rate and protocol agile



Surveillance Applications



Networks Supporting

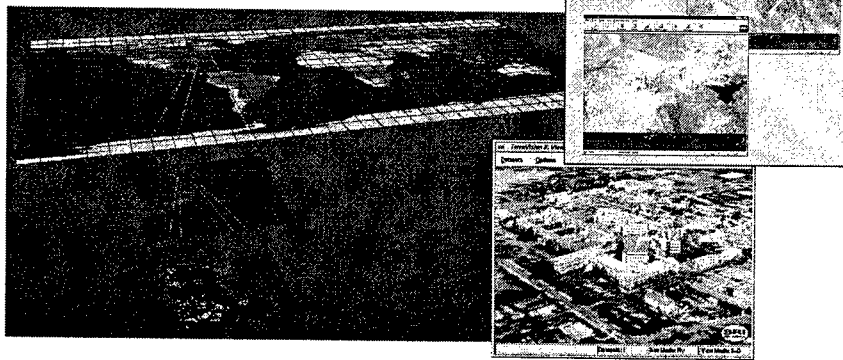
- distribution of multi-resolution representation of the globe and
- telepresence through video / sensor synthesis



Infrastructure: .geo domain



- Use DNS to encode latitude / longitude for any element in a hierarchical scheme.
- minutes.degrees.tendegrees.geo
- e.g., 37e47n.1e5n.10e20n.geo

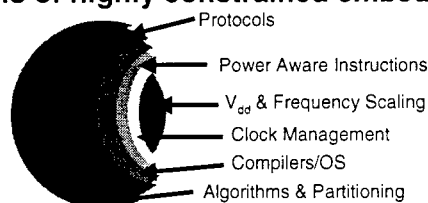




Signal Processing & Power Aware Computing/Communication

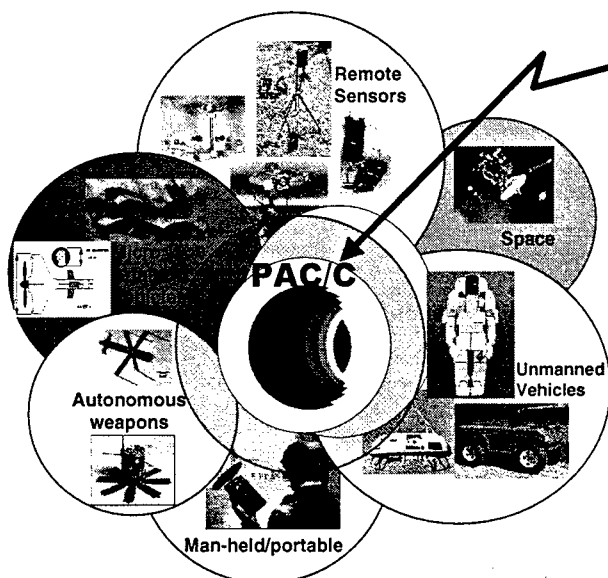


- Provide an integrated software / hardware technology suite with the potential to reduce power requirements by 100X - 1000X in (energy * delay) or performance / watt when compared to technology using conventional approaches
- Maximize energy conservation at each level while providing intelligent power aware management and optimization of energy and energy distribution at all levels of highly constrained embedded systems



Representative Program

PAC/C - Enabling Technology



- Power Aware technologies are critical across a broad range of applications.
- Broad cross section of low level technologies required
- Provide a technology suite for use by each end user

**Optimize
performance,
energy, power
demands against
instantaneous
mission
requirements**



Representative Program

Fault Tolerant Networks



Goal: Ensure continued availability of the network in the face of an attack while containing the resources available to the attacker

- **Fault-Tolerant Survivability**
 - ◆ Apply fault tolerance techniques to networking protocols
 - ◆ Better understanding of network fault modeling
 - ◆ Explore network overlays as survivability mechanism
- **Denying Denial-of-Service**
 - ◆ Allocation methods to constrain attacker's resource use
 - ◆ Progress-based protocols link allocation to level of trust
- **Active Network Response**
 - ◆ Exploit active networks for traceback
 - ◆ Attacker fencing



Bio-Futures Computation in Bio-Substrate

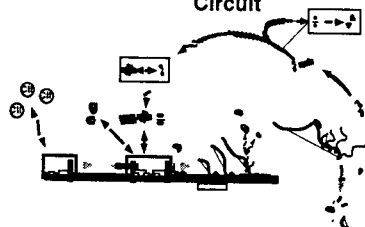


- **Hybrid Circuit Models for Biological Information Processing (Bio-Spice)**
 - ◆ Hybrid stochastic - deterministic systems
 - ◆ Gene regulation control models to predict intervention in pathogens,
 - ◆ Design optimal micro-organisms for bioreactors, biomass energy harvesting
- **DNA Computation & Devices**
 - ◆ Controlled DNA computing on substrates
 - SAT problems; bio-chips for multi-agent detection
 - Algorithmic self-assembly: sheets, cages (crystallography, molecular electronics)
 - ◆ Gates and integrated logic from DNA gene control circuits
 - ◆ Memory, databases.
- **Cellular Control systems**
 - ◆ Integrated cellular control combining
 - Sensing (aptamers)
 - Actuation (DNA lattice registers, biomotors, production of target biomolecules)
 - Local distributed control
 - ◆ Demonstrate control of physiology of normal and pathological cells
 - Sense state of cell
 - Engage gene control networks
 - Produce regulating gene products to switch cell state

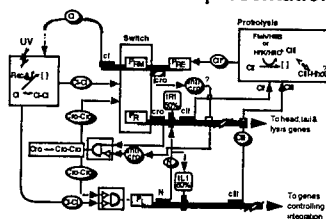


Modeling and Simulation Approach

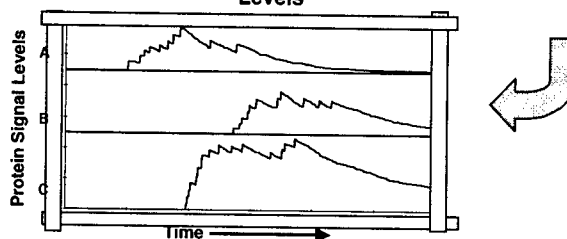
Molecular Components of Genetic Feedback Circuit



Genetic Circuit Representation



Stochastic Mechanisms Produce Fluctuating Signal Levels



Gene Regulation Networks

Science & Technology

- ◆ Develop tools for characterizing the fundamental architecture and design features underlying the dynamic behavior of genetic regulatory networks

Technology Needs

- ◆ Computer aided design tools for rational design and manipulation of metabolic systems and products
- ◆ Broad DOD payoffs
 - Rational Rx for CB and toxic agents
 - New concepts & distributed sensing and control



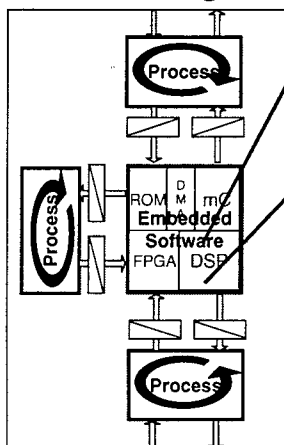
Embedded Software: Opportunities and Challenges

Dr. Janos Sztipanovits, DARPA/ITO



The Technology Challenge

Embedded systems: Information systems tightly integrated with physical processes



Problem indicators:

- Integration cost is too high (40-50%)
- Cost of change is high
- Design productivity crisis

Root cause of problems is the emerging new role of embedded information systems:

- Exploding integration role
- New functionalities that cannot be implemented otherwise
- Expected source of flexibility in systems

Problem: Lack of design technology aligned with the new role



Problem for Whom?

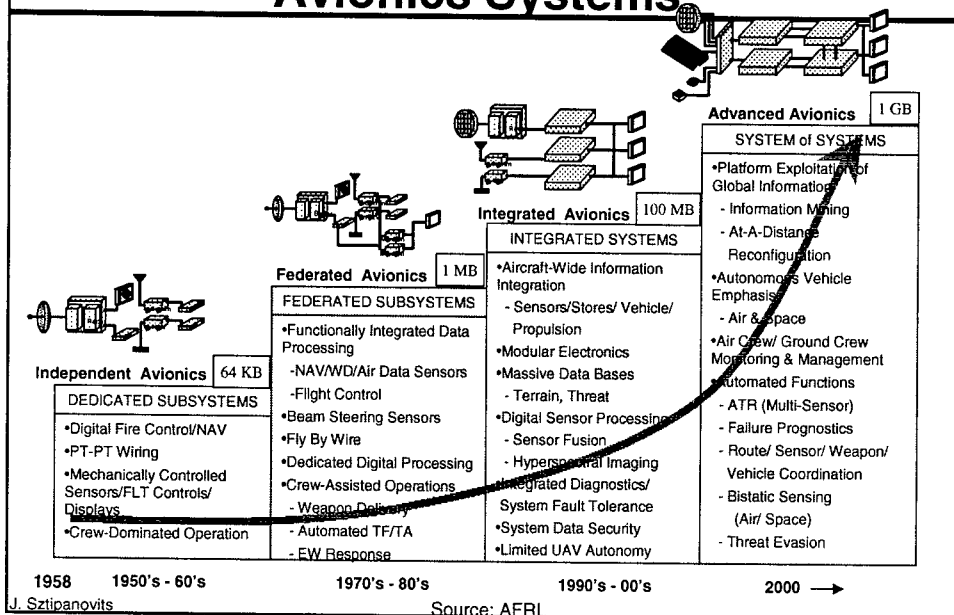


- ◆ **DoD (from avionics to micro-robots)**
 - Essential source of superiority
 - Largest, most complex systems
- ◆ **Automotive (drive-by-wire)**
 - Key competitive element in the future
 - Increasing interest but low risk taking
- ◆ **Consumer Electronics (from mobile phones to TVs)**
 - Problem is generally simpler
 - US industry is strongly challenged
- ◆ **Plant Automation Systems**
 - Limited market, conservative approach

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DoD Example: Avionics Systems





Technology Themes



◆ Software and Physics

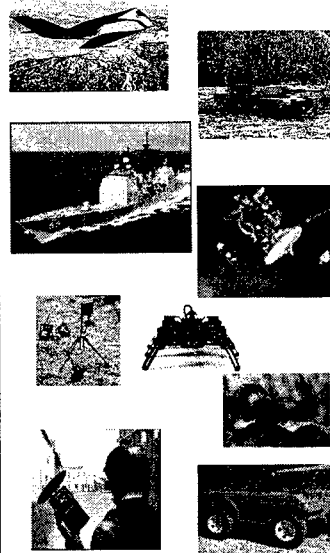
- Establish composability in SW for physical characteristics; System/software co-design and co-simulation environments; New methods for system/code composition

◆ Embracing Change

- Adaptive Component Technology; Adaptable composition frameworks; QoS middleware for embedded systems

◆ Dealing with Dynamic Structures

- Property prediction without assuming static structures; Monitoring, controlling and diagnosing variable structure systems.



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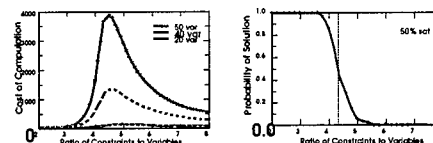


Why Can We Make a Difference?

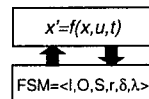


New, critical insights in fundamentals:

Phase transitions have been found in computational requirements for solving fundamental “intractable” problems.

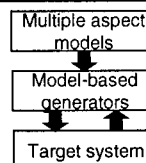


Emerging theory of hybrid systems provides a new mathematical foundation for the design and verification of embedded systems



- Model checking
- Compositional synthesis
- Simulation

Revolutionary changes in software creation: Model-based generators, aspect languages, DSL-s offer new foundation for design automation and adaptation.



- Formal modeling
- Verification tools
- Automated code synthesis

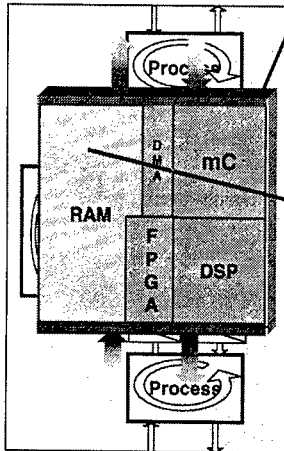
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Theme 1: Software and Physics



Embedded software: Defines physical behavior of a complex nonlinear device



Embedded System: A physical process with dynamic, fault, noise, reliability, power, size characteristics

Embedded Software: Designed to meet required physical characteristics

Hard Design Problem:

- Both continuous and discrete attributes (a lot)
- Every module has impact on many attributes (throughput, latency, jitter, power dissipation,...)
- Modules contend for shared resources
- Very large-scale, continuous-discrete, multi-attribute, densely-connected optimization problem

Primary challenge: Cost-cutting physical constraints destroy composability

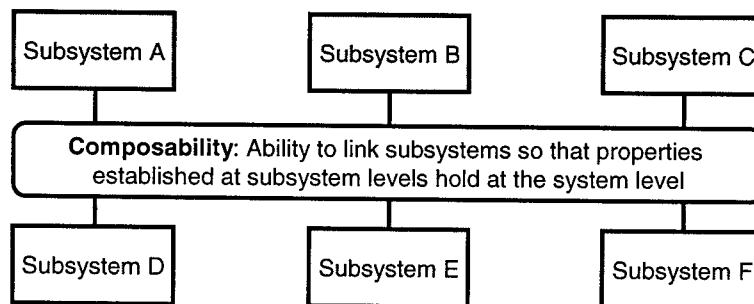
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Why Is this a Problem?



We have focused on functional composition...



But cross-cutting physical constraints weaken or destroy composability

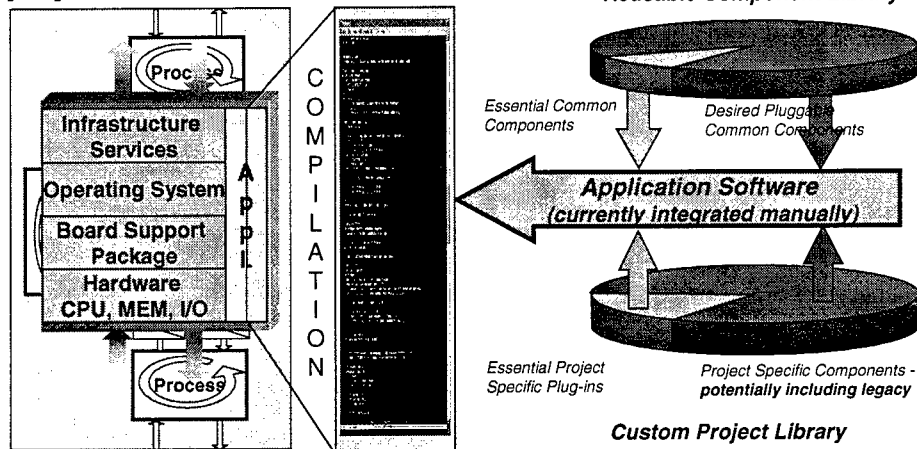
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Current Technology: Functional Composition



Functional composition does not address physical constraints



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Goal: Design Automation Tools for Embedded Systems



- ◆ **Compose model-based design frameworks:**
 - Use existing CAD, EDA, CASE and systems Engineering frameworks as seeds
 - Add customizable design views and notations
 - Provide multi-resolution simulation
 - Add automated analysis and system/software synthesis
- ◆ **Capabilities:**
 - Co-evolve **integrated** physical and information system **MODELS**
 - **Synthesize/customize** software and system components **directly from models**
 - Establish **composability** for physical behavior

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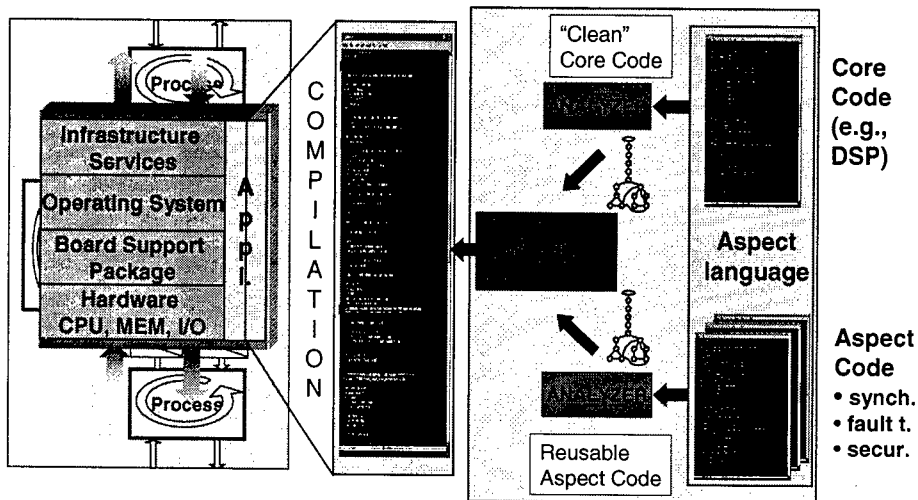
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ITO: Program Composition for Embedded Systems (PCES)



Aspect languages will change programming:



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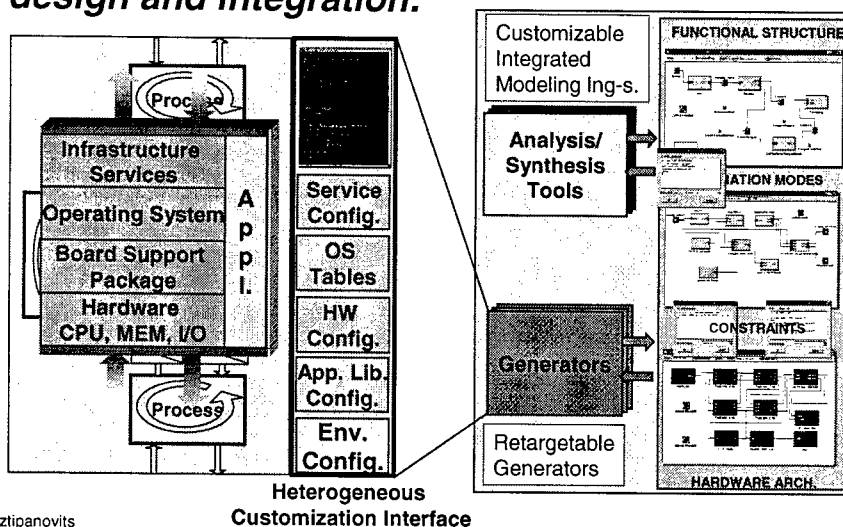
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ITO: Model-Based Integration of Embedded Software (MoBIES)



Model-based integration will change system design and integration:



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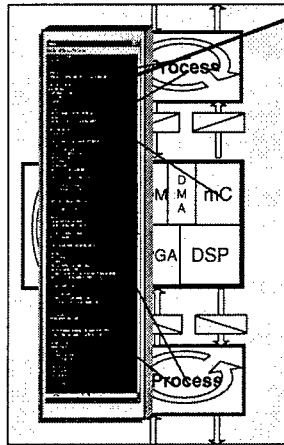
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Theme 2: Embracing Change



Source of change: environment, requirements



Hard Problem: Due to its integration role, system-wide constraints accumulate in software:

- Process properties - algorithms, speed, data types
- Algorithms, speed, data types - resource needs
- Shared resources - speed, jitter,..
- ..scattered all over the software.

Condition for managing change:

- Constraints need to be explicitly represented
- Effects of changes need to be propagated by tracking constraints

**Flexibility is essentially a
SYSTEM-WIDE CONSTRAINT
MANAGEMENT PROBLEM**

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Goal: Adaptive Component Technology for Embedded SW



◆ **Builds on object component technology (CORBA, COM) but provides:**

- Internal mechanisms to respond to changes
- Physically and computationally “self-aware” components

◆ **Capabilities:**

- Insulates software from hardware with small performance penalty
- Increases tolerance to unexpected changes
- Optimizes performance
- Increases tolerance to faults

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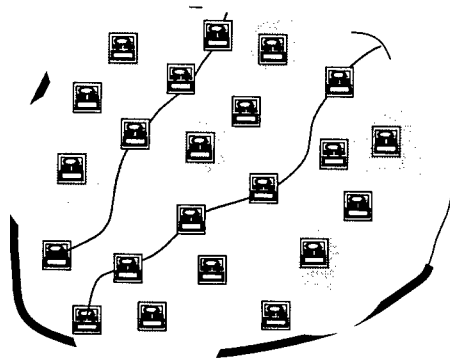


Theme 3: Dealing With Dynamic Structures



A new category of systems:

**Embedding +
Distribution +
Coordination**



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LARGE number of tightly integrated, spaciouly and temporarily distributed physical/information system components with reconfigurable interconnection.

Why should we work on this?

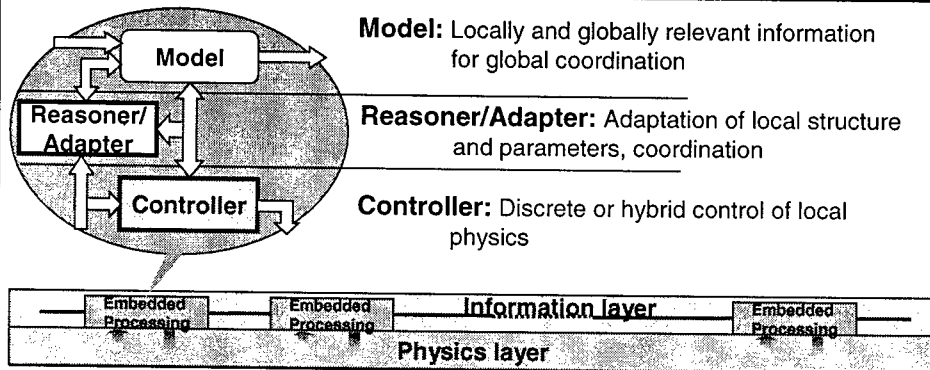
The wave is coming:

- Tremendous progress in MEMS, photonics, communication technology. **We need to build systems now from these.**
- Identified applications with **very high ROI: strong application pull**
- **Almost total lack of design theory technology: The problem is extremely hard.**

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Problem Abstraction



Distribution:

- Heterogeneous, simple components (10^2 - 10^5)
- Changing interconnection topology
- **Embedded synthesis** for dynamic distribution, reconfiguration

Coordination:

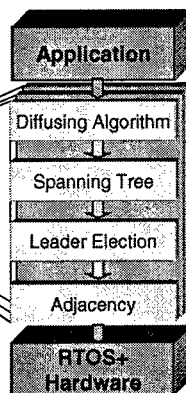
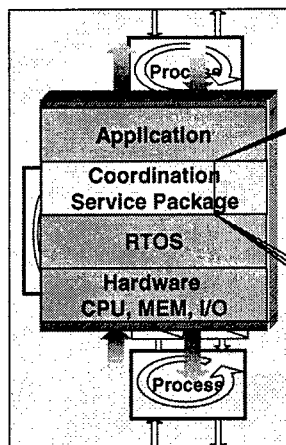
- Global **coordination** of local interactions
- Consistency of globally relevant information
- Requirements are determined by locality of physics

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Goal: Services for Coordination



- Applications determine the type of services required
- Physical characteristics of the system determine dynamics, accuracy and required fault behavior of services
- Services are built in layers with rich interdependence
- Algorithms used in components depend on the distributed computation model

Hard Problems: Hybrid self-stabilization, customizable design, predictable dynamics, time bounded synthesis, automated composition.

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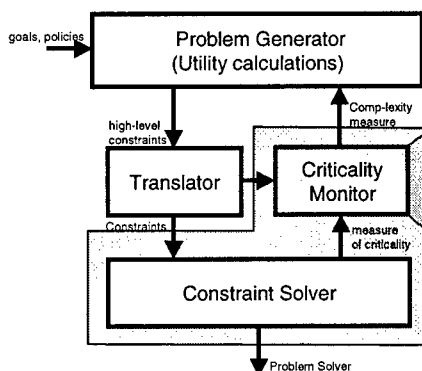


Practical Use of Phase Transitions:

Approach to Synthesis Services

Approach: Transition-aware, sub critical problem solver

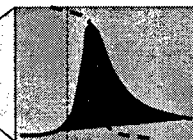
Challenge: Problem statistics, order parameter.



1. Dynamically adjust the problem to keep it "left of the phase transition".

2. Criticality monitor gives assessment of problem complexity using simple analysis methods.

3. Constraint solver rapidly solves sub-critical problem instances.



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What Are We Doing?



Software and Physics

- System/Software co-[design, simulation, analysis]-----
- New methods for system/code composition-----
- Frameworks and middleware for embedded SW-----
- Hybrid optimization, analysis-----

Embracing Change

- Adaptive components for embedded systems-----
- Methods for controlling flexibility-----
- Adaptable frameworks and QoS middleware-----
- Programming methods to achieve flexibility-----

Networked Embedded Systems

- Predicting global properties from local component descriptions without assuming static structures-----
- Monitoring, controlling and diagnosing of variable structure hybrid systems-----
- Dynamic composition frameworks and middleware for networked embedded systems-----
- Controlling physical, chemical and biological properties via embedded information processing---

Relevant existing programs: (MoBIES, PCES, SEC)

- Coordinate efforts
- Leverage to increase common technology base
- Primary impact on Themes 1-2

New-start program:

- **Networked Embedded Systems Technology (NEST)**
- Planned program:**
 - Adaptive and Reflective Middleware Systems



Conclusion



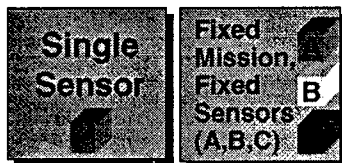
- ◆ **Embedded Software is an important area for DARPA due to the exploding integration role of information technology across military platforms.**
- ◆ **Existing and planned programs establish a new re-integration of physical and information sciences. This will make a huge difference in our ability to:**
 - Design software for achieving physical behavior,
 - Make software able to absorb change in physical systems,
 - Build, integrate physical systems dynamically from sparsely and temporarily distributed components.
- ◆ **To do this means changing culture. DARPA's focused investment is critical to catalyze and accelerate this process.**

Future Embedded Computing Architectures

Robert B. Graybill
Program Manager
DARPA/IITO

Embedded Computing System Requirements Revolution

Have



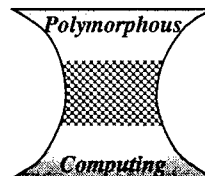
**BOUNDED MISSION
CAPABILITY**



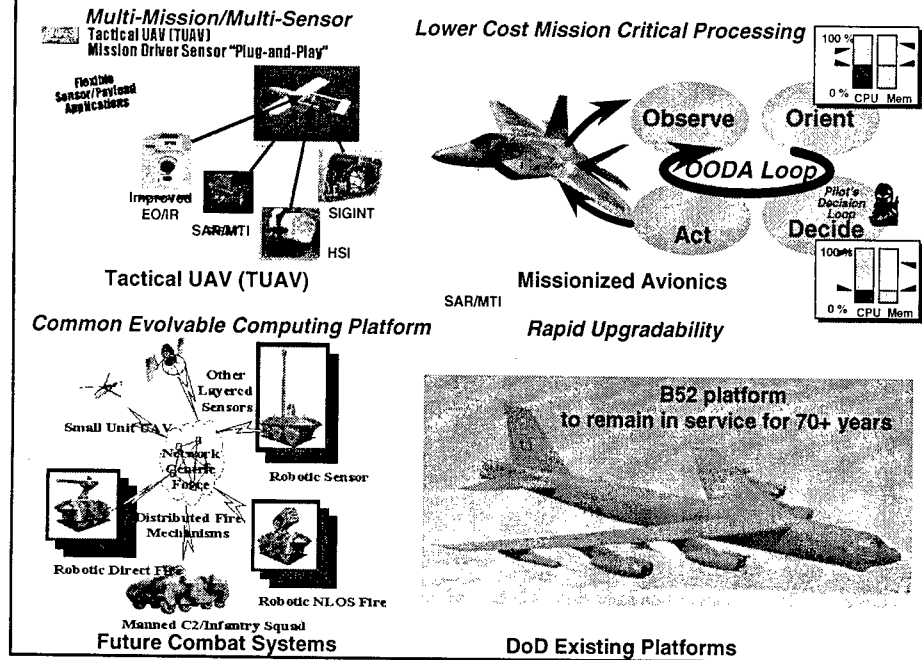
Could Have



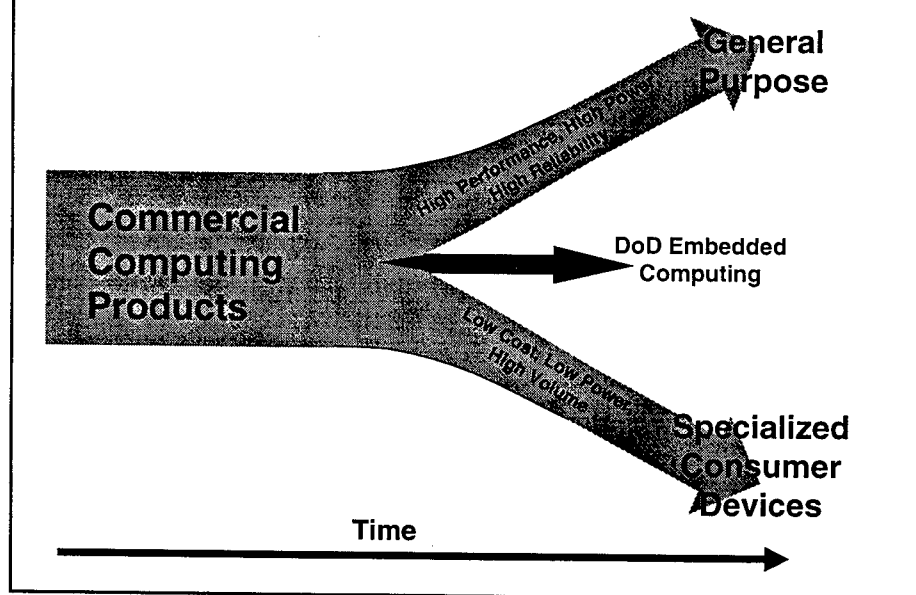
**DYNAMIC MISSION
CAPABILITY**



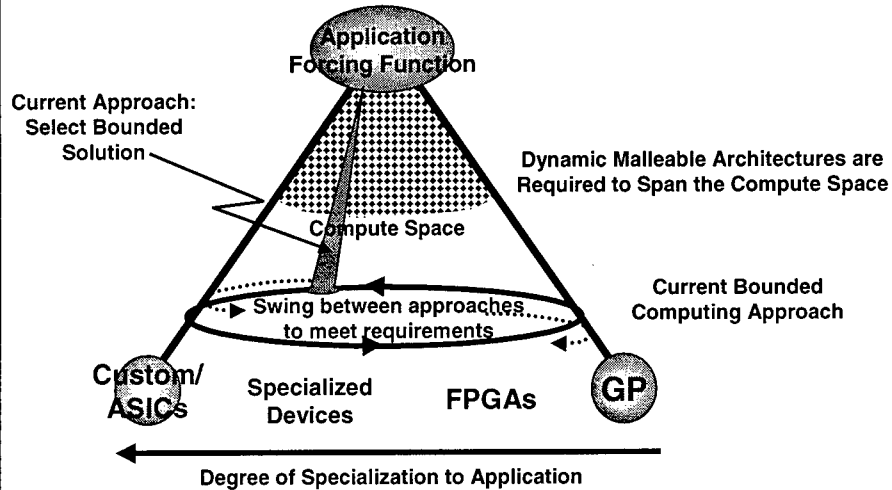
Challenge Applications



Commercial Support of DoD Computing Requirements

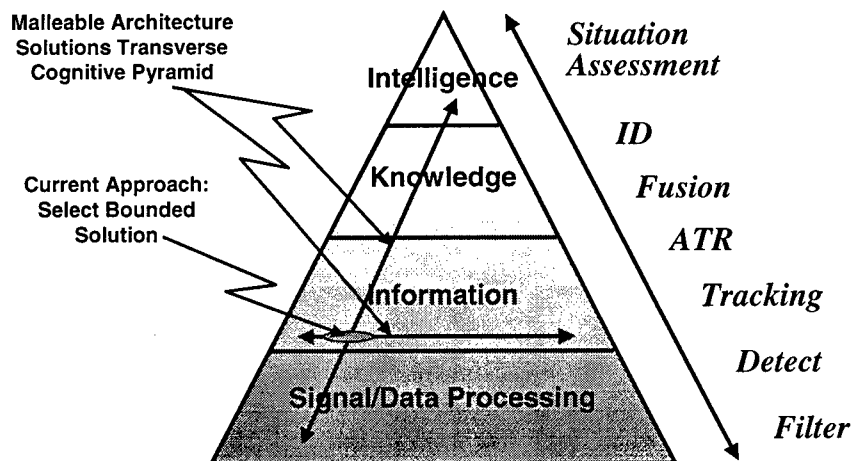


Current Architecture Solutions

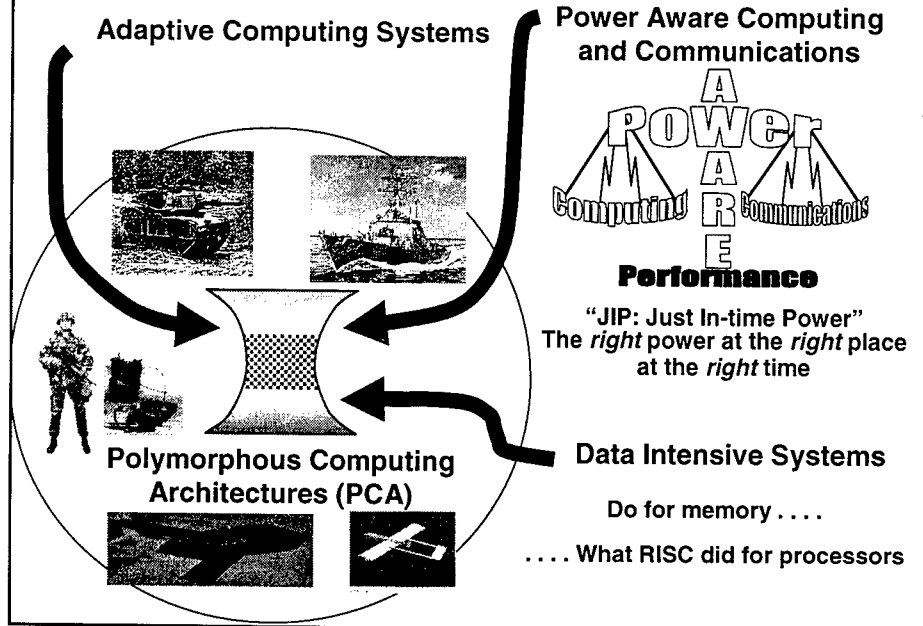


New Class of Missions Require a Transversal of the Architectural Space

New Class of Missions Require Application Space Diversity

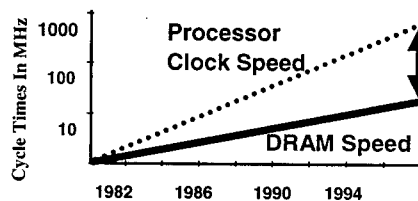
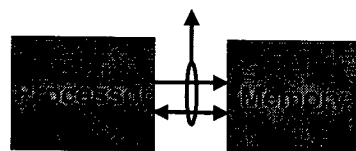


Mission Aware Embedded Computing Activities



Data Intensive Systems

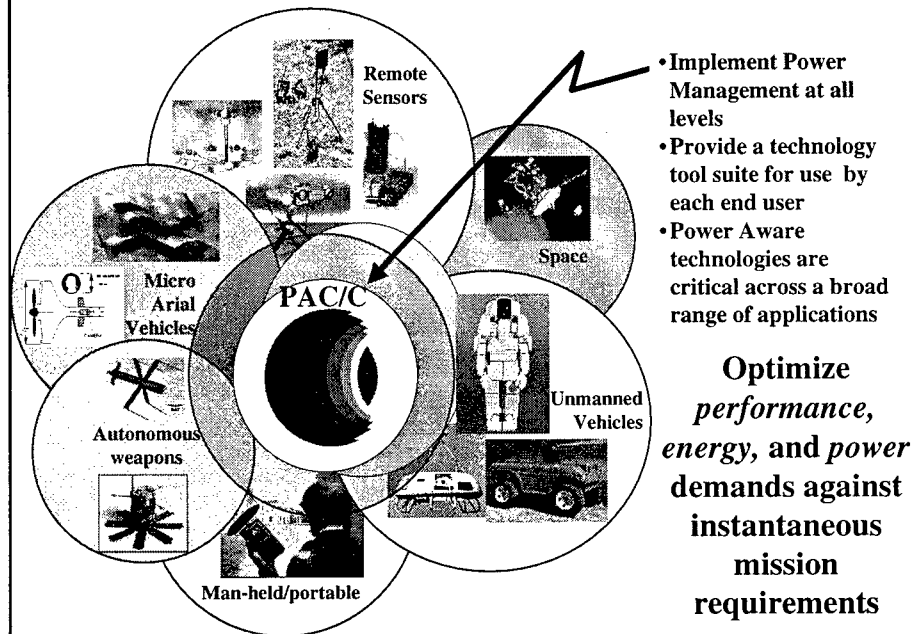
The Problem: Data-Starved Defense Applications



Solution:

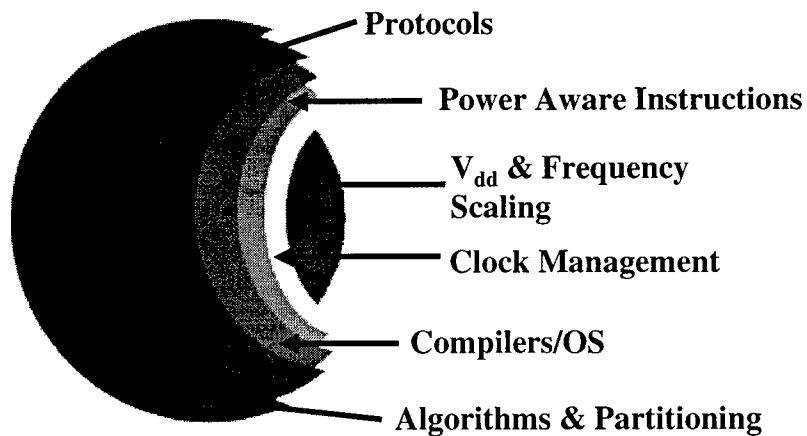
- **In Situ Processing**
 - *Logic within memory chips manipulates data within the memory subsystem*
 - *Memory within computational streams*
- **Adaptive Cache Management**
 - *Applications manage memory hierarchy so data placement and control flow is tailored to application specific needs*

PAC/C - Enabling Technology



PAC/C Approach

Power Aware Technology at All Levels



Polymorphous Computing Architectures (PCA)

Enable reactive multi-mission and in-flight retargetable embedded information computing systems that will reduce mission computing payload adaptation, optimization, and verification from years to months to minutes.

**Polymorphous
Computing**

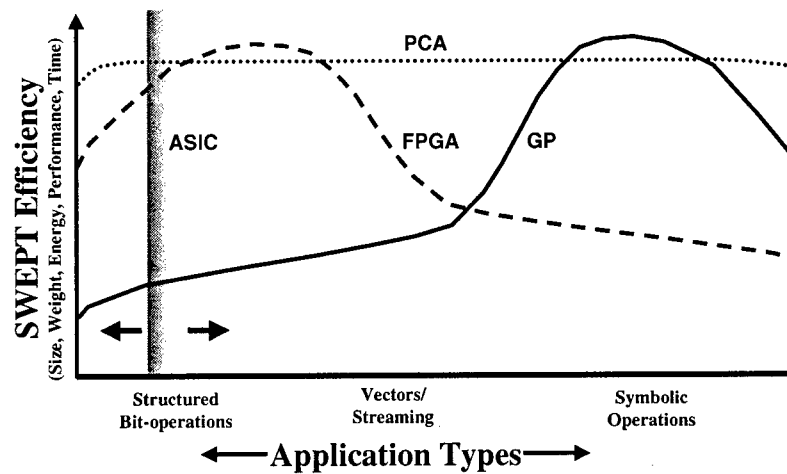


Polymorphic - Adj. having, taking, or passing through many different forms or stages. (Greek *polus* many + *morphe* form)

Polymorphous Computing Architecture (PCA)

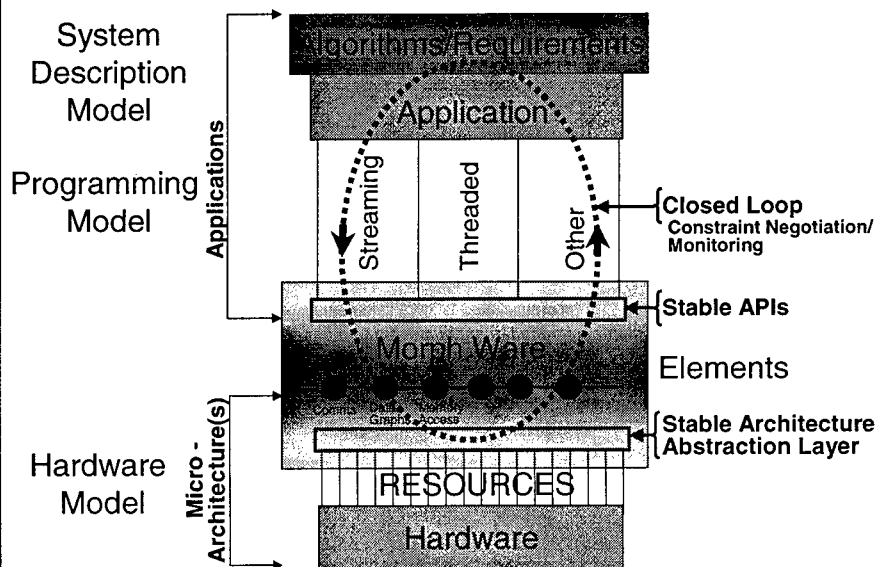
- **What will we do?** Develop an adaptable (polymorphic) middleware/micro-architecture that can rapidly adapt as required.
- **How is this different?** Today's embedded computing systems are generally optimized using a static architecture.
- **What is the impact?** Provide the warfighter the ability to always have access to the best available embedded computer capability:
 - Ease of HW upgrade throughout the platform's lifecycle
 - Rapid multi-mission/multi-sensor adaptability.
- **What is the product?** Provide a validated (via prototype testing) suite of polymorphic computing architectures (PCA) technologies for DoD embedded computing applications.

Efficiency versus Application Space



Hard Problem: Optimized Performance Over Broad Application Space

PCA Architecture Concept



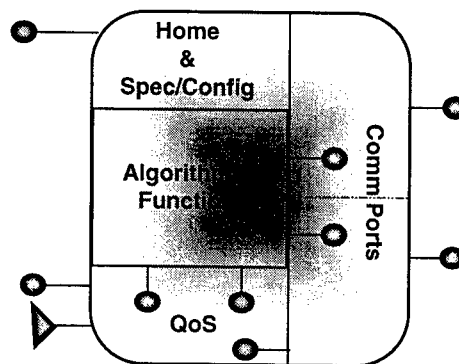
Abstract Hardware Model Presented to Software

■ Must present a range of abstractions

- Compute
 - Vector to multi-processor machines
- Communication
 - Circuit switch to packet router
- Memory
 - Vector registers to caches
- Verification
 - Functionality to performance metrics

Support Broad Range of Models

Polymorphous Software Component



Measurable and Verifiable Configurations/Behavior

PCA Enables

- **Multi-mission, multi-sensor, and in-mission reconfiguration**
- **Rapid technology insertion**
- **Deterministic behavior within SWEPT (Size, Weight, Energy, Performance, Time) constraints**
- **Component based validation**
- **Preservation of software investment**

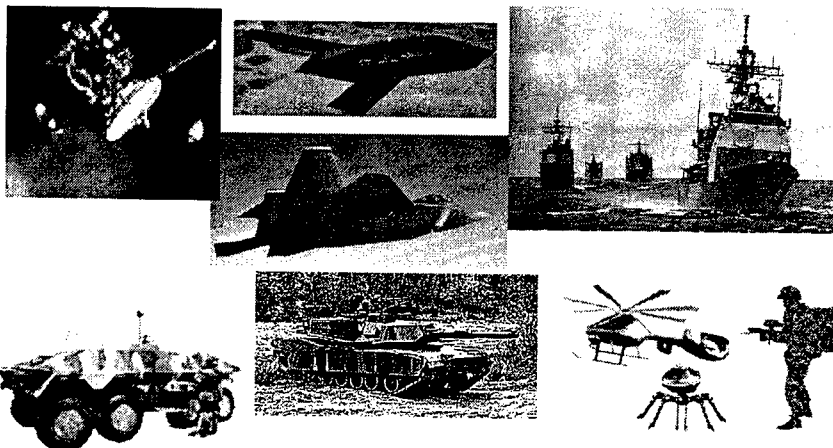
**Forever Change the Way DoD Develops
Embedded Software & Hardware Computing Systems**

Summary - Future Directions -

New Ideas

■ Embedded Computing	➔ Polymorphous Computing
■ High Performance Scientific Computing	➔ Fill the Technology Research Pipeline ?

