

APPLIED ANALYSIS PROGRAM

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**COMPUTING AND INFORMATION
SCIENCES DIVISION**

**ARMY RESEARCH OFFICE
ARMY RESEARCH LABORATORY**



RECENT PROGRAM CHANGES



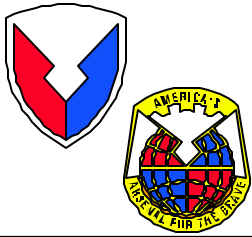
- **Scope widened from mathematical analysis to mathematical, engineering and/or behavioral analysis**
- **Increased focus on complex phenomena for which first/basic principles have not yet been well developed**
 - **Physical phenomena**
 - **Behavioral phenomena**
 - **Abstract phenomena in information theory and networks**
- **Balance between analysis for “hard,” physics-based areas and analysis for “soft,” information- and behavioral-based areas shifted toward latter**
- **New name: ?**



RESEARCH OBJECTIVES



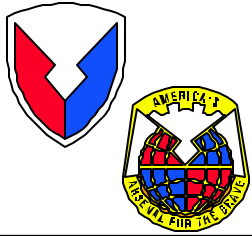
- Fundamental mathematics-oriented research with the objectives
 - Develop quantitative models of complex phenomena, especially those for which current models are not based on first/basic principles
 - Develop new metrics, preferably those based on first/basic principles, for these models



RESEARCH OBJECTIVES



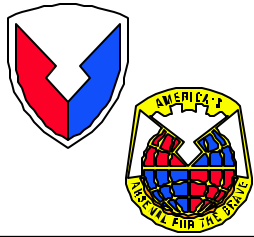
- Nonlinear multiscale/multiresolution analysis for
 - Advanced complex materials for structures, armor, sensors
 - Inverse scattering in complex media
 - Modeling of multiscale objects and functions
 - Nonlinear dynamics for communication
 - Data fusion in complex networks
 - Dynamics of distributed networks of embedded sensors and actuators
 - Additional areas of opportunity (behavioral modeling, very low signal-to-noise speech recognition, information flow, network tomography)



RESEARCH AREAS NOT BEING CONTINUED



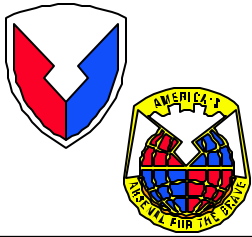
- Soil and granular materials
- Fluid flow
- Photonic bandgap materials



SCIENTIFIC BARRIERS



- Solid materials: Homogenization, linkage of scales
- Inverse scattering: Loss of information due to attenuation, complexity of medium
- Modeling of multiscale objects and functions: Shape preservation for multiscale data
- Nonlinear dynamics: Symbolic dynamics (alphabets with greater information-transfer capabilities)
- Data fusion: Metrics (function spaces), integration of power and communication constraints into metrics, linkage of scales
- Dynamics of distributed sensor/actuator networks: Metrics, hybrid (continuum/digital) nature of interactions
- Additional areas: Fundamental principles, metrics



IMPORTANCE TO THE ARMY



Advanced Solid Materials for Structures, Armor and Sensors

- Ultralightweight structures for helicopters and ground vehicles
- Advanced composites and multiscale materials for armor
- Prediction of penetration and anti-penetration
- Smart materials for advanced sensing and control devices

Inverse Scattering

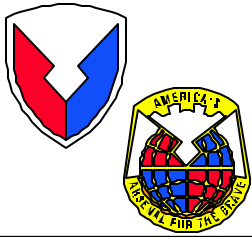
- Rapid detection/ID of landmines with low false alarm rates

Modeling of Multi-scale Objects and Functions

- Real-time visualization with glitch-free zoom-in/out

Nonlinear Dynamics

- Low-power communication
- High wireless data-transmission rates
- Low probability of interception and detection (LPI/LPD)



IMPORTANCE TO THE ARMY



Data Fusion

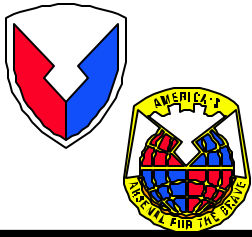
- Information processing in large arrays of acoustic, IR, and other small sensors
- Comprehensive situational awareness
- Replacement of landmines

Dynamics of Distributed Sensor/Actuator Networks

- Behavior of integrated defense systems, including identification of “unexpected” failure modes before they occur

Additional Areas of Opportunity

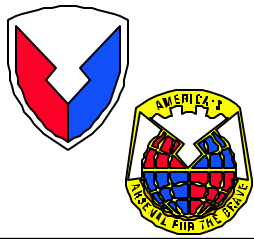
- Behavioral modeling: Operations planning, training
- Speech recognition: Hands-off operation on battlefield
- Information flow: Planning of defense info networks
- Network Tomography: Defense of wireless and wired networks



