BROAD AGENCY ANNOUNCEMENT

(BAA) INTRODUCTION:

This publication constitutes a Broad Agency Announcement (BAA) as contemplated in Department of Defense Grant and Agreement Regulation (DODGARS) 22.315(a). A formal Request for Proposals (RFP), solicitation, and/or additional information regarding this announcement will not be issued. Request for same will be disregarded.

The Office of Naval Research (ONR) will not issue paper copies of this announcement. The ONR and Department of Defense (DoD) agencies involved in this program reserve the right to select for award all, some or none of the proposals submitted in response to this announcement. The ONR and other participating DoD agencies provide no funding for direct reimbursement of proposal development costs. Technical and cost proposals (or any other material) submitted in response to this BAA will not be returned. It is the policy of ONR and participating DoD agencies to treat all proposals as sensitive competitive information and to disclose their contents only for the purposes of evaluation.

The DoD Multidisciplinary University Research Initiative (MURI), one element of the University Research Initiative (URI), is sponsored by the DoD research offices: the Office of Naval Research (ONR), the Army Research Office (ARO), and the Air Force Office of Scientific Research (AFOSR) (hereafter collectively referred to as "DoD agencies").

Awards will take the form of grants. Therefore, proposals submitted as a result of this announcement will fall under the purview of the Department of Defense Grant and Agreement Regulations (DoDGARs).

Potential offerors may obtain information on ONR programs and opportunities by checking the ONR website at http://www.onr.navy.mil. Specific information about BAAs and amendments and updates to this BAA will be found at that site under the heading “BAAs”.

I. GENERAL INFORMATION

1. Agency Name

Office of Naval Research
875 North Randolph Street - Suite 1425
Code 03R
Arlington, VA 22203-1995

2. Research Opportunity Title

Multidisciplinary University Research Initiative (MURI)

3. Program Name

Fiscal Year (FY) 2009 Department of Defense Multidisciplinary Research Program of the University Research Initiative

4. Research Opportunity Number

BAA 08-019

5. Response Date

White Papers: Friday, 31 October 2008

Full Proposals: Friday, 9 January 2009

6. Research Opportunity Description

Synopsis

The MURI program supports basic science and/or engineering research at U.S. institutions of higher education (hereafter referred to as "universities") that is of critical importance to national defense. The program is focused on multidisciplinary research efforts that intersect more than one traditional science and engineering discipline to address issues of critical concern to the DoD.

The FY 2009 MURI competition is for the 32 topics listed below. Detailed descriptions of the topics can be found in Section VIII entitled, “Specific MURI Topics”, of this BAA. The detailed descriptions are intended to provide the proposer a frame of reference and are not meant to be restrictive to the possible approaches to achieving the goals of the topic and the program. Innovative ideas addressing these research topics are highly encouraged.

White papers and full proposals addressing the following topics (1) through (9) should be submitted to ONR:

(1) Cellular, Molecular, Genetic and Biochemical Correlates of Training
(2) Removing the Botnet Threat
(3) Machine Intelligence and Adaptive Classification for Autonomous Systems
(4) Highly Decentralized Autonomous Systems for Force Protection and Damage Control
(5) Bio-inspired Autonomous Agile Sensing and Exploitation of Regions of Interest within Wide

Complex Scenes
(6) Computational Intelligence for Decentralized Teams of Autonomous Agents
(7) Dynamic Biological Adaptations to the Undersea Light Field
(8) Grounding Language Understanding in Cognitive Architecture
(9) Tailoring Electronic Bandgap of Nanostructured Graphene

White papers and Full proposals addressing the following topics (10) through (21) should be submitted to the Air Force Office of Scientific Research (AFOSR):

(10) Neurological System-Inspired Multifunctional Materials Design for Autonomous State Awareness against Exogenous Threats
(11) Chemical Energy Enhancement by Nonequilibrium Plasma Species
(12) Ultracold Molecules
(13) Search for New Superconductors for Energy and Power Applications
(14) Complex Nonperiodic Nanophotonics
(15) Multi-Scale Fusion of Information for Uncertainty Quantification and Management in Large-Scale Simulations
(16) Learning Decision Architectures for Intelligent Cooperative Control of Autonomous Systems
(17) Information Dynamics In Networks
(18) Synthesis, Analysis, and Prognosis of Hybrid-Material Flight Structures
(19) Biophotonics: Optical Effects through Nature's Photonic Control
(20) Fundamental Graphene Material Studies and Device Concepts
(21) Application Software and Data Protection for Untrusted Platforms

White papers and full proposals addressing the following topics (22) through (32) should be submitted to the Army Research Office (ARO):