Multi-Mission Environments and Polymorphous Architectures



***Laying the Embedded Computing Technology
Foundation for the Dynamic Battlespace***



Secure Networking

Dr. Douglas Maughan

DARPA / ITO

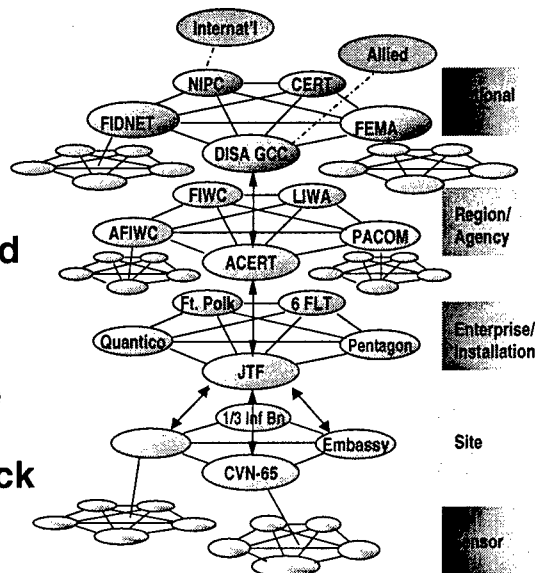
dmaughan@darpa.mil

1

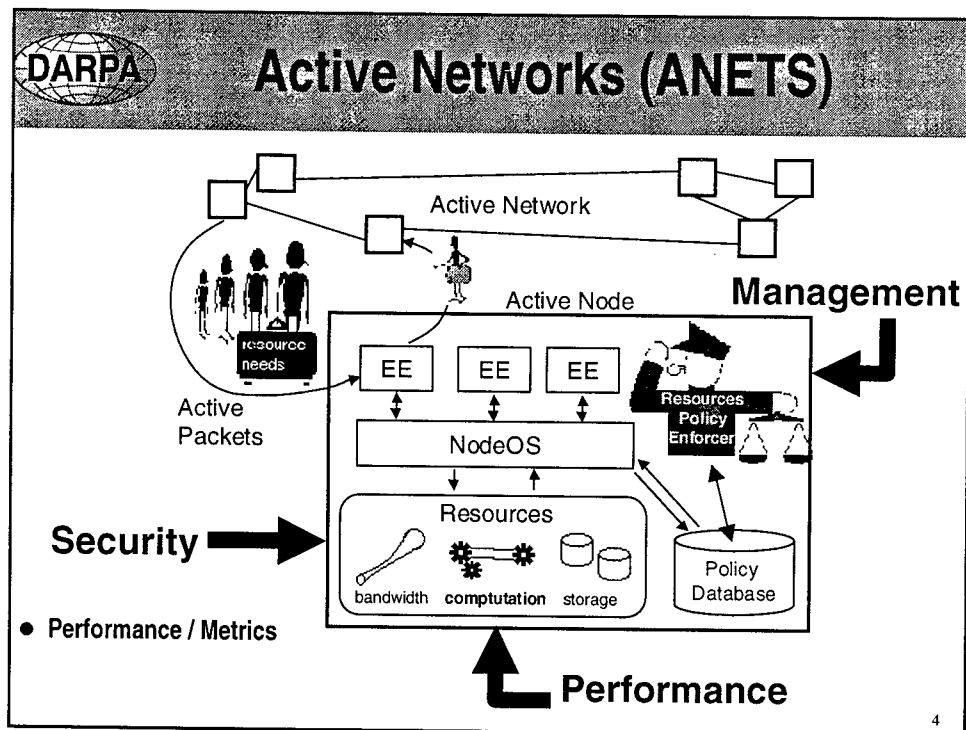
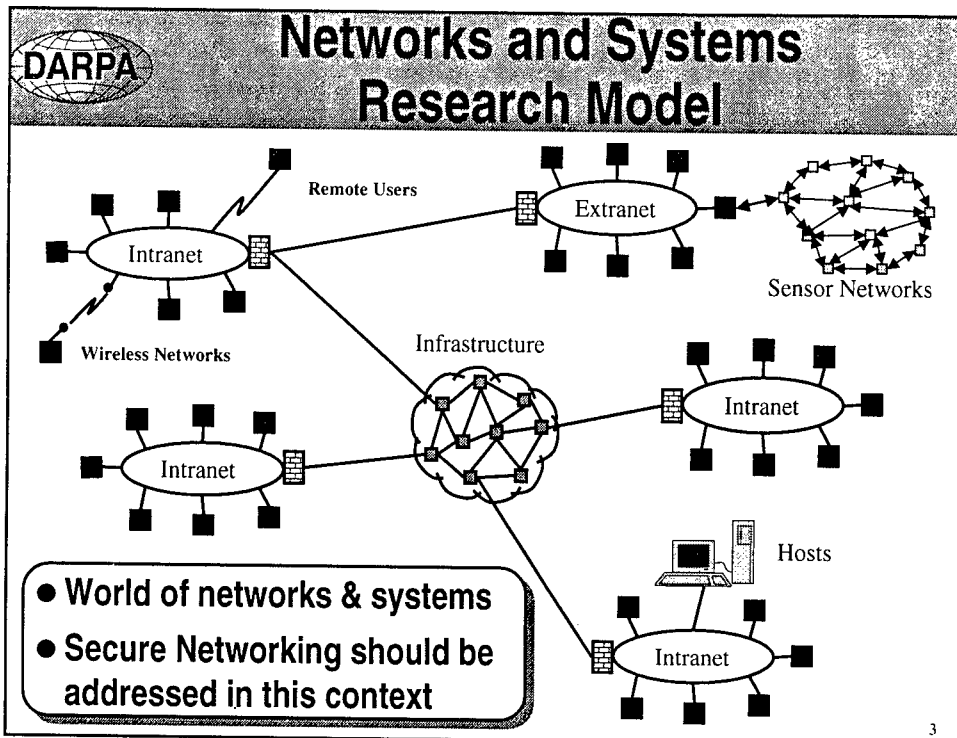


Network Reliance is Pervasive

- DoD depends on networking technology for information dominance at all levels of command hierarchy, BUT ...
- DoD networks are increasingly vulnerable to attack



2



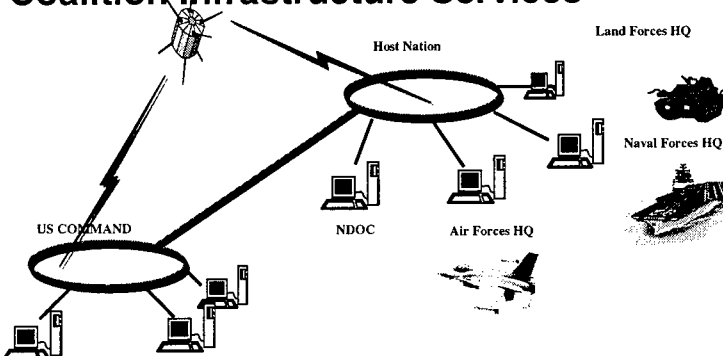


Dynamic Coalitions (DC)

Goal: Manage dynamic coalition formation and secure sharing by authorized members

- Multi-Dimensional Coalition Policies
- Secure Group Management
- Coalition Infrastructure Services



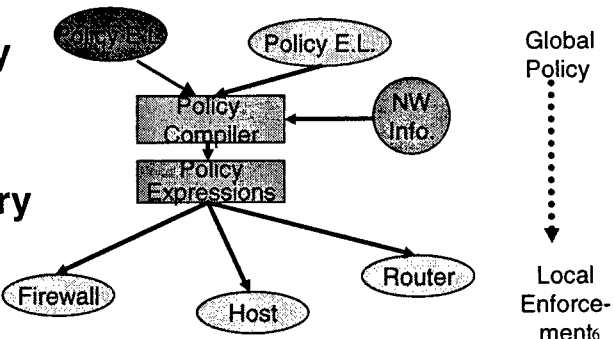


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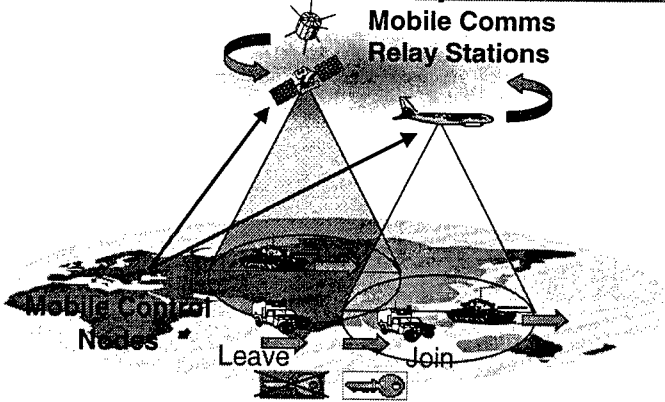
Multi-Dimensional Coalition Policies (MDCP)

- Establish “standard” language for policy expression
- Capability to negotiate policies with potential coalition partners (implies multiple at same time)
- Dynamic policy management
 - ◆ Multi-game
- Policy discovery





Secure Group Management (SGM)



- New techniques for sender authentication
- Scalable distribution - group creation & re-key
- Leverage secure multicast standards work

7



Coalition Infrastructure Services (CIS)



- Scalable techniques for timely propagation of revocation information (e.g., compromised keys, expired certificates, etc.)
- Extend current technologies of cross-certification for rapid coalition deployment capabilities
- Secure identification/trust technologies (e.g., credentials)

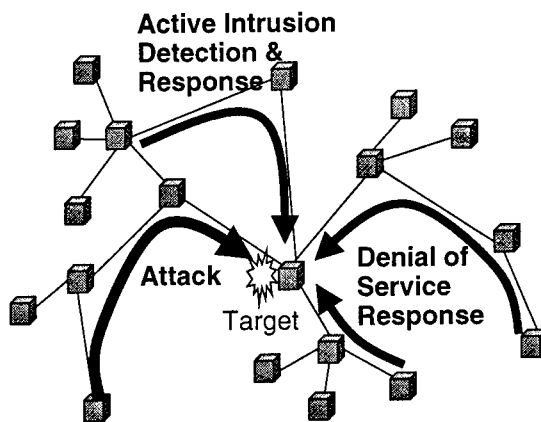
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Fault Tolerant Networks (FTN)

Goal: Ensure continued network availability in the face of attack while containing attacker resources

- Fault-Tolerant Survivability
- Denying Denial-of-Service
- Active Network Response

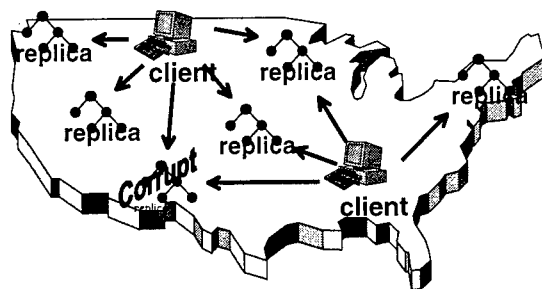


9



Fault-Tolerant Survivability (FTS)

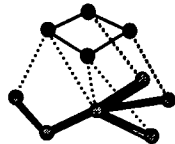
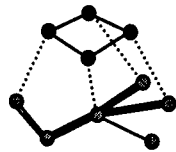
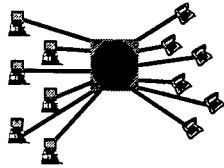
- Replication and partitioning of network services; Redundancy of network resources
- Better understanding of network fault modeling
- Survivable virtual network overlays
- Create network self-healing capabilities



10



Denying Denial-of-Service (DDOS)



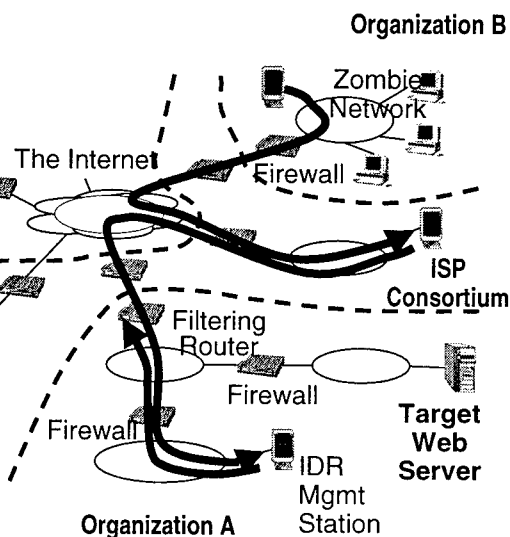
- Develop market-based resource allocation strategies to limit resource consumption by attacker
- New communication protocols that execute based on incremental progress within trust chain
- Create accurate mechanisms for reliably attributing DoS attacks
- Harden current routing and naming infrastructure protocols against DoS attacks

11



Active Network Response (ANR)

- Leverage advanced intrusion detection techniques
- Active networks to assist with attacker tracing and fencing
- Immediate reaction to real-time attack, limiting damage and begin recovery



12



Survivable Mobile Wireless Networking

Ensure future mobile, wireless networks are resistant to attacks via dynamic and adaptive configuration strategies

- Develop capabilities for dynamic, survivable wireless network establishment
- Leverage wired information assurance solutions
- Create survivable key management capabilities to protect against compromise and enable rapid recovery and reconstitution
- Develop node adaptation strategies leveraging active networking

13



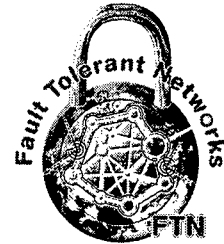
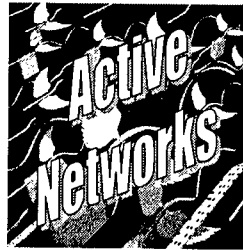
Summary / Conclusion

- Networking technology is the cornerstone of DoD communication architectures of the future (e.g., JV 2010, JV 2020)
- Increasing environments of collaboration require technologies for secure sharing of data and resources
- Networks at all levels of command hierarchy must be resistant to attack and “operate through” those attacks which are successful

14



Secure Networking



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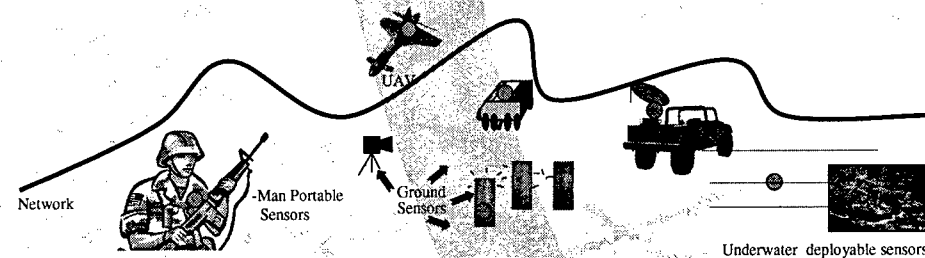
SensIT: Sensor Information Technology

Networked Micro Sensor Technology

21 Ideas for the 21st Cent. Business Week. 8/23-30, 1999

**Program: Rapid and Accurate
Information Technology Enabling
Networked Detection, Tracking
of Threats**

**DARPA/ITO
PM: Sri Kumar**



Sensor Information Technology

Goal

Software for distributed Micro Sensor Networks

Thrusts

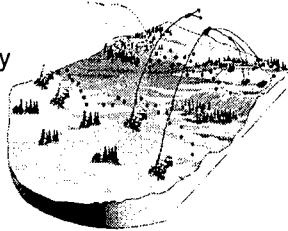
- New networking methods
- Leverage distributed computing paradigm for
 - Reliable extraction of right and timely information from sensor field
 - Networked signal and information processing
 - Dynamic querying and tasking



Software Supporting New Capabilities

System Parameters

- Latency
- Energy
- Autonomy
- Survivability



For Networked Micro-Sensors

- Interactive
- Programmable
- Multi-Tasked
- Short Range
- Algorithms to exploit proximity of devices near threats
 - drastically improved S/N
 - exploit multi-modal sensors
 - collaborative processing

Low-Cost, Rapid, and Accurate:

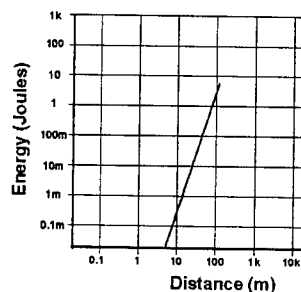
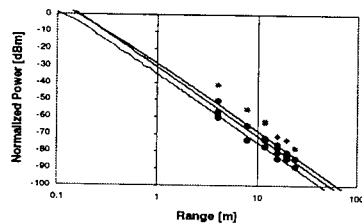
- Detection
- Identification
- Tracking
- Targeting
- Communication to overhead asset

3



Environment

- ◆ Operating Conditions
 - Harsh, Uncertain, Dynamic: Adaptive
 - Autonomous Operation
 - Scale: Too many devices for manual configuration
- ◆ Dynamic availability of resources
 - Energy/Power, BW, MIPS Constraints



4



Challenges

◆ Networking

- Reliable, Survivable, Secure
- For Ad-Hoc, Rapidly Deployable Devices
- Seamless Fixed/Mobile Device Interaction

◆ Networked Computing

- Extract Useful Information from Sensor Field
- Collaborative Processing
- Dynamic Query, Tasking
- Reliable and Efficient

5



SensIT: Tasks

- ◆ Networking
- ◆ Collaborative Signal Processing
- ◆ Query/Tasking
- ◆ Software Integration/Experimentation

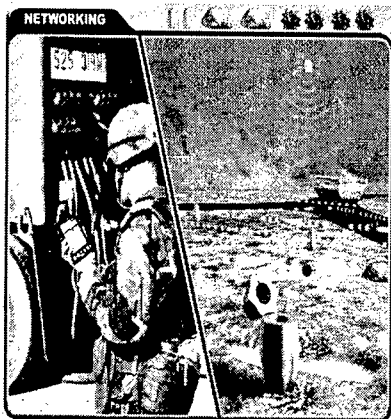
6



Networking: Fixed Sensor Devices

Characteristics:

- Ad-hoc, self-assembled
 - minimal state; IP-alternative
- Low-latency
- Survivable, secure



New Approaches:

- No IP-address
 - No global topology
- Data-centric vs. end-end connections
- Application specific
- Survivability, adaptation through redundancy
- Diffusion routing

Tradeoffs:

- Latency
- Reliability
- Power/Energy?

Deployment Density/Size?

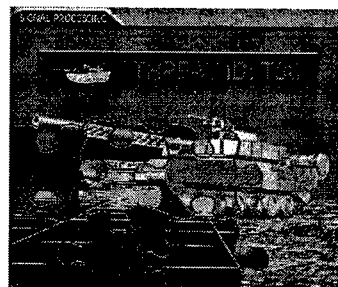
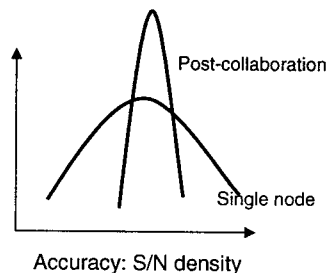
- Scaling effects

7



Collaborative Information Processing

- ◆ Exploit Dense Spatial Sampling
 - Networked Consensus
- ◆ Distributed Signal Processing Algorithms
 - Asynchronous
 - Progressive Accuracy
 - Efficient: Energy, BW, MIPs
- ◆ Deployment Density
 - Performance
 - How does it scale?

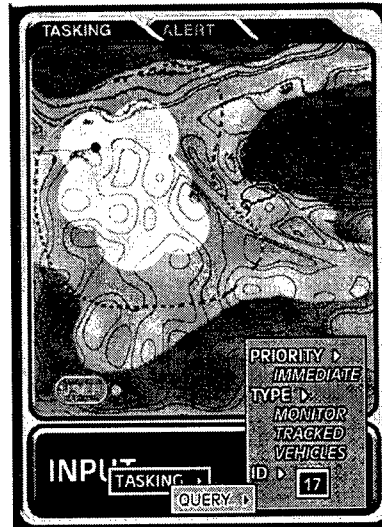


8



Querying and Tasking

- ◆ Simple User Interface
 - Query/Tasking Language
- ◆ Query/Task Processing
 - Distributed; Multi-tasking
- ◆ Distributed Micro Database
 - Data Organization
 - Placement and Caching
 - Scalable
- ◆ Capacity



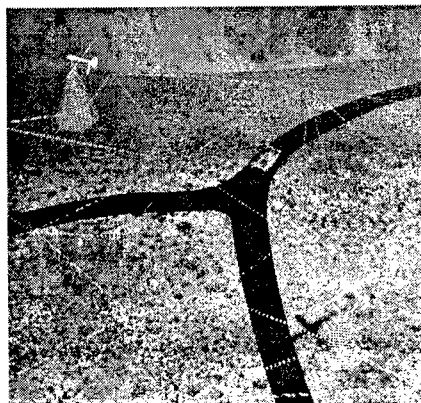
9



Fixed/Mobile – Internetworking

- ◆ Discovery (Identity, Services)
- ◆ Engagement (Fixed/Mobile)
 - Single Point/Multi-Point
 - Handoffs
 - Depth of Engagement
 - Edge
 - Deeper
 - Planned and Ad-hoc
 - Intermittent Connectivity
- ◆ Leveraging Mobility
 - Cueing; Fill Holes
 - When and Where; Task/Code Migration

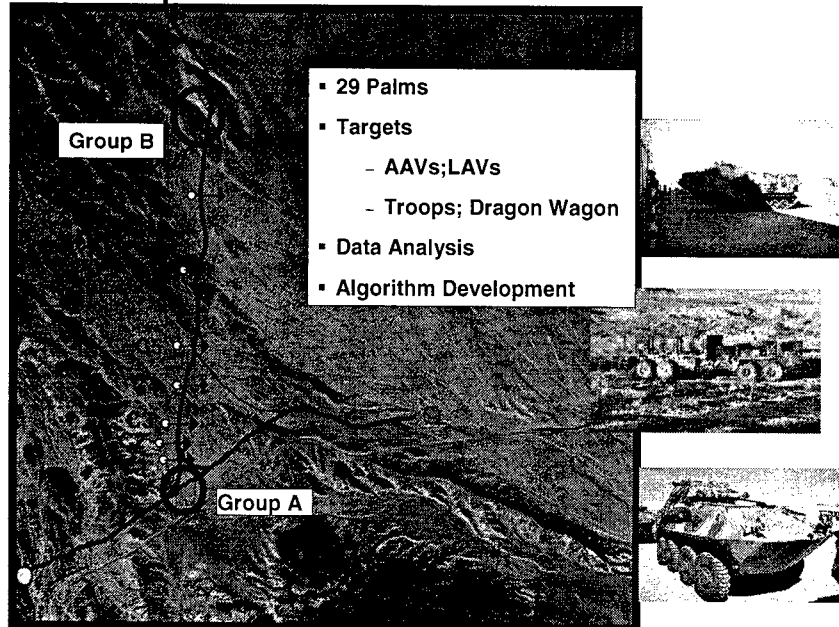
Mobile Sensors, Mobile Query



10



Experiments: Field, Lab



SensIT: Impact

◆ Function

- Detection
- Identification
- Location
- Tracking

◆ Targets

- Personnel
- Wheeled/Wing
- Tracked

◆ Environment

- Open field
- MOUT

◆ Users

- Dismounted soldiers
- Command post
- Force level
- Intelligence

◆ Application

- Personal
- Platoon
- Battalion
- Border and base security
- Air campaign
- Land mine replacement

**Embedded IT Enabling Revolution
in Networked Sensing**

Information Systems Office



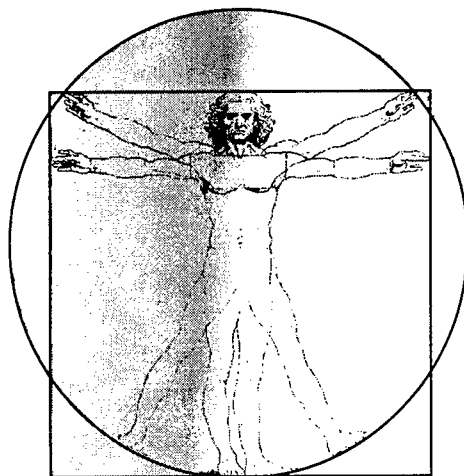
Dr. W. M. Mularie

Director, Information Systems Office

703-696-7438 • wmularie@darpa.mil



Information Systems Prosthetic



Challenge:

**Overcome
Human
Limitations**

- Speed
- Complexity

Autonomic

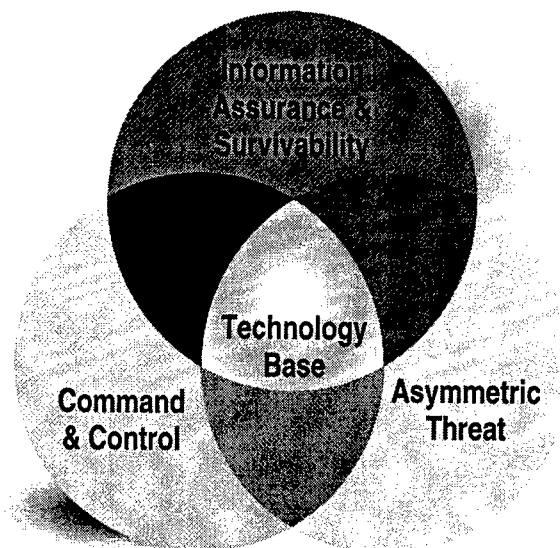


Human





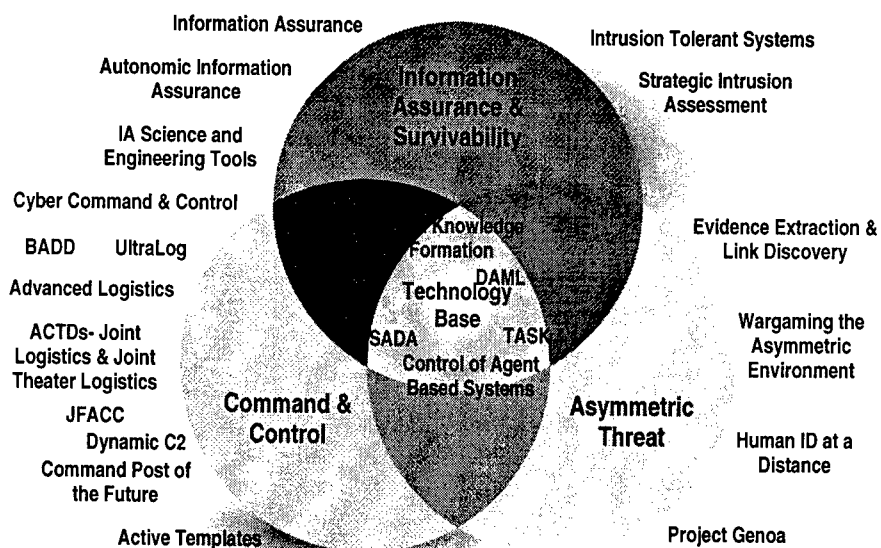
ISO Program Areas



3



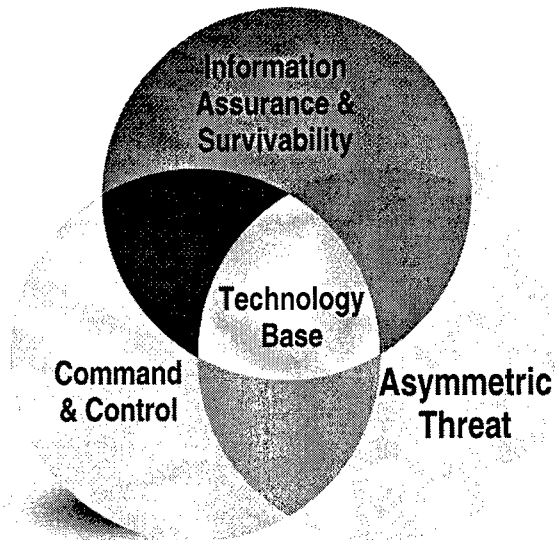
ISO Program Areas



4



ISO Program Areas



Unconventional yet highly lethal attack by a loosely organized group of transnational terrorists

5



The Nuclear Threat *A Historical Perspective*

...I conceded that more intelligence about their war-making capabilities was a necessity."

• President Dwight D. Eisenhower

Post - Attack Preparation

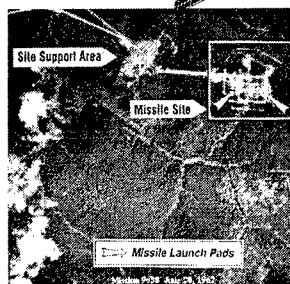
"Need to Know Sooner"

1950

"Mummy, what happens to us if the bomb drops?"

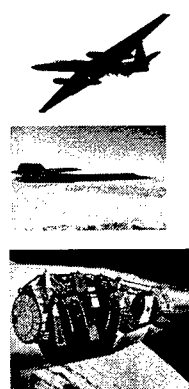


1955



Yurya ICBM Complex of a SS-7 Launch Site (Mission 9038, June 28, 1962)

1960





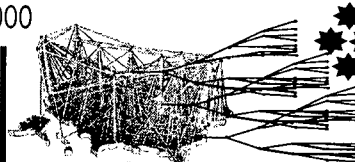
The Asymmetric Threat Today's Perspective

Post - Attack Preparation

Preemptive: "Need to Know Sooner"



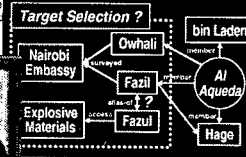
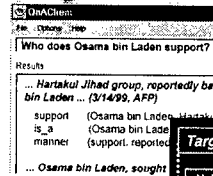
2000



Model-Based Agents

Behavior & Intent Models

Open Source Evidence
Extraction & Link
Discovery



Human Identification



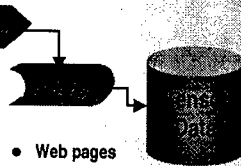
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Asymmetric Threat A Surveillance Problem

• Needle in the haystack

♦ Find the parts of the needle



- Web pages
- Individual sightings (e.g. HID)
- News feeds
- Online databases
- Other Intel



Cues



Histories



Threats

Threat Description

New Features

Known Threats

New Behaviors

Forensic Studies

Analysts

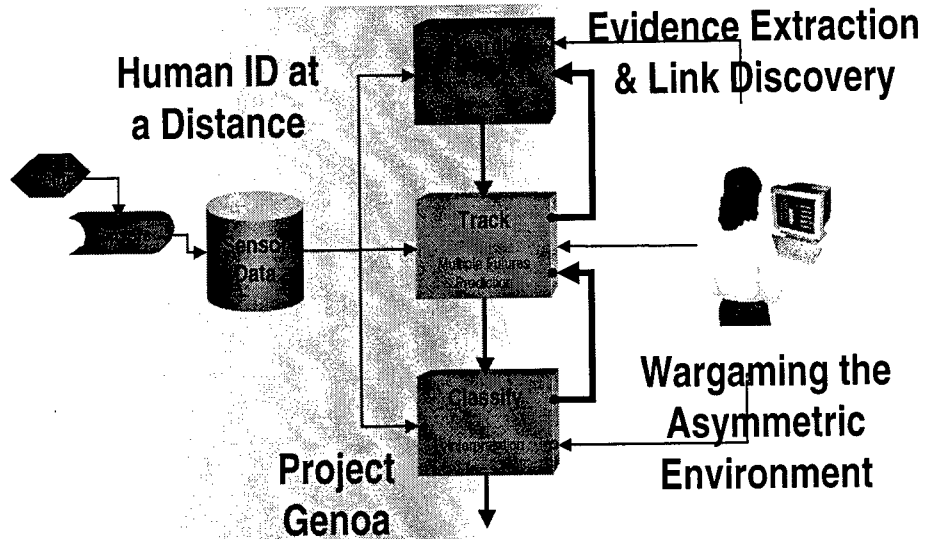
Autonomic

Human

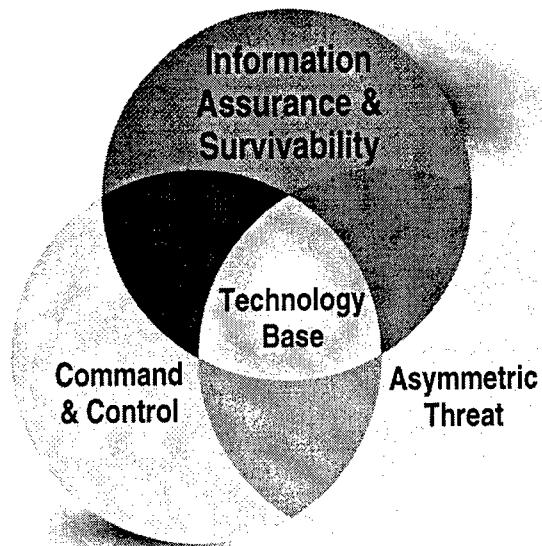
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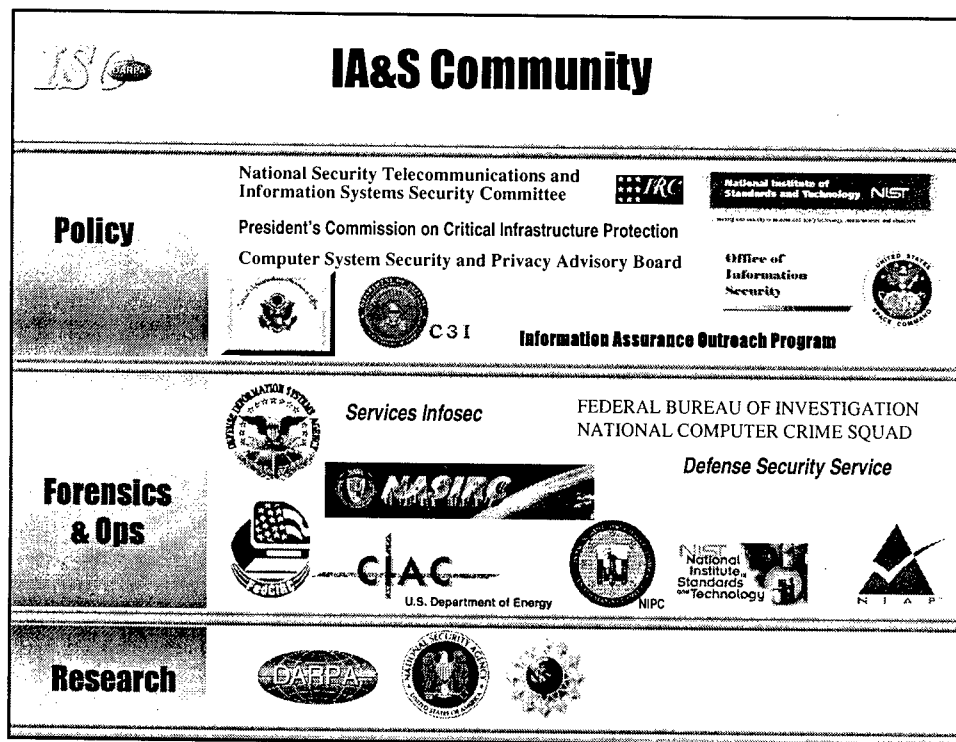
Asymmetric Threat Programs



ISO Program Areas



Mitigate national and defense computing infrastructure vulnerabilities that could be exploited by information warfare enemies



Information Assurance & Survivability Problem Space

The Problem:

- Our current DOD information security strategy is failing to keep pace with the current threats.
- We anticipate that future threats will be more sophisticated and widespread.

12



IA&S Responses

- **Change the “business model”**
 - ◆ Operationally focused, system oriented
 - ◆ Transfer technology directly to DoD systems
 - ◆ Let commercial systems catch up to military-level security
- **A broadening of our view of “solution space”**
 - ◆ Host-based/software approach
 - ◆ Include communications and computer architectural engineering
- **A broadening of operational focus**
 - ◆ Wireless, mobile
 - ◆ Operational challenge problems

13



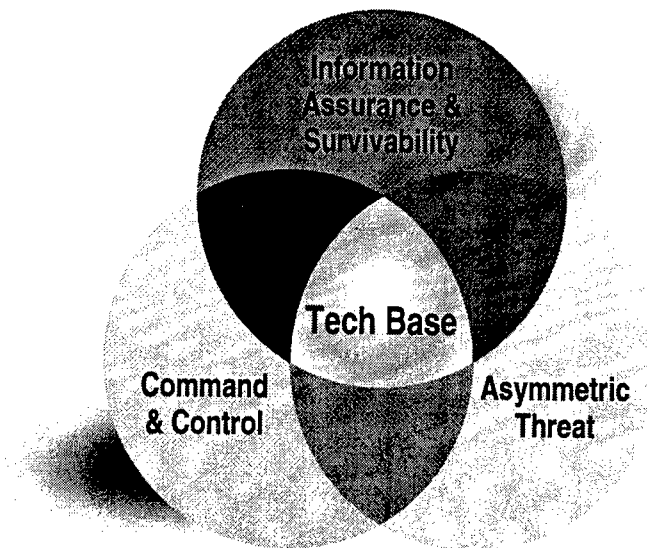
FY01 IA&S Themes

- **DoD System Focus**
- **Operational Experimentation**
- **Security in Mobile, Wireless Domain**
- **Impact Upon Command and Control**
- **Next-Generation Secure Systems**

14



ISO Program Areas



15



Tech Base: *Supporting ISO, Commercial & DoD Systems*



Rapid Knowledge Formation



DARPA Agent Markup Language



DASADA



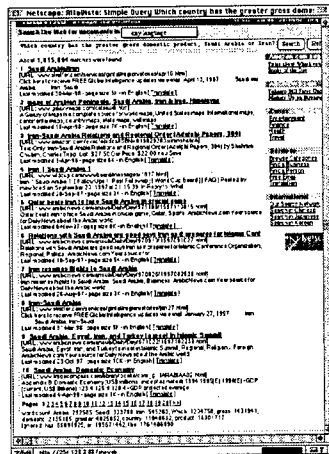
Task Agent Software Kit

- Agents
- Run time integration of heterogeneous systems
- Reinforcement learning
- Hybrid nonlinear dynamic control
- Mobile agents
- Neural nets
- Scalability
- Interoperability
- Agent clusters and interactions
- Knowledge bases
- System science
- Dynamic assembly of software

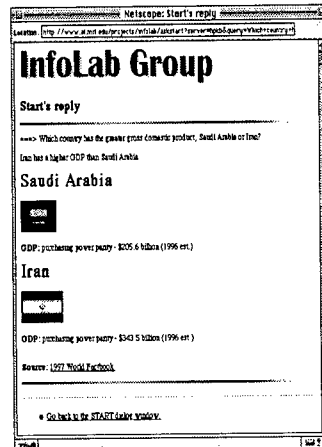
16

Knowledge-Based Information Retrieval

Which country has the greater gross domestic product: Saudi Arabia or Iran?

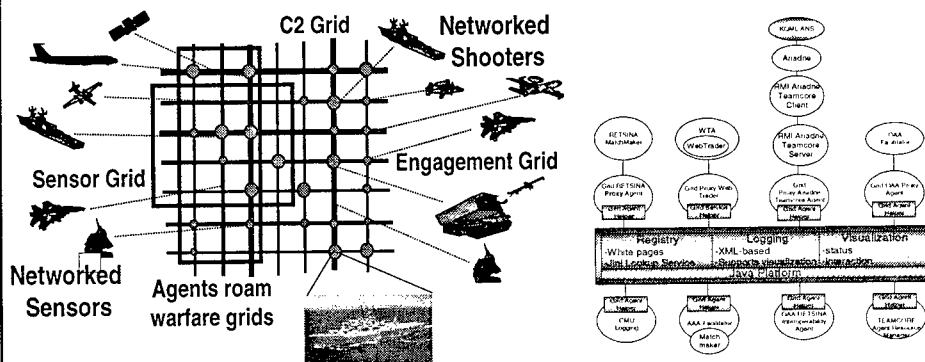


**Altavista: 1M responses,
first 10 (at least) irrelevant**



START (An HPKB Technology): Retrieved just the right information

CoABS Grid: *Multi-Agent System Interoperability*

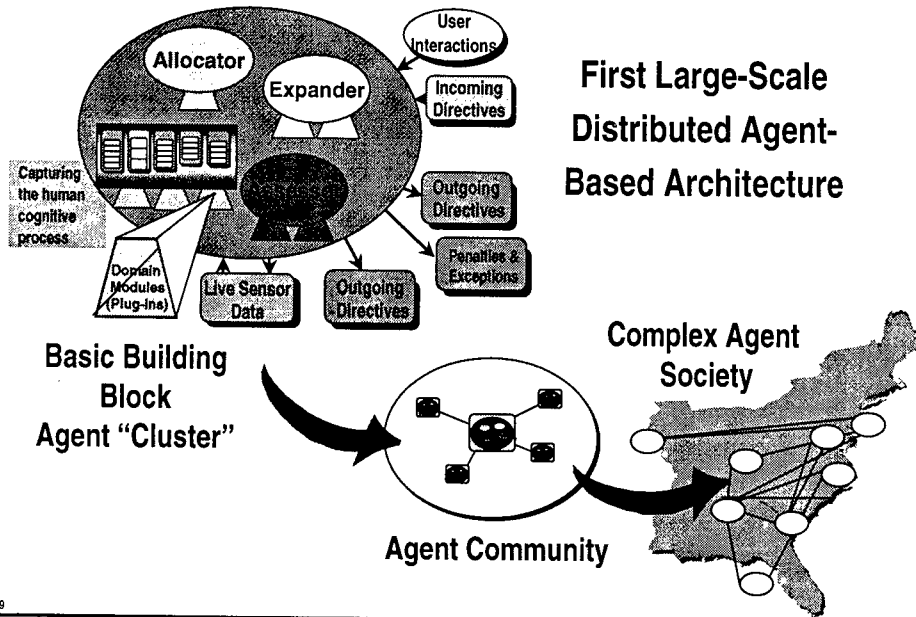


Navy Experiment: Cooperative Agents for Specific Tasks (CAST)

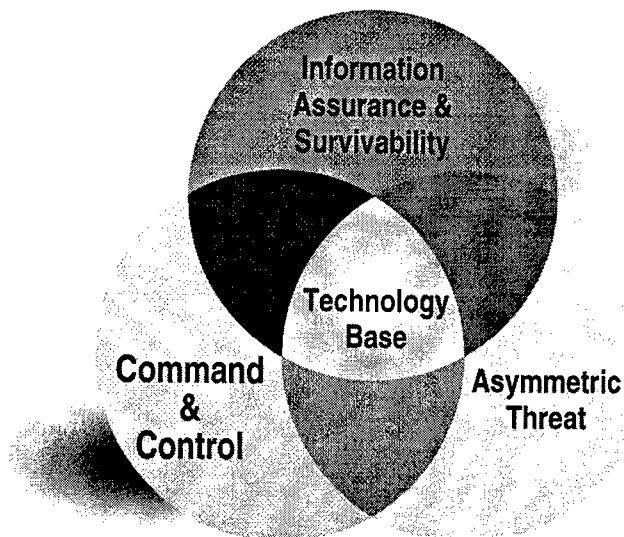
- **Facilitates interoperability of diverse systems**
 - ◆ Enables dynamic connection of disparate information sources and C2 applications
 - ◆ Enables software systems to cooperatively solve user tasks
- **Grid Agent Helper and the Grid Service Helper facilitate CoABS component access to Grid services and to other registered Grid components**



Cognitive Agent Architecture



ISO Program Areas

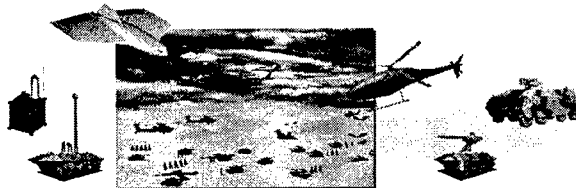
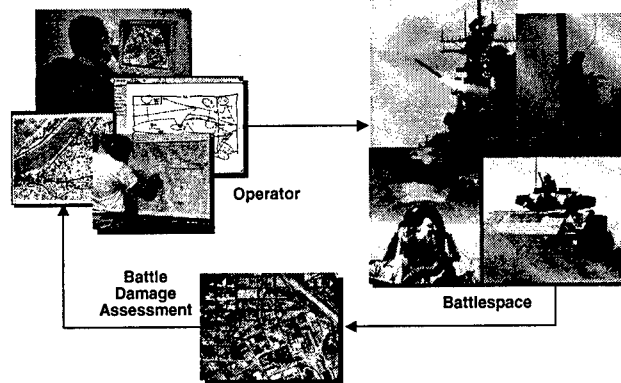




Current Command & Control Limitations

Limitations Today

- Operator reaction limited
- Feedback loop is not coordinated
- Unsynchronized
 - ♦ Things start to break
- OODA loop broken e.g., Kosovo



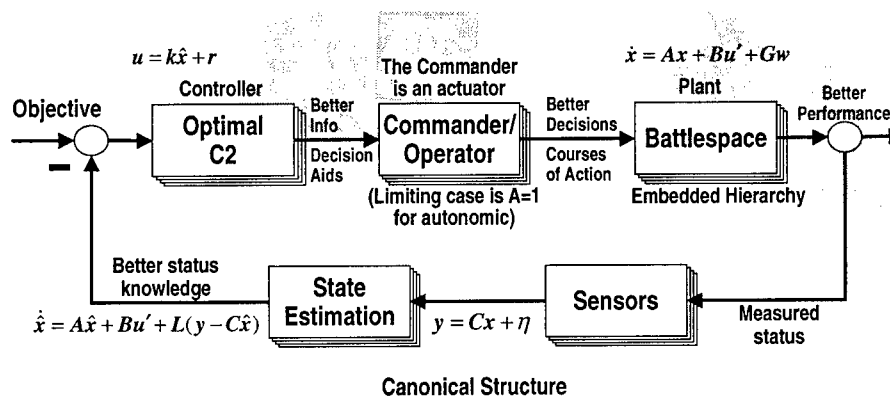
The Future

- Autonomic systems
- Higher op tempo
- Synchronized ops
- Human becomes more of a limitation

21



Dynamic Control Concept *Man & Machines*



Synchronization of manned & autonomic forces in space, time, and purpose can be achieved through the application and extension of control theory

22



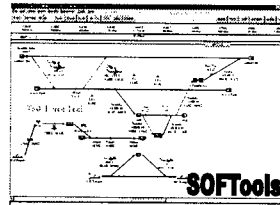
Command & Control Programs



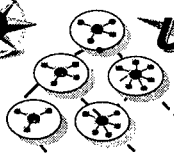
CPOF

Command
Post of the
Future

Active
Templates

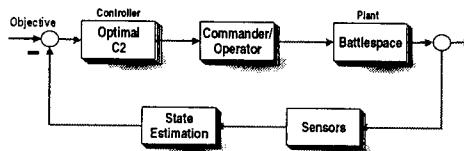


Advanced
Logistics
Project



Ultra Log

Ultra Log



Man & Machine
Command & Control

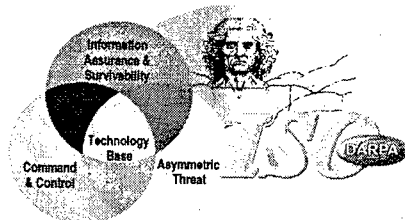


Joint Logistics
& Joint Theater
Logistics ACTDs

23



Information Systems Office Today's Speakers



Information
Assurance &
Survivability
Brian Witten

Technology
Base

John Salasin - DASADA
Jim Hendler - Agents

Command
& Control

Todd Carrico - Ultra Log

Asymmetric
Threat

Tom Armour

24

BARPATECH
2000
ISG

Information Assurance & Survivability

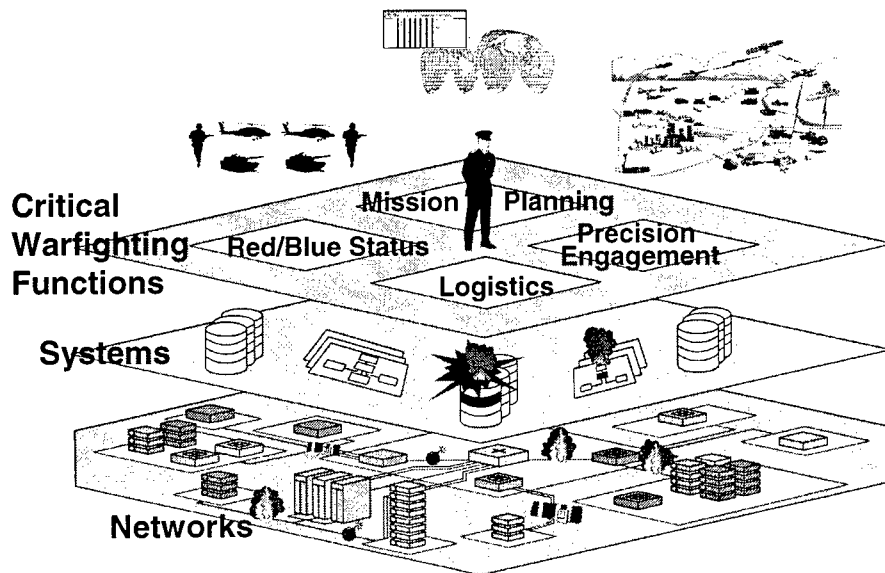


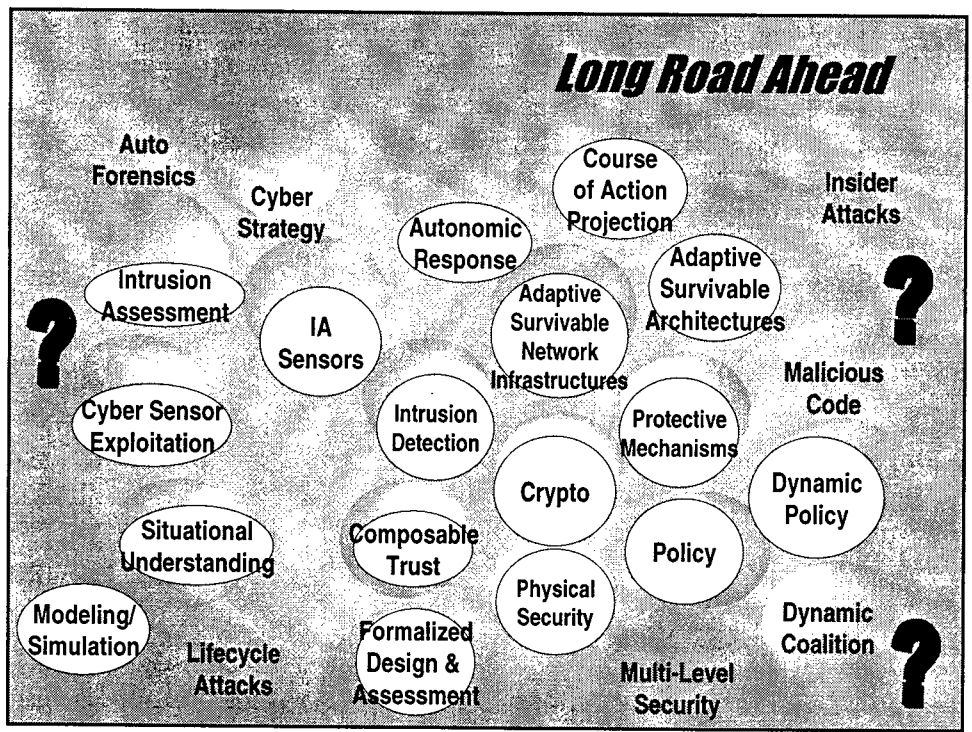
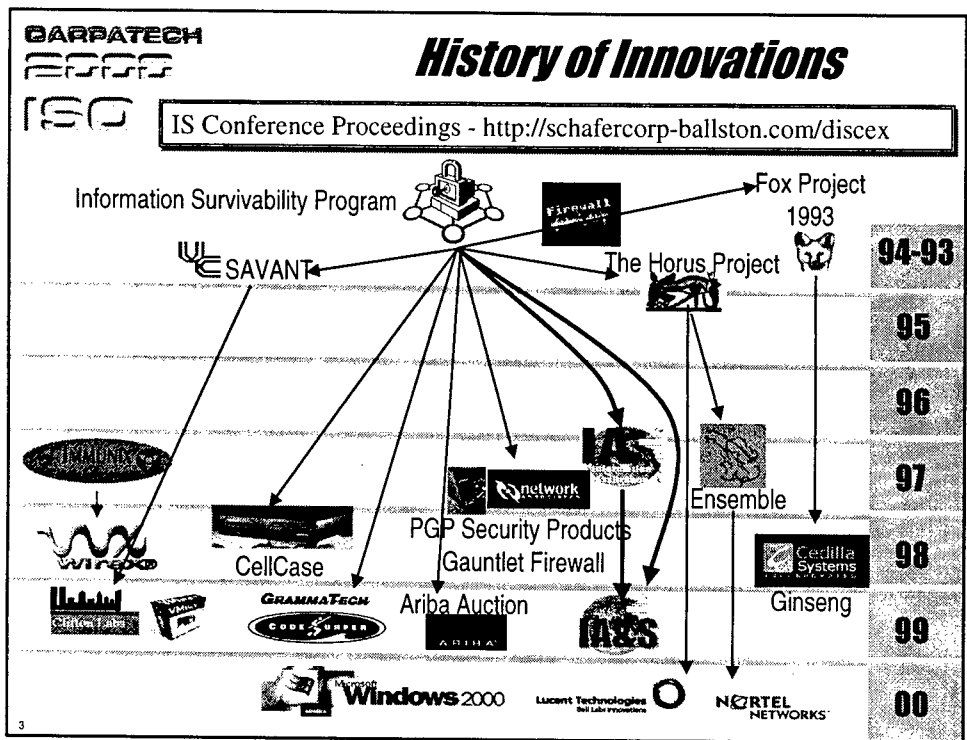
Brian Witten

Information Systems Office

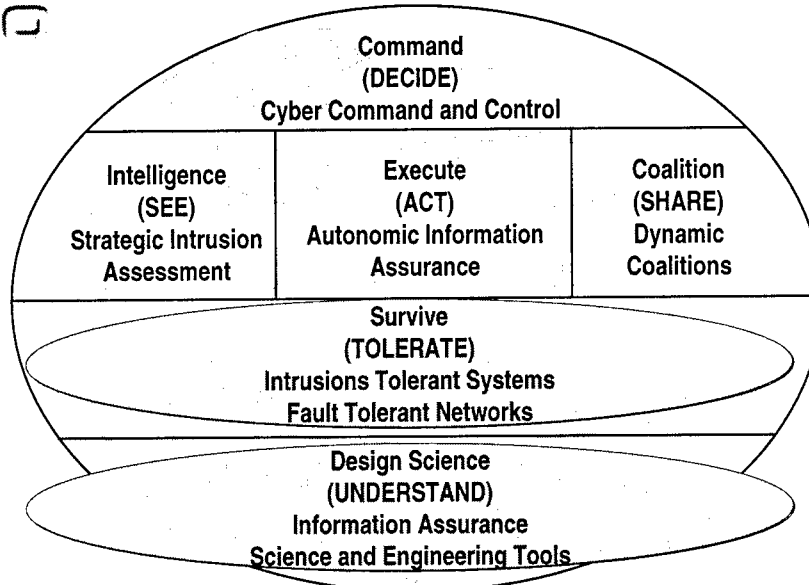
BARPATECH
2000
ISG

Can we trust the data we are fighting on?