PRINCIPAL CUSTOMERS



- **Office of Deputy Undersecretary of the Army for Operations Research** [Joseph]
- **Ballistic Missile Defense Organization** [Joseph]
- **Army Research Laboratory**
 - Computing and Information Sciences Directorate [Larson, Luskin, Schumaker, Mitter]
 - Sensors and Electron Devices Directorate [Venakides, Kuchment, Eicke, Mitter]
 - Survivability/Lethality Directorate [Schumaker]
 - Weapons and Materials Research Directorate [Kohn, Olmstead, Kinderlehrer, Babuska]
- **Aviation and Missile Command**
 - Redstone Missile RDEC [Venakides, Kuchment, Hale, Larson]
- **Chemical and Biological Defense Command**
 - Research and Technology Directorate, Edgewood RDEC [Joseph]
- **Communications and Electronics Command**
 - Mine Detection Division, NVEDS [Dugan, Klibanov]
- **Corps of Engineers**
 - Waterways Experiment Station [Shearer, Cushman]
 - Topographic Engineering Center [Schumaker]
- **Space and Missile Defense Command**
 - Missile Defense and Space Technology Center [Joseph]
- **Tank and Automotive Command**
 - Propulsion Team, Research Business Group, Tank and Auto. RDEC [Majda, Bourlioux]
 - National Automotive Center, Tank and Automotive RDEC [Babuska]
- **Training and Doctrine Command**
 - Dismounted Battlespace Battlelab [Mitter]



PROGRAM CONTENT: THEORETICAL ANALYSIS



- Theoretical analysis is sparsely represented in Army intra- and extramural programs.
- Army research related to theoretical analysis includes computational and engineering research for both “hard” and “soft” areas.
- The Applied Analysis Program provides theoretical analysis complementary to computational and engineering research.



PARTICIPATION IN FUNDED MULTIDISCIPLINARY INITIATIVES

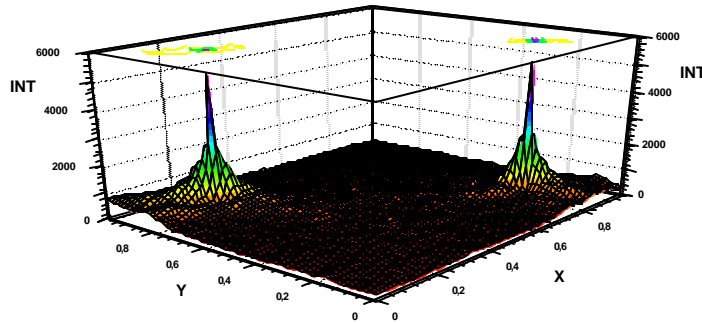


- 6 MURIs started in FY 96 (ARO, ONR, AFOSR)
- Dendritic Polymers (97) (ARO)
- **Digital Nonlinear/Chaotic Communication Devices (98) (ARO)**
- Nonclassical Info Representation & Manipulation (99) (ARO)
- **Data Fusion in Large Arrays of Microsensors (Sensorweb) (00) (ARO)**
- Decision Making under Uncertainty (00) (ONR)
- Mobile Augmented Battlespace Visualization (00) (ARO)
- Solitonic Information Processing (00) (ARO)
- Quantum Communication and Quantum Memory (00) (ARO)
- Digital Libraries for Constructive Math Knowledge (01) (ARO)
- Quality of Service for Distributed Systems (01) (ARO)
- Network Surveillance (01) (ARO CIP)
- Information Assurance in Wireless Networks (01) (ARO CIP)
- Critical Infrastructure Performance Assessment (01) (ARO CIP)
- Heterogeneous Distributed Computing Systems (01) (ONR CIP)



Digital Communication Devices Based on Nonlinear Dynamics and Chaos

Larry Larson, UCSD



Processing Gain of Chaotic Synchronized Phased Array Antenna Elements in the Presence of Multiple Interfering Sources.

MURI OBJECTIVE

Design simple, strongly nonlinear electronic/optical digital communication devices operating in chaotic regime with minimal control circuitry

DOD CAPABILITIES ENHANCED

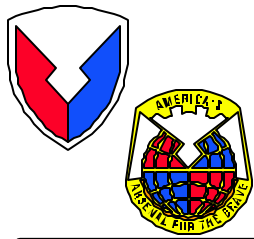
- Small, light-weight, low-power transmitters and receivers with much greater bit rates
- Low probability of interception/detection (LPI/LPD)