(22) Disruptive Fibers for Flexible Armor
(23) Network-based Hard/Soft Information Fusion
(24) Tailored Stress-Wave Mitigation
(25) Integrated Quantum Circuits
(26) Adaptive Structural Materials
(27) Transformational Optics
(28) Emergent Phenomena at Complex Oxide Interfaces
(29) Application of Systems Biology to Regenerative Medicine
(30) Mechanisms of Bacterial Spore Germination
(31) Opportunistic Sensing
(32) Cyber Situation Awareness

Proposals from a team of university investigators may be warranted because the necessary expertise in addressing the multiple facets of the topics may reside in different universities, or in different departments in the same university. By supporting multidisciplinary teams, the program is complementary to other DoD basic research programs that support university research through single-investigator awards. Proposals must name one Principal Investigator as the responsible technical point of contact. Similarly, one institution will be the primary awardee for the purpose of award execution. The relationship among participating institutions and their respective roles, as well as the apportionment of funds including sub-awards, if any, must be described in both the proposal text and the budget. Historically Black Colleges and Universities and Minority Institutions (HBCU/MIs) (as defined by 10 U.S.C. 2323a (1) (c)) are encouraged to participate in the MURI program, either as the lead institution or as a member of a team. However, no specific funds are allocated for HBCU/MI participation.

7. Point(s) of Contact

One or more Research Topic Chiefs are identified for each specific MURI Topic. Questions of a technical nature shall be directed to one of the Research Topic Chiefs identified in Section VIII entitled, "Specific MURI Topics" of this BAA.

Questions of a *policy nature* shall be directed to ONR as specified below:

ONR MURI Program Point of Contact:
Dr. Bill Lukens MURI Program Manager
Office of Naval Research, Code 03R
E-mail Address: 363 MURI@onr.navy.mil

Mailing address:
Office of Naval Research
One Liberty Center
875 North Randolph Street, Suite 1425
Arlington, VA 22203-1995

Questions of a *business nature* shall be directed to the cognizant Contract Specialist, as specified below:

Primary:
Kristin Fuller
Contract Specialist
Contract and Grants Awards Management, Code ONR 0251
Office of Naval Research
875 North Randolph Street, Suite 1425
Arlington, VA 22203-1995
E-Mail: kristin.fuller@navy.mil

Secondary:
Vera M. Carroll
Acquisition Branch Head
Contract and Grants Awards Management, Code 0251
Office of Naval Research
875 North Randolph Street, Suite 1425
Arlington VA, 22203-1995
E-mail: carrolv@onr.navy.mil

**** Important Notices Regarding Questions of a Business Nature ****

- All questions shall be submitted in writing by electronic mail.
- Questions presented by telephone call, fax message, or other means will not be responded to.

- Questions regarding **white papers** must be submitted by 2:00 p.m. Eastern Time on **Friday, 17 October 2008.** Questions received after this date and time may not be answered and the due date for submission of the white papers may not be extended.
- Questions regarding **full proposals** must be submitted by 2:00 P.M. Eastern Time on **Friday,12 December 2008.** Questions after this date and time may not be answered and the due date for submission of the proposals will not be extended

8. Instrument Type(s)

It is anticipated that all awards resulting from this announcement will be grants.

9. Catalog of Federal Domestic Assistance (CFDA) Numbers

12.300 ONR
12.800 AFOSR
12.431 ARO

10. Catalog of Federal Domestic Assistance (CFDA) Titles

Basic and Applied Scientific Research, (ONR)
Air Force Defense Research Sciences Program, (AFOSR)
Basic Scientific Research, (ARO)

11. Additional Information

The Non-ONR Agency Information:
Air Force Office of Scientific Research
875 North Randolph Street
Suite 325, Room 3112
Arlington, VA 22203-1768

Army Research Office
4300 S. Miami Blvd
Durham, NC 27703-9142

II. AWARD INFORMATION

It is anticipated the awards will be made in the form of grants to universities. The awards will be made at funding levels commensurate with the proposed research and in response to agency missions. Each individual award will be for a three year base period with one 2-year option period to bring the total maximum term of the award to five years. The base and option period will be incrementally funded.

Total amount of funding for five years available for grants resulting from this MURI BAA is estimated to be about $203M, pending out-year appropriations. MURI awards are $1.5M per year, with the actual amount contingent on availability of funds, the specific topic, and the scope of the proposed work. It is strongly recommended that potential proposers communicate with the Program Topic Chief regarding these issues before the submission of formal proposals. **Depending on the results of the proposal evaluation, there is no guarantee that any of the proposals submitted in response to a particular topic will**

be recommended for funding. On the other hand, more than one proposal may be recommended for funding for a particular topic.

III. ELIGIBILITY INFORMATION

This MURI competition is open only to and full proposals are to be submitted only by, U.S. institutions of higher education (universities) including DoD institutions of higher education, with degree-granting programs in science and/or engineering.* Ineligible organizations (e.g., industry, DoD laboratories, Federally Funded Research and Development Centers (FFRDCs), and foreign universities) may collaborate on the research but may not receive MURI funds, directly or via subaward.