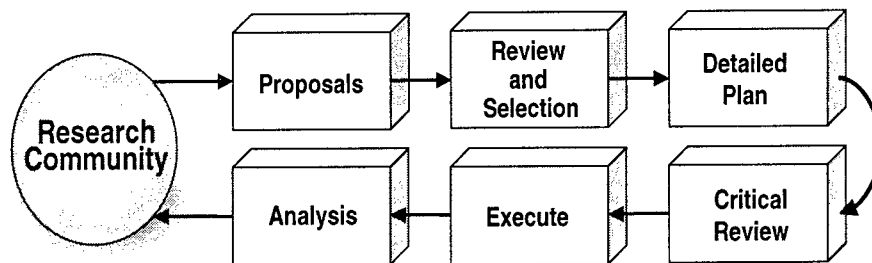




Objectives



Approach: Scientific Experimentation



Grand Hypotheses:

- Layered Defense
- Dynamic Defense
- Assurance Methodology
- Automated Response
- Automated Decision Support

Types of Experiments:

- Field Experiments
- Red Team Lab Exercise
- Laboratory Experiments
- Interdisciplinary White-Boarding
- Component Specific Testing

DARPA/TECH

ISG

ISG

Contact

Autonomic Information Assurance..... Brian Witten
Dynamic response
bwitten@darpa.mil

Cyber Command & Control..... Catherine McCollum
Human directed strategy
cmccollum@darpa.mil

Dynamic Coalitions..... Doug Maughan
Coalition policy mechanisms
dmaughan@darpa.mil

Fault Tolerant Networks..... Doug Maughan
Tolerant mechanisms
dmaughan@darpa.mil

IA Science & Engineering Tools..... Michael Skroch
Design tools & models
mskroch@darpa.mil

Information Assurance..... Michael Skroch
Composable trust
mskroch@darpa.mil

Intrusion Tolerant Systems..... Jay Lala
Tolerant systems
jlala@darpa.mil

Strategic Intrusion Assessment..... Catherine McCollum
Attack recognition & correlation
cmccollum@darpa.mil

Cyber Sensor Grid..... Catherine McCollum

Malicious Code Mitigation..... Michael Skroch

Reliable Mobile Agents..... Brian Witten

Secure Operating Systems..... Doug Maughan

Security of High Speed Networks..... Doug Maughan

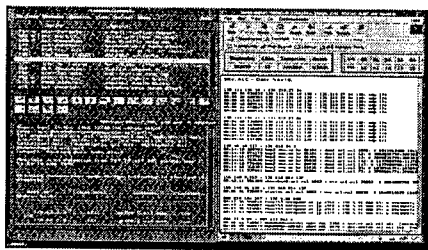
7

DARPA/TECH

ISG

ISG

New Focus: Cyber Sensor Grid



Sniffer data

```
% IS - I
header,79.2 (info), Sun Oct 03 21:57:43 1999, + 510000000 msec
argument, 0x1b7, child PID
subject, aheberle, staff, aheberle, staff, 408, 407, 24, 6 han
return, success, 0

header,107.2 (info), Sun Oct 03 21:57:43 1999, + 510000000 msec
path, (info)
attribute, 10055.5 bin bin, 26738688, 427674.0
subject, aheberle, staff, aheberle, staff, 430, 407, 24, 6 han
return, success, 0

header,121.2 (info), Sun Oct 03 21:57:43 1999, + 510000000 msec
path, (info)
attribute, 10055.5 bin bin, 26738688, 136738.0
subject, aheberle, staff, aheberle, staff, 430, 407, 24, 6 han
return, success, 0
```

Audit data

Bayesian
Techniques

Neural nets

Statistical
Analysis

Graphical
analysis

Hidden Markov
Model Detection

Signature-based
detection

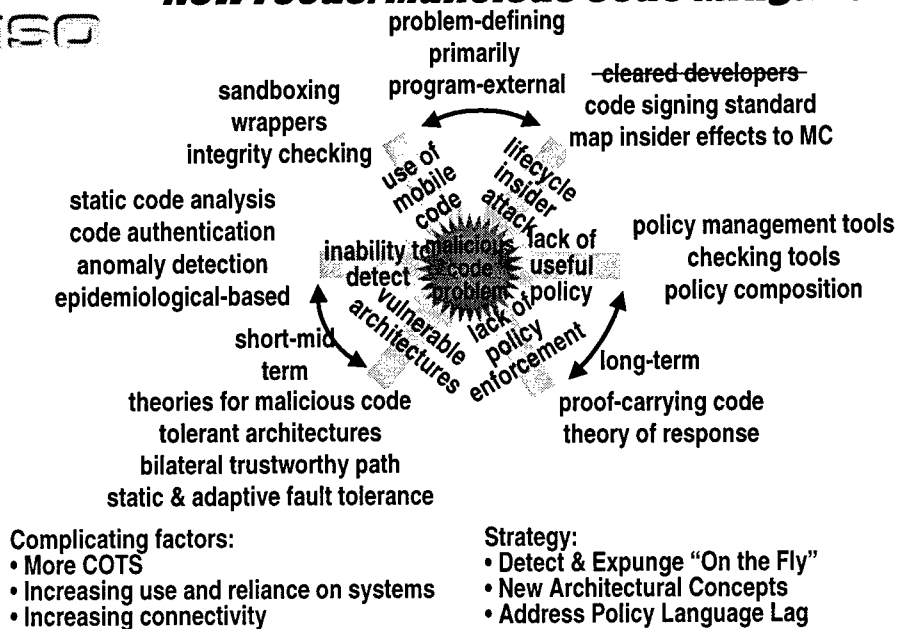
Combined
Sniffer
Audit



Attack space

8

New Focus: Malicious Code Mitigation



New Focus: Reliable Mobile Agents

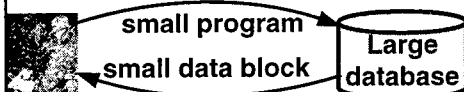
Mobile Agents are:

Programs that can migrate from machine to machine under their own control.

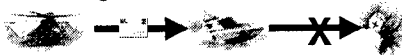
Code mobility...

Functionally enhances:

1. Efficiency

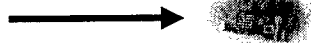


2. Disconnected operations (e.g., wireless networks)



3. Flexibility

Install new functionality on remote machines.



Presents Survivability Opportunities:

1. Availability

No central failure point.



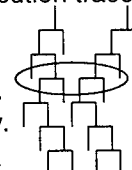
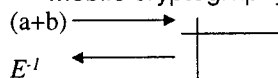
2. Integrity

Fluidly reinforce execution traces.

3. Confidentiality

Code fragmentation.

Mobile cryptography.



Conclusions:

- National Level Problem
- DARPA “high-risk”/
“high-reward” focus

New Focus Areas:

- Cyber Sensor Grid
- Malicious Code Mitigation
- Reliable Mobile Agents

Proven Success:

- ARPANET
- Firewall Toolkit

Waiting Gold:

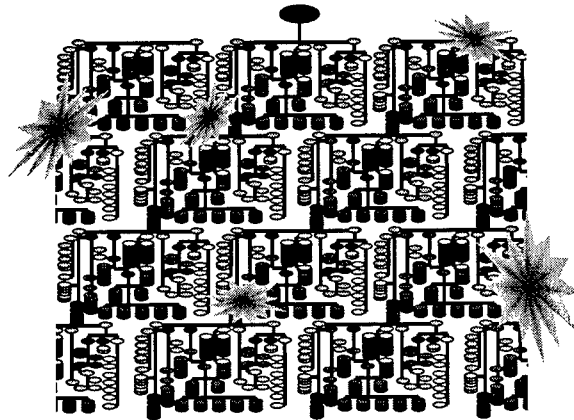
- Secure Domain Name Service
- Internet Protocol Security (IPSEC)
- Secure Border Gateway Protocol
- Next Generation Intrusion Detection

More to Come:

- Denying Denial-of-Service
- Self-Healing Systems
- Proof Carrying Code
- Trace Back
- Dynamic Defense
- Metrics & Science Based Design

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2222
150

ULTRA*LOG



*Large-Scale,
Robust,
Secure Agent
Technology for
Today's
Chaotic
Wartime
Environments*

Todd M. Carrico

Information Systems Office

BARPATECH
2222
150

ALP: Achieving Focused Logistics

Getting Control of the Logistics Pipeline...

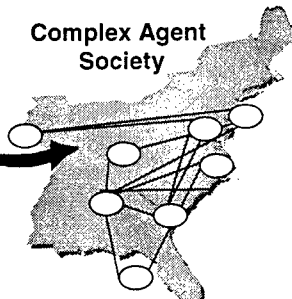
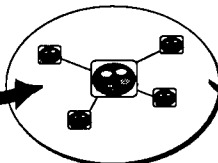
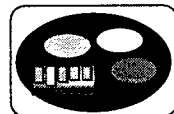
- Planning, Managing, and Providing Visibility
- All Echelons, All Phases of Operations
- Continuous Planning and Execution



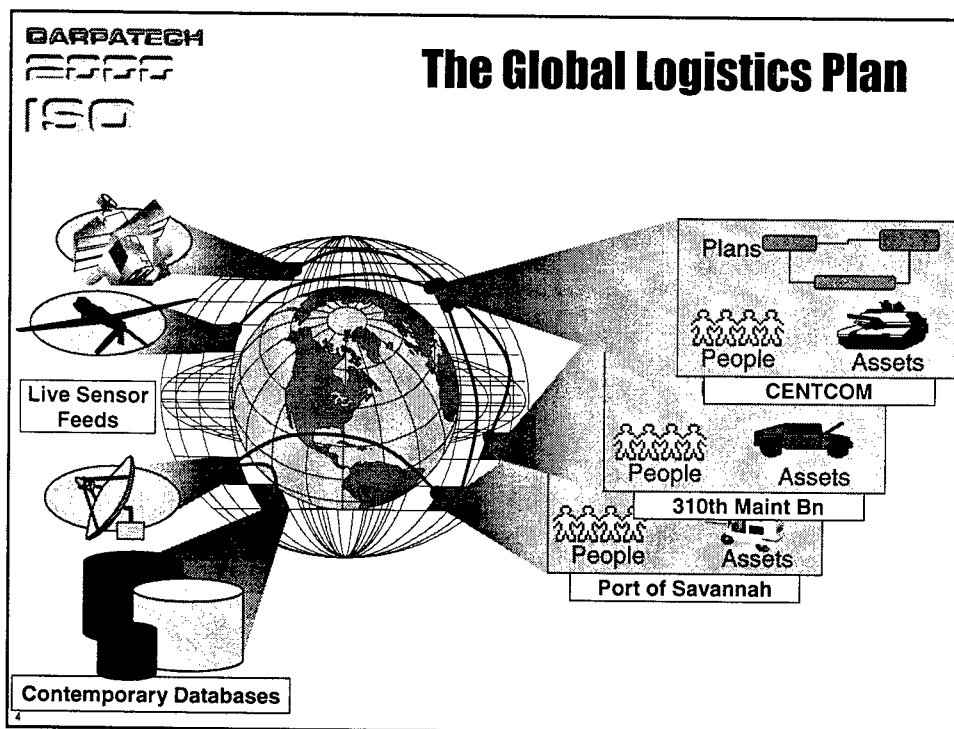
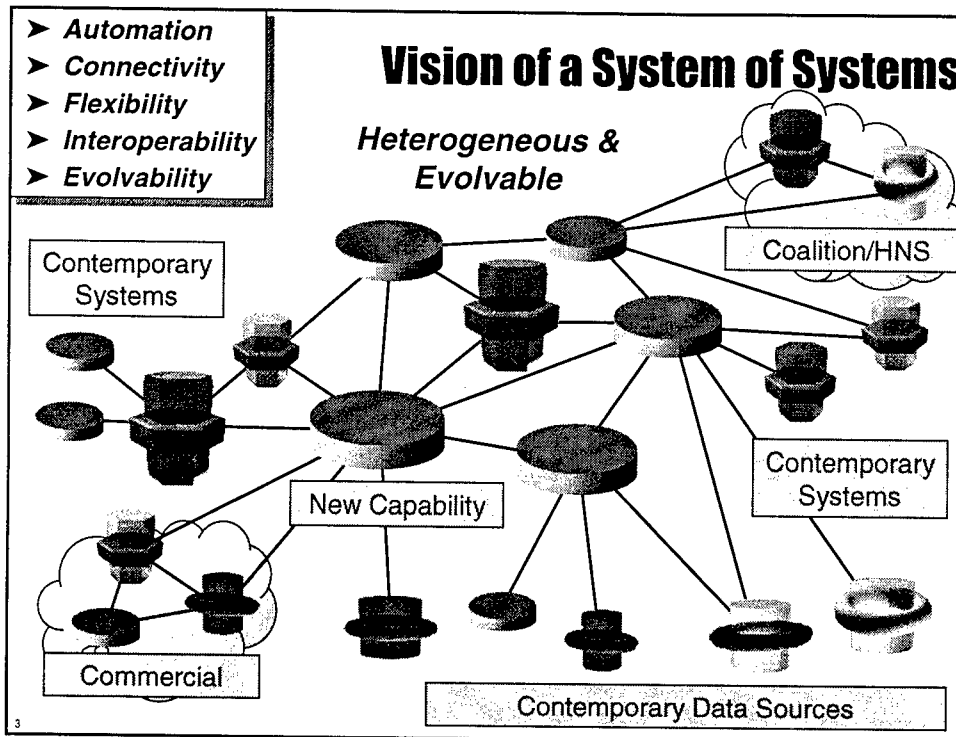
Basic Building Block
Agent "Cluster"

Agent Community

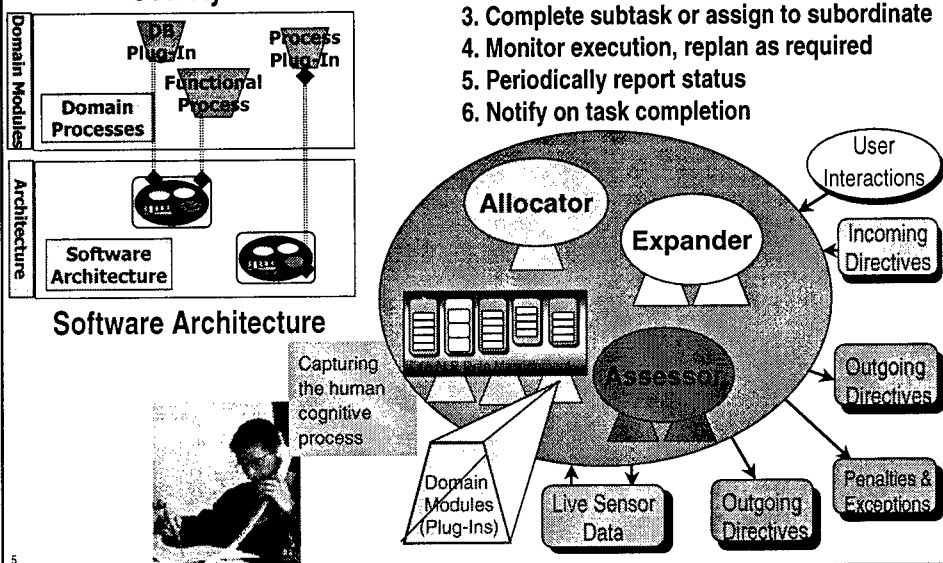
Complex Agent
Society



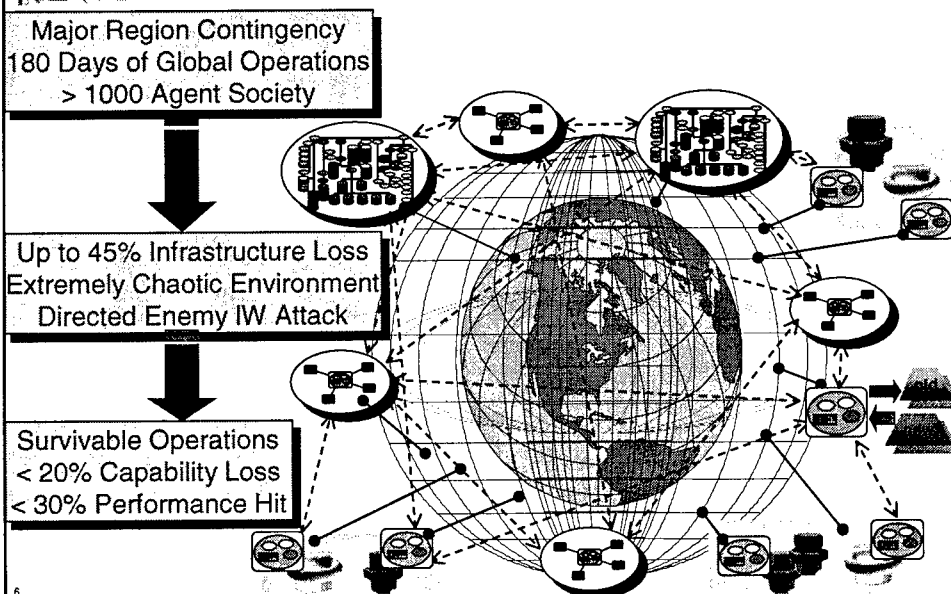
First Large-Scale Distributed Agent-Based Architecture

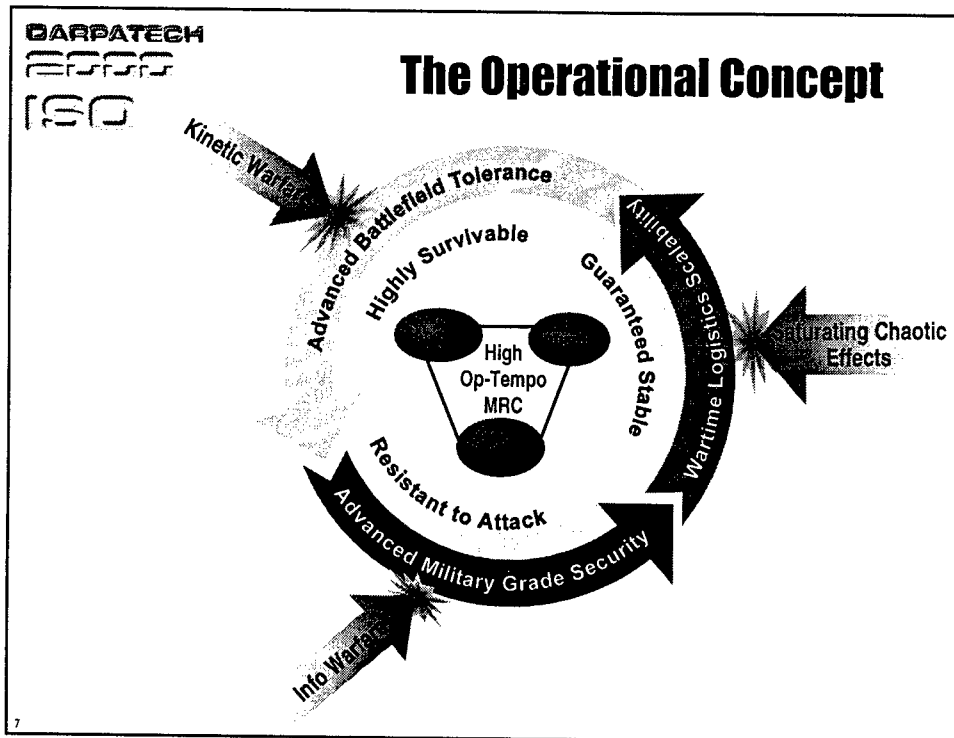


1. Receive tasking
2. Decompose task into doable subtasks
3. Complete subtask or assign to subordinate
4. Monitor execution, replan as required
5. Periodically report status
6. Notify on task completion



The Ultra*Log Challenge





DARPA/TECH
ISQ

Extending the Cognitive Agent Architecture

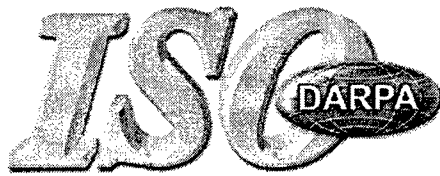
	Currently under ALP	Future with Ultra*Log
Robustness	Basic Fault Tolerance > Localized persistence of state > Stable under intermittent comms > Run-time manual reconfiguring	Adv Battlefield Grade Tolerance > Dynamic comms-aware redundancy > Catastrophic fault isolation / recovery > Dynamic adaptation to environment Highly Survivable
Security	Std Commercial Grade Security > Signed JARS, applets, config files > PKI certifications > Inter-community VPNs	Advanced Military Grade Security > Multi-layered, mode resistant security > Assured, adaptive availability > Assured data integrity / pedigree Resistant to IW Attack
Scalability / Stability	Peacetime Logistics Scalability > Time-phased locality of information > Efficient simple negotiations > Rich encapsulation of functionality > Optimized task grammar / data model	Wartime Logistics Scalability > Streamlined / compressed negotiation > Variable fidelity adaptive processes > Resource pooling / Mode mgmt Guaranteed Stable
Project Objective	Large-Scale Distributed Agent Architecture for Logistics	Integrated System Solution for Agent Societies operating in Intense IW Environment

8

Conclusion

- The Ultra*Log BAA is out (www.darpa.mil)
- The first-round of proposals are coming in
- The BAA will be open for another year
- Want maximum participation from all sectors
- Seeking leading-edge technologies in security, robustness and scalability
- Goal is to enhance the COUGAAR (Cognitive Agent Architecture: www.cougaar.org) technology so it can support a massive-scale, trusted, distributed agent infrastructure for logistics

Asymmetric Threat Initiative

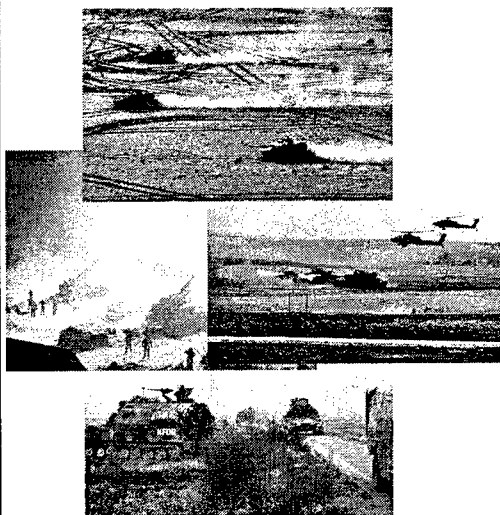


Tom Armour
Information Systems Office

DARPA TECH
2000
ISO

Threat Development and Detection *Then & Now*

Conventional



Asymmetric



Asymmetric Threat Projects

- Human Identification at a Distance
- Evidence Extraction and Link Discovery
- Wargaming the Asymmetric Environment
- Project Genoa
- Rapid Knowledge Formation
- Agent-Based Computing

3

Human Identification at a Distance (HumanID)

Core Biometrics



Face

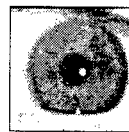


Gait

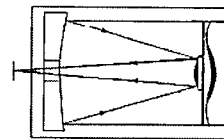


Facial IR

Novel Techniques



Iris



Sensors

Data

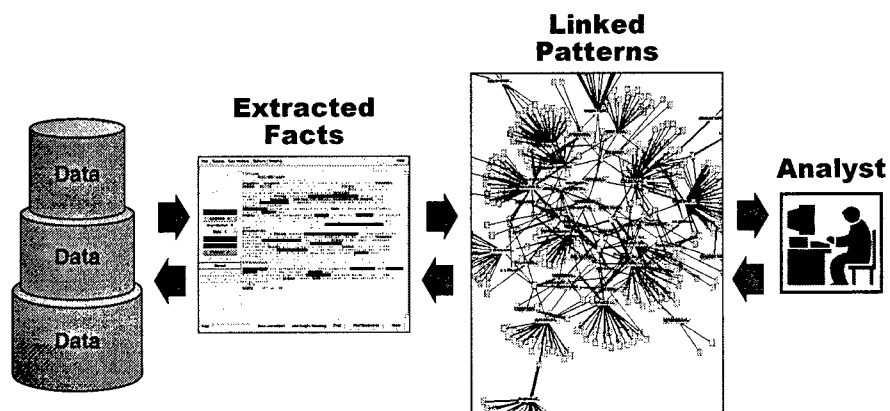


4

Asymmetric Threat Projects

- Human Identification at a Distance
- Evidence Extraction and Link Discovery
- Wargaming the Asymmetric Environment
- Project Genoa
- Rapid Knowledge Formation
- Agent-Based Computing

Evidence Extraction and Link Discovery



Evidence Extraction for Link Discovery Step 1: Extracting Relational Facts

OnAClient
File Options Help

Who does Osama bin Laden support? [Send] [Clear]

Results

... *Hartakul Jihad group, reportedly backed by Saudi dissident Osama bin Laden ... (3/14/99, AFP)*

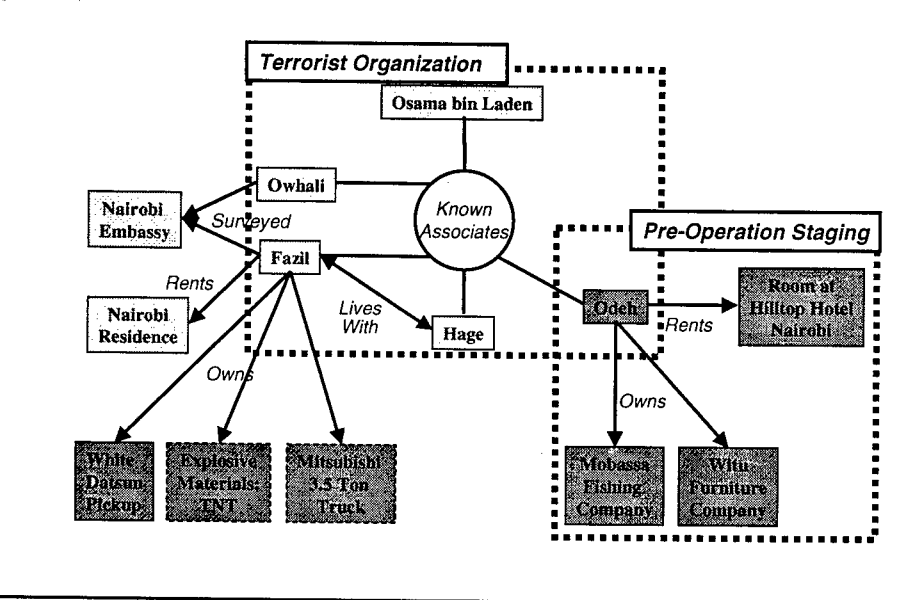
support (Osama bin Laden, Hartakul Jihad group)
is_a (Osama bin Laden, Saudi dissident)
manner (support, reportedly)

... *Osama bin Laden, sought by United States as is behind an armed Moslem movement active in*

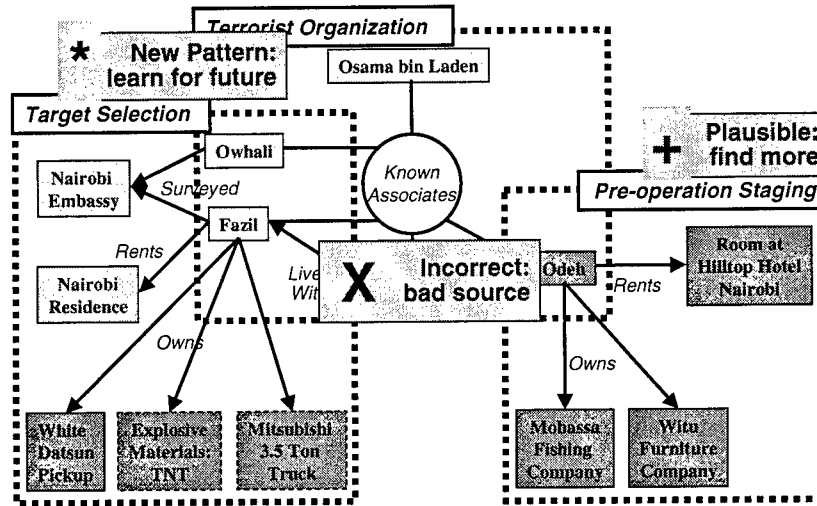
support (Osama bin Laden, armed Moslem movement, Algeria)
location (armed Moslem movement, Algeria)
oppose (United States, Osama bin Laden)
is_a (Osama bin Laden, terrorist)
charact. (terrorist, dangerous)

Link Analysis Tool

Evidence Extraction and Link Discovery Step 2: Recognizing Relational Patterns



Evidence Extraction and Link Discovery Step 3: Analyst's Feedback



Asymmetric Threat Projects

- Human Identification at a Distance
- Evidence Extraction and Link Discovery
- Wargaming the Asymmetric Environment
- Project Genoa
- Rapid Knowledge Formation
- Agent-Based Computing

Project WAE

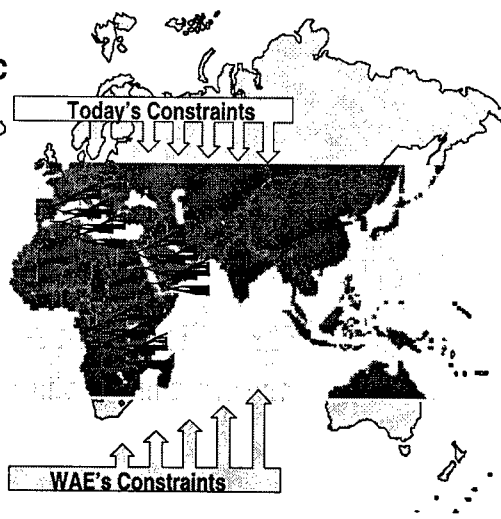
Prediction & Emulation

• Today's Asymmetric Environment

- ◆ Data
- ◆ Data mining tools
- ◆ Analyst experience

• WAE's Asymmetric Environment

- ◆ Predictive Modeling
- ◆ Emulation



Conventional Warfare

Operations Other Than War (OOTW)

Terrorism Counter-Terrorism

Project WAE

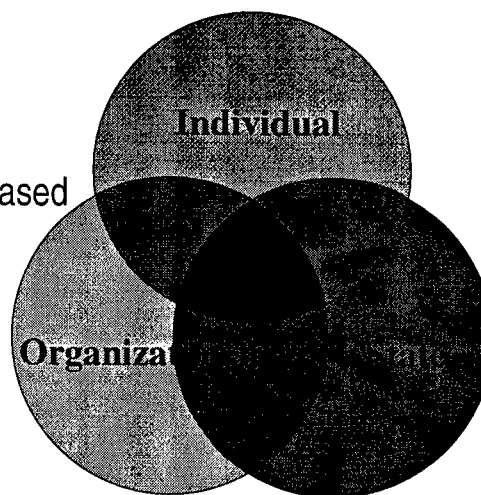
Prediction & Emulation

• Existing State of the Art

- ◆ Generic models
- ◆ Optimization or doctrine-based

• WAE's Approach

- ◆ Behavior
- ◆ Intrinsic (i.e. cognition)
- ◆ Extrinsic (i.e. culture)

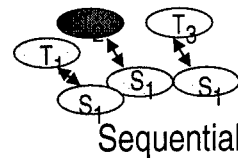


Project WAE Prediction & Emulation

Existing State of the Art

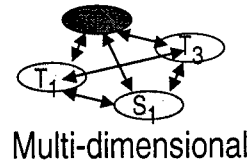
- ◆ Sequential opponents
- ◆ Cumulative Error

Two very different results



Technology Areas Of Interest

- ◆ Multi-dimensional games
- ◆ Non-zero sum game
- ◆ Valuated state space for qualitative data



Upcoming BAA's

Evidence Extraction and Link Discovery

- ◆ Expected in the Fall of 2000

Wargaming the Asymmetric Environment

- ◆ Expected in the Fall of 2000

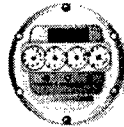
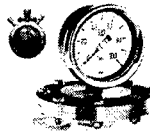
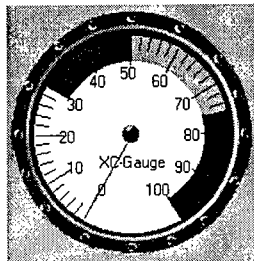
GARPATECH

ESSE

ISO

Dynamic Assembly for System Adaptability, Dependability and Assurance (DASADA)

The
software
revolution
requires
dynamic
gauges



But
gauges
made it
happen
And an
ability to
dynamically
update and
use models



John Salasin, PhD
Information Systems Office



GARPATECH

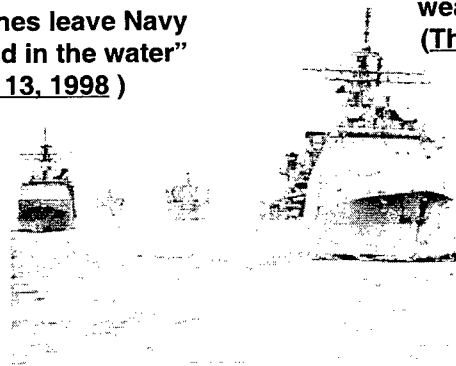
ESSE

ISO

Problem

**"Software glitches leave Navy
Smart Ship dead in the water"
(GCN July 13, 1998)**

**"Glitch in combat systems
software knocks out
weapons capability"
(The Virginian-Pilot,
July 8, 1998)**

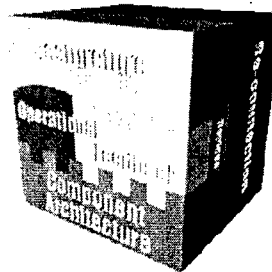


**We can't completely model today's complex systems.
Therefore, we can't: Understand them; Predict them;
Control them; Automatically compose or adapt them.**

Why DASADA

Industry hasn't done it,
 DoD needs it

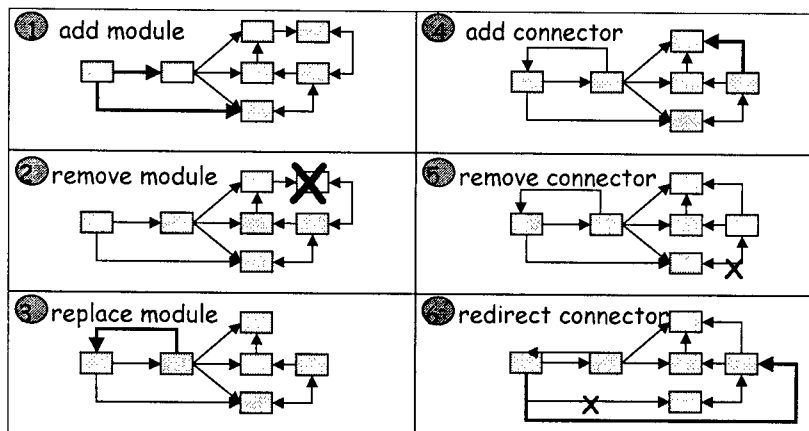
Software Fix(s), re-connector(s),
 glue and gauges



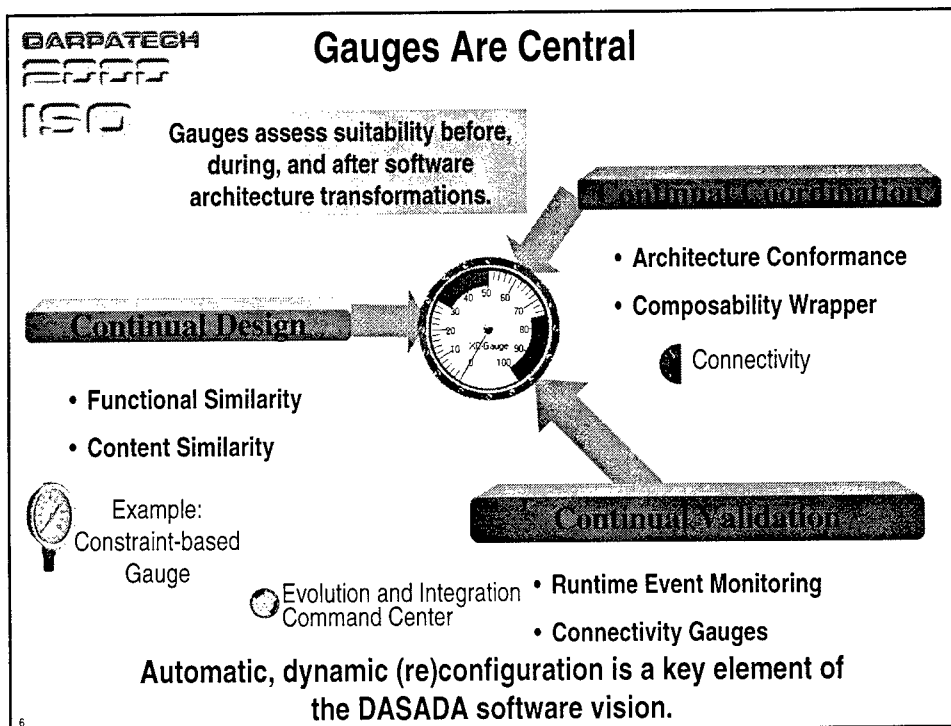
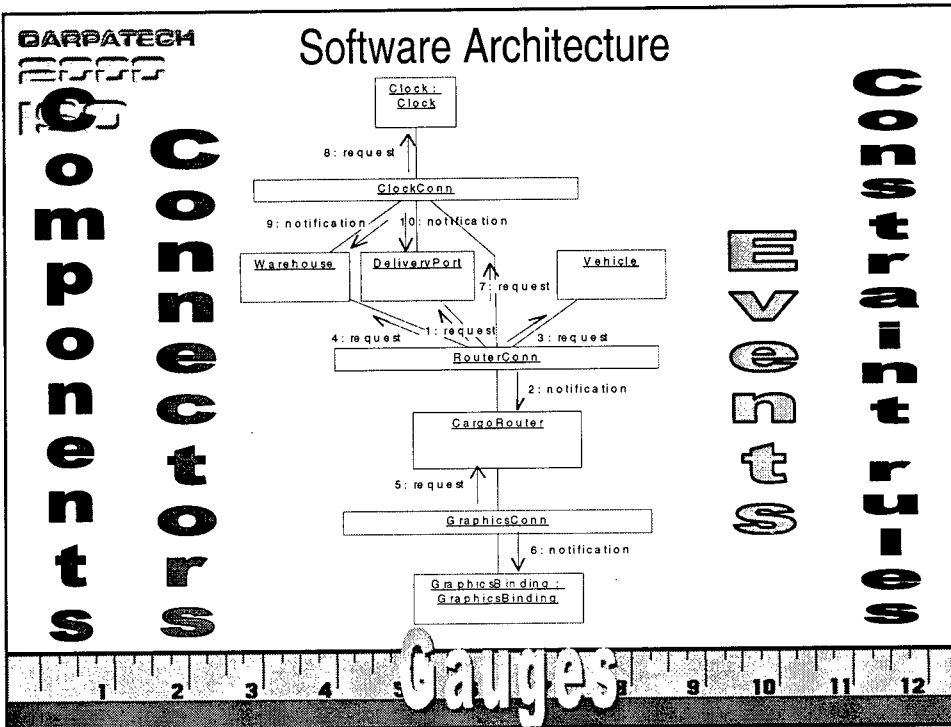
Predictable composition is key to reduced cycle time

- Dynamically assemble, reconfigure, and evolve systems
- Easily introduce new components to add functionality
- Adaptively and dynamically scale systems
- Continuously upgrade components

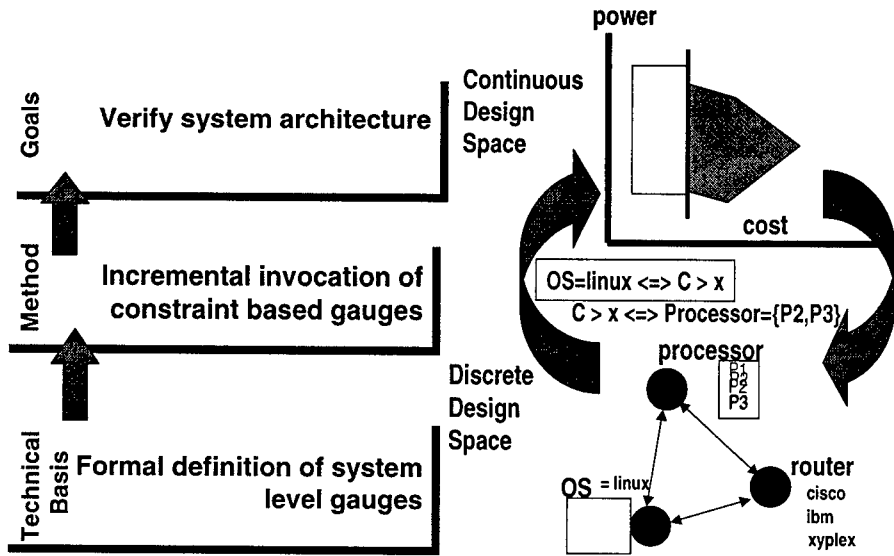
Transformation Based Architecture



Assess suitability before, during, and after architecture transformations

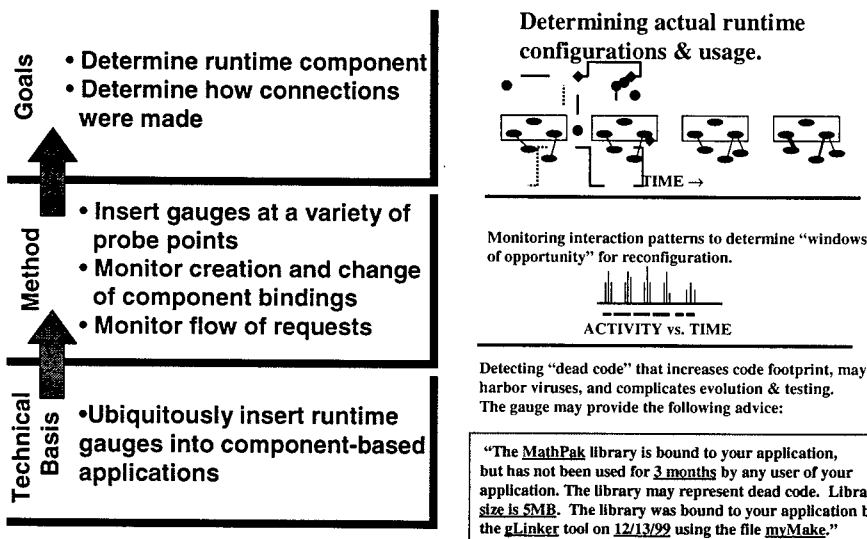


Constraint Gauges



7

Connectivity Gauges



8

Gauge Infrastructure: Evolution and Integration Command Center

Goal	• Enable “go/no-go” decision for re-configuration tasks • Monitor “live” evolution of systems

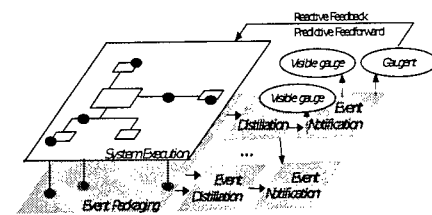
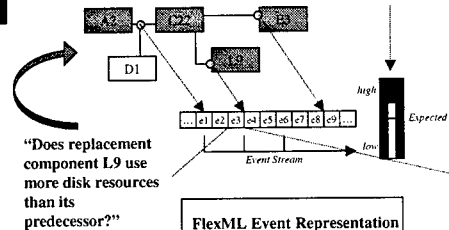
Method

- Rapid hypothesis testing
- FlexML event description
- Dynamic probing of components

- Architectural models show how to develop testing regiment

"monitor average server HTTP response time as the new database back-end engine is brought on-line"

Insert probes based
on Architectural Mode
Generate gauges

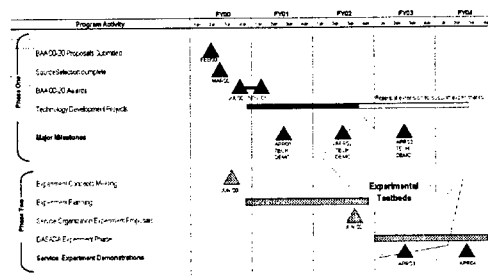


DASADA Phase 2: New Opportunities: Transition Technology to Experiments

GUARANTEE CRITICAL PROPERTIES

REDUCE TIME TO INTEGRATE

INCREASE ASSURANCE EFFICIENCY



Phase 2 Plans

- (Partially) funded planning efforts in FY01-02 (estimate \$25K/year)
- Experiments conducted in FY03-04 (estimate 2-3 @ \$5,000K each)
- Requires application by DoD organization

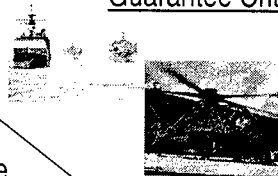
Looking for programs with:

- Real problems
- Ability to evaluate the impact of the technology(ies)
- Interest and commitment of the Service organization and contractor(s)

Example Problems for Technology Transition to Experiments

Guarantee Critical Properties

Architectural assessment
guarantees critical
properties



Reduce Time To Integrate



Models of architecture and
behavior reduce
integration time/cost.

NEW OPPORTUNITIES

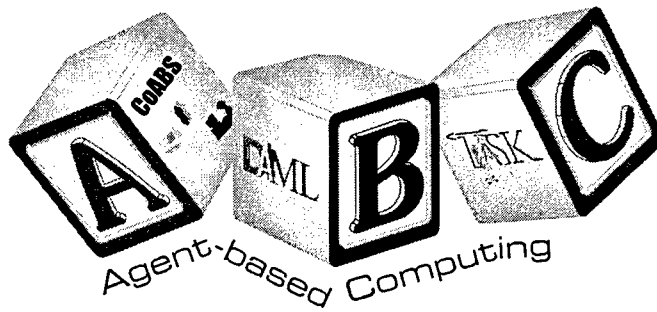
Increase Assurance Efficiency



Update models and axioms based
on operational experience

Action Items

- Watch our progress – at ISO WWW site.
- Think about becoming active in planning an experiment – info at ISO WWW site
- Contact us (jsalasin@darpa.mil)



Jim Hendler
Information Systems Office

"Agent" is used for many things...

Mobile Code "Intelligent" Interfaces "Disembodied" Code
Applets Semantic Brokering
Information Filtering Negotiation Protocols
Distributed Component Libraries
Information Extraction
Auction Mechanisms UAV Ops Dynamic Middleware
Active Messaging Robots Search Tools
Mobile Networking

...And the DoD needs all of them!