SCIENTIFIC/TECHNICAL APPROACHES

- Investigate robust chaotically modulated communications techniques
 - Pulse and frequency modulation for wireless
 - Continuous feedback for free-space optical
 - Bit-error rate and multi-user performance analysis of chaotic modulation
 - Control techniques to improve performance
- Investigate propagation and interference issues of chaotically modulated communications devices

ACCOMPLISHMENTS

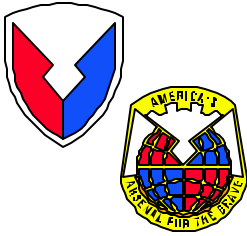
- Developed Viterbi decoding algorithm for symbolic-dynamics-based chaotic modulation
- Excellent agreement obtained between theory, simulations and experimental results in chaotic pulse position modulation electronic comm link
- Developed improved code division multiple access (CDMA) code based on chaotic algorithms
- Developed and demonstrated all-optical synchronization of free-space optical data link



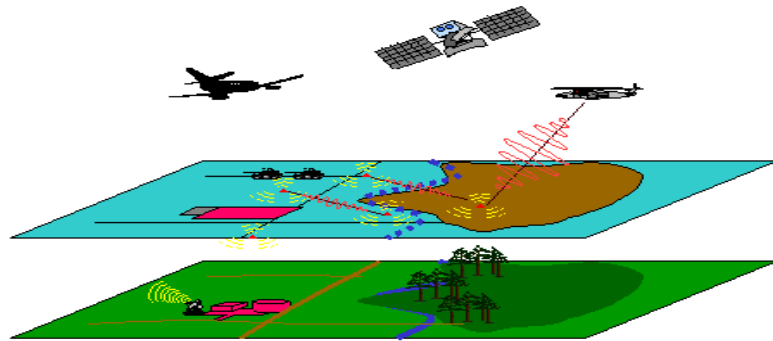
NONLINEAR DEVICES MURI: WORKSHOP AND REPORT



- **Workshop “Communicating by Chaos: Digital Signal Generation by Simple Nonlinear Devices” held 5 June 1996 at ARO/ARL in Research Triangle Park, NC**
- **Workshop jointly sponsored by ARO/ARL Math, Physics and Electronics Divisions and ARL Information Sciences and Technology Directorate**
- **Workshop produced draft of 39-page report that outlines 6.1-6.2-6.3 R&D (including context for Nonlinear Devices MURI)**
- **Report published in November 1996**



Data Fusion in Large Arrays of Microsensors (Sensorweb) Sanjoy Mitter, MIT



Data Fusion for Large Distributed Sensor Arrays

MURI OBJECTIVES

Develop the scientific foundations for the effective use of large arrays of sensors with limited sensing, computational, and communication capabilities

DOD CAPABILITIES ENHANCED

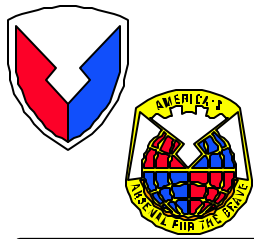
- Scalable methodologies for distributed fusion and self-organization for sensor arrays
- Basis for assessing fundamental performance limits and tradeoffs in such sensor arrays

SCIENTIFIC/TECHNICAL APPROACHES

- Develop methods for representation of uncertain information in sensor networks and associated fusion algorithms
- Investigate information-theoretic bounds on performance of such networks and algorithms for information transmission
- Investigate learning and adaptation methods for identifying coherent patterns in distributed sensor data

ACCOMPLISHMENTS

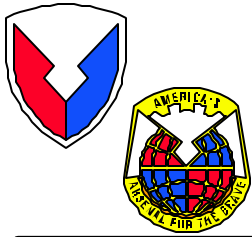
- MURI kickoff meeting on July 17, 2000 with official program start of August 1, 2000
- Projects just initiated in each of the technical areas
- Initial discussions held with several industrial and FFRDC groups in order to define transition paths and opportunities



DATA FUSION MURI: WORKSHOP AND REPORT



- **Workshop “Distributed Microsensing: Devices, Networks and Information Processing” held 11-12 January 1999 at ARL in Adelphi, MD**
- **Workshop jointly sponsored by Applied Analysis Program, MCS Division, ARO, ARL and Signal Processing Division, SED Directorate, ARL with strong participation by Battlefield Environment Division and Comm & Network Systems Division, IST Directorate, ARL**
- **Workshop produced draft of 35-page report that outlines 6.1-6.2-6.3 R&D (including context for Data Fusion MURI)**
- **Report published in June 1999**



CONCLUSION



- **Balance between “hard,” physics-based and “soft,” information/behavioral-based areas shifted toward latter**
- **Increasing participation in large, multidisciplinary projects**
- **Single-investigator projects as well as large projects integrated with Army/DoD needs and laboratories**
- ***Program Update* with information on research interests and funding opportunities is emailed out 3–10 times/year.**
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