- **These capabilities map to critical military problems**

- ◆ Asset assignment in real-time <-> e-comm auction mechanisms
- ◆ Bandwidth restrictions <-> active messaging
- ◆ Comm QoS problems <-> mobile code
- ◆ Data visualization <-> interface agents
- ◆ Elint filtering <-> disembodied "monitor" code
- ◆ Field upgradable software <-> applets
- ◆ Gathering open source intelligence <-> Info agents
- ◆ High speed, small unit ops <-> autonomous behaviors
- ◆ Information assurance <-> agent wrappers
- ◆ Joint force & coalition interoperability <-> agent middleware
- ◆ Zero casualty ops <-> UAVs, robots

Which grow out of the definition of agency

- **An agent is a software component or system that is:**

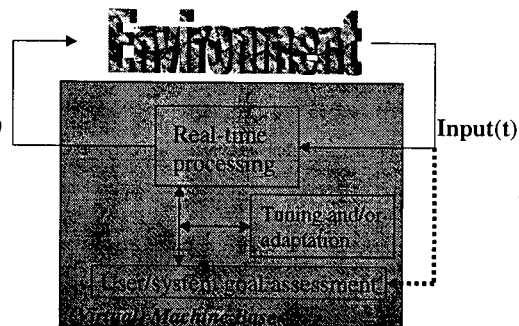
- ◆ Dynamic in its behaviors (not single I/O mapping)
- ◆ Embedded in, and "aware" of, an environment
- ◆ User enabled/steered, but "empowered" to act for user
- ◆ Able to improve its behavior over time

Autonomous
 Communicative
 Capable
 Adaptive



These are important properties for software systems

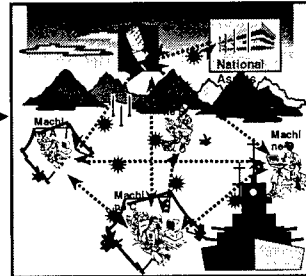
Output(t+1)



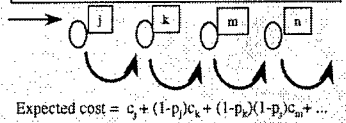
DARPA's ABC programs merge science and practice

- **Military TIEs stress *interoperability***

- ◆ OOTW
 - NEO Challenge Problem
- ◆ Theater Ballistic Missile Defense
 - Used in Fleet Battle Experiments
- ◆ Coalition Force Interoperability
 - DERA/AFRL/DARPA Project underway
- ◆ Others
 - Air Mobility Command, JIATF-E



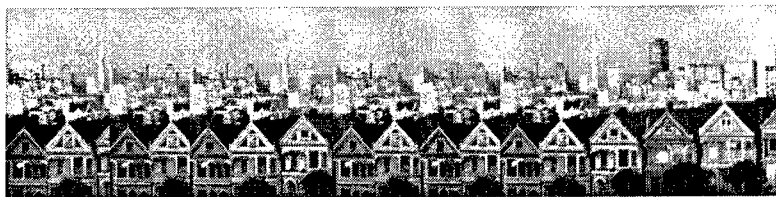
Site j "costs" c_j to visit and has probability p_j of success.
 Visit sites until none left or successful.



- **Scientific TIEs stress *scaling***

- ◆ Negotiation Experiments
 - 1st results favor auctions
- ◆ Mathematical Analyses
 - New results for agent mobility
- ◆ Control Scheme Comparison
 - Analysis of time/ Experiments designed

Common Architecture

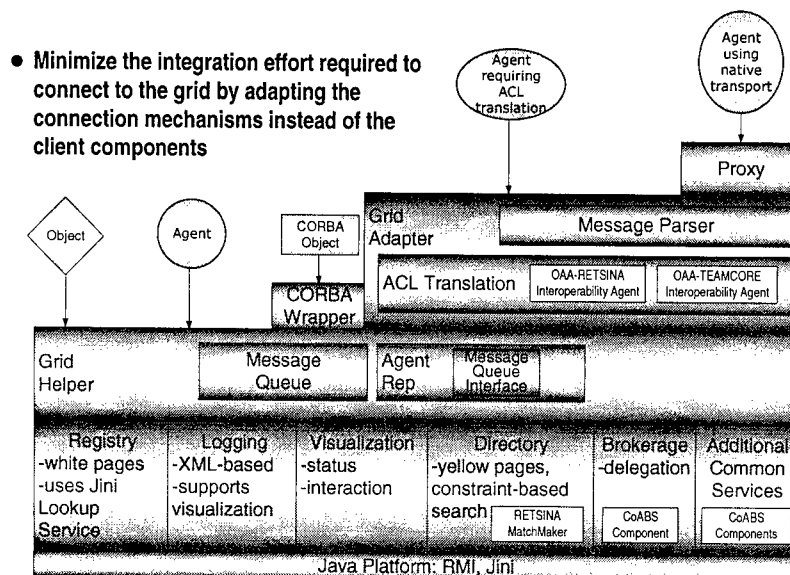


VS

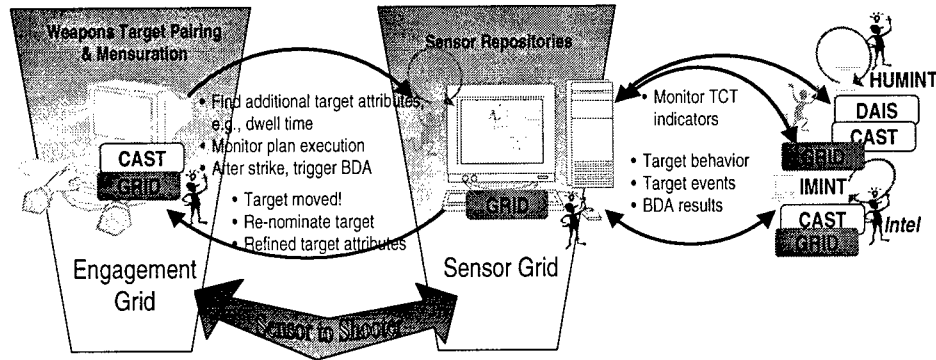


Heterogeneity

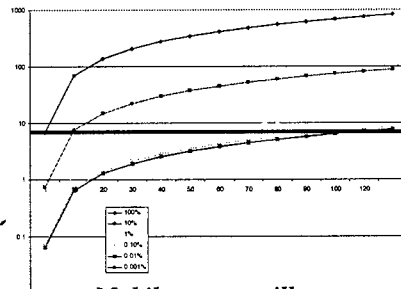
CoABS Grid “Architecture”



Agents CAST/Grid used in Missile Defense Cell, Fleet Battle Experiment - Foxtrot, Dec 1999



Agents Analysis of Bandwidth Usage



Mobile agents will decrease bandwidth usage. More powerful servers help, not hurt, scaling possibilities when bandwidth limited.

- Analyzed scaling of mobile-agents based on performance parameters from FBE-Echo
- Developed mathematical model of bandwidth trade-offs for mobile-agent vs. broadcast of information (limitation: assuming homogeneous information needs across space)

Computational resources allocated to agent j from client i is S_{ij} . Using on the server machine is:

$$T_{op}(i, j) = \frac{c_{ij}(D, R_{ij}, B_{ij})}{S_{ij}}$$

For example, only the relevant data is sent back to the client machine. The transmission channel is B_{ij} . The data transmission time is therefore given by:

$$T_{tr}(i, j) = \frac{D_{ij} R_{ij} B_{ij}}{B_{ij}}$$

The total time is the sum of the computation time and the transmission time:

$$T_{tot} = \max_{i=1, \dots, n} \max_{j=1, \dots, m} \left(\frac{c_{ij}(D, R_{ij}, B_{ij})}{S_{ij}} + \gamma \frac{D_{ij} R_{ij} B_{ij}}{B_{ij}} \right)$$

$$= \max_{i=1, \dots, n} \max_{j=1, \dots, m} \left(T_{op}(i, j) + \gamma T_{tr}(i, j) \right)$$

Grid Transition Plan

- **Beta Release of Grid (FY99- 3QFY00)**
 - ◆ CoABS demo described previously
 - ◆ Working with other DARPA Programs (ALP, CPoF, AIA)
- **Military Transitions Focus of 3QFY00-FY02**
 - ◆ Navy Fleet Battle Experiments (Funded by CoABS)
 - ◆ Air Mobility Command (Funded by AFRL, uses Grid)
 - ◆ Bilateral Air Planning (Funded by UK DERA, AFRL; uses Grid)
 - ◆ Intelink Management Office (Funded by IMO, DARPA)
 - ◆ Possibility of use for CC21 ACTD (ONR lead)

New Program: DAML (DARPA Agent Markup Language)

```
<Title> Beyond XML
<subtitles> agent semantics </subtitles> </title>
<USE-INTROLOGY ID="pp" ontology" VERSION="1.0" PREFIX="pp" URL=
"http://wp.darpa.mil/ppr.html">
<CATEGORY NAME="pp presentation" FOR="http://wp.darpa.mil/handler/agents.html">
<RELATION-VALUE POS1="Agents" POS2="handler">
```



DAML:

Create technologies to enable software agents to identify, communicate with, and understand other software agents dynamically (i.e., on the fly at run time, not built in at development time).

```
<INTROLOGY ID="presentation ontology" VERSION="1.0" DESCRIPTION="Some model for
presentation presentation">
<DEF-CATEGORY NAME="Task" IS-A="Flex Feature">
<DEF-CATEGORY NAME="Subtask" IS-A="Flex Feature">
<DEF-RELATION NAME="role-of"
SUBSET="as a role of"
<DEF-ARG POS=1 TYPE="presentation">
<DEF-ARG POS=2 TYPE="presentation">
```

DARPA Agent Markup Language

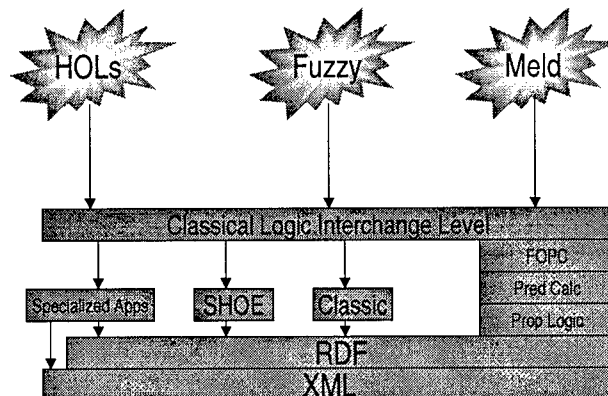
- **DARPA is working on the development of the DARPA Agent Markup Language (DAML)**

- ◆ A "semantic" language that ties the information on a page to machine readable semantics (ontology)
 - Currently being explored at University level
 - ◆ SHOE (Maryland), Ontobroker (Karlsruhe), OWL (Washington Univ)
 - ◆ Largely grows from past DARPA programs (I3, ARPI)
 - But not transitioning
 - ◆ W3C focused on short-term gain: HTML/XML

```
<Title> Beyond XML
<subtitle> agent semantics </subtitle> </title>
<USE-ONTOLOGY ID="PPT-ontology" VERSION="1.0"
PREFIX="PP" URL="http://iwp.darpa.mil/ppt..html">
<CATEGORY NAME="pp.presentation"
FOR="http://iwp.darpa.mil/jhender/agents.html">
<RELATION-VALUE POS1 = "Agents" POS2 = "/jhender">
```

```
<ONTOLOGY ID="powerpoint-ontology" VERSION="1.0"
DESCRIPTION="formal model for powerpoint presentations">
<DEF-CATEGORY NAME="Title" ISA="Pres-Feature" >
<DEF-CATEGORY NAME="Subtitle" ISA="Pres-Feature" >
<DEF-RELATION NAME="title-of"
SHORT="was written by">
<DEF-ARG POS=1 TYPE="presentation">
<DEF-ARG POS=2 TYPE="presenter" >
```

DoD and W3C working together



DAML and the "Semantic Web"

TASK Description



Create the engineering
discipline of agent-based
computing

Infinite-horizon problems: $V_t = V_t$ for any t and r .

1. Expected value per time step
2. Expected cumulative value until goal reached (e.g., $E(v)$)
3. Expected discounted cumulative value for discount $0 \leq \gamma \leq 1$

Discounted case

- The value of being in state x after n stages is $\gamma^n V(X = x)$.

- Let $\Omega_X = \{1, 2, \dots\}$ and the state transition probabilities

$$p_{ij}(d) = P(X_t = j | X_{t-1} = i, D_t = d) \quad i, j \in \Omega_X \quad d \in \Omega_D$$

- A policy δ maps states Ω_X to actions Ω_D

- Expected discounted cumulative value for policy δ and state i

$$E_\delta(E_i X = n) = V(X = i) + \gamma \sum_{j \in \Omega_X} p_{ij}(\delta(X = i)) E_\delta(E_j X = n) \quad i \in \Omega_X$$

- The optimal expected discounted cumulative value

$$E(E_i X = n) = \max_{\delta} E_\delta(E_i X = n) \quad i \in \Omega_X$$

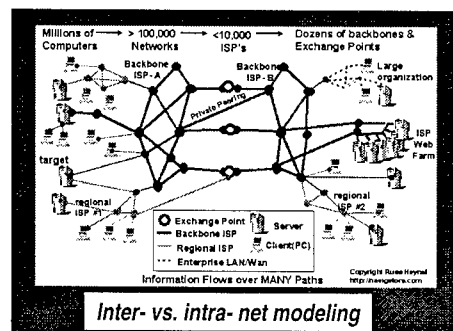
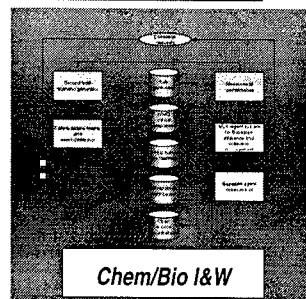
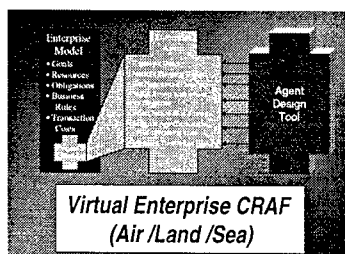
- Which satisfies the optimality equation

$$E(E_i X = n) = \max_{\delta} \left[V(X = i) + \gamma \sum_{j \in \Omega_X} p_{ij}(\delta(X = i)) E(E_j X = n) \right] \quad i \in \Omega_X$$

Optimal Bayesian State Estimator

$$\pi(t)(x) = \frac{Pr(y(t) | X_t = x) \sum_{x' \in \Omega_X} Pr(X_t = x' | X_{t-1} = x', u(t)) \pi(t-1)(x')}{\sum_{x' \in \Omega_X} \left[Pr(y(t) | X_t = x') \sum_{x'' \in \Omega_X} Pr(X_t = x'' | X_{t-1} = x'', u(t)) \pi(t-1)(x'') \right]}$$

TASK Challeng(ing) Problems



Task PIs will "strut their stuff" against
three currently unsolvable problems

Conclusions

- **Agents are important to the military...**
 - ◆ Across a wide variety of problems
 - Early results already exciting
- **... But much R&D remains to be done**
 - ◆ Just because it is software, it does not have to be soft science...
 - Solid experimental studies can be performed
 - ◆ ... But the theory of computing needs fixing
 - Largely based on a 40-year old model of computation
- **DARPA is taking the DoD lead in understanding this new form of computation**
 - ◆ CoABS: Ongoing program (3rd year)
 - ◆ DAML/TASK: New Starts, BAA still open (16 DAML projects & 15 TASK projects already funded)

"Press clippings"

From DSB "21st Century Defense Technology Strategies", Nov. 1999

"A key program at DARPA in this technology area is called CoABS. The goal of this program is to design, implement, and test a prototype 'agent grid'...[the DoD] must continue to fund the science and technology initiatives that will lead to the intelligent agents envisioned herein. DARPA and the Service laboratories have focused their resources on developing intelligent agent technology that leverages and supplements private-sector technologies in order to meet warfighter needs."

"DAML could take search to a new level", PC Week, Feb. 7, 2000

"A new language known as DAML addresses an important unmet need --- making Web sites more understandable to programs and nontraditional browsing devices...One advantage DAML may have over other emerging web technologies is the involvement of DARPA, which has been instrumental in the creation of the Internet and many Internet technologies."

Figure 5-4 shows one approach to building such a grid of agents, currently under development in DARPA's Control of Agent-Based Systems (CoABS) initiative ... This combination of agent-based codes, agent mark-up languages, and an interoperability infrastructure that enhances agent (and legacy) communication provides an "information web" structure that goes beyond the specific needs of the JBI. However, the study team sees this infrastructure as a military necessity, and the study team joins the Defense Science Board and others in endorsing the military development of such an approach ... transition of DARPA agent technology to AFRL has begun, and the study team recommend high priority be given funds for this transition --
From AF SAB, "Building the Joint Battlespace Infosphere", Nov. 1999

"An effort is about to begin to establish a new agent language intended to progress well beyond current Web languages (HTML, XML) that will provide readable (interoperable) semantics." **From NSB, "Network-Centric Naval Forces", 2000**

Fleet Battle Experiment (FBE) reviews by CDR, USN

"I believe we have made significant strides in application of the agent technology to the Navy future warfighting concepts. I view CAST as a long term investment--the acorn that may grow into a giant oak tree 5-10 FBEs down the road. FBEs are conducted every six months and are iterative, incremental concept development events and we are very supportive of continued CAST involvement in future FBEs."

DARPA Tech 2000

Advanced Technology Office Overview

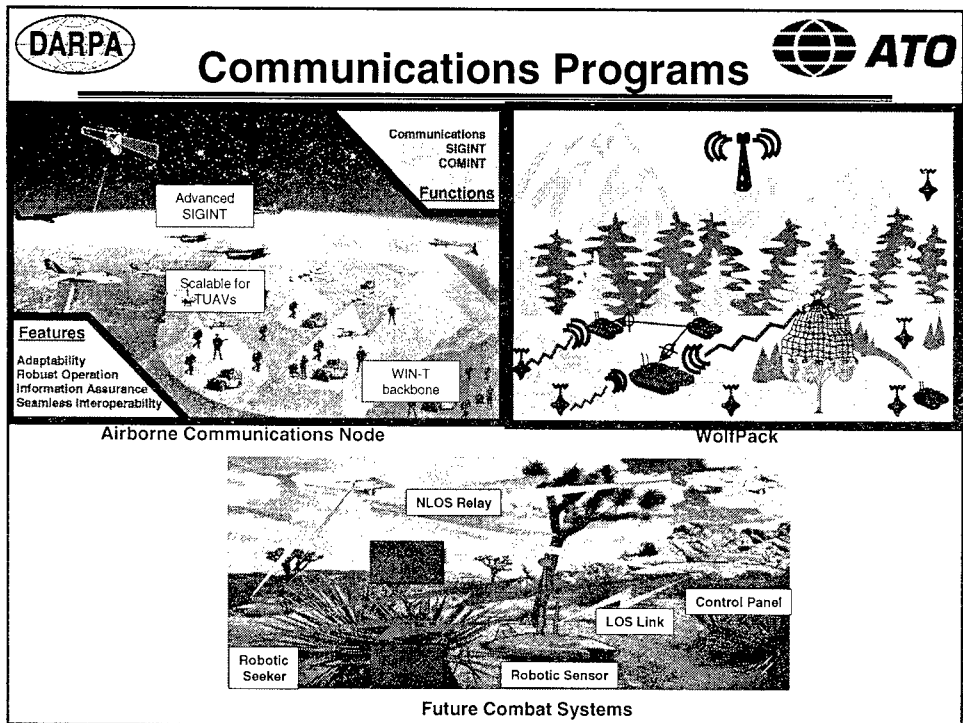
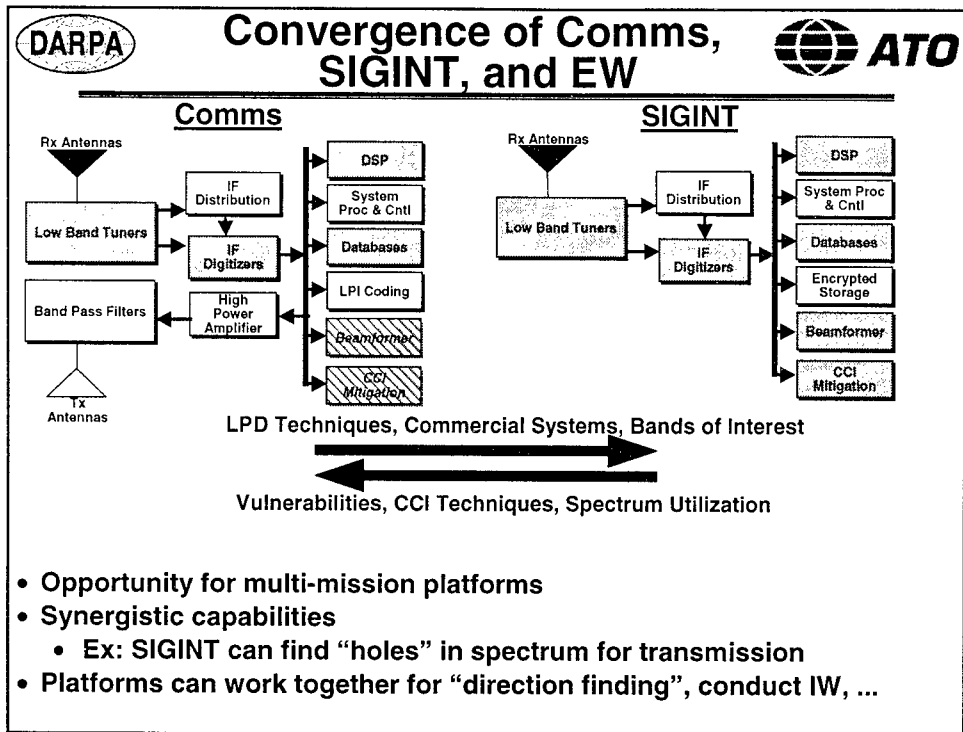
Dr. Thomas Meyer
ATO Director
September 2000



Focus Areas



- **Communications**
- **Maritime**
- **Early Entry/Special Operations**

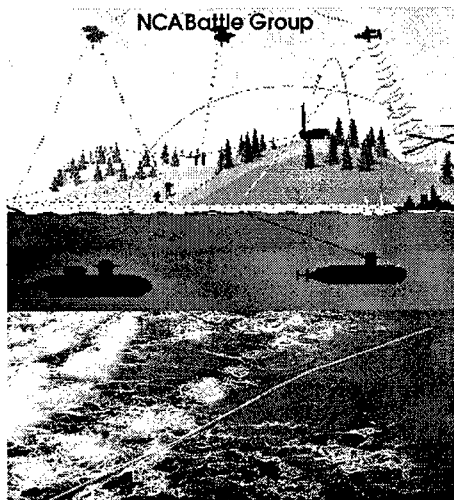




Buoyant Cable Antenna Array (BCAA)



ATO



- Joint DARPA/Navy prototype effort
- Coherently combine signals from multiple, floating, inter-connected antenna elements to provide high data-rate submarine connectivity
- Satellite-limited connectivity to a submarine at depth and speed



Communications Challenges

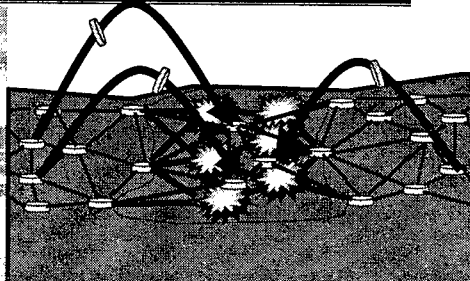
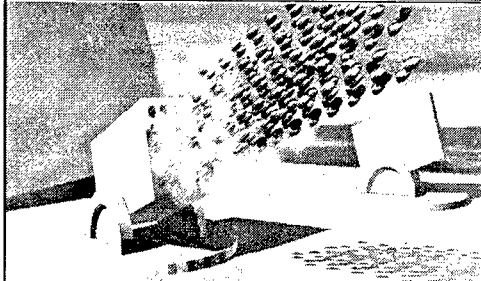


ATO

- Bandwidth
- LPD/LPI Waveforms
- RF Information Assurance
- Mobile Ad-hoc Networks
- Accurate Geolocation

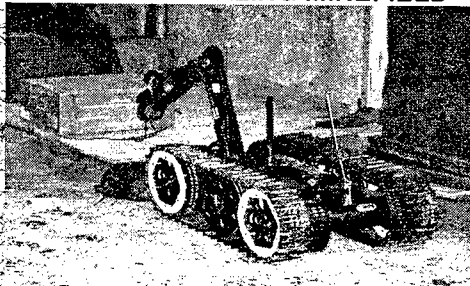
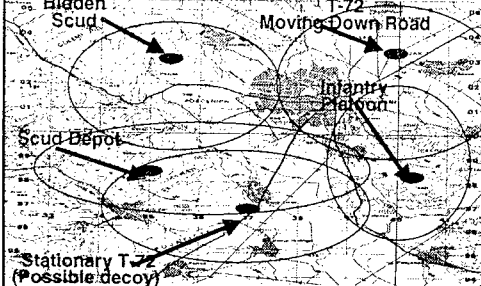


Early Entry/Special Operations Programs



METAL STORM

SELF-HEALING MINEFIELD

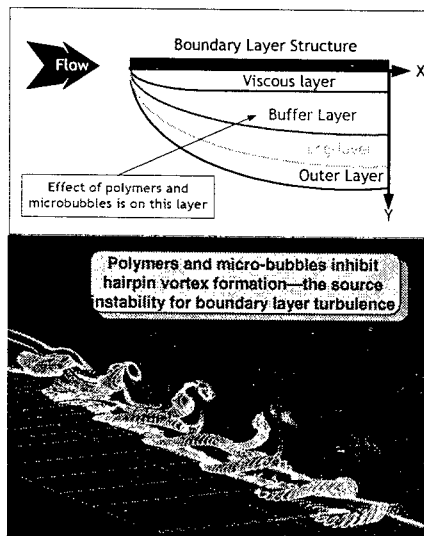


TACTICAL SENSORS

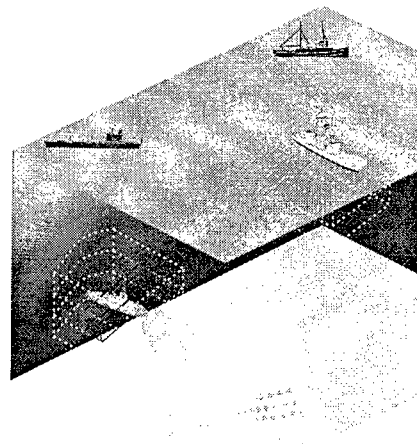
TACTICAL MOBILE ROBOTICS



Maritime Programs



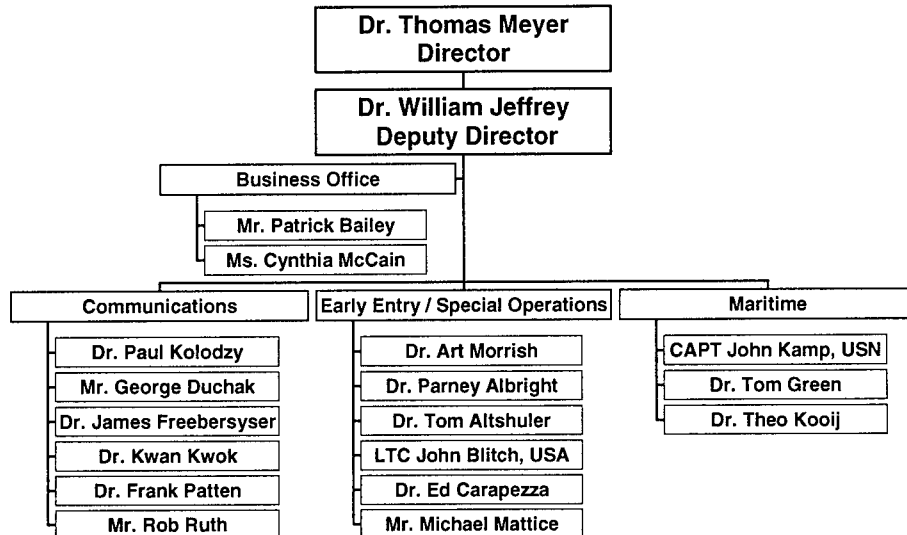
Friction Drag Reduction



Robust Passive Sonar



ATO Staff



<http://www.darpa.mil/ato>



Opportunities



- **New Programmatic Opportunities**

- WolfPack
- Future Combat Systems C3
- Robust Passive Sonar
- Friction Drag Reduction

- **Advanced Technologies BAA for FY01**

- Looking for Great Ideas

- **Looking for great people in all areas**

DARPA Tech 2000

WolfPack

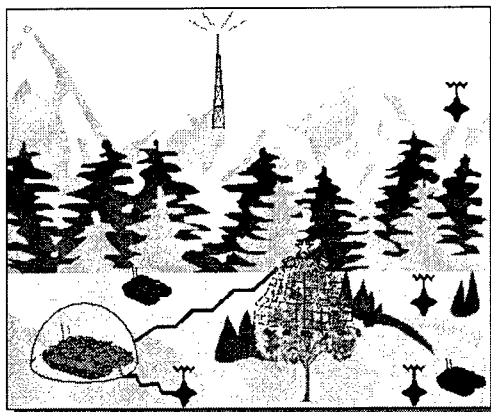
Dr. Paul Kolodzy
Program Manager
(pkolodzy@darpa.mil)



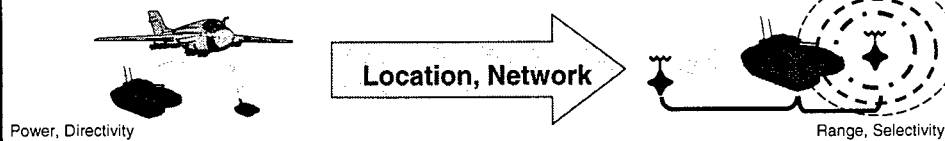
WolfPack



- Deny the enemy the use of radio communications (20 to 2,500MHz) throughout the battlespace by a distributed network of emplaced autonomous, cooperative jammers and
- Avoid disruption of friendly/neutral radio communications



Precision, distributed jamming over a 100 km by 100 km area

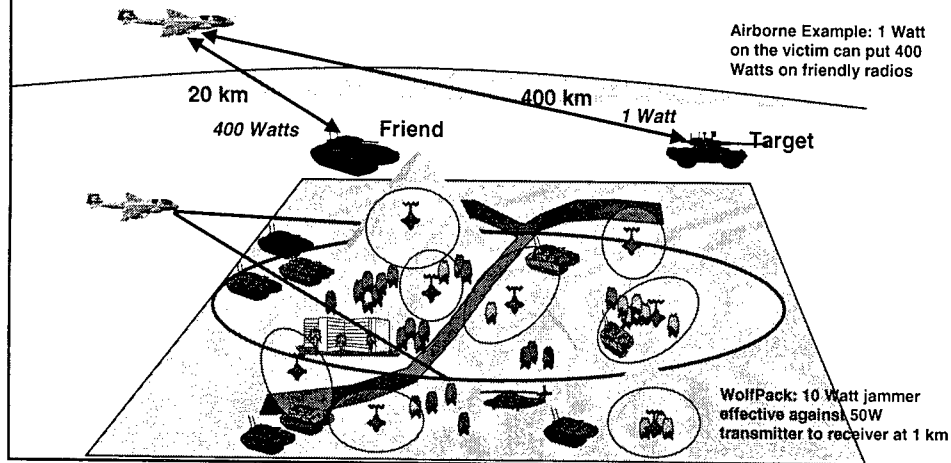


DARPA



Distributed Jamming

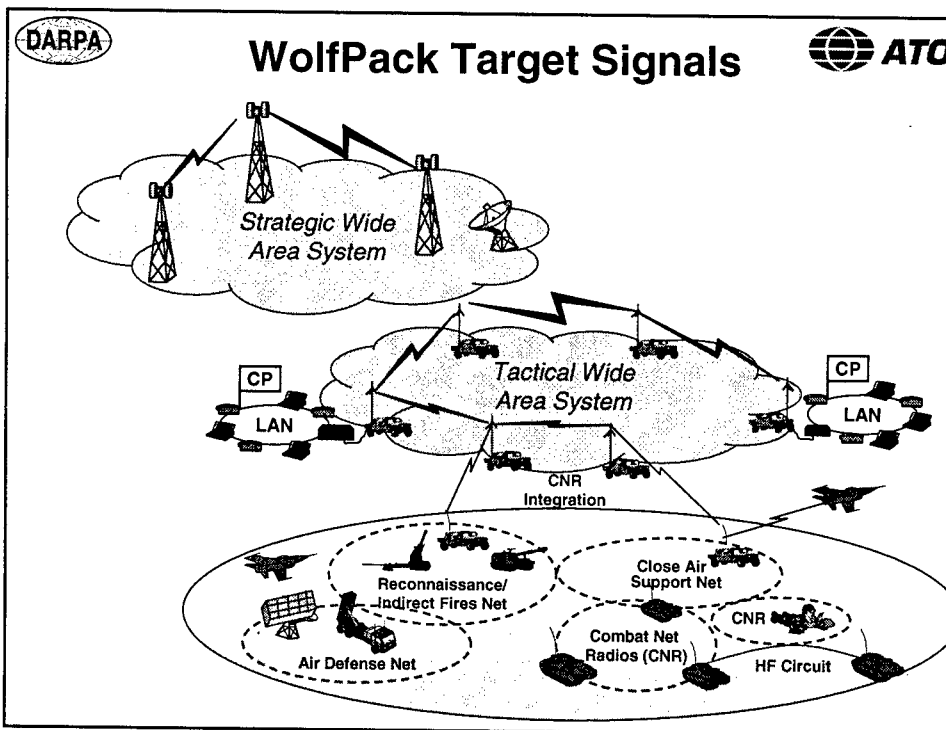
- Airborne jammers can impact friendly communications (Near-Far Problem)
- WolfPack networked, close-approach jamming concept
 - Precisely reacts to target emitters with low power and energy requirements
 - Significantly reduces Blue communications fratricide



DARPA



WolfPack Target Signals





Prevent Enemy Reporting and Coordination of Ground Forces

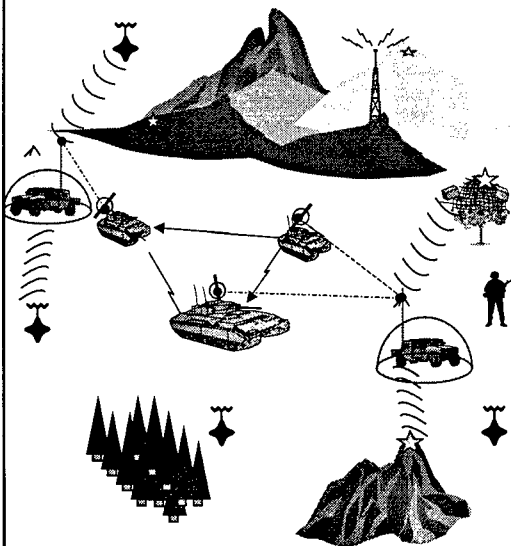


Electronic Counter Measures Mission

- Spectrum Characterization
 - System detects transmissions
 - Determines network links and nodes, and projects intent
- WolfPack Reaction
 - Prevent (jam) link closure
 - Exfiltrate enemy emitter information
- Result
 - Enemy C2 denied and targets identified

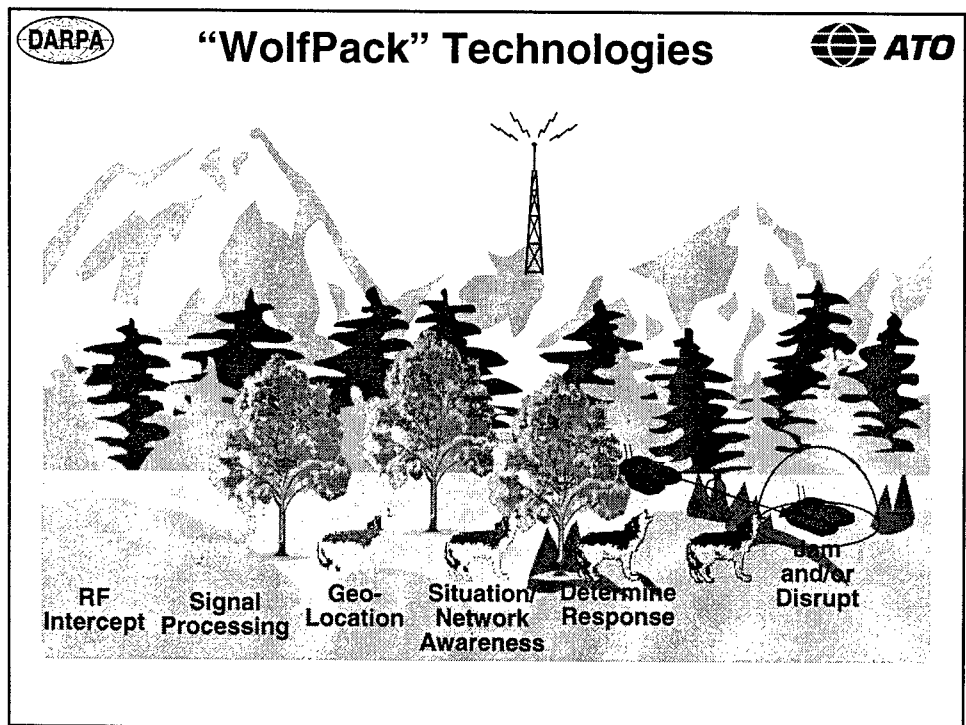
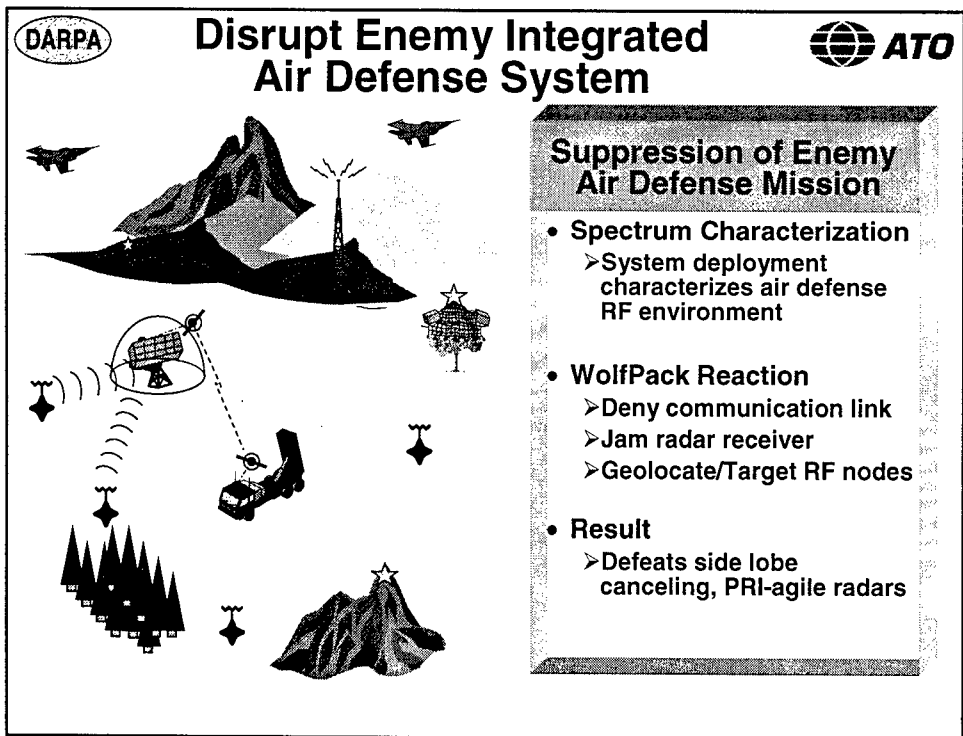


Prevent Enemy Detection of Friendly Communication



Electronic Counter Counter Measures Mission

- Spectrum Characterization
 - System detects enemy locations and networks
 - Analyzes friendly networks
- WolfPack Reaction
 - Raise "local noise level" on friendly force frequency
- Result
 - Friendly transmissions and intentions are masked



DARPA Tech 2000

Warfighter Visualization

Dr. Norman Whitaker
nwhitaker@darpa.mil



Thrust Areas



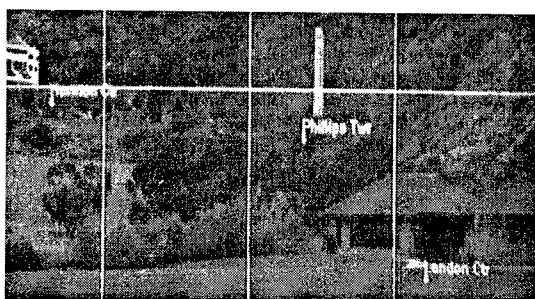
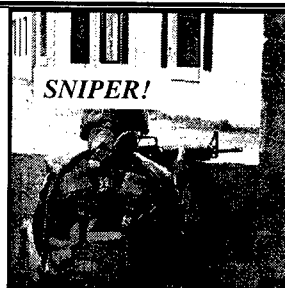
- **Visualization Tools for Individuals and Small Teams**
- **2D and 3D Environments**
- **Targeting from Unmanned Aerial Vehicles**



Warfighter Scene Overlays



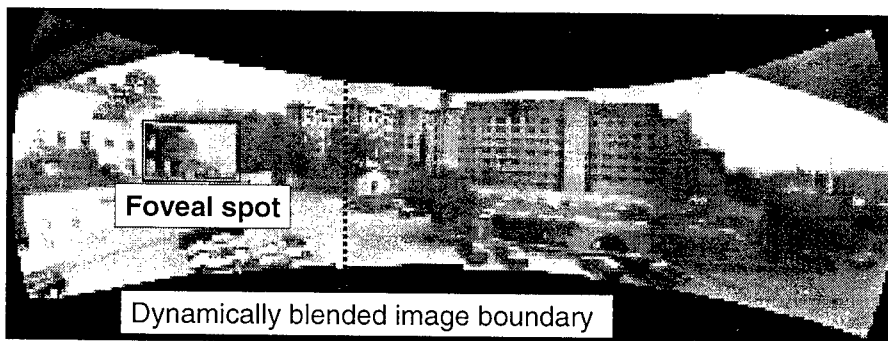
- Tactical annotations in “warfighter coordinates”



USC, HRL



See Through Turret



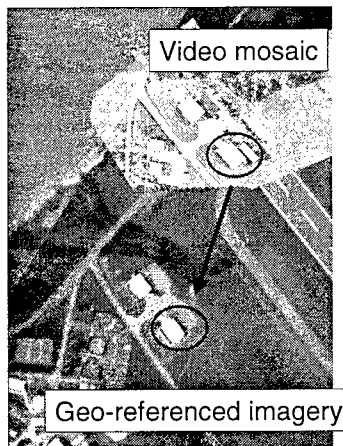
- 360° views for “buttoned up” commander



Honeywell, Sarnoff



Real-time UAV Video Geo-registration



TIGER Targeting System: Used during Allied Force

Sarnoff, Cambridge Research



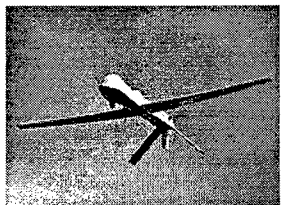
JSTARS-UAV Cross-Cueing



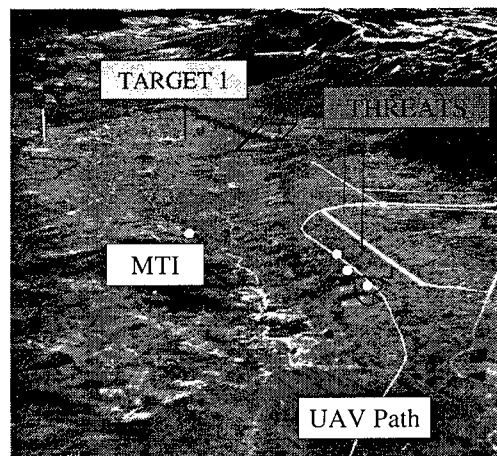
• Visualization for UAV sensor operator



JSTARS



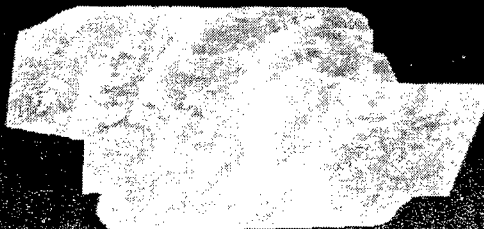
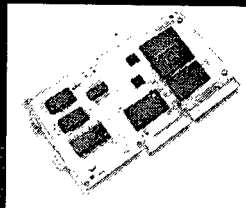
PREDATOR



Cambridge Research, USAF UAV Battlelab



Sample Acadia Chip Capabilities ATO



Moving Target Indication



3D Visualization

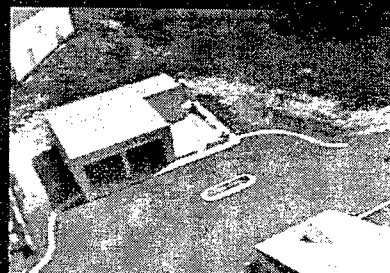


GOALS

- Registration of video to 3D model
- Projection of new views



Raw ground video



Raw aerial video

Samoft



3D Visualization Results



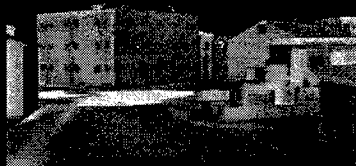
Video registered to model



"Flashlight" video



Re-rendered view



Runner's Viewpoint



Airborne Communications Node (ACN)

George Duchak

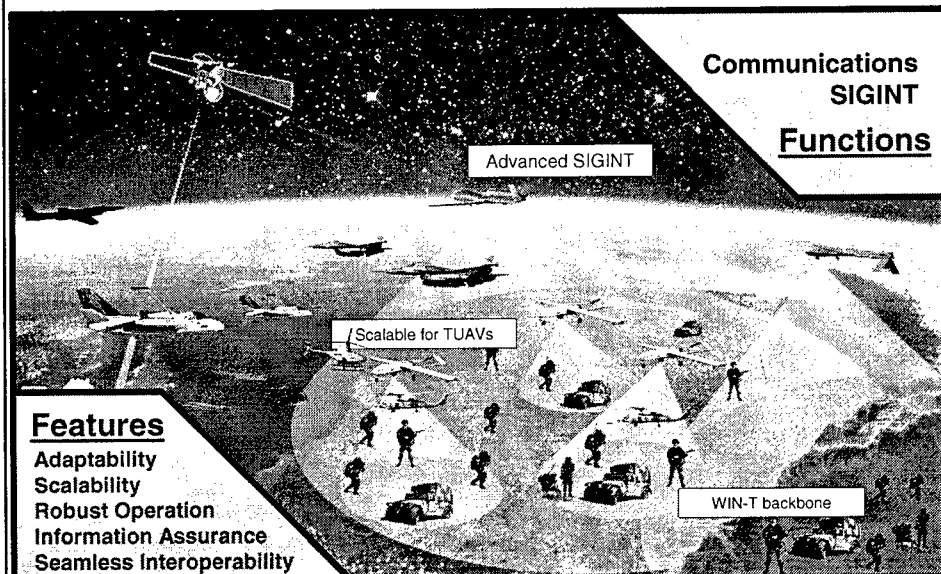
(gduchak@darpa.mil)



ACN390-001

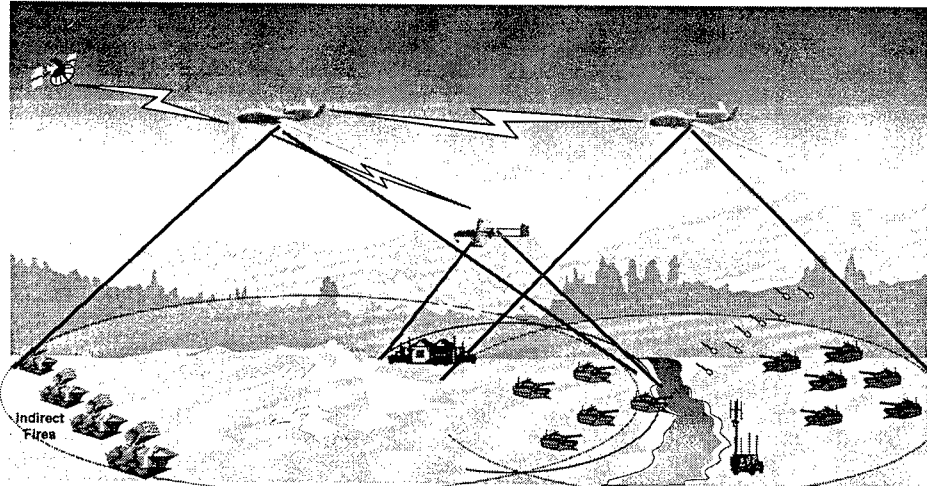


Airborne Communications Node (ACN) Concept





ACN Utility



- BLOS Connectivity
- Relief of SATCOM Oversubscription
- "Surge" Communications and Tactical SIGINT Capacity
- Reduced Logistics for Comm Infrastructure
- Enhanced Mobility
- SIGINT / Communications Synergy

ACN377-001



ACN Utility: Relieve SATCOM Oversubscription



Within the Battlespace:

- 2.5 GBPS Wideband (170 Accesses)
- 675 Narrowband Networks

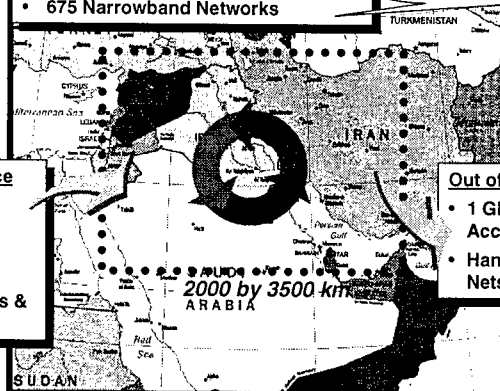
"Within the Battlespace"

Requirements are:

- > 50% of Wideband Total
- > 95% of Narrowband Total

Into the Battlespace

- 1.15 GBPS Wideband (360 Accesses)
- Hand-full of Narrowband Nets & P-Ps



Out of the Battlespace:

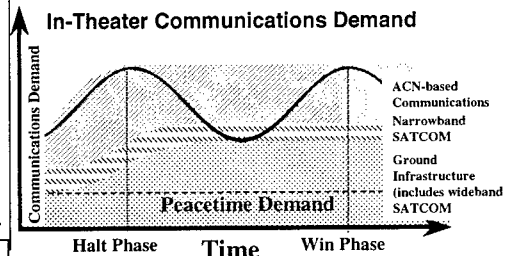
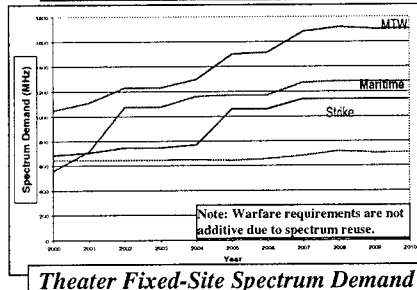
- 1 GBPS Wideband (310 Accesses)
- Handful of Narrowband Nets & P-Ps

ACN Can Offload "Within the Battlespace" Accesses and Provide BLOS Connectivity to Fiber Nodes for "Outside the Battlespace" Accesses

Source: "The Demand for SATCOM Today and in the Future", J6



"Surge" Communications Capacity ATO



Surge Capacity ACN Provides Dynamic "Surge" Capacity to Meet Communications Demands

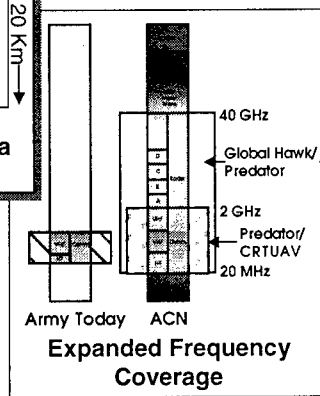
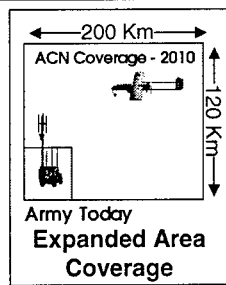
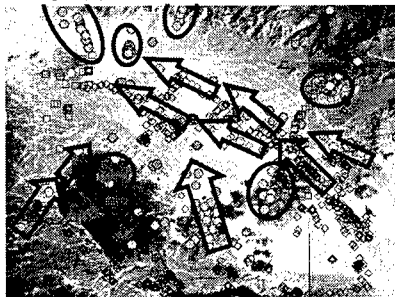
	Global Hawk	CRTUAV	Predator
Frequency	30 MHz - >17 GHz	30 MHz - >2.8 GHz	30 MHz - >17 GHz
BW/Ch	>40 MHz	>40 MHz	>40 MHz
# Channels	>100	> 4	12 - 16
Weight	<900 lbs	20-25 lbs	~100 lbs

Demand from OSAM "Warfighter Spectrum Requirements Analysis", 19 April 2000



Tactical SIGINT ATO

Example Tactical Situational Awareness



Payload Functionality

- Emitter Characterization
- Emitter Geolocation
- Nodal Analysis
- Spectrum Mapping



Reduced Logistics & Improved Mobility



Army Gulf War Communications Infrastructure

ARMY COMMUNICATIONS

- One Theater Signal CMD
- Three Signal Bde HQS
- One JCSE
- Five EAC Signal BNS
- Eight Corps Signal BNS
- Eight DIV Signal BNS
- ~ 13,000 Soldiers

LIFT

- 40 C5s



- 24 Ships

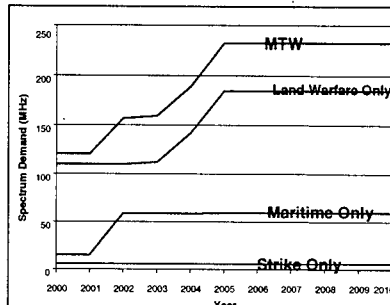


Mobility

- Demand for Mobile Communications Services Will Increase 92% by 2005
- Supports Mobile Ad Hoc Networking

Logistics

ACN Reduces the Support Required to Build and Maintain the Comm and SIGINT Infrastructure

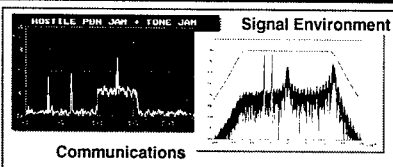


Mobile Spectrum Demand

Demand from OSAM "Warfighter Spectrum Requirements Analysis", 19 April 2000



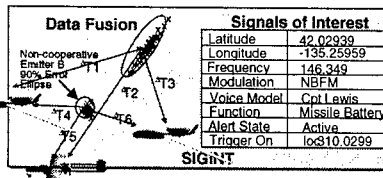
Communications / SIGINT Synergy



Communications

- Wideband Receiver Can Support:
 - + Dynamic Spectrum Allocation -- Transmit in the Spectrum "Holes"
 - + Signals-of-Interest (SOI) Detection

- Onboard Assets Can Track SOI
 - + Crosslinks for Precise Geolocation
 - + Antenna and Signal Processing Supports Tracking with a Single Platform



Signals of Interest

Latitude	42.02939
Longitude	-135.25959
Frequency	146.349
Modulation	NBFM
Voice Model	Cpt Lewis
Function	Missile Battery
Alert State	Active
Trigger On	loc310.0299

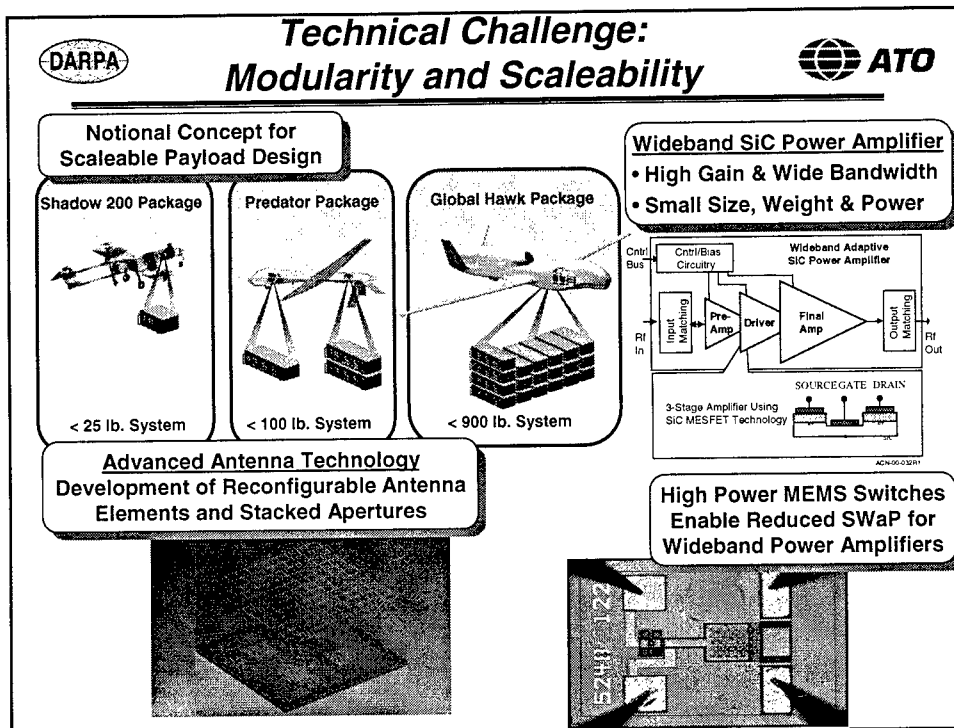
Information Warfare Protocol Stack

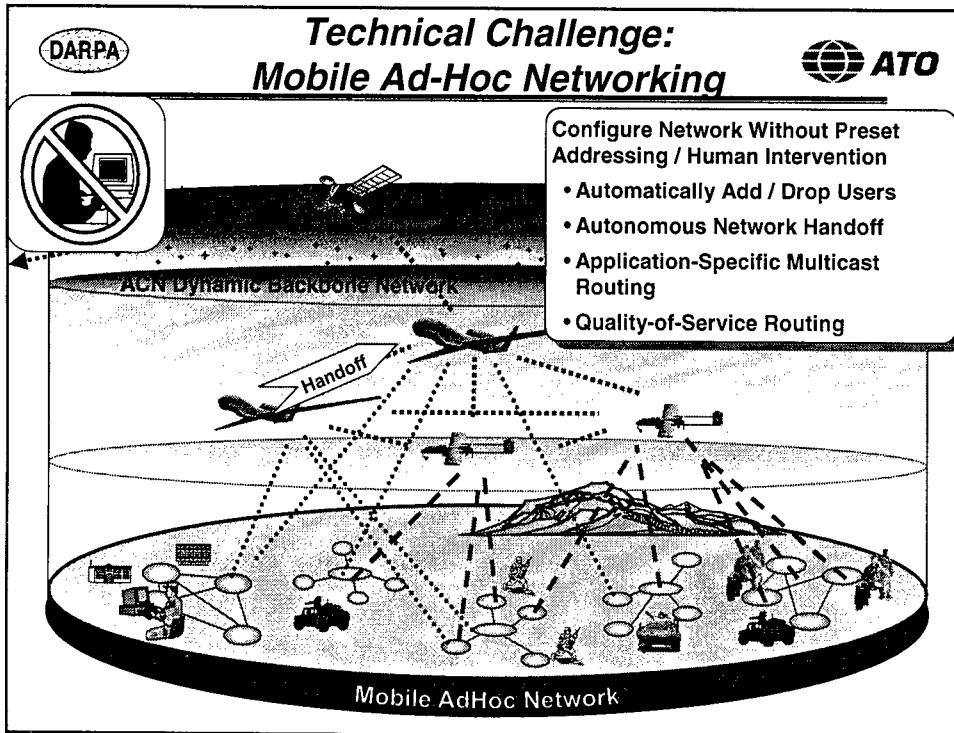
APP	APP	APP	APP
DATA	DATA	DATA	DATA
NET	NET	NET	NET
PHY	PHY	PHY	PHY

Surgical Attacks

- Modify the SOI and Retransmit the Signal for Information Warfare

- Common Hardware & Software Reduces:
 - + Size, Weight, and Power
 - + Life Cycle Cost





ACN Opportunities

DARPA **ATO**

<u>Major Program Events</u>	
Phase II Program Kickoff	May 2000
Architecture Review	Sep 2000
System Performance Review	Sep 2001
System Design Review ("PDR")	Jan 2002
Phase III Readiness Review ("CDR")	Aug 2002

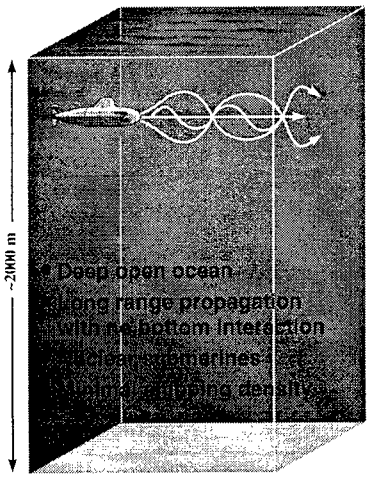
DARPATECH 2000

Robust Passive Sonar

Dr. Thomas J. Green, Jr.
Program Manager
September 2000

 **Anti-Submarine Warfare (ASW)**  **ATO**

Cold War ASW



~2000 m

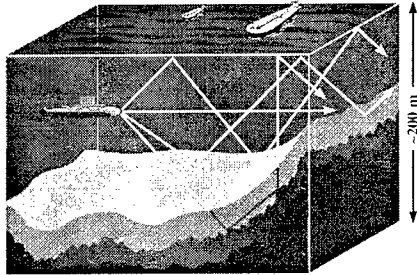
Deep open ocean

Long range propagation with no bottom interaction

Quiet submarines

Minimal shipping density

Current Littoral ASW



~200 m

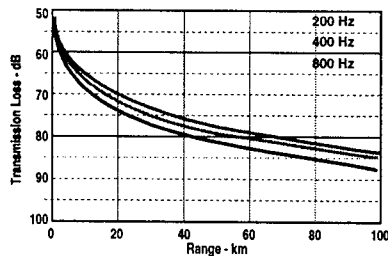
- Shallow water coastal regions
- Multipath propagation with significant attenuation
- Quiet diesel-electric submarines
- Significant shipping noise interference
- Dynamic engagements



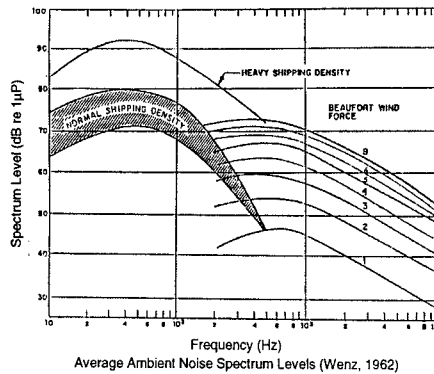
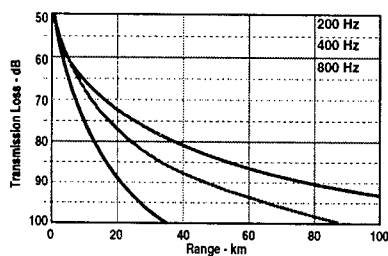
Littoral ASW Implications



April Strait of Korea



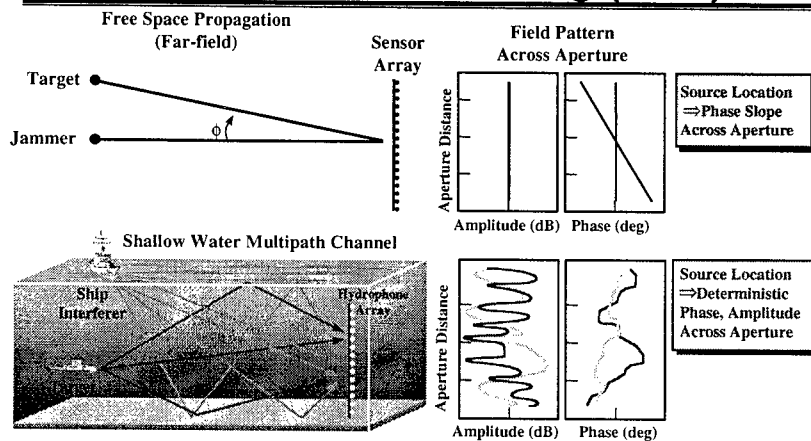
September



Loss of sensitivity due to heavy shipping density can produce dramatic reductions in detection range

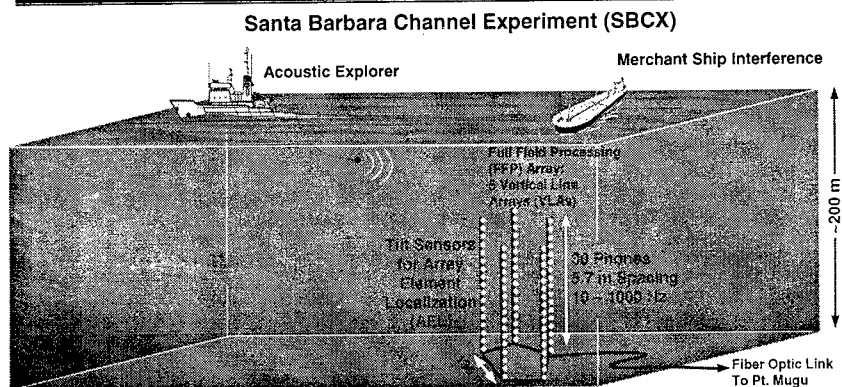


Matched Field Processing (MFP)



- Steering vector derived from propagation model
- Exploits channel multipath for detection/localization
- Adaptivity rejects interference and reduces sidelobes
- Main issues
 - Robustness to environmental uncertainty
 - Estimating scene statistics with limited snapshots

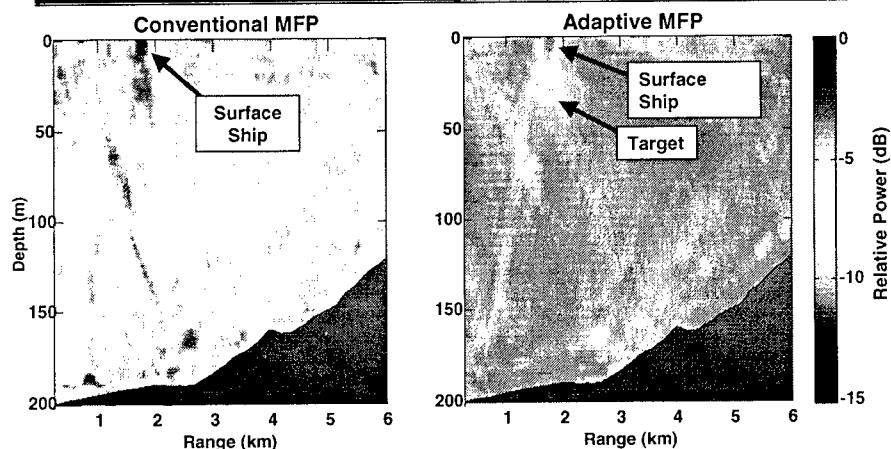
DARPA SB Channel Experiment (SBCX) ATO



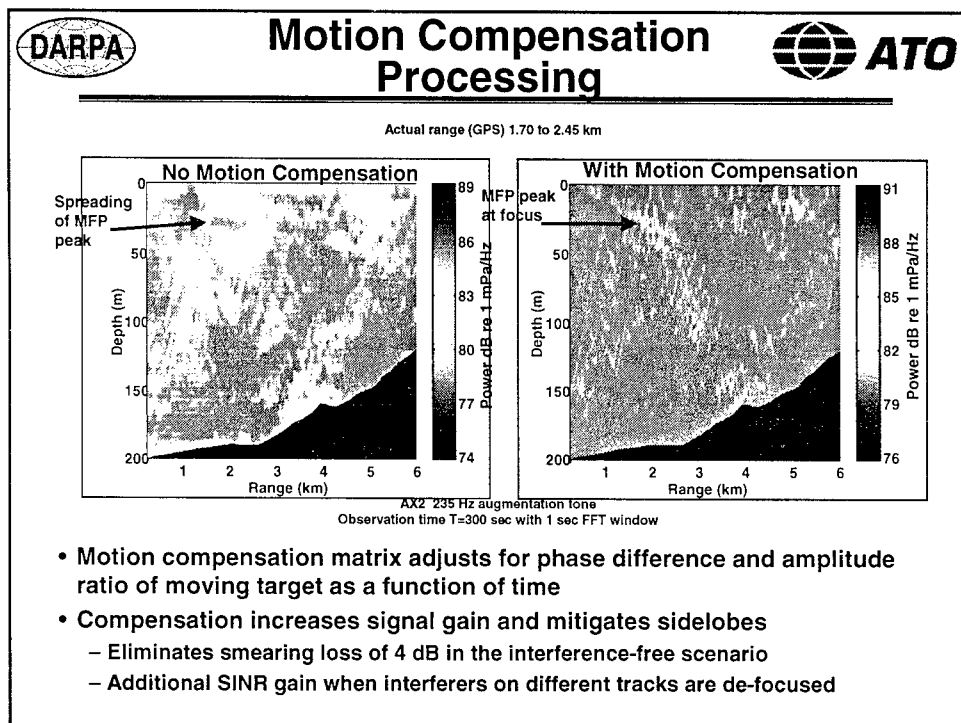
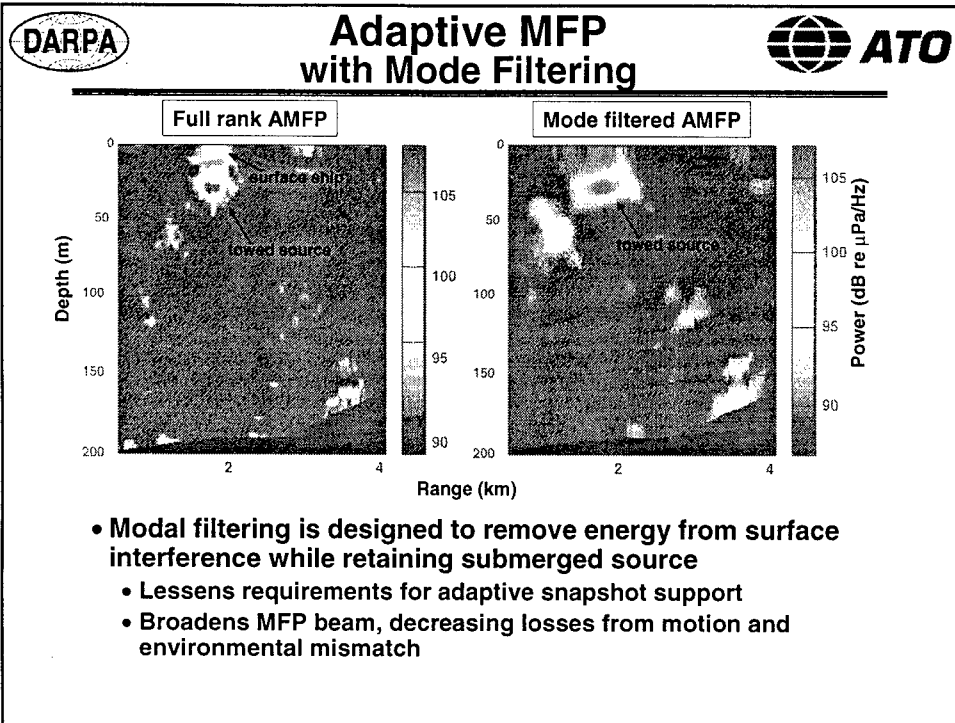
Objectives:

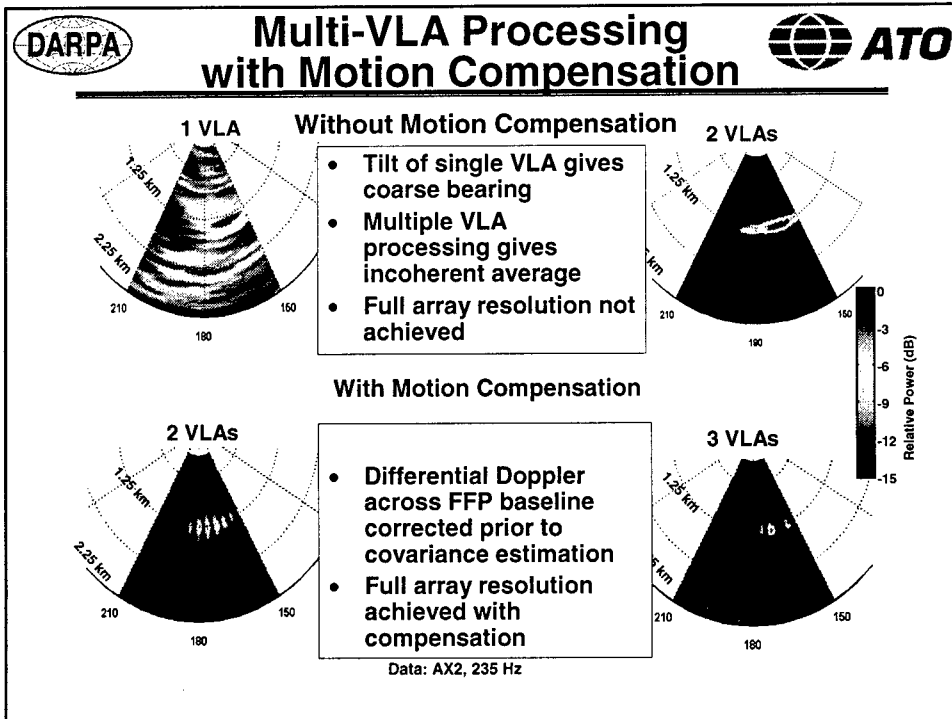
- Establish fundamental limits to signal and noise gains with Adaptive Matched Field Processing (AMFP) for passive broadband detection, localization, and classification
- Extrapolate measured performance to other threats, environments, and sensors of interest

DARPA Adaptive Target Localization with Surface Ship Interference ATO



AMFP utilizes adaptivity and environmental knowledge to provide correct localization of weaker, submerged source in the presence of surface interference







Robust Passive Sonar



Target sensors:

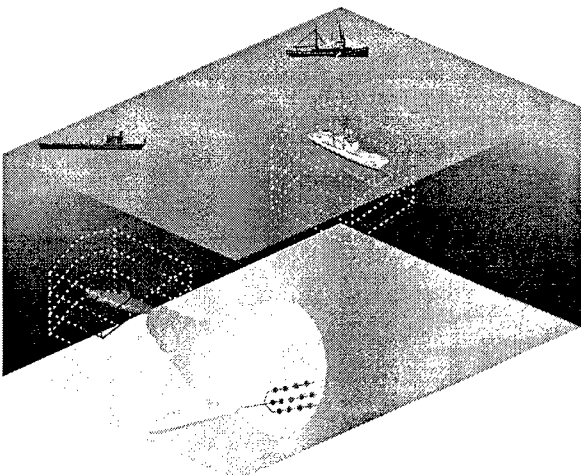
TB-29

- Large aperture with many elements
- Heading sensors to support advanced processing

SURTASS

Twin Line

Prototype Sensors



*Revolutionary Tactical Control for Littoral ASW:
> 10 dB Gain in Figure of Merit*



Approach



- Conduct system analysis for performance assessment
- Extend SBCX concepts to tactical systems
- Integrate processing techniques into end-to-end sonar
- Conduct focused sea tests and experiments
- Utilize high-quality, ground-truthed tactical data sets to verify performance



We Need Your Help!



Technology Areas

- Systems analysis
- End-to-End processing systems
- Advanced beamforming concepts
- Automation
- et al.

Procurement Plans

- Broad Agency Announcement
- Unsolicited white papers

New Ideas Needed



Drag Reduction Program

Dr. Penrose (Parney) C. Albright
palbright@darpa.mil



What are we trying to accomplish?

Develop friction-drag-reduction technology ...

With *demonstrable operational* value to the future naval and/or sealift fleets

Using extensive computational modeling and experiments

We will exploit *new approaches to multi-scale modeling...*

Developed within the materials science community

Enabled by massively parallel computer architectures

To develop a *multi-scale modeling capability*
for turbulent flow

We will leverage the simulation results to guide *focused* near-full-scale ($Re \sim 10^8$) experiments



Drag reduction implications



Speed at constant power is a weak function of drag

At least ~50% reduction in friction drag is required to meaningfully *increase speed*

Promising only when residual drag is insignificant

Proportional reduction in fuel consumed at constant speed

Potential increase in payload

- Long-range (long-endurance) ships have large fuel fractions ~0.2-0.5
- Military ships typically have small payload fractions — 0.1 or less
- E.g., 20% friction drag reduction $\Rightarrow$ ~50% increase in payload

Proportional increase in range and endurance at constant speed

Reductions in friction drag of <~20% probably uninteresting



Where we are today



Friction drag constitutes...

Roughly 50% of the drag on surface ships

Roughly 65% of the drag on submarines

Decades of research have identified two very promising techniques for reducing friction drag: polymers and microbubbles

70-80% reduction in skin-friction drag coefficient *in the laboratory*

But, success in the *practical* implementation of these techniques has eluded us for more than 25 years

- Too much polymer has to be carried, and the polymer degrades at high speeds
- Power requirements for injecting microbubbles are below the break-even point



Where we are today: Polymers ATO

Key Results

- ~80% reduction in drag in small-scale lab experiments
 - ~50% reduction for short periods in full-scale experiments

Significant recent advances in first-principles modeling

- Direct Numerical Simulation (DNS) with a constitutive relation for the polymer stress tensor
- Excellent qualitative agreement with experimental observations associated with drag reduction
- Indicated potential for optimization
 - E.g., equivalent drag reduction at 1/10 the needed concentration with 3x polymer chain extensibility

Limitations

- Number of grid points needed for a DNS simulation of *ship* flow prohibitive
 - Computational state-of-the-art for polymer modeling $Re_d \sim 5 \times 10^3$
 - ~ 10^6 grid points
 - Ship $Re_d \sim 10^6$
 - Number of grid points needed $\sim (Re)^{9/4}$



Where we are today: Microbubbles ATO

Key Results

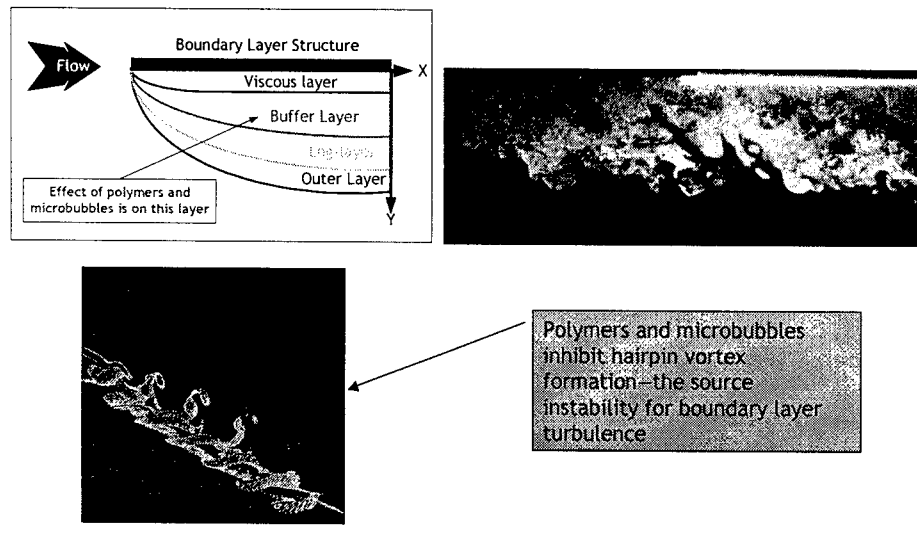
- ~80% reduction in drag demonstrated in small-scale experiments
- No full-scale data (Japanese planning an experiment)

Limitations

- Experimental results at low Re ($\sim 10^6$)
- No validated or accepted theory
- Rudimentary modeling; No DNS-level computations attempted



Impact of Polymers and Microbubbles



Approach (1 of 2)



Develop a *multi-scale* modeling capability

RANS modeling regime
 $Re_x - 10^8$

LES modeling regime
 $Re_x - 10^7$

- Models for KE; τ ; ϵ ; Π
- Boundary conditions

DNS modeling regime
 $Re_x - 10^5$

- Exact behavior at all scales
- Detailed modeling of different drag-reduction mechanisms
- Parametric studies

- Subgrid models
- Boundary conditions



Approach (2 of 2)



Perform *focused* experiments

Subscale (e.g., flat plate) experiments to test computational insights

Near-full-scale tests ($Re \sim 10^8+$) with *test-bed models* that address candidate high-payoff friction drag reduction concepts

With DNS, determine best drag reduction candidates

With engineering models, determine best implementation candidates

Fully exploiting simulation results at both *small* and *large* scales allows intelligent experimentation that is affordable and effective



Mid-term and Final Exams



Mid-term exam (~2.5 years)

Have we demonstrated a capability to predict the best techniques for drag reduction and their implementation?

- If yes, then do we believe we can achieve a 30–50% reduction in skin-friction drag *that can be practically implemented?*
- If no, then do we have high confidence that a continuation of the computational effort for 2 more years will be successful?

Final exam (4.5 years)

Have we demonstrated and experimentally validated a predictive modeling capability for skin friction drag reduction?

Have we demonstrated a 30–50% reduction in skin-friction drag *that can be practically implemented?*

Are these results validated in near-full-scale experiments?



Summary



Revolutionary friction-drag reduction (~50%) should be established as program goal

Decades of research can be leveraged to move toward militarily important technology

Considerable work done from molecular-scale theoretical through full-scale experimental regimes

Not reduced to practice after more than 25 years

Massively-parallel super computers, computational techniques, and existing experimental facilities could enable a breakthrough

Multi-scale modeling of turbulent drag reduction

Near-full-scale experiments closely coupled with models



Special Projects Office

James F. Carlini
Director

DARPA Tech 2000
8 September 2000

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Special Projects Office



Dominate Surface Threats

- Moving, Emitting, CC&D
- Underground Facilities
- Entire Kill Chain
 - Surv-Combat ID-Engagement-BDA
- Emphasize Robustness

Counter Emerging Threats

- Chem-Bio Defense Systems
- Cruise Missile Defense

Critical Supporting Technologies/Systems

- Navigation
- Advanced Sensors
- Signal Processing

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2



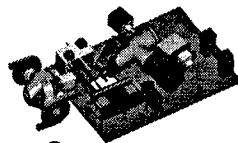
Chem/Bio Defense Activities



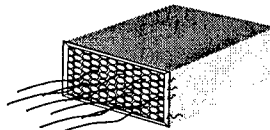
Component Technologies

- Detectors/ID
- Reporters
- Fluidics
- Collector materials
- Decon agents

Component Systems



- Sensors



- Filtration, etc.

Complete Defensive Systems



- Building Protection

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3

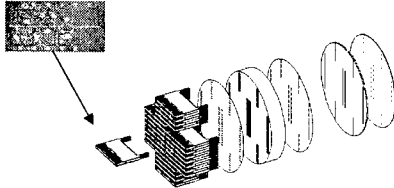


Low-Cost Missile Defense Technologies

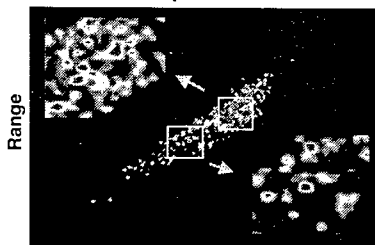


Seekers

MEMS ESA Antenna



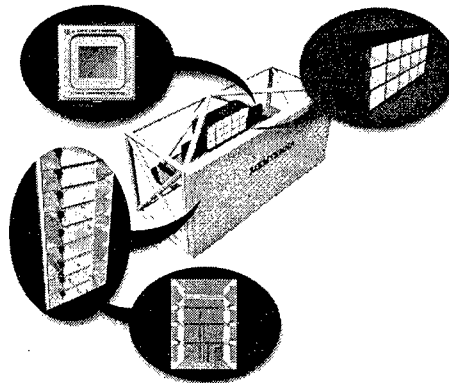
Noise Radar Map



Doppler

Fire Control Sensors

MEM-tenna



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4



Surface/Underground Threats



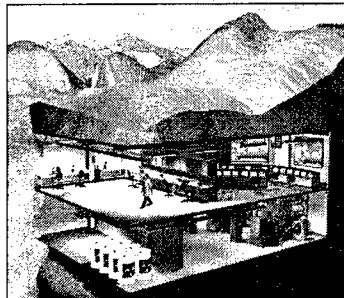
Foliage



Emitters



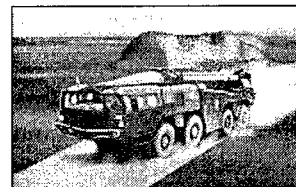
Underground



Decoys/Deception



Movers



Focus on Entire Kill Chain, Firepower, Affordability

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5



Counter Underground Facilities

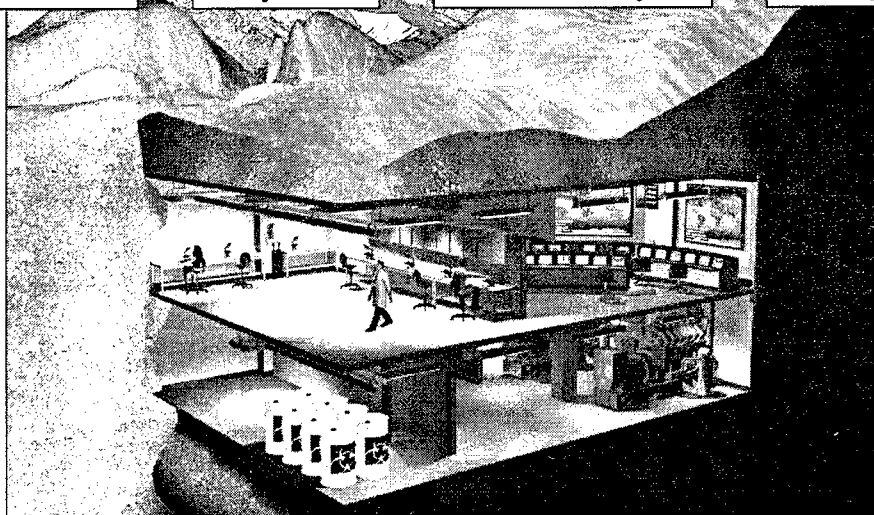


Function?

Operational
Cycle?

Physical Features/
Vulnerability?

Battle
Damage?



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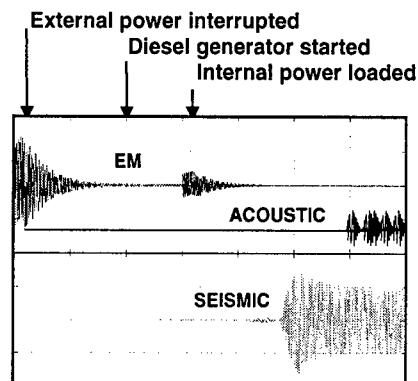
6



Sample Technical Thrusts



- Passive Acoustic, Seismic & EM (PASEM):
 - Detection and localization of UGF vulnerabilities and operational tempo



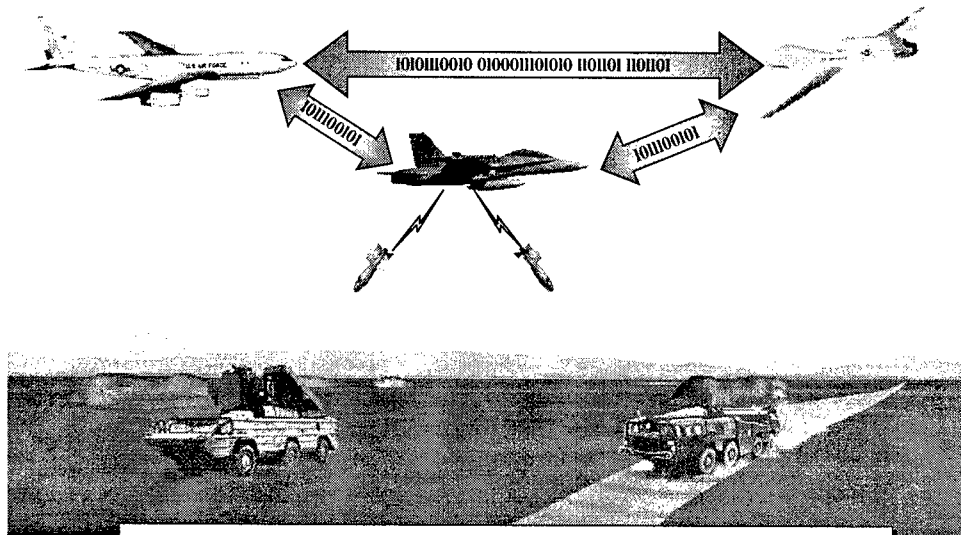
- Effluents Detection and Localization:
 - Vents / Facility Function / BDA

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7



Surface Targets – Movers and Emitters



Rapid, Extremely Precise,
Networked Targeting and Engagement

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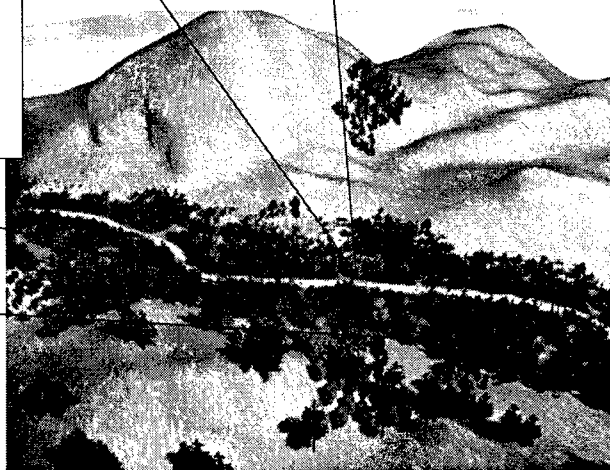


Surface Targets - Foliage



Challenges:

- All-terrain GMTI
- Simultaneous ESM / GMTI / SAR
- Robust Terrain Characterization
- Combat Identification



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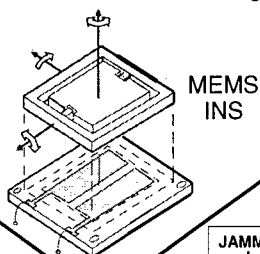


Critical Technologies



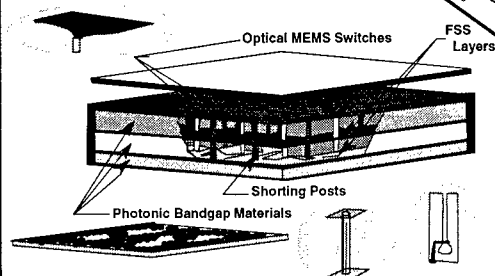
Navigation

Robustness, Precision, Packaging



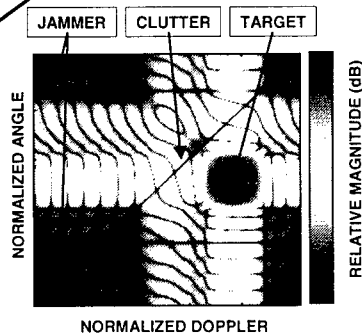
Advanced RF

Radar, ESM, Comm



Signal Processing

Robustness, ECCM



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10



Other Opportunities



- Tactical Networking Technologies
 - Wideband, low latency, reconfigurable
- Real-Time BDA
 - In-mission, all-weather
- Combat ID for Stressing Surface Threats



Points of Contact



• Chem-Bio Defense Systems	Amy Alving, Steve Buchsbaum, Millie Donlon
• Low-Cost Missile Defense Technology	Ed Gjermundsen, John Smith
• Underground Facilities	Dan Cress, Steve Buchsbaum
• Moving Targets (AMSTE)	Steve Welby
• Emitting Targets (AT3)	Jim Carlini
• Concealed Targets, Decoys	Lee Moyer, Bob Hummel



Points of Contact (continued)



• Tactical Targeting Networks	Peter Highnam
• Real-Time BDA	Steve Welby
• Surface Target Combat ID	Bob Hummel, Ed Gjermundsen
• Navigation Technologies	Greg Vansuch
• RF Technologies	John Smith
• Advanced Signal Processing	Joe Guerici



Biological Warfare Defense Systems

Amy E. Alving
Deputy Director
Special Projects Office

DARPA Tech 2000
6-8 September 2000

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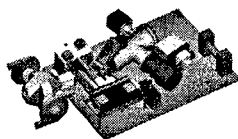
Chem/Bio Defense Activities



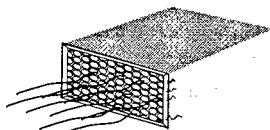
Component Technologies

- Detectors/ID
- Reporters
- Fluidics
- Collector materials
- Decon agents

Component Systems



- Sensor systems



- Filtration systems

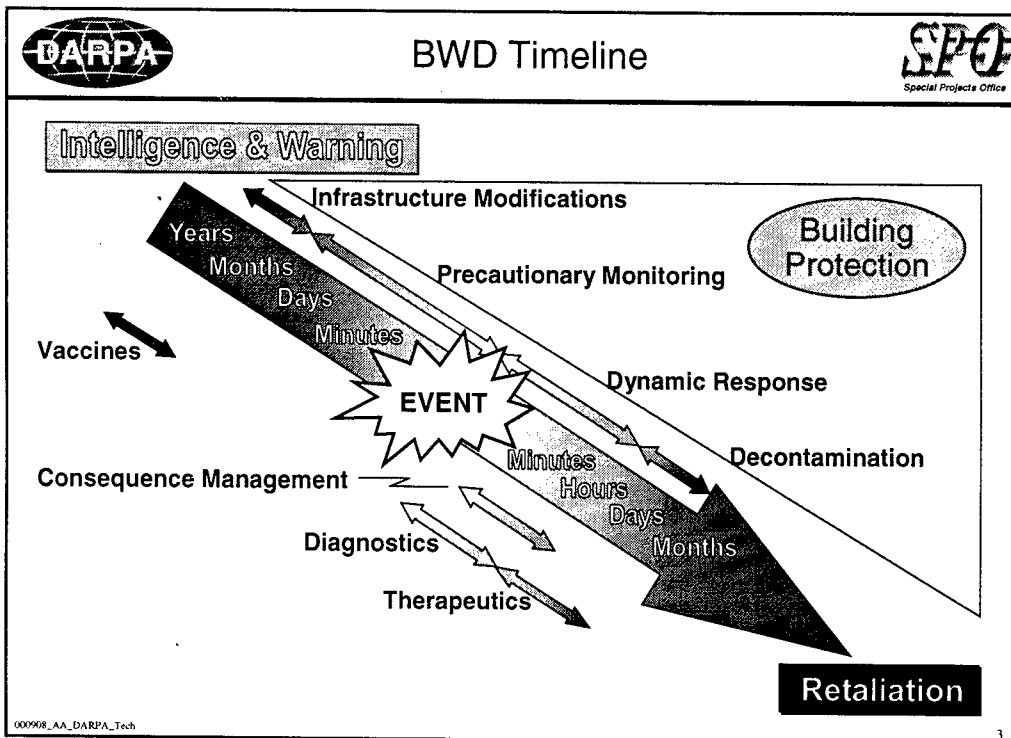
Complete Defensive Systems



- Building Protection

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2



DARPA **Building Protection** **SPO**
Special Projects Office

Threat:

- Focus is on protecting military buildings (C², barracks, ...) from:
 - attack by chem or bio warfare agents;
 - external or internal release.

Goal:

- Make buildings far less attractive targets.

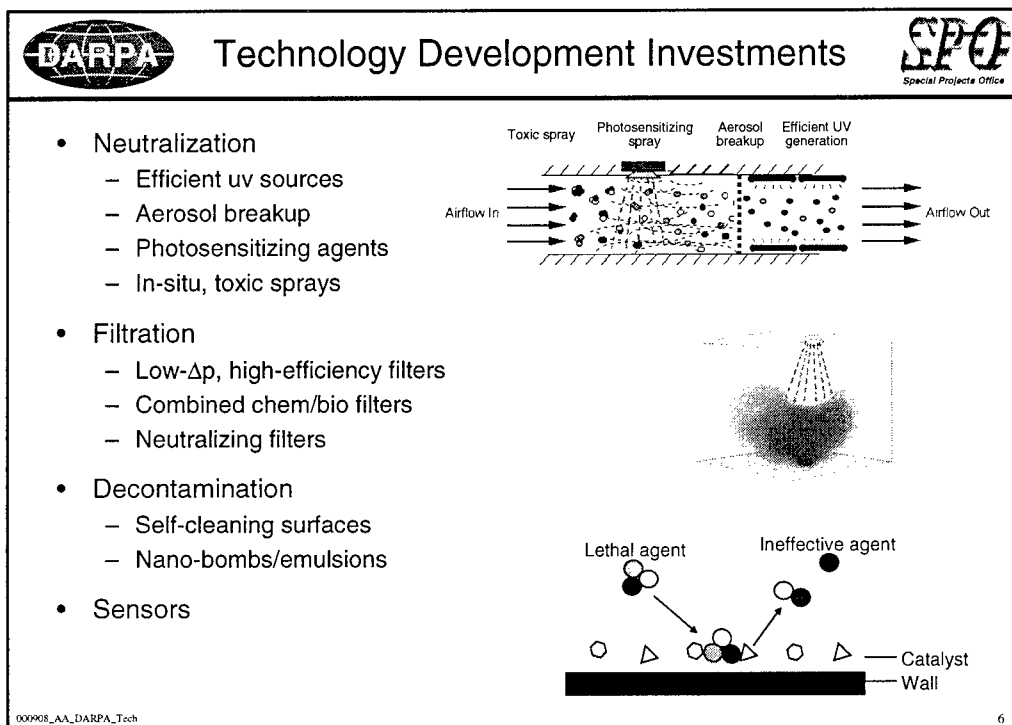
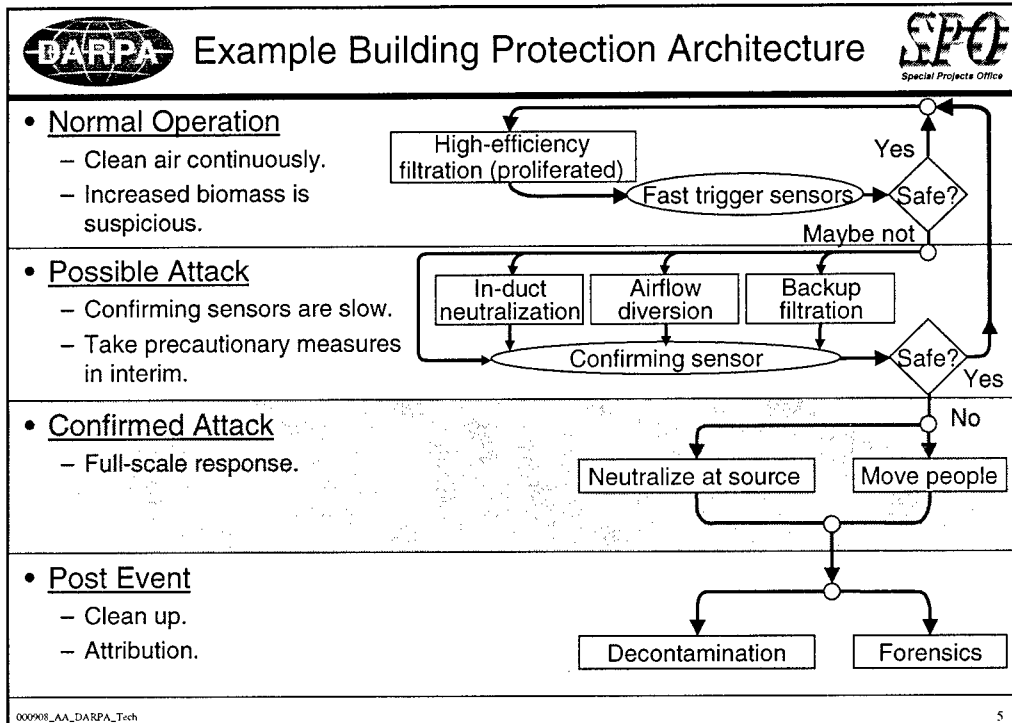
Approach:

- Reduce effectiveness of attack via dynamic response of HVAC (and other) infrastructure.

Objectives:

- Protect human inhabitants.
- Restore building to function, quickly.
- Preserve forensic evidence.

The diagram is labeled with **000908_AA_DARPA_Tech** and the number **4**.





Integrated System Experimentation & Demo



Systems design

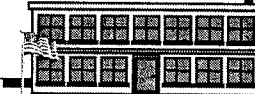
- Strategies
- Architectures
- Trades
- Requirements

Systems implementation

- Full-scale testbed of end-to-end system
- Experimentation
- Model validation

Demonstration

- Demo protection at military facility



Systems challenges

- Interpreting sensor response
- Localization of release location
- Optimizing response options
- Robust control algorithms
- Containment of agent at source
- Side effects of neutralization techniques
- Auto calibration/rare-event readiness
- System dependence on threat, release style
- Modeling of component and system behavior and protection afforded

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Building Protection Program Elements



FY01 – FY03

Technology Development

- Chem components
- Bio components

Insertion opportunity

FY01 – FY04

Systems Experimentation

- Implement, test, optimize
- Measure system performance:
 - FY01: external release
 - FY03, FY04: internal release

FY04 – FY05

Demonstration

- Military installation
- Based on experiments

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8



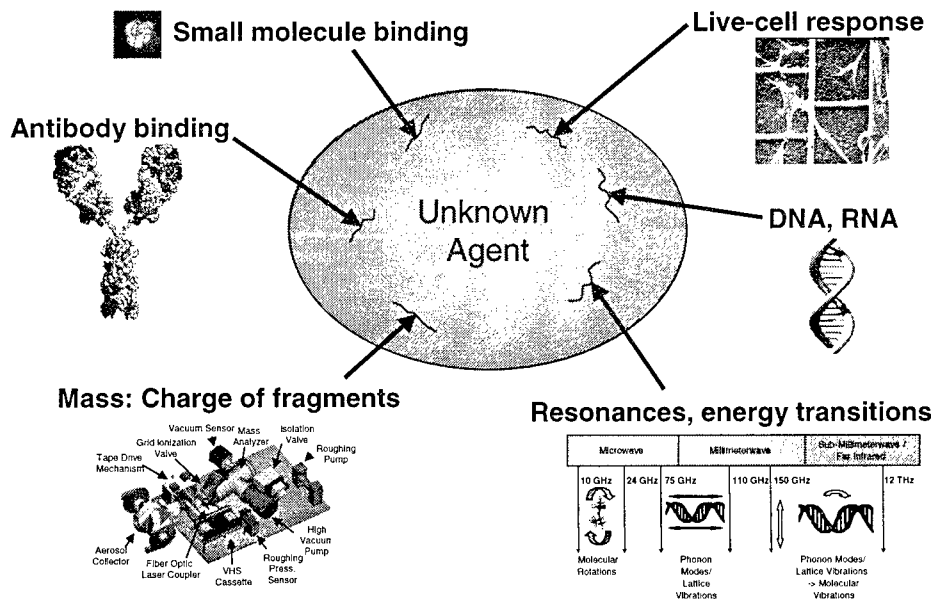
Bio Sensor Needs



- Bio sensors are a key component of many defensive architectures.
- Today's bio sensors do not perform well enough to enable their use in complex architectures.
- Fixing this shortcoming requires both novel sensor technologies and a change in how we design and develop sensor systems.

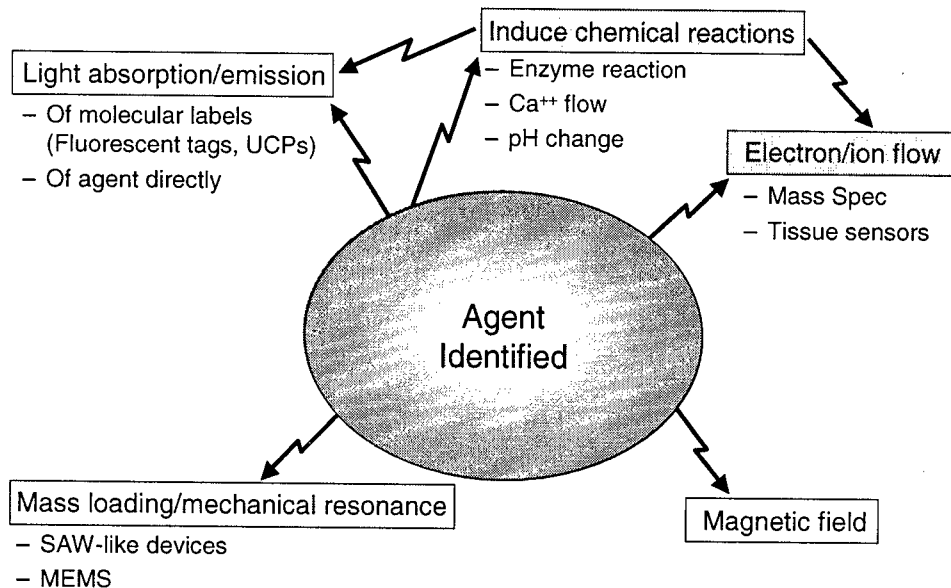


Sensor Systems – Identification Mechanisms





Sensor Systems – Reporting Techniques



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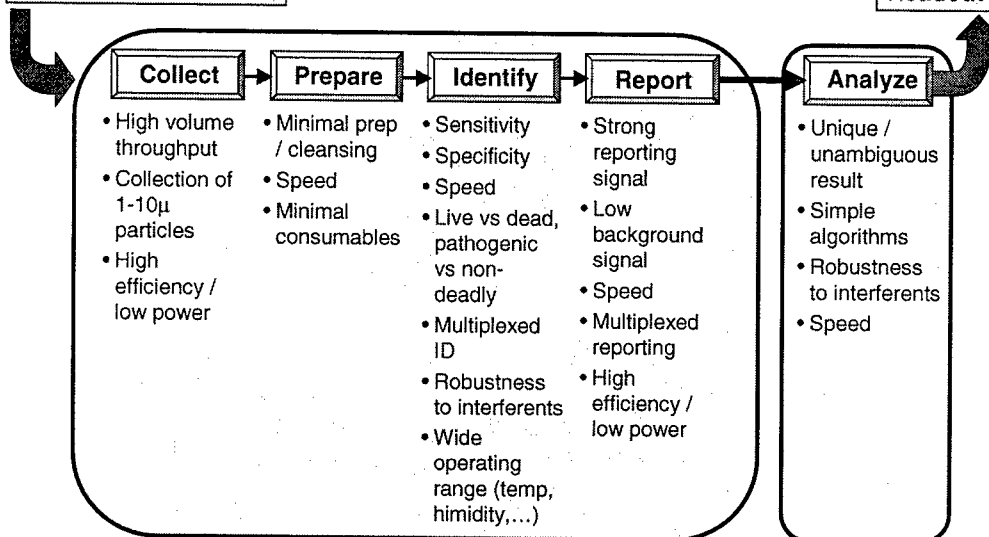


Components of (Bio) Sensors



Environmental Sample

Readout

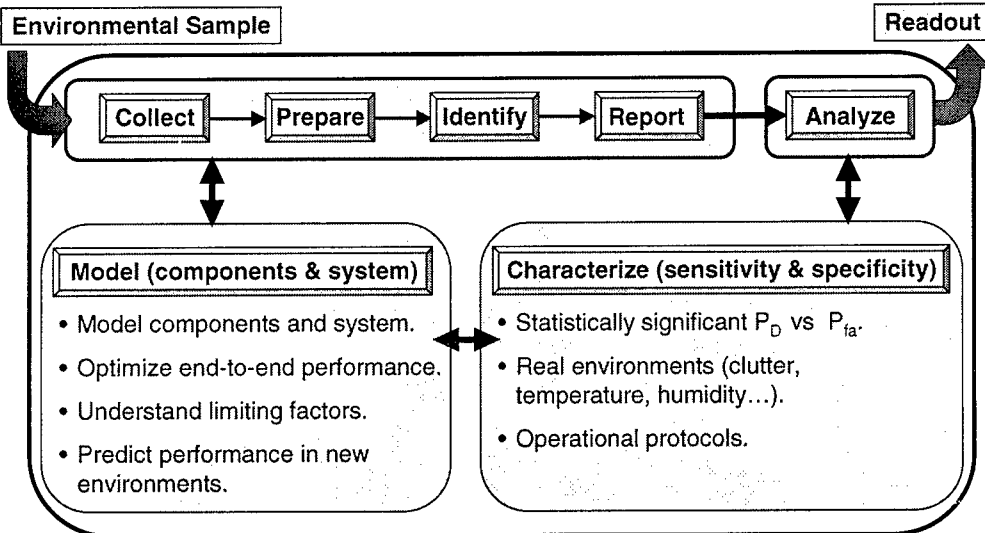


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Bio Sensor Systems



Mass Spec Prototype Development

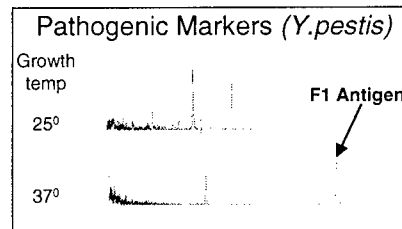


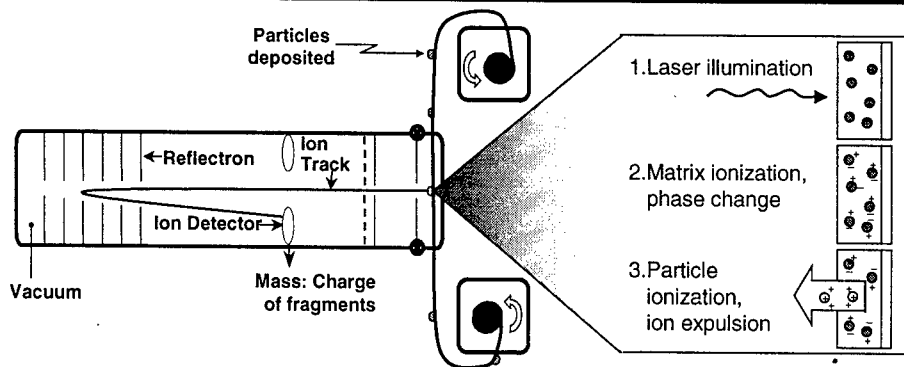
Hardware proof of concept

- Technology components:
 - MALDI ionization
 - TOF reflectron
- Successfully generates spectra of whole proteins.

Systems Issues

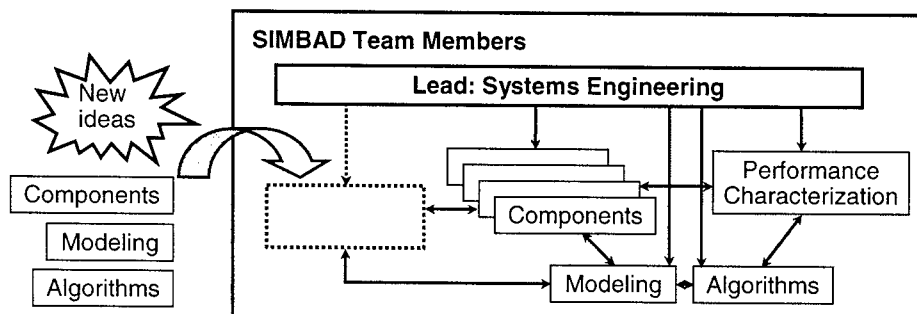
- Agent signature library
- Stability of signature
- Instrument calibration
- Background signature characterization
- Signature quenching
- Algorithms for signature extraction
- Signature predictions
- Matrix modeling, optimization





- Ionization process plays important role in system sensitivity and variability.
- Modeling effort is underway to guide system optimization, interpretation of output.

- Purpose: To develop and demonstrate prototype advanced sensor systems that work. They must be:
 - optimized;
 - well characterized;
 - reliable.
- Approach: New “way of doing business”:
 - No stovepipes.
 - Strong systems-engineering lead.
 - Broad technical expertise.
 - End-to-end development.





Contacts & Other Interests



Contacts

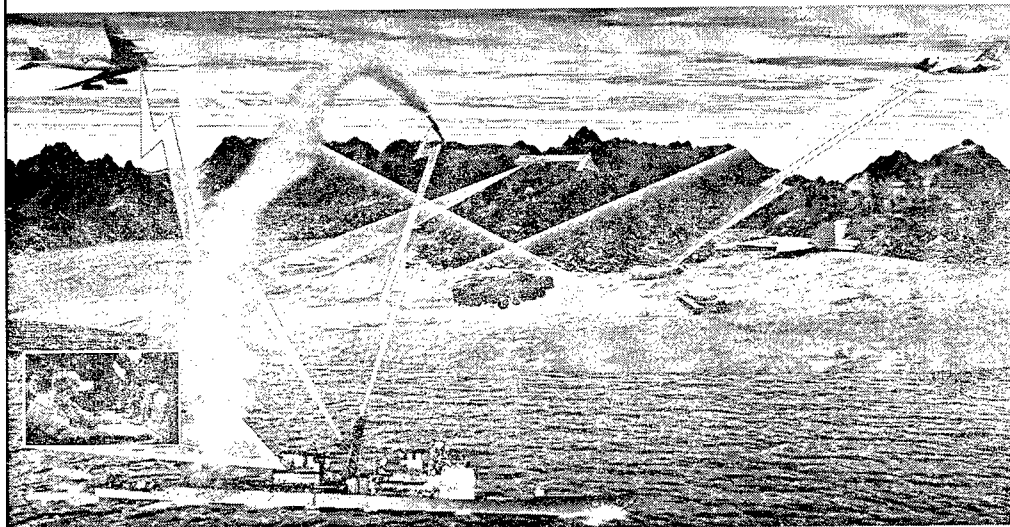
- Office coordination Amy E. Alving
- Building protection tbd
- Sensors Steve Buchsbaum, Millie Donlon

Other interests

- Bio surveillance systems
- Novel forensics
- Portal barriers for bio/chem
- Production detection



Networked Targeting Technology



Stephen Welby
Special Projects Office



Next Generation Time Critical Targeting



Future Battlespace Dominance *Requires* the Ability to Hold
Opposing Forces at Risk:

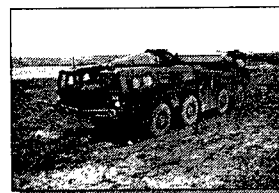
- At Any Time
- In Any Weather
- Fixed, Stationary or Moving



Opponents Will Take Advantage of Delays or Shortcomings in US
Quick Reaction Targeting Capabilities to Shelter Threat Systems

Examples:

- Use of mobility to protect threat surface-to-surface and surface-to-air missile systems
- Use of very short duration air defense emissions to avoid anti-radiation missile targeting





Key Enabler: Robust Tactical Networks



- Significant Investment Has Led to Widespread Planned Availability of Tactical Data Links
- This Investment Can Be Leveraged to Enable New **Rapid Reaction Targeting Concepts** Through the *Dynamic Synchronization of Sensors and Strike Weapons* Systems Across Large Areas over Tactical Networks
- Networked Targeting Offers Significant Advantages in *Precision* Over Traditional ISR and Traditional Stand-Alone Weapon Delivery Systems
- Networked Targeting Precision Supports:
 - Increased Lethality
 - Minimizes Collateral Damage
 - Increased Effectiveness
 - Minimizes Risk to US and Coalition Forces

The DARPA Special Projects Office is Aggressively Pursuing Networked Targeting

3



DARPA Special Projects Office Networked Targeting Programs



- **Affordable Moving Surface Target Engagement (AMSTE)**
 - Network Ground Moving Target Indication (GMTI) Sensors with Precision Weapons to Enable Precision, Stand-Off Engagement of Movers
 - Networked Targeting Permits:
 - Multi-Lateration of Stand-Off ISR and Strike GMTI Radars for Targeting Precision
 - Precision Tracking of Targets From Nomination through End Game with Targeting Updates to Weapons in Flight
 - Use of Low Cost GPS Guidance and Low Cost Seekers
- **Advanced Tactical Targeting Technology (AT3)**
 - Network Threat Warning Receivers to Enable Rapid, Precision Geolocation of Short-Dwell Emitters
 - Networked Targeting Permits:
 - Very Rapid Reaction Against Pop-Up Threats (seconds)
 - Extremely Precise Geolocation

4



The AMSTE Motivation



- Technology Investments Have Enabled US Forces to Hold Fixed and Stationary Targets at Risk
- AMSTE Will Extend US Battlefield Dominance to Moving Threats
 - Extend our capabilities to permit all weather engagement of vehicles on the move
 - Deny opponents the sanctuary of movement



- Existing Technologies Provide the Basis for the *Affordable* Precision Targeting of Moving Surface Targets

- Planned GMTI sensors
- Precision weapons
- Communication networks
- High performance processing

AMSTE is a systems-of-systems approach, coupling capable sensors to precision weapons through robust sensor-to-sensor and sensor-to-weapon networks

5



AMSTE Focus



Target *moving* surface threats from long range and rapidly *engage* with precision, stand-off weapons

Key AMSTE Characteristics:

All-Weather Engagement:	Requires use of multi-laterated, geo-registered GMTI sensors
Targeting Focused:	Requires ability to maintain threat track from nomination through engagement
Precision Engagement:	Requires ability to provide fire control updates to weapons in flight

**AMSTE Technologies support a seamless moving target engagement from
Nomination ➡ Track Maintenance ➡ Engagement**

6



AMSTE Challenges



Issues

- *Track Accuracy*
- *Precision Endgame*
- *Track Maintenance*
- *Affordability*

Approach

Networking of Standoff/Penetrating Sensors
GMTI Radar Multilateration
Advanced Tracking Algorithms
Grid-locking and Geo-registration

In-Flight Weapon Target Updates
Weapon Data Links
Precision Fire-Control Tracking
Low-Cost Seekers

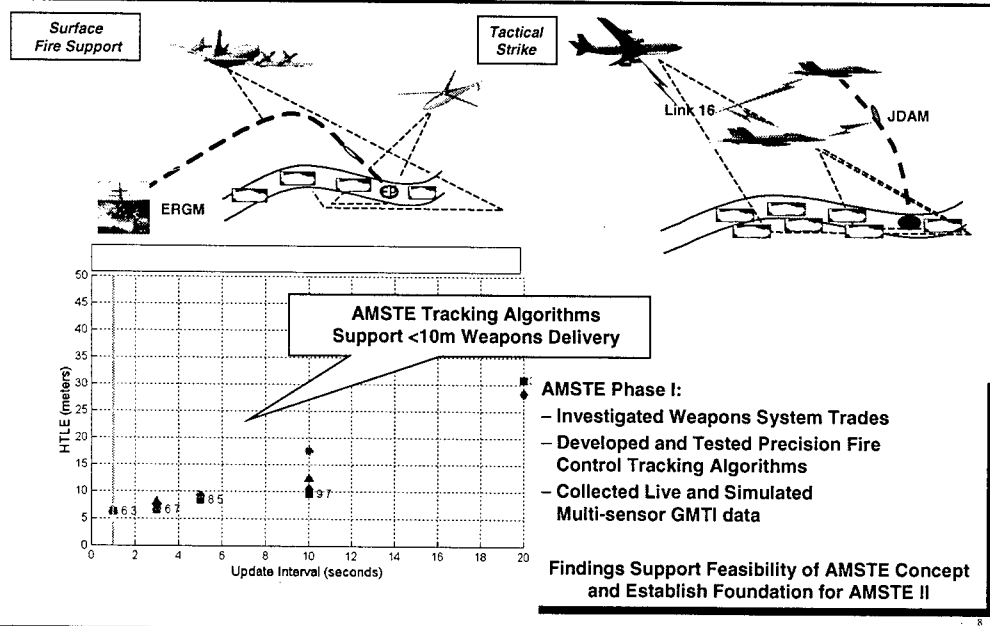
Feature Aided Tracking

Maximize use of existing resources and minimize the need for new systems

7



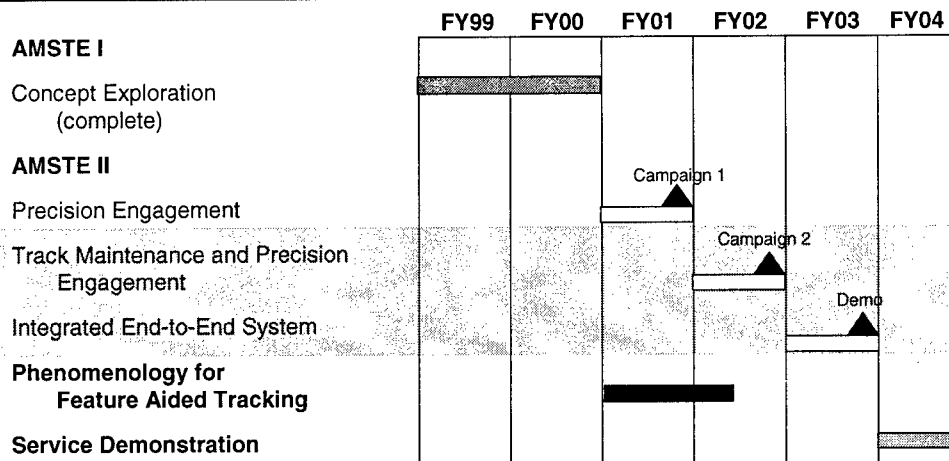
AMSTE I Accomplishments



8



AMSTE Program Schedule and Milestones

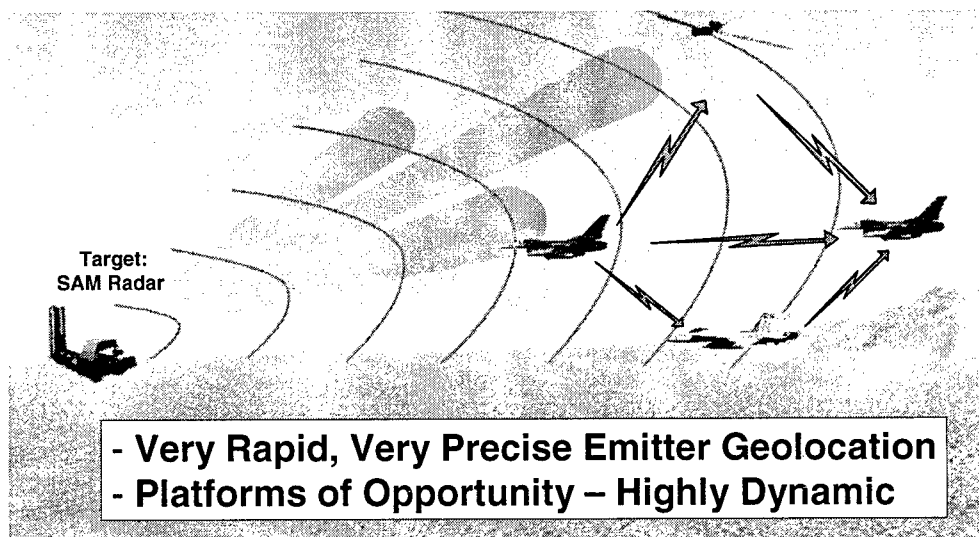


**AMSTE II will use an Integrated, System-of-Systems Approach
to Demonstrate an Affordable
Moving Surface Target Engagement Solution**

9



Advanced Tactical Targeting Technology (AT3)



10



AT3 Challenges



Issues

- *Exploit Threat Sidelobe Emissions*
- *Common Pulse, Ambiguity Resolution, Geolocation*
- *Network Management, Collector Cueing, Traffic Load Reduction*
- *Multipath, RF Agility, etc.*

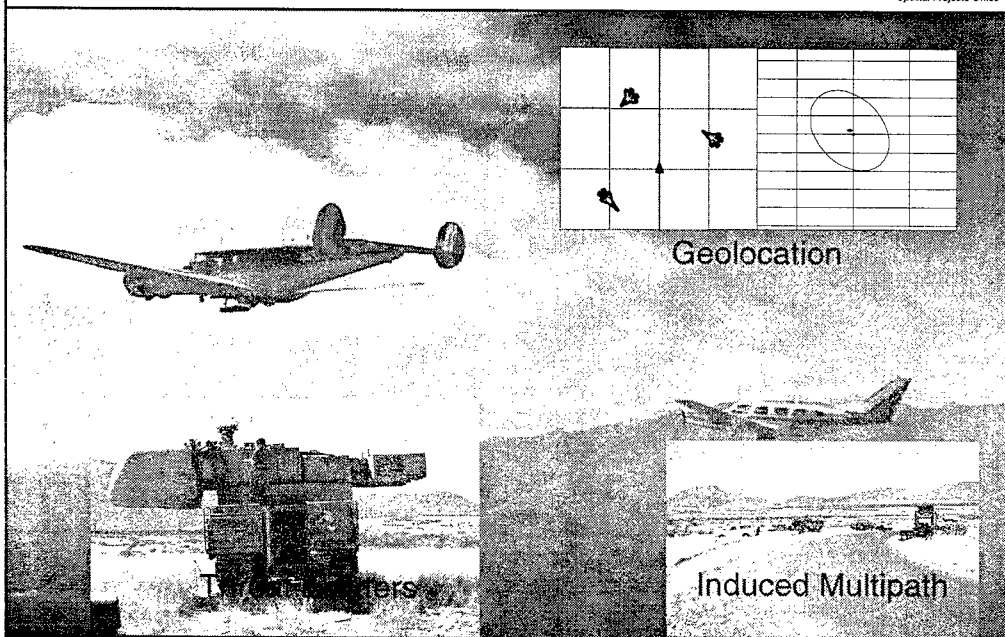
Approach

- Affordable, High Performance Digital Receiver
- Exploit Correlations within Pulse Trains and Between Collector Platforms
 - Coherent vs. Non-coherent
- 7-D Precise Registration of Battle Space
- Network Simulation/Analysis Traffic Management/Data Compression
- Novel, Transparent Tactical Network Approaches
- Leading Edge, Inter-Collector Multipath Decorrelation, Digital Receiver Flexibility, Other

11



AT3 Phase I





AT3 Phase II



Status

- Raytheon (Tucson, AZ) Proceeding to FY02 Data Collection and Real Time Flight Demonstration

Opportunity

- Innovative Multi-Ship Algorithm Development
 - Dense Pulse De-interleaving
 - Highly Agile Emitters
 - Coherent Techniques
 - Polarization Exploitation, etc.
- Explore Trade Space in Non-Real Time Environment



13



Tactical Networking Technology Opportunities



- Networked Targeting Can Be Limited By Tactical Network Capacity, Latency and Rigidity
 - The Need:
 - Increased bandwidth and on-the-fly reconfigurability
 - Very low latency data transfer
 - Advanced network planning/management
 - Compatibility with legacy systems
- New Applications for Tactical Networking Concepts
 - Synchronization of Strike and Sensor Assets for Real-Time Battle Damage Assessment

14



DARPA Special Projects Office Networked Targeting Programs



- DARPA SPO Is Aggressively Pursuing The Networked Targeting Paradigm Through Advanced Applications Such as AMSTE and AT3
- Near Term Experimentation with Networked Targeting Must Involve Both Technologists and Users
 - Co-development of Advanced System Concepts and Supporting Tactics, Training and Procedures is Critical to Successful Transition of Networked Targeting Approaches
- Networked Targeting Approach Offers Promise In Many Other Mission Areas by Realizing Tighter Coupling Between Sensors and Shooters



Counter Concealed Target Technologies

Mr. Lee R. Moyer
Special Projects Office

DARPATech 2000
6-8 September 2000

1



CC&D Tactics Pose A Challenge to U.S. Targeting Systems



The Challenge:



- Camouflage, Concealment and Deception techniques include:
 - Masking: Foliage cover, radar camouflage nets, chaff, weather
 - Tactics: Rapid movements between hide locations during deployment or after firing, emitting or over-flight
 - Decoys: Divert attention, generate false information

DARPA/SPOs objective is to develop technologies that effectively counter an adversary's use of CC&D



DARPA/SPO Is Addressing CC&D Tactics Through a Variety of Approaches



- Foliage Penetration (FOPEN) Synthetic Aperture Radar (SAR)
 - High-resolution, fully polarimetric imaging of stationary targets
- FOPEN Ground Moving Target Indication (GMTI) Radar
 - Moving target detection and tracking from airborne platforms
 - Low-cost, ground-based, bistatic radars to track vehicles and personnel in foliage
- Multi-Sensor Fusion
 - Fusion of FOPEN and microwave (μ W) SAR and GMTI, ESM and spectral sensor data to enhance identification and reduce the false alarm rate
- Target Identification
 - Close-in sensor packages
 - Multi-look 3-D laser radar (LADAR) imaging

3

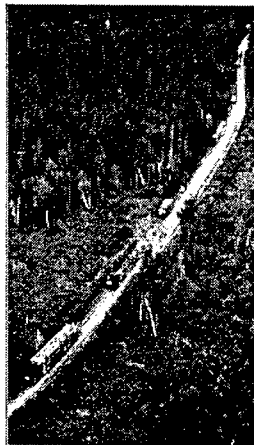


FOPEN Radar Denies an Enemy the Ability to Maneuver and Hide Under Foliage

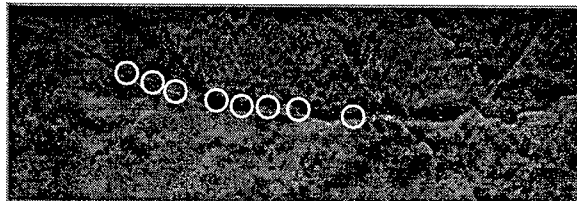


Example of Foliage-Obscured Vehicles

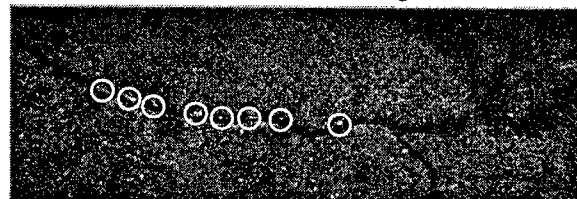
- Depression Angle: 45°, Resolution: 1 m x 1 m
- Vehicles Masked By Trees, Along Logging Road in Maine



Photograph



Conventional SAR Image



FOPEN SAR Image

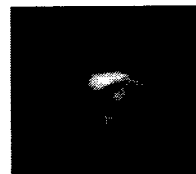
4



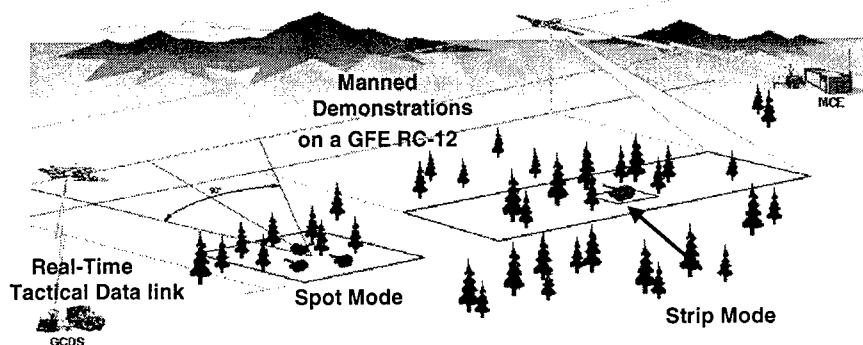
DARPA/SPO Is Presently Developing a FOPEN SAR to Detect Stationary Targets



- The FOPEN SAR is a real-time dual-band system
 - Horizontally polarized VHF SAR for target cueing
 - Fully polarimetric UHF SAR for target discrimination and false alarm rejection
 - System being installed and tested on Army RC-12
 - Form, fit and function compatible with Global Hawk UAV



VHF Target Cue



5



FOPEN SAR: Challenges and Opportunities



- Automatic Target Detection and Cueing (ATD/C) algorithms
 - Enhance target detectability
 - Minimize false alarms
- Advanced processing algorithms
 - RFI suppression
 - Waveform optimization
 - Change detection
 - Target classification
 - Interferometry / stereo / tomography
- FOPEN SAR applications
 - Battle space characterization
 - Environmental monitoring
 - Terrain mapping



UHF Target Chip



UHF Clutter Chip

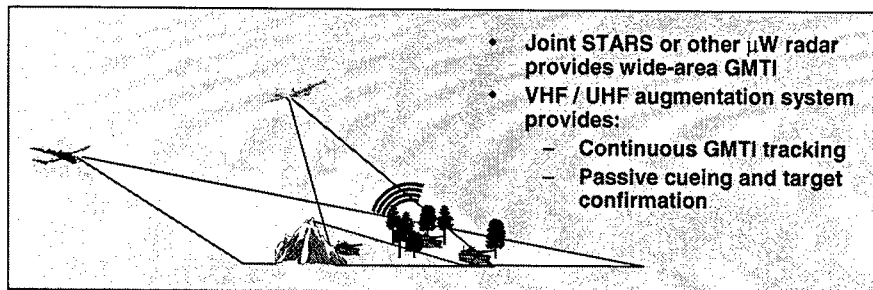
6



DARPA/SPO Is Assessing Integrated VHF / UHF GMTI Radar and ESM Technologies



- VHF / UHF GMTI radar provides all-terrain, all-weather capability
 - Track targets under foliage
 - Provide a high target position update rate
- Bistatic GMTI operation enhances system survivability
- Concurrent ESM uses allocated system resources to identify targets and locate emitters



7



Integrated VHF/UHF System Technologies: Challenges and Opportunities



- System architecture
 - Monostatic and bistatic concepts
 - Deployment on UAVs and other suitable platform
 - Integration / utilization of GMTI radar and ESM
- Airborne hardware components
 - Transmitter, antenna, receiver and signal processor
- Adaptive, non-adaptive and ESM processing algorithms
- Concept of Operations (CONOPS)
 - Utilization of GMTI radar and ESM resources
 - Interaction with FOPEN SAR and microwave radars

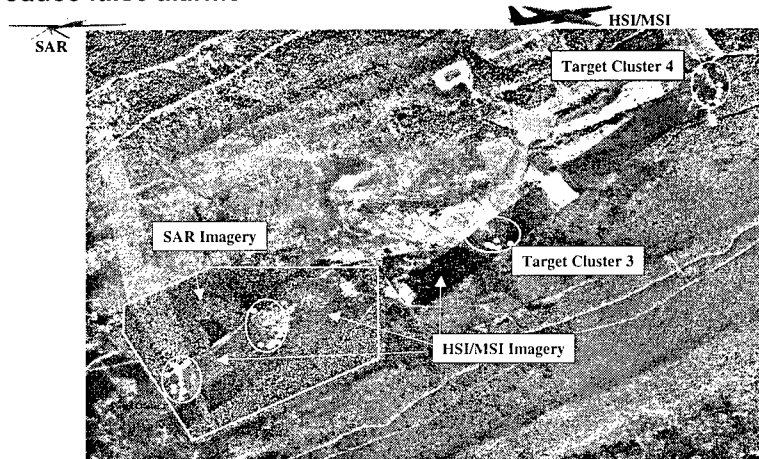
8



DARPA/SPO Is Assessing Multi-Sensor Fusion to Counter CC&D Tactics



- **Objectives:** Enhance detections, perform target identification and reduce false alarms



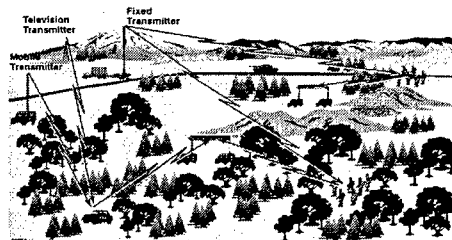
9



Ground-Based FOPEN GMTI Ground Radar



- **Objective:** Provide effective, low-cost force protection for ground units
 - Detect personnel / vehicles through foliage
 - Personnel detection to ranges of 4.5 km
 - Vehicle detection to ranges of 7 km
 - Use either cooperative or non-cooperative transmitter
 - Cooperative units could also provide communication / navigation functions
 - HDTV station could serve as non-cooperative illuminator
- **Program goals:**
 - High performance
 - Rapid deployment
 - Light weight
 - Low cost

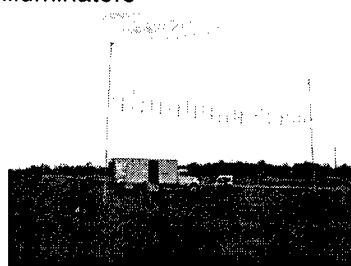




Ground-Based FOPEN GMTI Radar Challenges and Opportunities



- Low-cost, light-weight antenna and receiver technologies
 - Wide tunable bandwidth
 - Rapid deployment
- Algorithms
 - Cooperative and non-cooperative illuminators
 - Adaptive processing
 - Tracking
- CONOPS
 - Emitter selection
 - Emitter functions
 - Deployment geometries



Proof-of-Concept System

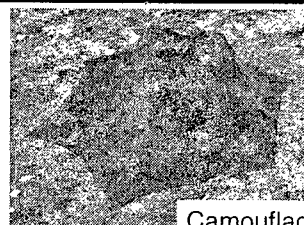
11



Hard-to-Identify Targets



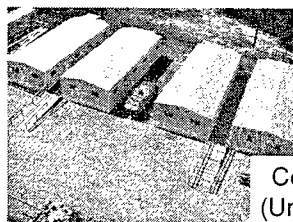
Foliage



Camouflage

Approaches:

- Close-in sensor package
- LADAR for 3-D sensing
- Multi-mode sensing



Complex Environments
(Urban, Clutter, Proximity)



Decoys

12



Summary



- DARPA/SPO's goal is to develop and demonstrate viable Counter CC&D technologies and to transition them to the Warfighter
 - Currently addressing the detection of concealed targets through a variety of airborne and ground-based sensor efforts
 - Increasing emphasis is being placed on tracking (GMTI), identification and engagement
- DARPA/SPO welcomes the presentation of new and innovative concepts for surveillance, identification and engagement of stressing surface targets



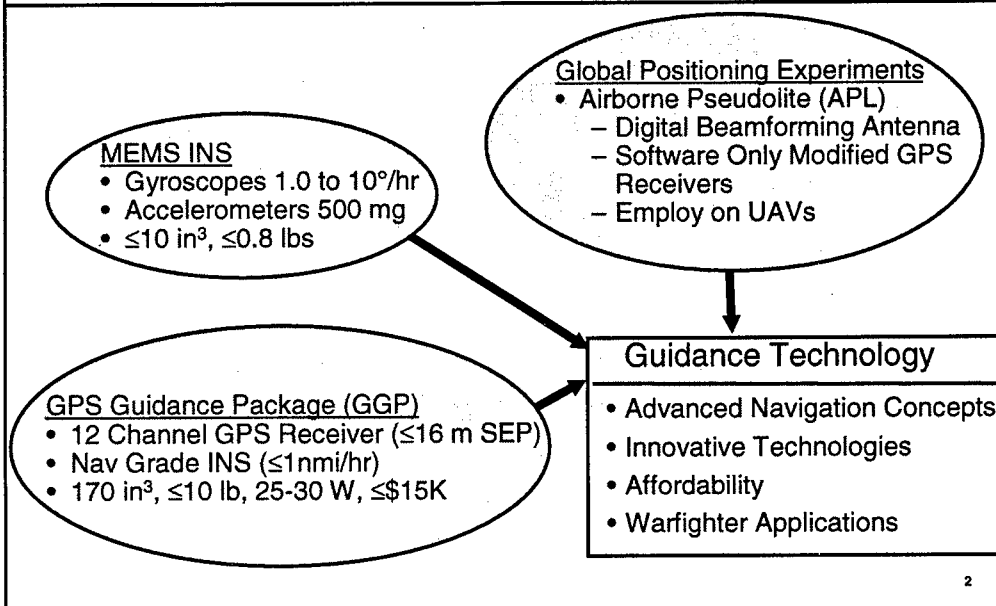
DARPA Guidance/Navigation Technology

Lt Col Greg Vansuch
Special Projects Office

DARPA Tech 2000
6-8 September 2000



Guidance Technology Programs





Motivation

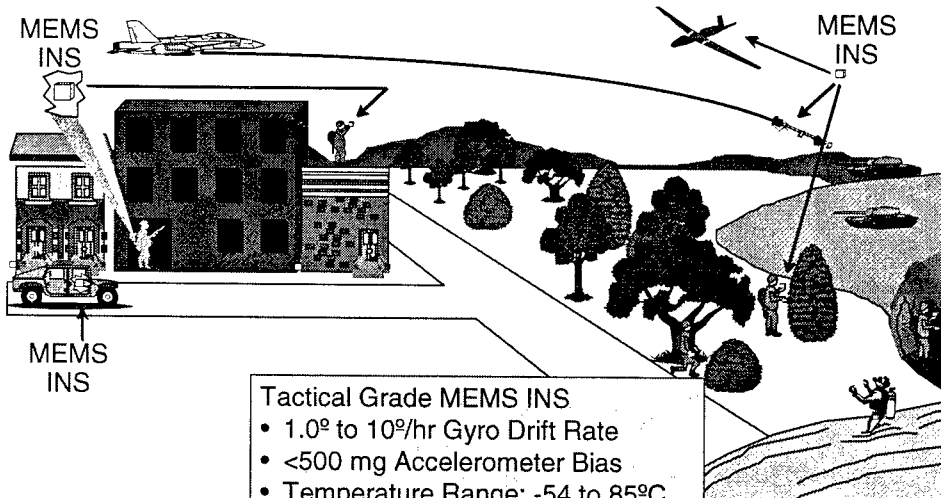


- GGP Lowers Cost, Improves Reliability and Improves Performance of Tightly Coupled GPS/INS Navigation
 - Surface to Surface Projectile Launchers (MLRS, HIMARS), Aircraft (F/A-18, Apache), Surface Navigation (M1A2, AAV), Long Time of Flight Missiles (Tomahawk)
- Tactical Grade MEMS INS Enables Many Applications
 - Inertial Munitions, Personal Inertial Navigation, Personal Underwater Navigation, Micro-Air Vehicles, Tactical Missiles, Unmanned Aerial Vehicles, Sea/Land Vehicle Sensors
- GPX Pseudolites Provide an Augmentation to GPS Signals Under Conditions of Jamming
 - First Launch of L_M Capable Satellite is 2008 or Later
 - IOC for Block IIF Satellites is 2016
 - At Least 10-15 Years Benefit from Airborne Pseudolites

3



Micro-Electromechanical System (MEMS) Inertial Navigation System (INS)



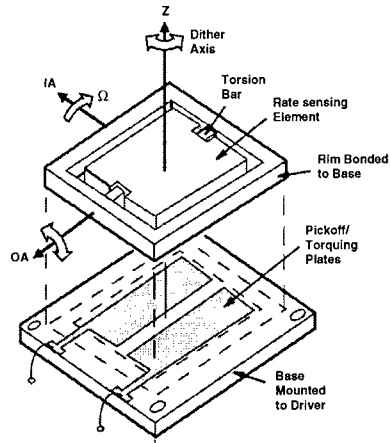
4



Current MEMS INS Gyroscope Designs



•Litton—Silicon Gyroscope (a conceptual example)



Principle of Operation

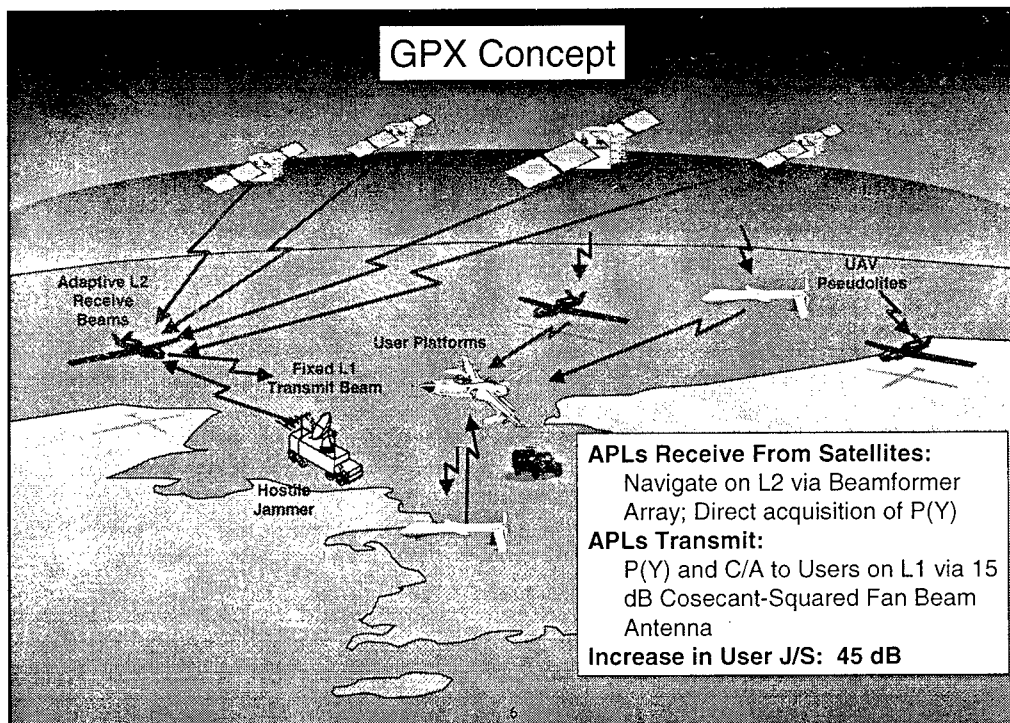
- Coriolis Force Sensors
- Measure platform rotation (Ω) around Input Axis (IA)
- Dither device around Dither Axis (z) to produce v and $-v$ on opposite sides
- Sense Coriolis rotation around Output Axis (OA) using pickoff plates

$$F_{\text{Coriolis}} = -2 m \Omega \times v$$

- Draper--Tuning Fork Gyro (TFG)
- Kearfott--Micromachine Vibrating Beam Multisensor (MVBM)

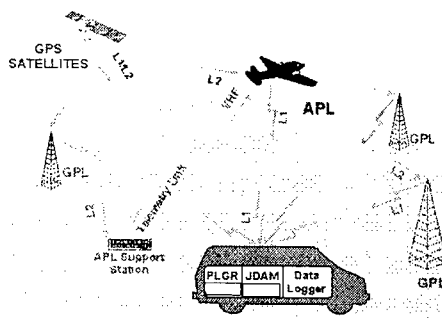
5

GPX Concept





First Flight Demonstrations (GPX)



- First Airborne Pseudolite (APL) Broadcast (9/99)
- Full End-to-End APL/GPL/UE Performance Demonstrated Live in Cedar Rapids, IA (11/99)
 - 3 GPLs Located on Fixed Towers
 - One APL on Sabreliner Commercial Jet
 - Handheld PLGR GPS Receiver and JDAM GPS Receiver Located in Moving Van
 - Demonstrated and Assessed Geolocation Performance in a Variety of Static and Dynamic Scenarios; User Receivers Operated Without GPS Satellites

Successful Navigation Demonstration

Demonstrated Range Error of 4.36 m (Original Estimate 4.5m; Goal 10m)

7



UAV Flight Demonstration



When

April 2000

Where

Fort Huachuca, AZ

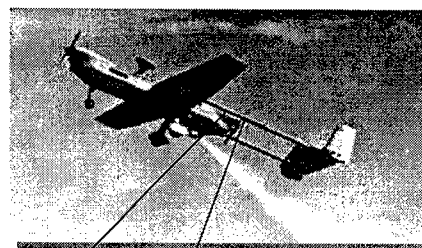
What

Demonstrate APL Effectiveness against GPS Jamming

Results

- Modified PLGR, JDAM worked in jamming
- Unmodified PLGR jammed

Hunter UAV



Boom Pod



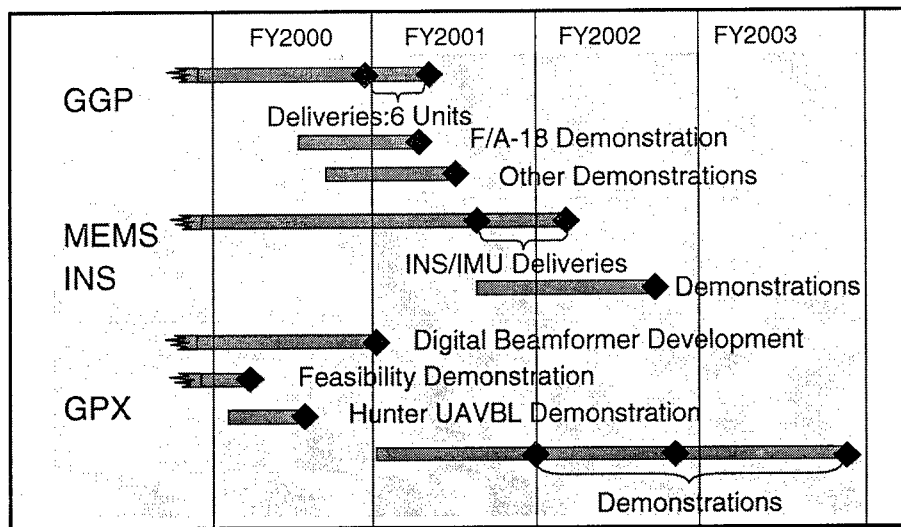
- Air Force UAV Battlelab and DARPA Funding

Successful Navigation in Jamming

8



Guidance Technology Schedule



9



Conclusions



- GGP
 - Potential F/A-18 and MLRS Demonstrations
- MEMS INS
 - Laboratory Results Indicate Progress Toward 1-10°/hour Over Military Environment
- GPX
 - Successful Feasibility Demonstrations Completed
 - Demonstrations of Beamformer, Transmitter, Transparency, Multiple Platforms, and Live Fire Being Planned
- New Ideas?

Multifaceted, Innovative
Navigation and Guidance Technologies
for the Warfighter

10



Defense Sciences Office

Michael J. Goldblatt
Director
mgoldblatt@darpa.mil

<http://www.darpa.mil>

DSO Overview - New slide 1



Mission

"Technology Harvesting"

Identify and vigorously pursue the most promising technologies within the science and engineering research communities and develop them into new DoD capabilities.

DSO Overview - New slide 2





In Practice

- Respond to technological opportunity
- Emphasize a *multidisciplinary* technical approach
- Recognize defense / commercial *industry as customer*



Personnel

Director, Dr. Michael J. Goldblatt
Deputy Director, Dr. Steven G. Wax

Materials, Mathematics and Devices

Dr. Valerie Browning
Dr. Leo Christodoulou
Dr. William Coblenz
Dr. Ephraim Garcia
Dr. Dennis Healy, Jr.
Dr. Robert Nowak
Dr. William Warren
Dr. Stuart Wolf

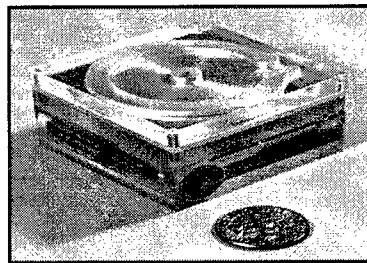
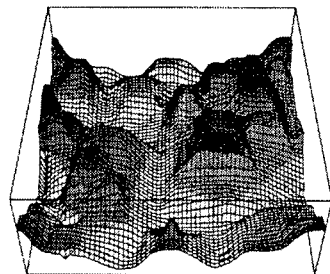
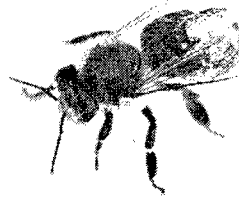
Advanced Biological and Medical Technologies

Dr. Robert Carnes
Dr. Eric Eisenstadt
Dr. Kurt Henry
Dr. Stephen Morse
Dr. Alan Rudolph
Dr. Wallace Smith





Technology Thrusts –Program Synergy

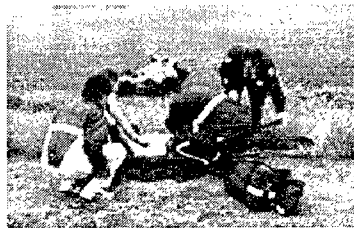
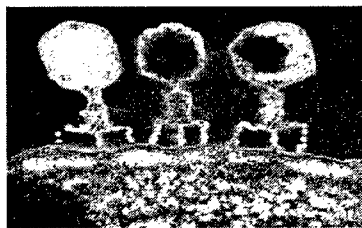
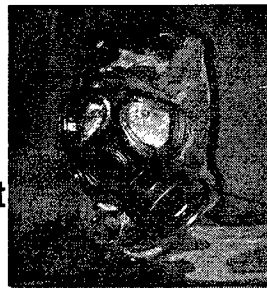


DSO Overview - New slide 5

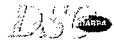


Biological Warfare Defense

- Medical countermeasures
- Advanced diagnostics
- External protection
- Consequence management
- Genomic sequencing

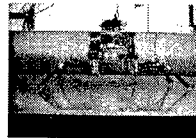
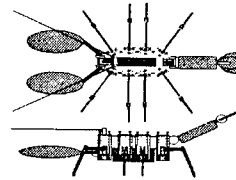
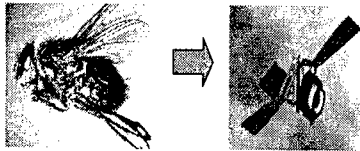


DSO Overview - New slide 6



Biology

- Cell and tissue-based biosensors
- Controlled biological systems
/Bio-inspired systems
- Fundamental research at the
[BIO:INFO:MICRO] interface

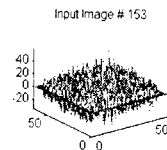
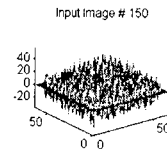
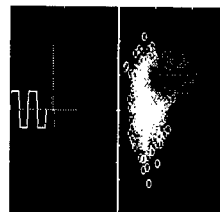
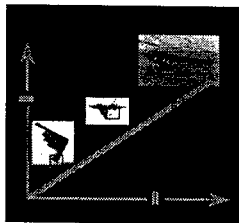


DSO Overview - New slide 7



Advanced Mathematics

- Signal and Image Processing
- Virtual Electromagnetic Test-range
- Physics-based Design for Materials Processing
- Scalable Strategies for Scientific Computations



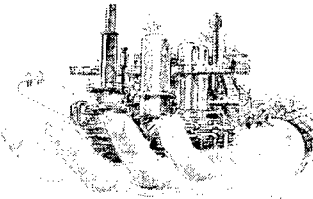
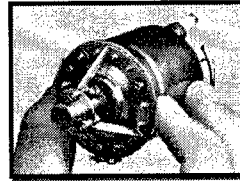
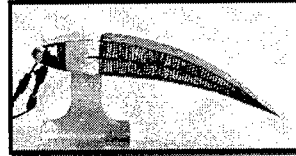
DSO Overview - New slide 8





Materials and Devices

- Functional materials and devices
- Smart materials and demonstrations
- Structural materials and components
- Mesoscopic machines
- Power generation and storage



DSO Overview - New slide 9



Developing New Ideas

- Materials Prognostics and Asset Readiness
- Quantum Information Science and Technology
- Biological Gears and Motors
- Performance Enhancement
- Digital Maps and Sensory Systems
- Biotechnology
- Activity Detection Technologies
- Meta Materials
- Living Machines

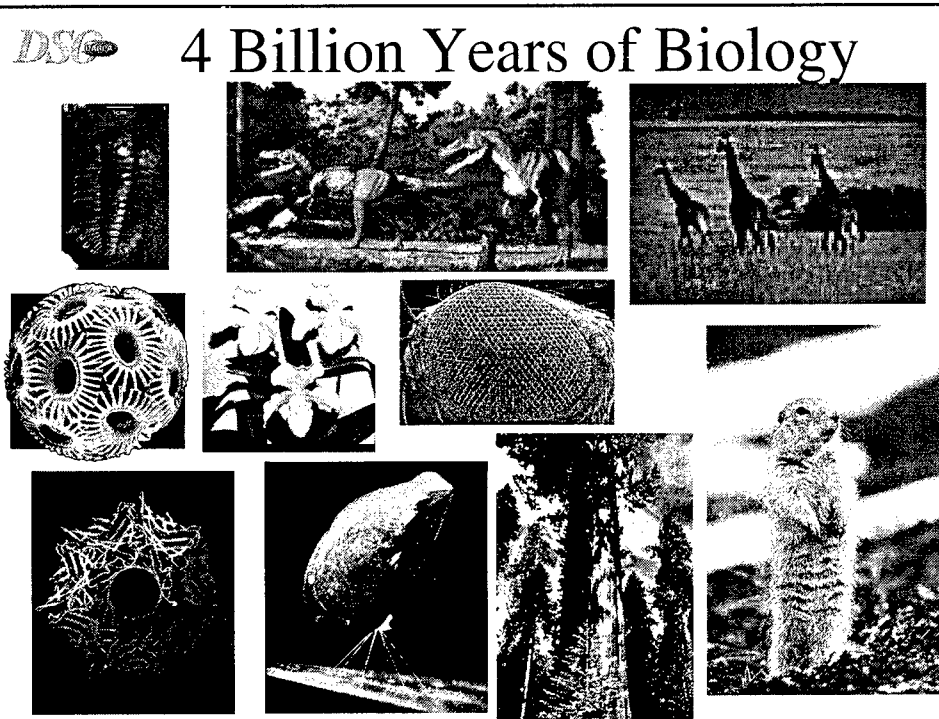
<http://www.darpa.mil/DSO/solicitations/>



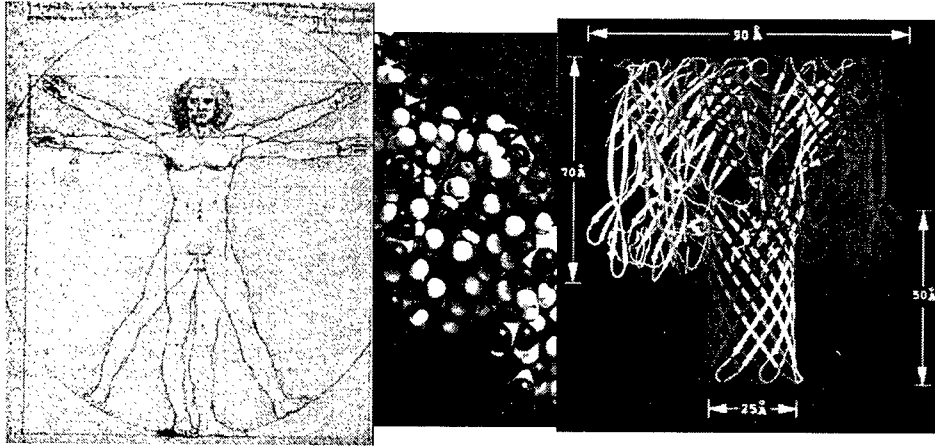
DSO Overview - New slide 10

Why and How DARPA/DSO Does Biology

Eric Eisenstadt



~50 Years of Molecular Biology



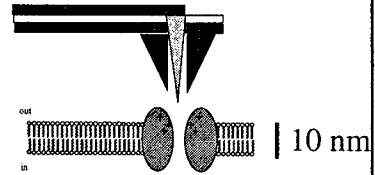
- 1953: Structure of DNA
- 2000: Human genome sequence

Improved DOD Capabilities via Biology

- Health
- Operations
- Materials synthesis

Deciphering Biology

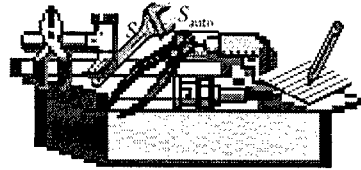
- Interrogate and manipulate biological systems with modern physical devices



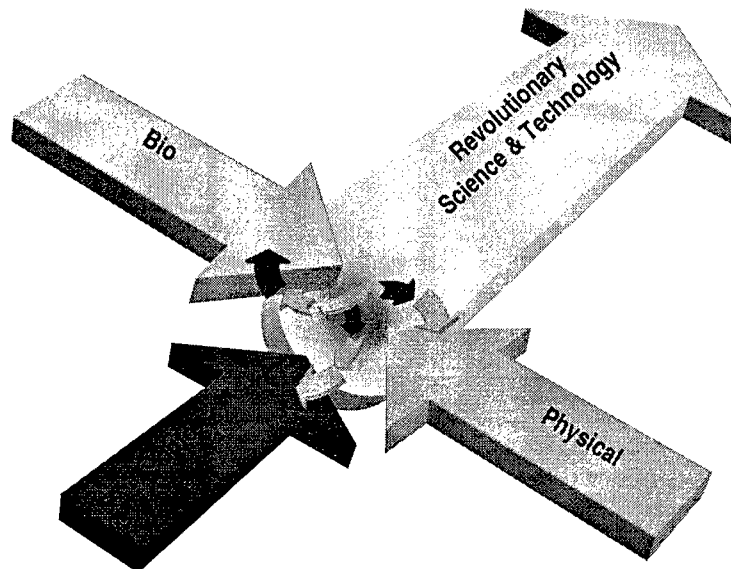
- Analyze, model and simulate with the full arsenal of math and computational tools

$$S_{\text{unreg}} = f'_{\text{unreg}}(R^*) = -k_{\text{deg}}$$

$$S_{\text{auto}} = f'_{\text{auto}}(R^*) = -\frac{nk_p P k_i a k_r}{(1 + k_p P + k_r R^*)^2} - k_{\text{deg}}$$



[Bio:Info:Physical]





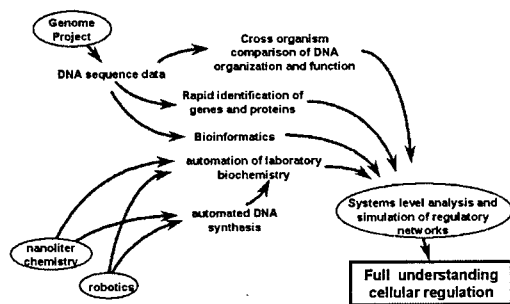
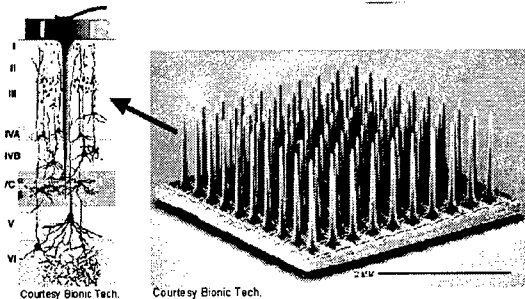
DARPA's Bio:Info:Physical Program

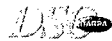
- First phase of DARPA BioFutures
- Fundamental research at universities
- Interdisciplinary
- Attack fundamental limits of understanding complex biological systems via the development and application of new devices and new information tools



Two Major Themes

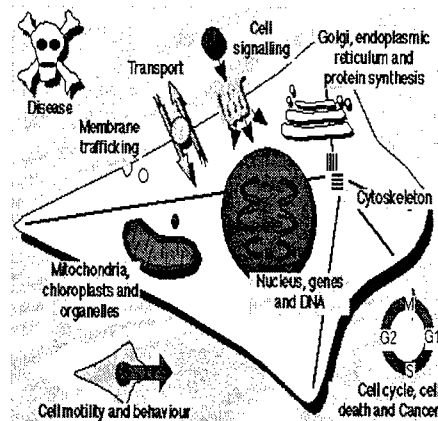
- **Neuroprocessing and neurocontrol via high density implantable MEMS devices**
- **Measuring and modeling the dynamic behavior of biological regulatory networks in living cells**





The Cell is a High Information Content Sensor!

- Cell is unit machine in biology responsible for systems level processing
- Cells respond to environment in specific, reproducible and redundant ways
- Cell sensors do not require specific identification of threat
 - Processing will result in identification
 - Amplification of response
- Response is predictive of functional consequences



Tissue Based Biosensors Program Concept

CBW Threat

Physiological Response

Human Health Risk Assessment

seconds	minutes	hours	days	years
Is it chem or bio?		Physiological consequences of exposure?		Long-term consequences of exposure?
Live vs dead?		Functional response and mechanism of action?		Genotoxicity?
Classification				Human performance deficits?
Known or unknown?				



Nature's Metabolic Engineering

You've got questions?

We've got answers...

Performance Specs

- 37° to -5° C Core temps.
- Heart rate: 300 to 7 bpm
- CBF: down to 7% of norm.
- BMR down to <10% of norm.
- 94% genetic homology with humans



Arctic Ground Squirrel



Natural Examples of Metabolic Control and Downregulation

Exploit the lessons learned from "Life on
the Edge"

**Extremophile
bacteria**



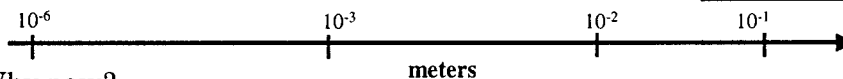
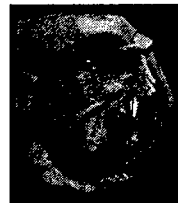
Dried *Tardegrade*



Frozen frog

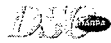


**Hibernating
squirrel**



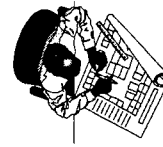
Why now?

- Recent discoveries in stasis strategies, genetics, and gene products now enable the development of a metabolic strategies and systems "toolbox".



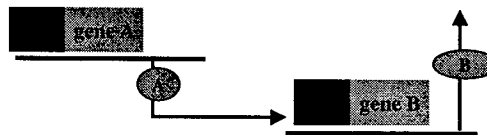
Sequencing Pathogen Genomes

- A genome sequence is a cell's blueprint
- Annotating a genome sequence yields the identity of its unique and common molecular parts
- Knowing the molecular parts permits rational design of countermeasures and detection strategies



A New Era in Biology, a New Era for DARPA

- Molecular anatomy
- Where the parts are
- How the parts work as a system



DARPA's role will be to develop not only new understanding but, more importantly, new biologically inspired systems, tools and devices that enhance DoD and national security



Semiconductor Spintronics Electronics for the 21st century

Stuart Wolf



Semiconductor Spintronics

Objective

To create a revolutionary new class of semiconductor electronics based on the spin degree of freedom of the electron in addition to, or in place of, the charge.



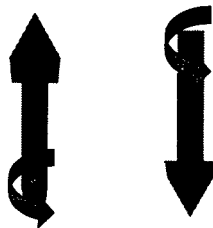
Rationale for Spintronics

Conventional Electronics → **Charge**

- Based on number of charges and their energy
- Performance limited in speed and dissipation

Spintronics → **Spin**

- Based on direction of spin and spin coupling
- Capable of much higher speed at very low power



Spintronics Challenge

In March of 1959, Richard Feynman challenged his listeners to build

“Computers with wires no wider than 100 atoms, a microscope that could view individual atoms, machines that could manipulate atoms 1 by 1, and circuits involving quantized energy levels or the interactions of quantized spins.”

Richard Feynman - “There’s Plenty of Room at the Bottom”
1959 Annual Meeting of the American Physical Society



Spintronics

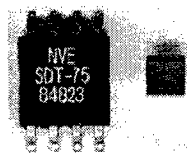
Magnetoresistive thin films and nanostructures are already extremely important scientifically, technologically and economically.

- ✧ Economics: -Today
 - Magnetic recording alone is a \$100 billion/yr

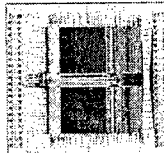


The IBM Travelstar disk drive uses magnetoresistive devices to achieve 4.1Gb/in²

- Tomorrow – Potential additional \$100 billion/year



Sensors-Isolators



Magnetic RAM

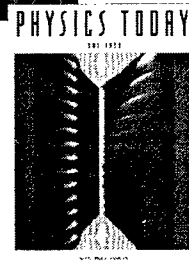
Non-Volatile
Radiation Hard
High Density
Very High Speed
Low Cost



Spins IN Semiconductors

New Direction-SPINS

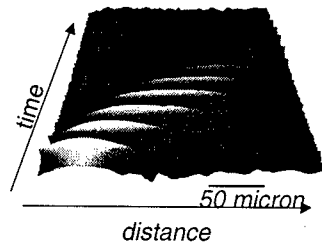
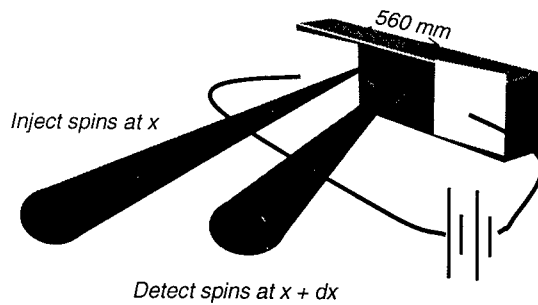
- Two recent discoveries
 - Optically Induced long lived coherent spin state in semiconductors
 - Ferromagnetism in semiconducting GaMnAs above 120K (Sendai, Japan 1998)
- Will lead to revolutionary advances in 21st Century photonics and electronics such as:
 - Very high performance opto-electronic devices
 - Very fast, very dense memory and logic at extremely low power
 - Spin quantum devices like Spin-FETs, Spin LEDs and Spin RTDs
 - **Quantum computing in conventional semiconductors at room temperature**
 - Many other applications that we can't even envision now



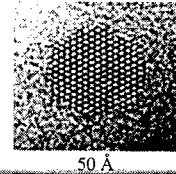


Injection and Motion of Coherent Spins in Semiconductors

- Spin coherence persists for 100s of nanoseconds over 100s of microns
- Largely insensitive to temperature



- Spin coherence also demonstrated in CdSe Quantum Dots
- Room temperature operation with nanosecond lifetimes



Enabler for Quantum Computation

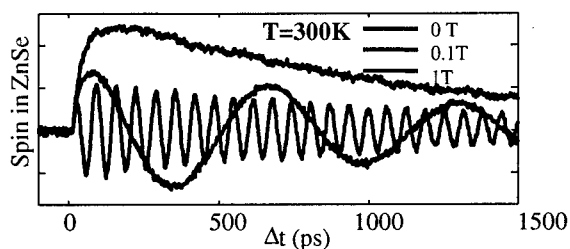
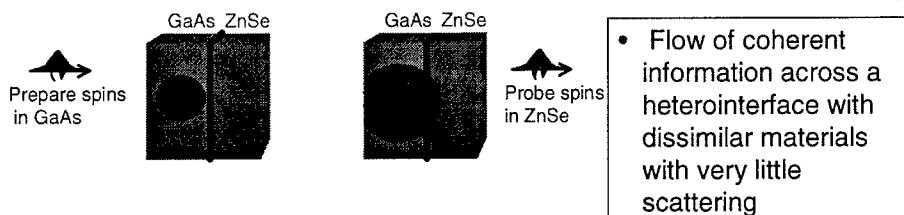


What Needs to be Done

- Since spin effects in semiconductors are largely **unexplored** it will be essential to
 - Explore ways to raise Curie temperature of magnetic semiconductors
 - Explore optical and transport properties which offer new spin dependent avenues
 - Understand and control interface effects and spin transport across interfaces
 - Demonstate spin coherent optical devices
 - Demonstrate spin quantum devices
 - Demonstrate quantum logic with 8 qubits or more at or near room temperature



Spin Transfer Through Heterointerfaces



UCSB



Spin Enhanced and Enabled Electronics

Quantum Spin Electronics

- Tunneling/transport of quantum confined spin states: natural frequency scale given by spin splitting: GHz-THz
- Spin dependent resonant tunneling diodes and spin filtering
- Spin FETs ("spin gating")
- Spin transistors
- Spin LEDs, electroluminescent devices, and spin Lasers

Coherent Spin Electronics

- Optically generated coherent spin states and coherent control of propagating spin information - optical encoders and decoders
- Directly generated coherent spin state and coherent control of propagating spin information

Quantum Information Processing

- Qubits using coherent spin states in quantum dots - quantum networks



Quantum Semiconductor Spintronics

Classical Bit (Boolean) 0 or 1 Two states

Quantum Bit (Qubit) $\alpha|0\rangle + \beta|1\rangle$ "Infinite" number of states

Where $(\alpha^2 + \beta^2) = 1$



$|0\rangle$



$|1\rangle$

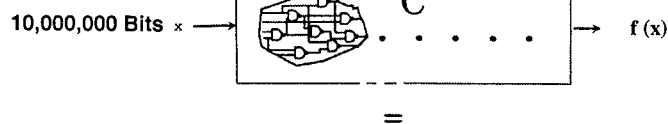


$\alpha|0\rangle + \beta|1\rangle$

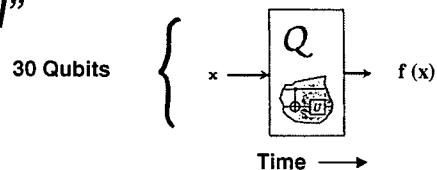


Quantum Spintronics

"Intel"



"Quintel"



Factoring: Given integer N , find integers p and q such that $N=pq$.

Exponential Speedup: $2^{N^{1/2}} \rightarrow N^2$

Optimization: Given algorithm for computing a function g , find input s such that $g(s)$ is minimal.

Quadratic Speedup: $2^k \rightarrow 2^{k/2}$



Quantum Spintronics

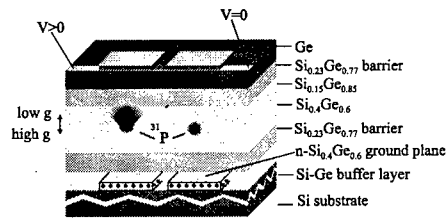
Qubit Implementations

➤ **Electron-Spin Resonance Transistor (ESRT):**

➤ **Long Dephasing Times (msec)**

➤ **High Switching Speed (GHz)**

➤ **Uses Silicon Technology And quantum dot expertise**



UCLA



*I predict that there will be
SPINS in your future*



DARPA's ADVANCED ENERGY TECHNOLOGIES

DARPATECH 2000

Dr. Robert J. Nowak
DARPA/DSO
(703) 696-7491 (voice)
(703) 696-3999 (fax)
RNOWAK@darpa.mil

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Advanced Energy Technologies Overview

- **Energy Conversion Strategies to Meet Portable Energy Shortfalls**

- ◆ **Near-term Demonstrations**
- ◆ **New Opportunities**

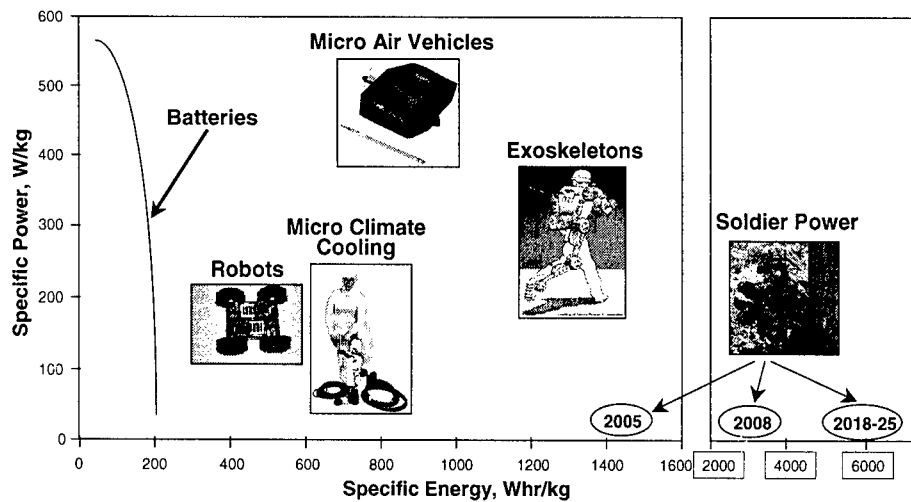
- **Energy Harvesting for Low-Power/ Long-Endurance Missions**

- ◆ **Near-term Demonstrations**
- ◆ **A New Breakthrough - Opportunity**

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Performance Shortfall for Today's Power Sources



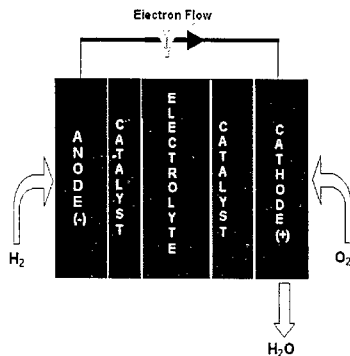
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Energy Conversion Technologies Considered For Portable Power Applications

Electrochemical $\epsilon \sim 100\%$

- Fuel Cells



Heat Engines $\epsilon = [(1 - T_L/T_H) * 100]\%$

Dynamic Systems

- Piston
- Turbines
- Stirling

Static Systems

- Thermoelectrics
- Thermionics
- Alkali Metal Thermal to Electric Conversion
- Thermophotovoltaics

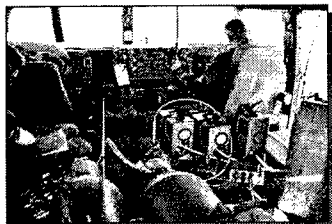
Fuel cells promise earliest but not only opportunity

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Marine Corps Air Ground Combat Center 29 Palms, CA, Fall 1999

TRAINING

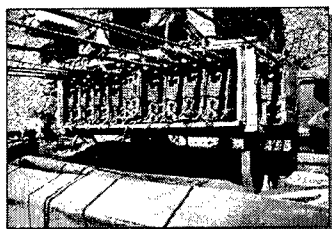


Fuel Cells aboard Humvee

MILITARY EXERCISE



Retransmission Site



PRC-119 Radios

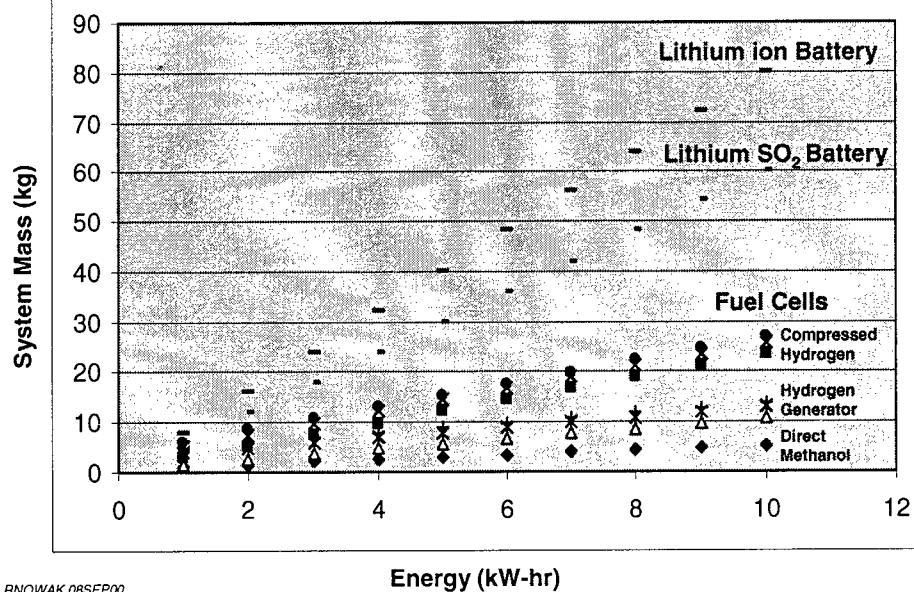
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COST ESTIMATE FOR ONE DAY, ONE RETRANS SITE

- BA5590 BATTERIES = \$900
- FUEL CELLS = \$26



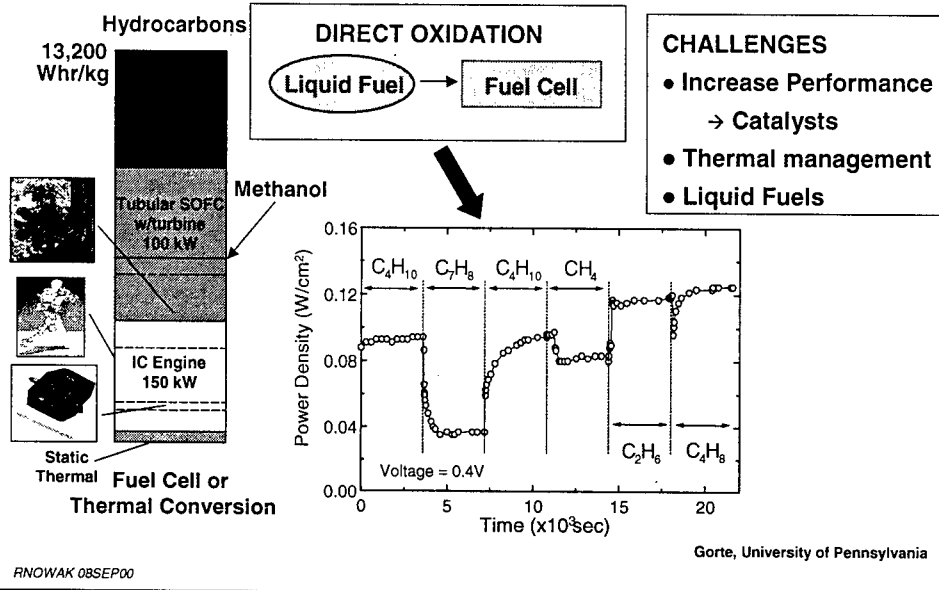
Lithium Battery / Portable Fuel Cell Comparison



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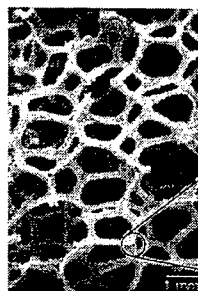


The Holy Grail? - Direct Conversion of Hydrocarbon Fuels

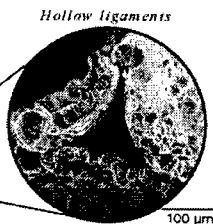


Thermal Management Opportunities

Superthermal Conductors and Heat Exchangers



EB - DVD
Inconel® 625 Foam



Hollow ligaments

100 μm

Aerogel Insulators



K_{solid} Aerogel = 0.002 W/mK @ 300K
 K_{solid} Silica = 1.4 W/mK @ 300K

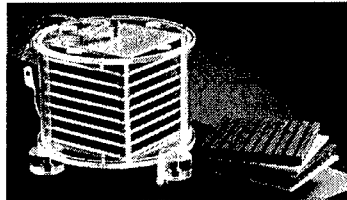
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Thermal Integration Opportunities

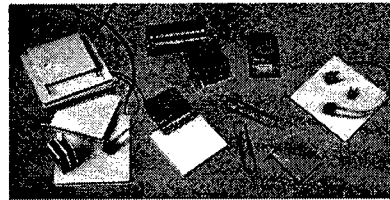
Cascading Systems

- ▼ Thermally integrate multiple technologies
 - ◆ Design
 - ◆ Fabrication



SOLID OXIDE FUEL CELL
1000 - 650 C

+



THERMOELECTRICS
1000 - 100 C

Integrated Efficiency >> Σ Individual Efficiencies

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Energy Harvesting for Low-Power/Long-Endurance Missions

Technical Goal

- Significantly increase mission endurance (>10x)
for soldiers and sensors

Technical Approach

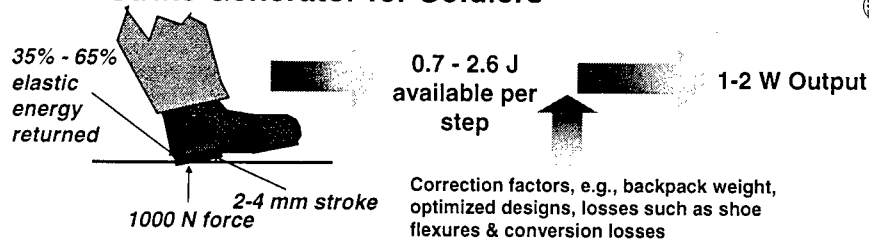
- Harvest energy and fuel from environmental sources
- Integrate harvesting system with devices

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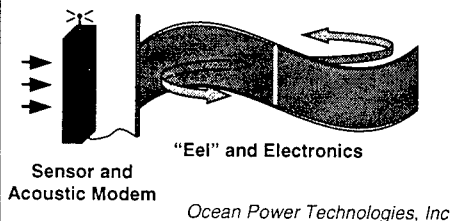


Mechanical to Electrical Energy Conversion

Heel-Strike Generator for Soldiers

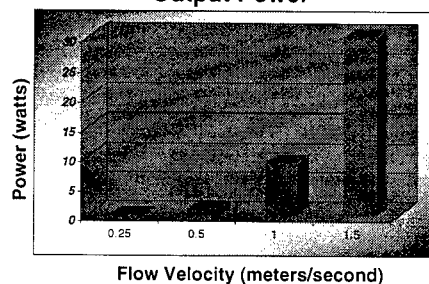


Energy Harvesting Eel for Undersea Power Generation



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Output Power



Fundamental Breakthroughs



November 1999 Rotary Motor Structure and Architectures



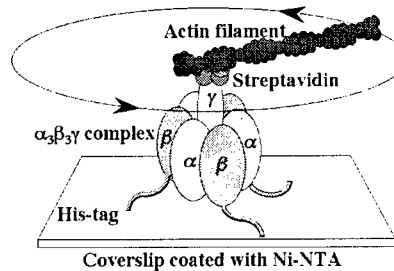
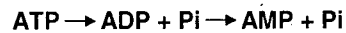
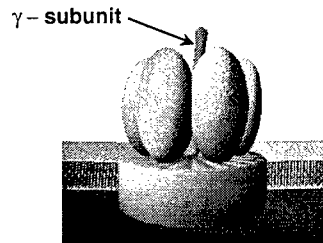
April 2000 Motor Proteins and Motion Systems Structure

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F₀F₁-ATPase Biomolecular Motor

Membrane-bound F₀-F₁ ATP Synthase



F₁-ATPase Biomolecular Motor with Actin Filament System (from Noji *et. al.* 1997)

- Ubiquitous enzyme
- Synthesize and hydrolyze ATP
- F₁ portion can act independently
- Gamma subunit of F₁ portion rotates (up to 17 r.p.s.)
- F₁ portion can generate up to 100 pN·nm torque

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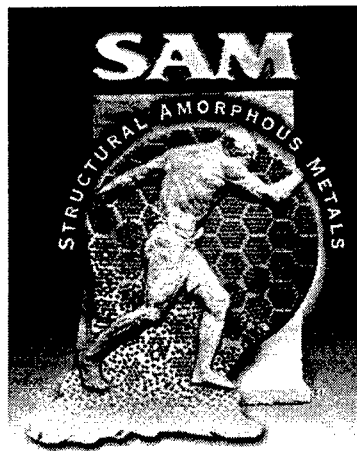


Biomolecular Motors

Technical Issues

- Determine and Apply Critical Engineering Steps Toward Biomotor Devices
 - Spatial and orientational control of motor elements at interfaces
 - Systems analysis of force production and work output (ATP in, work out), lifetime and robustness
- Design, Build and Test Prototype Devices which utilize the ATP and Biological Motors
 - Microvalves, pumps, fluidic movement, sensors and actuators, controlled release devices, robotics, ATP engines

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Structural Amorphous Metals

Leo Christodoulou

DARPA/DSO



Compelling Opportunity



- **A totally new class of materials has been discovered with a radical combination of properties**
- **There are unique, compelling and enabling applications in several key DoD areas (e.g., ship hulls, aircraft structures, penetrators, etc.)**
- **DARPA will have a program to develop the science and technology of this field, and demonstrate its utility in example challenge problems**

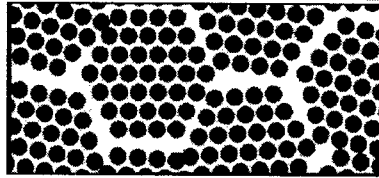


Amorphous Metals are Fundamentally Different from Conventional Metals



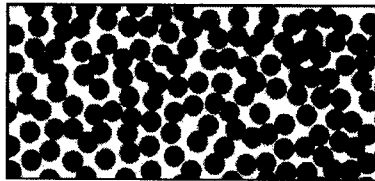
Crystalline (Normal) Metals

- *Long-range order*
- *Grain boundaries*



Amorphous Metals

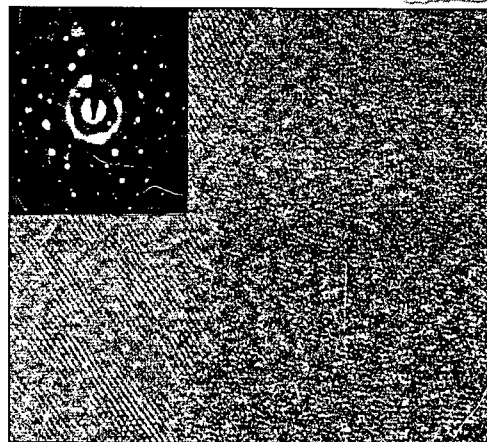
- *NO long-range order*
- *NO grain boundaries*



Atomic Arrangement in Crystalline and Amorphous Metals



- Micrograph shows:
 - Interface between amorphous and crystalline metal
 - Atomic planes of crystalline metal
 - Random arrangement of amorphous material
 - Diffraction information



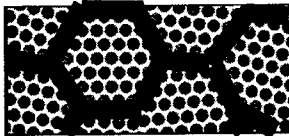
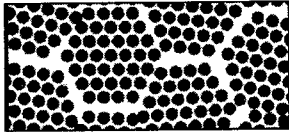
← Crystalline Amorphous →



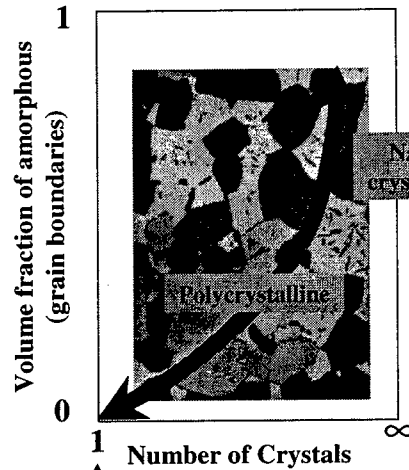
Since Their Discovery Metals have Relied on the Same Microstructural Constituents for their Properties



Polycrystalline



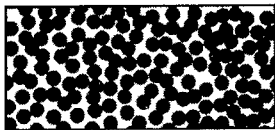
- Intersections of grains (grain boundaries) can be considered as "amorphous."
- Changes in grain size change the volume fraction of amorphous content



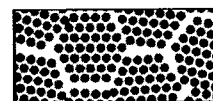
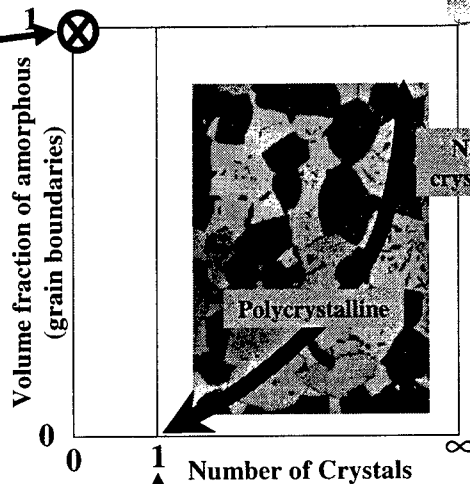
Structural Amorphous Metals Are New-to-the-World



Amorphous



- Amorphous Metals are NOT confined by limitations of crystalline materials
- Such an opportunity has NOT previously existed for structural materials.





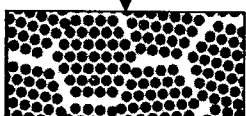
Transformations from the Amorphous to the Crystalline State Offer Unprecedented Materials Design Freedom



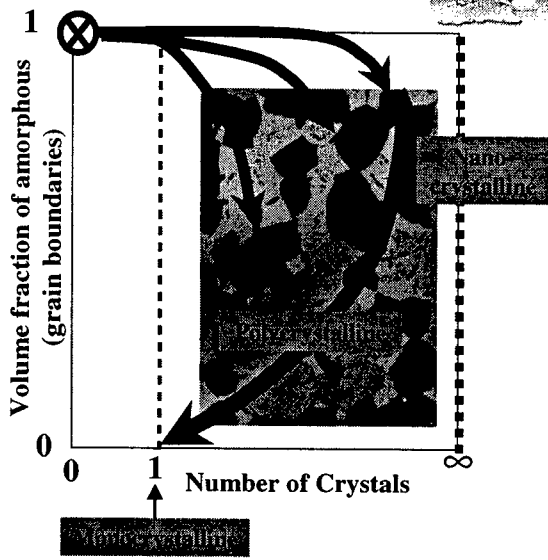
- Short-range order
- NO grain boundaries



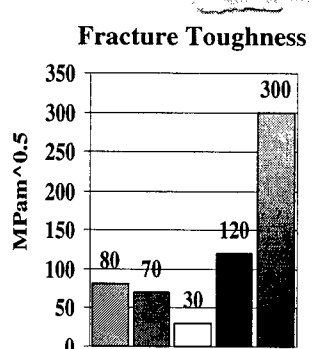
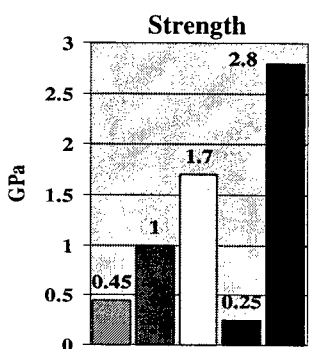
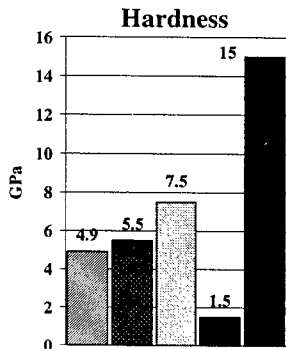
Transition path could be of CRITICAL importance



- Long-range order
- Grain boundaries



Why Amorphous Metals?



Steels

Carbon High Strength Tool	Stainless
Amorphous	Amorphous

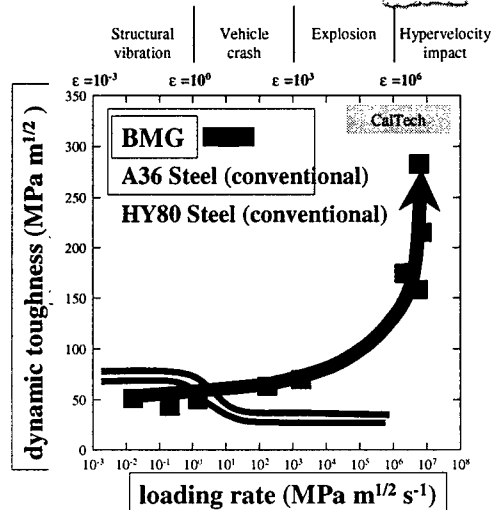
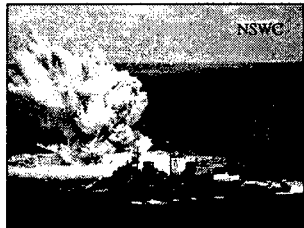
Amorphous Metals are in a Class of their Own!



New-to-the-World Structural Materials: Unexpected Strain Rate Response in SAM



- Dynamic toughness of SAM is **EXACTLY** the opposite of conventional materials -- toughness increases with strain rate
- Speculate that combination of high strength, hardness and dynamic fracture behavior will translate into useful naval and other structures



Wear and Corrosion



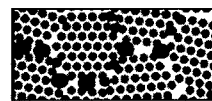
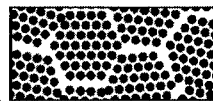
Challenge Problem:

Environmental conditions, e.g., marine environments, often induce degradation of properties due the presence of discontinuities within the material microstructure

Amorphous Materials:

- Do NOT have grain boundaries (no corrosion initiation sites)
- Exhibit high wear resistance (better than Si₃N₄)
- Are damage tolerant

Crystalline Localized Corrosion



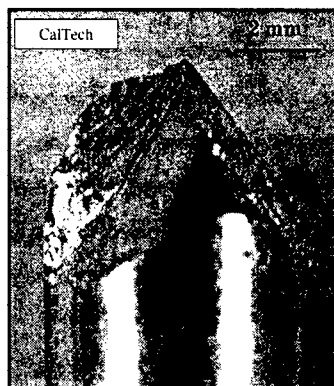
Amorphous Steel



???



Amorphous Metals as New Penetrator Materials



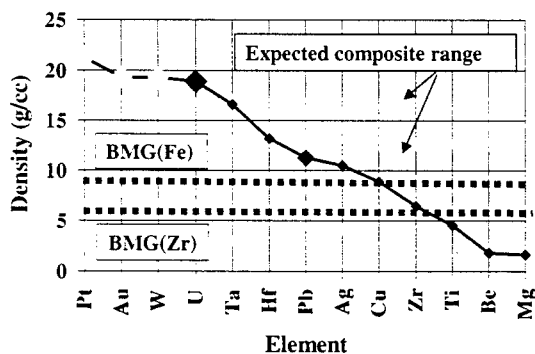
SAM materials known to exhibit self sharpening behavior



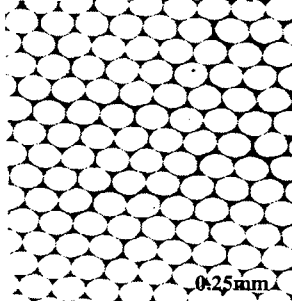
Penetrator Materials: Amorphous Metals Provide New Options



Need control of strength, toughness, elongation,
density and self-sharpening behavior.



W Wire / SAM Composite



$W V_f = 80\%$,
 $\rho = 16.8 \text{ g/cc}$

To achieve high density SAM must be turned into a composite.

$\rho_{DU} = 18.9$ $\rho_{BMG} = 5.9-8.0 \text{ g/cc}$. Tungsten is the obvious choice

Monolithic SAM may be sufficient in some applications.

Molecular Electronics (Moletronics)

William L. Warren, DARPA – DSO

Christie R. K. Marrian, DARPA - MTO



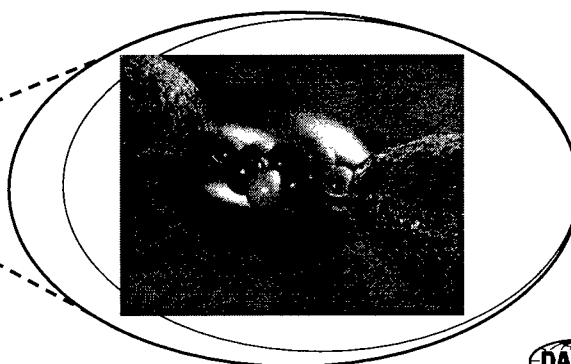
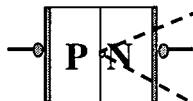
Moletronics – What's It All About?

*Replace conventional components with
self-assembled functional molecules*

P-N Diode
90,000 nm²



Molecule
9 nm²



Information Content

- One color photo ~ 10^5 b
- Average book ~ 10^6 b
- Genetic code ~ 10^{10} b
- Human brain ~ 10^{13} b
- Annual newspapers ~ 10^{14} b
- Library of Congress ~ 10^{15} b
- Human culture ~ 10^{16} b
- Annual television ~ 10^{18} b

Total ~ 10^{20} bytes

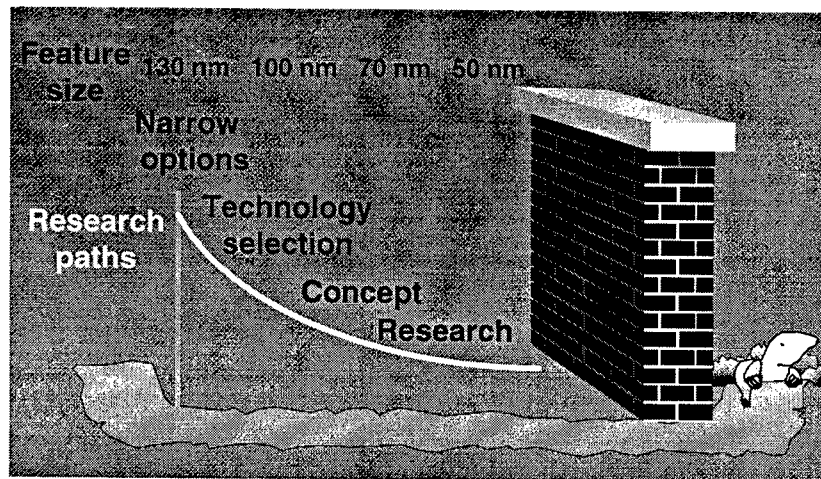
Imagine if we had a mole ($> 10^{23}$) of bytes!!

DARPA Tech 2000 Mole



Moletronics – An Underground Operation

Technical hurdles for “slice and dice” Si CMOS

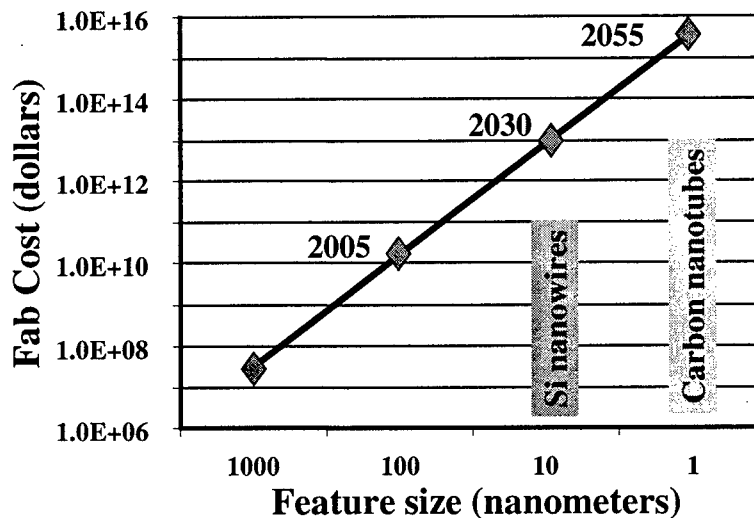


DARPA Tech 2000 Mole



Moletronics Overcomes Fabrication Costs for Lilliputian Computers

Moore's First Law vs. Moore's Second Law

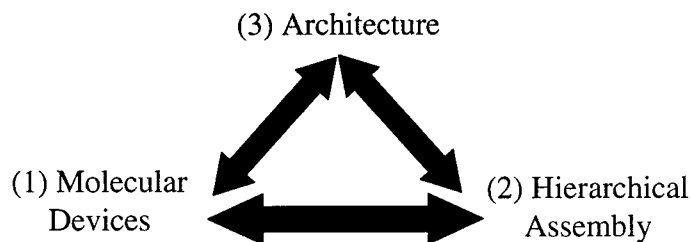


DARPA Tech 2000 Mole



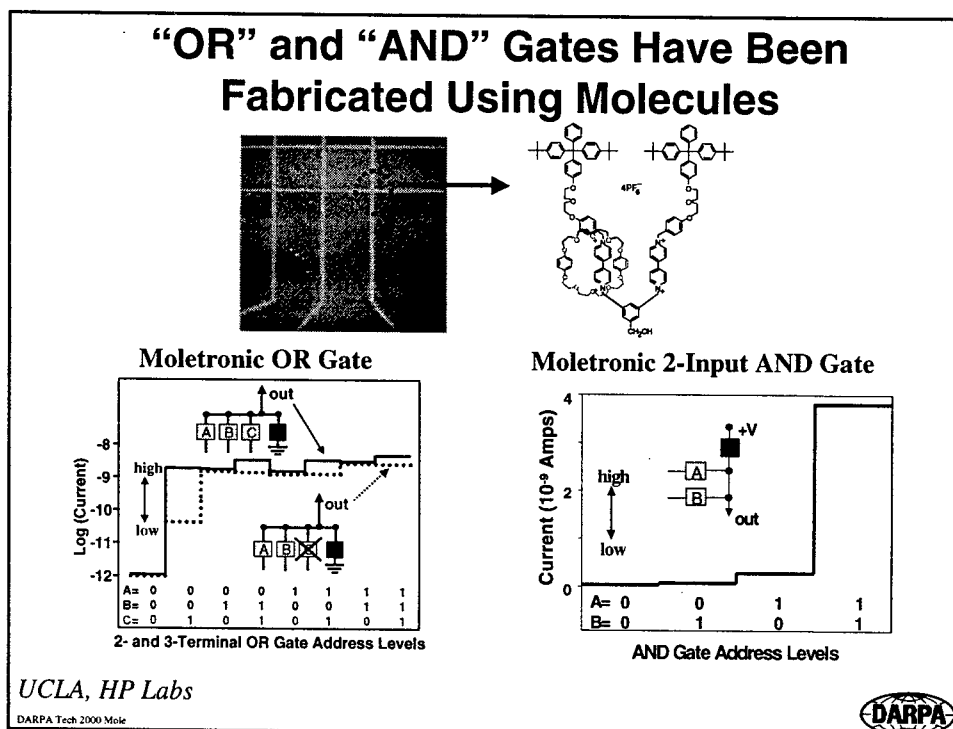
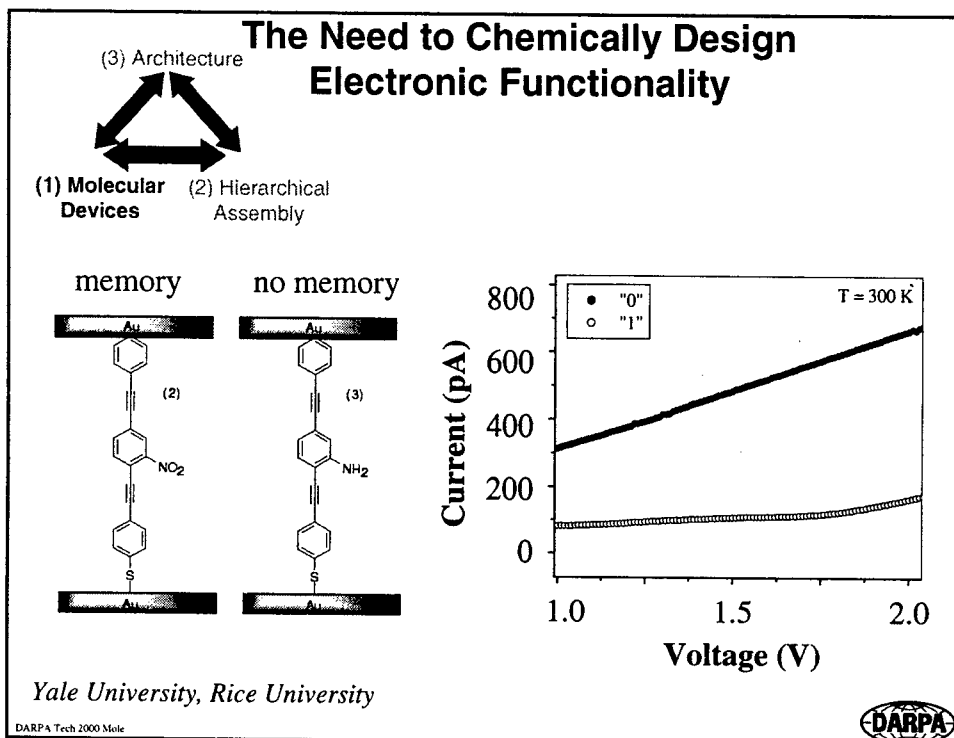
Moletronics: Re-Inventing the IC at Molecular Densities

- **Goal**
 - Demonstrate computational functionality and I/O in *scalable* molecular systems using hierarchical assembly at insanely high device densities
- **Moletronics Approach**



DARPA Tech 2000 Mole

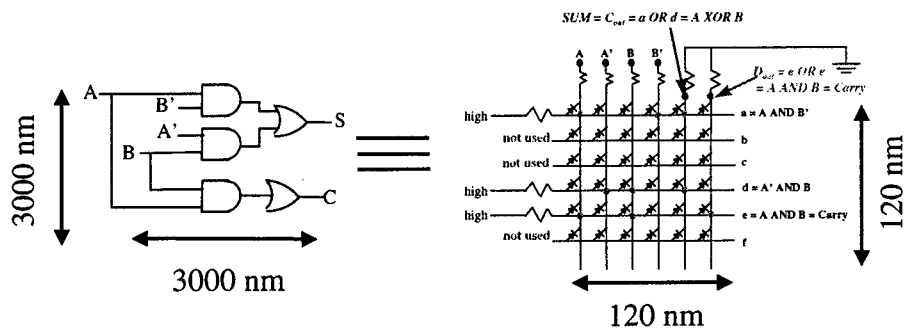




Mountains Into Molehills

Conventional Si

Moletronics



Logic gates ~ 3 transistors

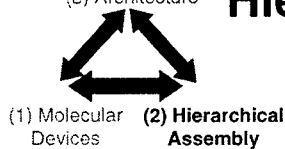
10 nm lines, 20 nm pitch

DARPA Tech 2000 Mole

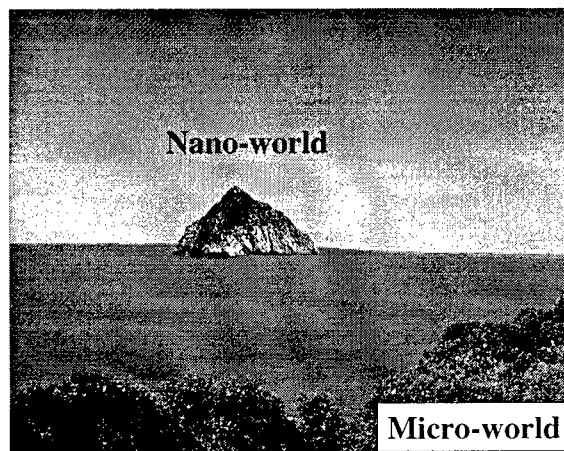


(3) Architecture

Hierarchical Assembly



Crossing the Chasm from the Nano to the Micro-World

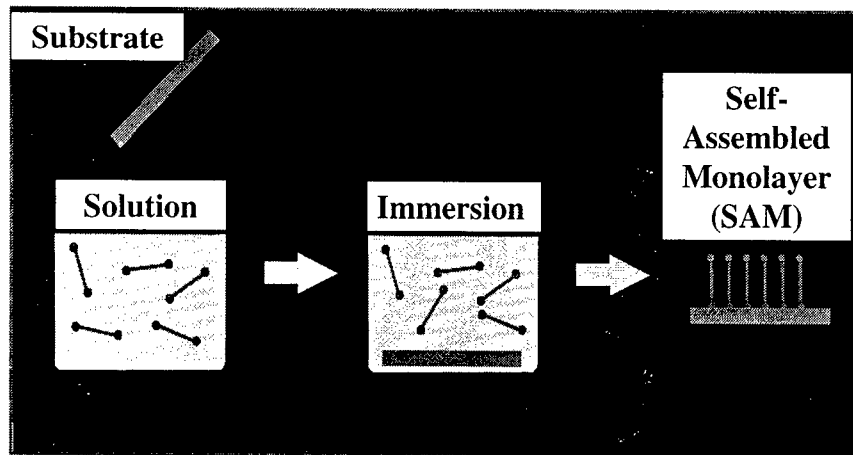


DARPA Tech 2000 Mole



Self-Assembly

Process in which structures naturally assemble into desired patterns based on thermodynamic equilibrium



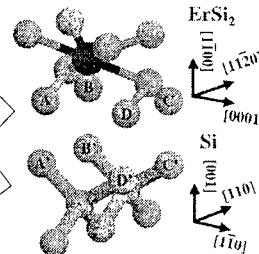
DARPA Tech 2000 Mole



Self-Assembly Makes Aligned Arrays of 2 nm Nano-Wires

Assembly dictated by anisotropic lattice mismatch with Si

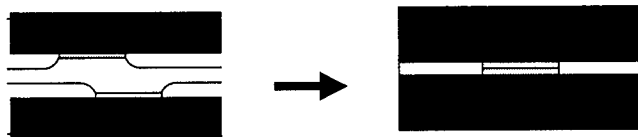
Unbelievable – 10 atoms wide,
2 atoms high, microns long!



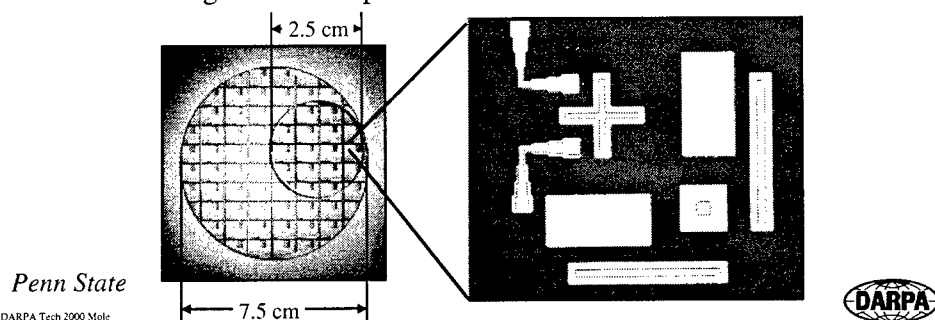
DARPA Tech 2000 Mole



Assembly of Cross-Bars Using Water (Hydrophobic/Hydrophilic Interactions)



- Chip border used as primary driving force for alignment
- Better than $1\text{ }\mu\text{m}$ alignment achieved across a 2.5 cm substrate
- Local alignment anticipated to be at least 10's of nm



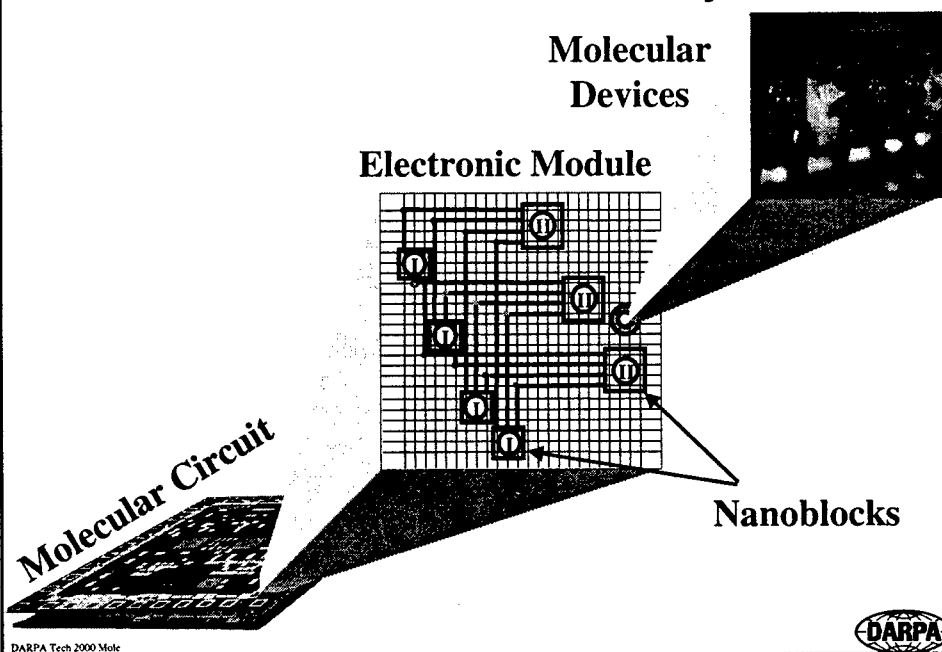
Hierarchical Assembly

Molecular
Devices

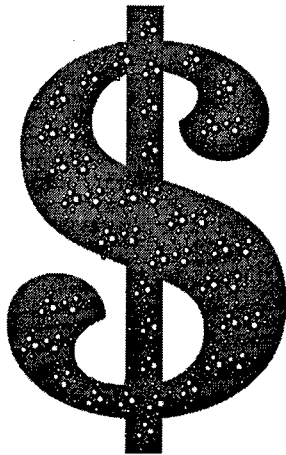
Electronic Module

Molecular Circuit

Nanoblocks



Moletronics Objective



*Hierarchical-Assembly Will Reduce The Cost
of Electronics Manufacturing*

DARPA Tech 2000 Mole



(3) Architecture



(1) Molecular
Devices

(2) Hierarchical
Assembly

Architecture and Defects

When a single defect
could kill 'ya



When defects won't
kill 'ya



- Scalable architectures
- Defect tolerance
- Algorithm development

DARPA Tech 2000 Mole



System Architecture Scalability

Power dissipation
Input/Output
Access times ...

Supercomputer

10^{12} devices in 1 cm^2

10^{12} Hertz switching speed

$\sim 10^4$ Watts!

Nanocomputer* ~ Pentium III

10^9 devices in 10^{-3} cm^2 !

10^9 Hertz

$\sim 10^{-2}$ Watts

DARPA Tech 2000 Mole

*Assumes $10^{12}/\text{cm}^2$ device density & 2.5 kT/operation



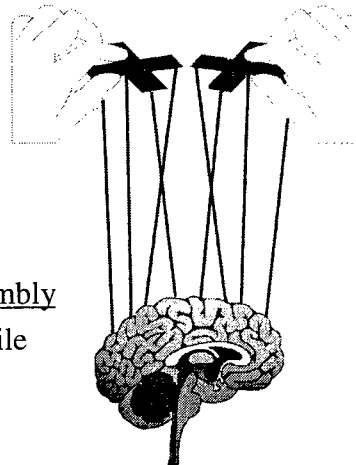
A Molecular Computer that Needs to be "Taken to School"

Old Way: Precision Design and Build

Design - Build - Compile

New Way: Directed Design and Self-Assembly

Build - Measure - Reconfigure - Compile



DARPA Tech 2000 Mole



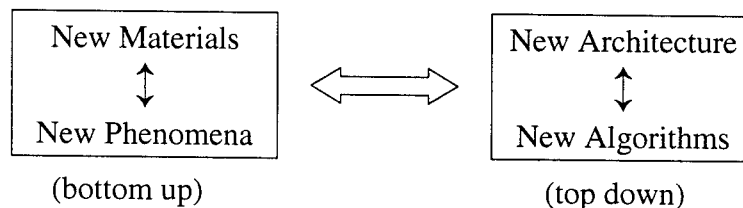
Comparisons Between Si CMOS and Moletronics

<u>Properties</u>	<u>Si CMOS</u>	<u>Moletronics</u>
Fabrication	Lithography	Hierarchical assembly
Defined properties?	Yes	No
Defects?	No	Yes
Power	Central	Distributed
Approach	Top-down	Bottom-up Top-down

DARPA Tech 2000 Mole



Conclusions



Molecular/nano materials
Self-assembly
Hierarchical assembly

•
•
•

Multi-state systems
Defect/fault tolerance
Algorithm development

•
•
•

DARPA Tech 2000 Mole



DARPA Tech 2000

List of Acronyms

A

A.cm-2	Mass. Centimeter squared
A/D	Analog/Digital
AAAV	Advanced Amphibious Assault Vehicle
AAVs	Autonomous Air Vehicles
ABC	Agent Based Computing
Abs	Absolute
ABS	Agent Based System
ACERT	Army Computer Emergency Response Team
ACL	Agent Communication Language
ACN	Airborne Communications Node
ACS	Adaptive Computing Systems
ACTDs	Advanced Concept Technology Demonstrations
ADP	Adenosine Di-Phosphate
ADXL	Analog Devices Accelerometer Series
AEL	Array Element Localization
AESA	Active Electronic Scanned Antenna
AF	Air Force
AF SAB	Air Force Science Advisory Board
AFB	Air Force Base
AFIWC	Air Force Information Warfare Center
AFRL	Air Force Research Laboratory
AFSS	Advanced Fire Support System
AI	Artificial Intelligence

AIA	Autonomic Information Assurance
AIM/DDB	Automated ISR Management/Dynamic Database
AlN	Aluminum Nitride
ALP	Advanced Logistics Program
AME	Advanced Microelectronics
AMFP	Adaptive Match Field Processor
AMP	Adenosine Tri-Phosphate
AMSTE	Affordable Moving Surface Target Engagement
AMTEC	Alkali Metal Thermal to Electric Converter
ANETS	Active Networks
ANR	Active Network Response
ANTS	Autonomous Negotiation Targets
AOA	Angle of Arrival
APCs	Armored Personnel Carriers
APIs	Application Programming Interfaces
APL	Airborne Pseudolite
APLA	Anti-Personnel Landmines
APPL	Application-specific Systems
ARL	Airborne Reconnaissance Low; Army Research Laboratory
ARPANET	ARPA Network
ARPI	ARPA (Advanced Research Project Agency) Rome Laboratory Planning Initiative
ASC/ENM	Aeronautical Systems Center
ASIC	All Source Intelligence Center
ASIC/CPU	Application Specific Integrated Circuit/Central Processing Unit
ASICs	Application Specific Integrated Circuits
ASTRO	Autonomous Space Transfer and Robotic Orbital
ASW	Anti-Submarine Warfare
AT3	Advanced Tactical Targeting Technology

ATD	Advanced Technology Demonstration
ATD/C	Automatic Target Detection/Cueing
ATDNet/MONET	Advanced Technology Demonstration Network
ATM	Asynchronous Transfer Mode
ATO	Advanced Technology Office
A-to-D	Analog to Dialog
ATP	Adenosine Mono-Phosphate; Advanced Technology Program
ATR	Automatic Target Recognition
Au	Gold
AWACS	Airborne Warning and Control System
AX	Acoustic Explorer

B

b	bytes
B	Billion
B/W	Biological Warfare
BAAs	Broad Area Announcements
BADD	Battlefield Awareness and Data Dissemination
BART	Bay Area Rapid Transit
BAW	Bulk Acoustic Wave
BCAA	Buoyant Cable Antenna Array
BDA	Battle Damage Assessment
BiCMOS	Bi-polar Complimentary Metal Oxide Semiconductor
BiFET	Bi-polar Field Effect Semiconductor
Bio	Biology
BIO:INFO:MICRO	Biology:Information:Microbiology
BioFlips	Bio-Fluidic Chips
BIT	Broadband Information Technology

BLM	Bilayer Lipid Membrane
BLOS	Beyond Line Of Sight
BM/C2	Battle Management/Command and Control
BM/C3	Battle Management/Command, Control and Communications
BMDO	Ballistic Missile Defense Office
BMG	Bulk Metallic Glass
BN HQ	Battalion Headquarters
BNS	Battalions
BOX	Barrier Oxide
BW	Biological Weapon; Biological Warfare; Bandwidth
BW/ch	Bandwidth per channel

C

C	Celcius
C/A	Course Acquisition
C2	Command and Control
C3	Command, Control, and Communications
C3I	Command, Control and Communications Intelligence
C4I	Command, Control, Communications, Computers and Intelligence
C4ISR	Command, Control, Communications, Computer, Intelligence, Surveillance and Reconnaissance
CAD	Computer Aided Design
CAPT	Captain
CASE	Computer-Aided Software Engineering
CAST	Cooperative Agents for Specific Tasks

CB	Chemical Biological
CBD	Chemical Biological Defense
CBW	Chemical Biological Warfare
CC&D	Camouflage, Concealment & Deception
CC21	Commander in Chief 21 ACTD
CCI	Co-channel Interference
CCIT	Coherent Communications, Imaging, and Targeting
CDC	Center for Disease Control
CDMA	Code Division Multiple Access
CDR	Critical Design Review; Commander
CdSe	Cadmium Selenide
CEC	Cooperative Engagement Capability
CENTCOM	Central Command
CEP	Critical Error Probability
CERT	Computer Emergency Response Team
CFD	Computational Fluid Dynamics
CHATS	Composable High Assurance Trusted Systems
Chem/Bio	Chemical/Biological
CIB	Common Imagery Base
CID	Criminal Investigation Division, Combat Intelligence Division
CINC	Commander in Chief
CIS	Coalition Infrastructure Services
CLB	Configurable Logic Block
cm	centimeter
cm/s	centimeter/second
cm ²	centimeter (squared)
CMD	Command
cm-k	centimeter-kelvin
CMOS	Complimentary Metal Oxide Semiconductor
CMU	Carnegie Mellon University

CNR	Combat Net Radios
CO	Carbon monoxide; Company
CoABS	Control of Agent Based Systems
COM	Component Object Model
COMINT	Communications Intelligence
Comms	Communications
CONOPS	Concept of Operations
CONUS	Continental United States
CORBA	Common Object Request Broker Architecture
COTS	Commercial-Off-The-Shelf
COTS	Commercial Off The Shelf
COUGAAR	Cognitive Agency Architecture
CP	Command Post
CPA	Closest Point of Approach
CpG DNA	Cytosine-phosphate-Guanine(base pair motif) Deoxyribonucleic Acid
CPoF	Command Post of the Future
Cpt.	Captain
CPU	Computer Processing Unit
CRAF	Civil Reserve Air Fleet
CRW	Canard Rotor Wing
CS	Computer Science
cu	cubic
CVBG	Carrier Battle Group
CW	Continuous Wave
CWRU	Case Western Reserve University

D

D+D	Denial and Deception
DAIS	Domain-adaptive Information System
DAML	DARPA Agent Markup Language
DARPA	Defense Advanced Research Project Agency
DASADA	Dynamic Assembly for System Adaptability, Dependability and Assurance
dB	decibel
dBm	Decibel-power of 1 mW
DC	Dynamic Coalitions; Direct Current
DCEs	Distributed Computing Environment
DDOS	Denying Denial-of-Service
deg	degree
DEMs	Digital Elevation Models
DEP/FFF	Dielectrophoresis/Field-Flow Fractionation
DFAD	Digital Feature Analysis Data
DIA	Defense Intelligence Agency
DIS	Data Intensive Systems
DISA	Defense Information Services Agency
DISA GCC	Defense Information Services Agency Global Command and Control
DISCEX	DARPA Information Survivability Conference and Exposition
DMA	Direct Memory Access
DNA	Deoxyribonucleic Acid
DNS	Direct Numerical Simulation
DNS	Defense Network Service
DNSSec	Domain Name Service Security
DoD	Department of Defense

DOF	Degree Of Freedom
DOS	Denial-of-Service
Dr.	Doctor
DRaFT	Digital Radio Frequency Tags
DRAM	Dynamic Random Access Memory
DSB	Defense Science Board
DSEAD	Distributed Suppression Of Enemy Air Defense
DSL-s	Digital Subscriber Line
DSO	Defense Sciences Office
DSP	Digital Signal Processor
DTED	Digital Terrain Elevation Data

E

EAC	Echelon Above Corp
EB - DVD	Electron Beam - Directed Vapor Deposition
ECCM	Electronic Counter-Counter Measures
ECM	Electronic Counter Measures
EDA	Electronic Design Automation
EDCS	Evolutionary Design of Complex Systems
EDFA	Erbium Doped Fiber Amplifier
EE	Electrical or Electronic Engineering
EEIs	Essential Elements of Information
EELD	Evidence Extraction and Link Discovery
Eg	Energy gap
EHF	Extremely High Frequency
ELINT	Electronic Intelligence
EM	Electromagnetic
EMD	Engineering Management Decision

EMI/EMC	Electro Magnetic Interference/Electro Magnetic Control
ENCOMPASS	Enhanced Consequence Management Planning and Support System
EO	Electro-Optical
EO/IR	Electro-Optical/Infrared
EP	Electronic Protection
EPLRS	Enhanced Positioning, Locating, Ranging System
Er	Erbium
ERGM	Extended Range Guided Munition
ErSi2	Erbium Silicide
ESA	Electronically Scanned Array
ESM	Electronic Support Measures
ESRT	Electron-Spin Resonance Transistor
eV	electron Volt
EW	Electronic Warfare

F

F&S	Force and System
FAME	Frequency Agile Materials
FBE	Fleet Battle Experiment
FCS	Future Combat Systems
FDOA	Frequency Difference of Arrival
FEM	Finite Element Model
FEMA	Federal Emergency Management Agency
FETs	Field Effect Transistors
FF	Fast Frigate
FFP	Full Field Processing
FFT	Fast Fourier Transform
FIDNET	Federal Intrusion Detection Network

FIPA	Foundation for Intelligent Physical Agents
FIWC	Fleet Information Warfare Center
FlexML	Flexible Markup Language; Flexible Motor Language
FLIR	Forward Looking Infrared
FLT	Flight
FoF1	path for a specific type of biomolecular motor
FOPC	First-order Predicate Calculus
FOPEN	Foliage Peneration
FPA	Field Programmable Array
FPGAs	Field Programmable Gate Arrays
FRR	Final Readiness Review
FSCS	Future Scout Cavalry System
FSMs	Functional Size Measurement
FTN	Fault Tolerant Network
FTS	Fault-Tolerant Survivability
FUE	Full Up Element
FY	Fiscal Year

G

g	gram
GaAs	Gallium Arsenide
GaAs/ZnSe	Gallium Arsenide/Zinc Selenide
GaMnAs	Gallium Manganese Arsenide
GaN	Gallium Nitride
GAO	General Accounting Office
Gb	Gigabytes
Gb/s	Gigabytes/per second
GBPS	Giga Bits Per Second
GCDS	Ground Control and Display System

GCN	Ground Control Network; Government Computer News
GDP	Gross Domestic Product
GFE	Government Furnished Equipment
GGP	GPS Guidance Package
GHz	Gigahertz
gm	grams
GMR	Giant Magneto-Resistance
GMTI	Ground Moving Target Indicator
Gohm	Gigaohm
GOPS	Billion Operations Per Second
GOPS/W	Billion Operations Per Second Per Watt
GOTS	Government Off the Shelf
Govt.	Government
GP	General Processor
GPL	Ground Pseudolight
GPS	Global Positioning System
GPS INS	Global Positioning System Inertial Navigation System
GPX	Global Positioning Experiment

H

h	heat transfer coefficient; Planck's constant
H ₂	Hydrogen gas
HBT	Heterojunction Bi-polar Transistor
HCLOS	High Capacity Line-Of-Sight
HDS	High Definition Systems
HDTV	High Definition Television
HERETIC	Heat Removal Thermal Integrated Circuits
HF	High Frequency

HFET	Heterojunction Field Effect Transistor
HID	Human ID at a Distance
HIMARS	High Mobility Artillery Rocket System
HLA	Horizontal Line Array
HMD	Helmet Mounted Display
HMMWV	High Mobility, Multi Wheeled Vehicle
HNS	Host-Nation Support
HOLs	High Order Logic
HP	Hewlett Packard
HPKB	High Performance Knowledge Base
HQS	Headquarters
hr	hour
HRR	High Range Resolution
HSCC	High Speed Connectivity Consortium
HSI	Hyperspectral Imager
HSI/MSI	Hyper-Spectral Imagery/Multi-Spectral Imagery
HTLE	Horizontal Target Location Error
HTML/XML	Hypertext Markup Language/Extensible Markup Language
HTTP	Hypertext Transfer Protocol
HumanID	Human Identification at a Distance
HUMINT	Human Intelligence
HV	High Vacuum
HW	Hardware
Hz	Hertz

I

I&W	Indications and Warning
I/O	Input/Output
I3	Intelligent Integration of Information

IA	Input Axis
IA	Information Assurance
IA&S	Information Assurance & Survivability
IADS	Integrated Air Defense System
IC	Integrated Circuits
ICBMs	Inter Continental Ballistic Missiles
ICL	Interactive Command Language
ID	Identification; Intrusion Detection
IDS	Intrusion Detection Systems
IEDM	International Electronics Device Meeting
IETF MANET	Internet Engineering Task Force Mobile Ad-hoc Network
IF	Intermediate Frequency
IFM	Interconnect Fabric Element
III-N	Type 3 material with Nitrogen
IMINT	Imagery Intelligence
IMO	Intelink Management Office
IMU	Inertial Measurement Unit
in	inches
InAs/GaSb/AISb	Indium Arsenide/Gallium Antimonide/Aluminum Antimonide
Info	Information
InP	Indium Phosphide
INSCOM	Intelligence and Security Command (US Army)
In-situ	In Place
INT	Intelligence
Inter-MCM	Interconnect connection for Multi-Chip Module
IOC	Initial Operating Capability
IOR	Interim Open Review
IP	Internet Protocol
IPB	Intelligence Preparation of the Battlefield
IPSEC	Internet Protocol Security

IR	Infrared
IS	Information System
ISAT	Incremental Satisfiability
ISCR	Interim System Concept Review
ISI-East	Information Sciences Institute-East
ISO	Informations Systems Office
Isp	Specific Impulse
ISP	Internet Service Provider
ISR	Independent Search and Rescue; Intelligence, Surveillance and Reconnaissance
ISRR	Interim System Risk Review
IT	Information Technology
ITO	Information Technology Office
IW	Information Warfare

J

J/S	Jammer to Signal Ratio
JARS	Java Applet Rating Service
JB	Joint Battlespace Infosphere
JCSE	Joint Communication Support Element
JDAM	Joint Direct Attack Munition
JFACC	Joint Force Air Component Commander
JIATF-E	Joint Inter-agency Task Force - East
JIP	Just In-time Power
Joint STARS	Joint Surveillance Target Attack Radar System
JPL	Jet Propulsion Laboratory
JSF	Joint Strike Fighter
JSTARS	Joint Surveillance Target Attack Radar System

JTF	Joint Task Force
JTIDS	Joint Tactical Information Distribution System
JV	Joint Vision

K

K	kilowatts, thousand
KB	Kilobytes; Knowledge Based
Kcal/mol	kilocalorie per mole
KE	Kinetic Energy
Kg	Kilogram
KHz	Kilohertz
KLA	Kosovo Libertation Army
Km	Kilometers
kohm	kilo-ohm
KQML	Knowledge Query and Manipulation Language
kW	kilowatts
kW-hr	kilowatts – hour

L

LADAR	Laser Radar
LAN	Local Area Network
LAVs	Light Armored Vehicles
lbs	pounds
LEDs	Light Emitting Diodes
LEO	Low Earth Orbit
LES	Large Eddy Simulation

Lg	gate Length
LIGA	Lithography
LIWA	Land Information Warfare Activity
LLNL	Lawrence Livermore National Laboratory
Lm	L-band (military code)
LMDS	Local Multiport Distribution Service
LO	Low Observable
LOS	Line Of Sight
LPD	Low Probability of Detection
LPI	Low Probability of Intercept
LTC	Lieutenant Colonel
LtCol	Lieutenant Colonel

M

m	meter
M&S	Modeling and Simulation
mA	milliamps
MAFC	Micro Adaptive Flow Control
MAFET	Microwave and Analog Front End Technology
MAR CAX	Marine Combat Arms Exercise
MARS	Mobile Autonomous Robot Software
MAV	Micro Air Vehicle
Mb	Megabytes
Mbps	Megabits per second
mC	Microcontroller
MC	Malicious Code
MCAGCC	Marine Corps Air Ground Combat Center
MCE	Mission Control Element
MCMs	Multi Chip Modules

MCS	Mission Control Station
MDCP	Multi-Dimensional Coalition Policies
MECH	Mechanized
MEMS	Micro Electro Mechanical System
MEMS INS	Micro Electro Mechanical System Inertial Navigation System
MEMS-RF	Micro Electro Mechanical System - Radio Frequency
MFP	Matched Field Processor
MHT	Multiple Hypothesis Tracker
MHz	Megahertz
Micro	Microsystems
MicroFlumes	Microfluidic Molecular Systems
micro-g	micro-gravity
Microsat	Microsatellite
MIMIC	Microwave Monolithic Integrated Circuits
MIPS	Model Integrated Program Synthesis
MIT	Massachusetts Institute of Technology
MIT/LL	Massachusetts Institute of Technology/Lincoln Laboratory
mK	milliKelvm
MLP	Molecular-Level Large-Area Printing
MLRS	Multiple Launch Rocket System
mm	millimeter
MMIC	Miniature Millimeter Wave Integrated Circuit
MMW	Millimeter Microwave
MOA	Memorandum Of Agreement
MoBIES	Model-Based Integration of Embedded Systems
Moletronics	Molecular Electronics
MOS	Metal Oxide Semiconductor
MOSFET	Metal Oxide Semiconductor Field Effort Transistor

MOUT	Military Operations in Urban Terrain
MOVINT	Movement Intelligence
MPG	Micro Power Generation
MRC	Major Regional Contingency
MRVs	Multiple Re-entry Vehicles
MS	Message Switch
ms	milliseconds
MSCR	Mission System Capability Review
msec	millisecond
MSIP	Multinational Staged Improvement Program
MSRR	Modeling and Simulation Resource Repository
MSTAR	Moving and Stationary Target Acquisition and Recognition
MTE	Moving Target Exploitation
MTI	Moving Target Indicator
MTO	Microsystems Technology Office
MTW	Major Theater of War
mV	millivolt
MV	Mega Volt
MVBM	Micro Vibrating Beam Multisensor
MVDR	Minimum Variance Distortionless Receiver
Mw	milliwatt

N

N	Negative charge
NA	Not Applicable
NAS	National Academy of Science
NASA	National Aeronautics and Space Administration

NATO	North Atlantic Treaty Organization
NAV	Navy
NAVAIR	Naval Air Systems Command
NAVSEA	Naval Sea Systems Command
NAWC-CL	Naval Air Warfare Center - China Lake
NCA	National Command Authority
NDR	Negative Differential Resistance
NFOV	Narrow Field of View
NGI	Next Generation Internet
Ni-NTA	Nickel NTA
NIPC	National Infrastructure Protection Center
NLOS	Non Line Of Sight
nm	nanometer; nautical miles
NMS	Network Modeling and Simulation
NodeOS	Node Operating Systems
NRL	Naval Research Laboratory
NRO	National Reconnaissance Office
ns	nanoseconds
NSA	National Security Agency
NSB	National Science Board
nsec	nanosecond
NSWC	Naval Surface Weapons Center
NTC	National Training Center
NTM	Notice to Mariners
NTON II	National Transparent Optical Network
nW	nanowatt

O

O&S	Operations and Support
O(n2)	Order N ²

O/E	Opto-Electronic
OAA	Open Agent Architecture
OCP	Open Control Platform
OMNET	Optical Micro-networks
ONR	Office of Naval Research
ONRAMP	Optical Network for Regional Access over Multi wavelength protocol
OODA	Observe, Orient, Decide, Act
OOTW	Operations Other Than War
Ops	Operations
OPTEMPO	Operational Tempo
Opto	Optical
OR	OR Logic Gate
ORBREP	Orbital Replenishment
ORUs	Orbital Replacement Units
OS	Operating Systems
OSAM	Office of Spectrum Analysis & Management
OSC	Operational System Concept
OWL	Ontology Web Language

P

p	Positive charge
P[CA]	Probability of Correct Association
P3I	Preplanned Product Improvement
pA	pico-Amperes
Pa	Pascal
PAC/C	Power Aware Computing/Communication
PACOM	Pacific Command
PACT	Photonic A/D Converter Technology
PAE	Power Added Efficiency

Pamp	Power amplified
PASEM	Passive Acoustic, Seismic & EM
PC	Personal Computer
PCA	Polymorphous Computing Architectures
PCB	Printed Circuit Board
PCES	Program Composition for Embedded Systems
PCI	Peripheral Component Interface
PCR	Polymerase Chain Reaction
PdH	Palladium Hydride
PDR	Preliminary Design Review
PEM	Proton Exchange Membrane
PFCT	Precision Fire Control Tracking
PG	Proving Ground
PGA	Pin Grid Array
PGP	Pretty Good Privacy
pH	Chemical standard indicating acidity of a solution alloy
PHEMTs	Pseudomorphic High Electron Mobility Transistors
Pi	Inorganic Phosphate
PI	Principal Investigator
PIM	Point or Path of Intended Movement
PKI	Public-Key Infrastructure
PLGR	Precision Lightweight GPS Receiver
PM	Program Manager
pN-nm	pico-Newtons-nanometer
POF	Plastic Optical Fiber
POM	Program Objective Memorandum
POWs	Prisoners Of War
P-Ps	Peer-to-Peers
PRI	Pulse Repetition Interval
psec	picosecond

PVR	Peak to Valley Ratio
pW	picowatt
P-WASSP	Photonic Wavelength & Spatial Signal Processing
PZT	Lead Zirconium-Titanium alloy

Q

QoS	Quality of Service

R

R	Resistance
R&D	Research & Development
RAM	Random Access Memory
RANS	Reynolds Average Navier Stokes
RDF	Resource Description Framework
RECAP	Reconfigurable Aperture
REMBASS	Remotely Monitored Battlefield Sensor System
RF	Radio Frequency
RFI	Radio Frequency Interference
R-FLICS	Radio Frequency Lightwave Integrated Circuits
RFP	Request For Proposal
RIE	Regative Ion Etching
RISC	Reduced Instruction Set Computer
RISC/DSP	Reduced Instruction SLT Computer/Digital Signal Processor
RKF	Rapid Knowledge Formation
RMI	Remote Method Invocation

RNA	Ribonucleic Acid
ROI	Region of Interest
ROM	Read Only Memory
RPS	Robust Passive Sonar
rps	rotations per second
RR&OE	Risk Reduction and Operational Evaluation
RST	Reconnaissance, Surveillance and Targeting
RSTV	Reconnaissance, Surveillance and Targeting Vehicle
RTOS	Run-Time Operating System
Rx	Receive; Prescription

S

S&T	Science & Technology
S/N	Signal to Noise Ratio
SAM	Structural Amorphous Materials; Self-Assembled Monolayer; Surface-to-Air Missile
SAR	Synthetic Aperture Radar
SAR/MTI	Synthetic Aperture Radar/Moving Target Indicator
SAS-SUO	Situation Awareness System-Small Unit Operation
SAT	Boolean Satisfiability Problem
SATCOM	Satellite Communications
SAW	Surface Acoustic Wave
SBCX	Santa Barbara Channel Experiment
SBIRS	Small Business Innovation Research Projects or Space Based Infrared Systems
SCD	Source Control Drawing

SDIO	Strategic Defense Initiative Office
SDR	Software for Distributed Robotics
SDRAM	Synchronous Dynamic Random Access Memory
SEAD	Suppression of Enemy Air Defense
SEC	Software Enabled Control
secs	seconds
SensIT	Sensor Information Technology
SEP	Spherical Error Probable
SETA	Scientific, Engineering and Technical Assistance
SGM	Secure Group Management
SHF	Super High Frequency
SHIPN	Secure High-speed IP Networking
SHOE	Simple HTML (Hypertext Markup Language) Ontology Extension
Si	Silicon
Si CMOS	Silicon Complementary Metal Oxide Semiconductor
Si fab	Silicon Fabrication
SIA	Semiconductor Industry Association
SiC	Silicon Carbide
SiGe	Silicon Germanium
SIGINT	Signals Intelligence
SINCGARS	Single Channel Ground and Air Radio Systems
SINR	Signal to Interference Ratio
SiO ₂	Silicon Dioxide
SMA	System Maturation Assessment
SMEs	Subject Matter Experts
SMF	Single-Mode Filter
SMP	System Maturation Plan
SOA	Semiconductor Optical Amplifier
SOFC	Solid Oxide Fuel Cell

SOG	Sensor Oversight Group
SOI	Signals of Interest; Silicon On Insulator
SONET	Synchronous Networking
SPINS	Spins IN Semiconductors
Spintronics	Spin Electronics
SPO	Special Projects Office
sq.km.	square kilometer
SQL	Structured Query Language
SRA	Specialized Repair Activity
SSA	Solid State Amplifier
STAB	Steered Agile Beams
STAP	Space-Time Adaptive Processing
START	SynTactic Analysis using Reversible Transformations
SUMOWIN	Survivable Mobile Wireless Networking
SUO	Small Unit Operations
SVC PLT	Services Platoon
SVR	Surface-to-Volume Ratio
SW	Software
SWaP	Size, Weight and Power
SWEPT	Size, Weight, Energy, Performance, Time
SWP	Size, Weight, Power

I

T&E	Test & Evaluation
T&V	Test and Verification
T/R	Transmit/Receive
TASK	Taskable Agent Software Kit
TASS	Terminal Analog Speech Synthesizer
TBD	To Be Determined

TBMD	Theater Ballistic Missile Defense
Tbytes	Terabytes
TCT	Time Critical Targets
TDOA	Time Difference Of Arrival
TE	Thermo Electric
TEls	Transporter Erector
TERCOM	Terrain Contour Matching
TF/TA	Terrain Following/Terrain Avoidance
TFG	Tuning Fork Gyro
TFR	Terrain Following Radar
TIDES	Trans-Lingual Information Detection
TIEs	Technology Integration Experiments
TIGER	Targeting by Image Geo Registration
TIM	Technical Interchange Meeting
TIS	Trusted Information Systems
TLE	Two Line Element
TMR	Tactical Mobile Robots
TNT	Tri-Nitro Toluene
TOC	Total Ownership Costs
Tox	Oxide Thickness
TPED	Tasking Processing Exploitation and Dissemination
TPSAs	Technologies Processes and System Attributes
TPV	Thermal Photo Voltaic
TRADOC	U.S. Army Training and Doctrine Command
TRL	Technology Readiness Level
TRSS	Tactical Remote Sensory System
TSM	Trunk Signaling Message
TST	Technical Support Team
TTO	Tactical Technology Office
TUAVs	Tactical Unmanned Air Vehicles

TV	Television
Tx	Transmit

U

UAVBL	Unmanned Air Vehicle Battle Laboratory
UAVs	Unmanned Air Vehicles
UC	University of California
UCAV	Unmanned Combat Air Vehicle
UCAV-N	Unmanned Combat Air Vehicle - Naval
UCB	University of California Berkeley
UCLA	University of California-Los Angeles
UCLA/HP	University of California Los Angeles/Hewlett-Packard
UDS-N	UCAV Demonstrator System - Naval
UE	User Equipment
UGF	Underground Facilities
UGS	Unattended Ground Sensors
UHF	Ultra High Frequency
UIUC	University of Illinois Urbanna-Champaign
UK DERA	United Kingdom Defense Evaluation and Research Agency
UL	Ultra Log
UNREP	Underway Replenishment
UOS-N	UCAV Operational System - Naval
UPa/Hz	Micro Pascals per Hertz
UPC	Unconventional Pathogen Countermeasures
US	United States
USA	United States Army
USAF	United States Air Force
USC	University of Southern California

USC/HRL	University of Southern California/HRL
USMC	United States Marine Corps
USN	United States Navy
USN-R	United States Navy - Reserve
USS	United States Ship
UV	Ultra Violet
uW	Microwave

V

V	Voltage
V/STOL	Vertical/Standing Take Off Landing
VCSELs	Vertical Cavity Surface-Emitting Lasers
V _d	drain Voltage
VHDL	VHSIC Hardware Description Language
VHF	Very High Frequency
VHF/UHF	Very High Frequency/Ultra High Frequency
VHSIC	Very High Speed Integrated Circuit
VLA	Vertical Line Arrays
VLSI	Very Large Scale Integration
Vol.	Volume
V _p	V-pi
VPNs	Virtual Private Networks
V _s	Saturation Velocity
VTOL	Vertical Take Off and Landing

W-Z

W	Watts
W/kg	Watt/kilogram
W3C	World Wide Web Consortium
WAE	Wargaming the Asymmetric Environment
WANs	Wide Area Networks
WASSP	Wavelength & Spatial Signal Processing
WBC	White Blood Cells
WBG	Wide Bandgap
WDM	Wavelength Division Multiplexing
WDM/TDM	Wavelength Division Multiplexing/Time Division Multiplexing
Whr/kg	Watt hour/kilogram
WIN-T	Warfighter Internet-Terrestrial
WMD	Weapons of Mass Destruction
WSTS	Weapons Systems Trade Studies
XML	Extensible Markup Language



DARPATECH

2000 SYMPOSIUM

DARPA