When a modest amount of additional funding for an ineligible organization is necessary to make the proposed collaboration possible, such funds may be requested via a separate proposal from that organization. This supplemental proposal should be attached to the primary MURI proposal and will be evaluated separately by the responsible Research Topic Chief. If approved, the supplemental proposal will be funded by the responsible agency using non-MURI funds. Since it is not certain that non-MURI funding would be available for ineligible organizations, Principal Investigators are encouraged to restrict funding requests to eligible organizations when practical.

IV. APPLICATION AND SUBMISSION INFORMATION

1. Application and Submission Process

The proposal submission process is in two stages. Prospective awardees are encouraged to submit white papers to minimize the labor and cost associated with the production of detailed full proposals that have very little chance of being selected for funding. Based on an assessment of the white papers, the responsible Research Topic Chief will provide informal feedback notification to the prospective awardees to encourage or discourage them to submit full proposals.

White papers arriving after the deadline may not receive feedback prior to full proposal submission. However, all full proposals submitted under the terms and conditions cited in the BAA will be reviewed.

Due Date: The due date for white papers is no later than 4:00 P.M. (Eastern Daylight Time) on Friday, 31 October 2008.

Where To Submit**:**

NOTE: White Papers sent by fax will not be considered.

Submission of White Papers:

*To the extent that it is a part of a U.S. institution of higher education and is not designated as an FFRDC, a University Affiliated Research Center (UARC) or other University Affiliated Laboratory (UAL) is eligible to submit a proposal to this MURI competition and receive MURI funds. However, the eligibility of a UAL (other than an FFRDC) to submit a URI proposal does not exempt the proposal from any evaluation factor contained in this Broad Agency Announcement, to include the potential impact on the institution's ability to perform defense-relevant research and to train students in science and/or engineering.

White papers may be submitted via e-mail directly to a Research Topic Chief, via the United States Postal Service (USPS), via a commercial carrier or may be hand delivered to the attention of a responsible Research Topic Chief at the agency specified for the topic.

Evaluation/Notification: Initial evaluations of the white papers will be issued on or about Monday, 10 November 2008.

Submission of Full Proposal:

Any Offeror may submit a full proposal even if its white paper was not identified as being of "particular value" to the Government. However, the initial evaluation of the white papers should give prospective awardee some indication of whether a later full proposal would likely result in an award.

NOTE: Full Proposals sent by fax or e-mail will not be considered.

Full proposals may be submitted electronically through grants.gov, via the United States Postal Service (USPS), via a commercial carrier or may be hand delivered to the agency specified for the topic.

Registration Requirements for Grants.gov: There are several one-time actions you must complete in order to submit an application through Grants.gov (e.g., obtain a Dun and Bradstreet Data Universal Numbering System (DUNS) number, register with the Central Contract Registry (CCR), register with the credential provider, and register with Grants.gov). See www.grants.gov/GetStarted to begin this process. Use the Grants.gov Organization Registration Checklist at www.grants.gov/assets/OrganizationRegCheck.doc to guide you through the process. Designating an E-Business Point of Contact (EBiz POC) and obtaining a special password called an MPIN are important steps in the CCR registration process. Applicants, who are not registered with CCR and Grants.gov, should allow at least 21 days to complete these requirements. It is suggested that the process be started as soon as possible.

Questions: Questions relating to the registration process, system requirements, how an application form works, or the submittal process must be directed to Grants.gov at 1-800-518-4726 or support@grants.gov.

2. Content and Format of White Papers and Full Proposals

The white papers and full proposals submitted under this BAA are expected to address unclassified basic research. The full proposal submissions will be protected from unauthorized disclosure in accordance with FAR 15.207, applicable law, and DoD regulations. Proposers are expected to appropriately mark each page of their submission that contains proprietary information. Grants awarded under this announcement will be unclassified.

White Paper Submission: Contents and Format of Applications

Each topic in this announcement has one or more Research Topic Chiefs identified from one of the participating agencies; ONR, AFOSR, or ARO. You should submit your application to one of the Research Topic Chiefs at the agency for which you are applying.

White paper format should be as follows:

- Paper Size - 8.5 x 11 inch paper
- Margins - 1 inch
- Spacing - single
- Font - Times New Roman, 12 point
- Number of Pages - no more than four (4) single-sided pages (excluding cover letter, cover, and curriculum vitae). White papers exceeding the page limit may not be evaluated.

White Paper content should be as follows:

- A one page cover letter (optional)
- A cover page, labeled "PROPOSAL WHITE PAPER," that includes the BAA number, proposed title, and proposer's technical point of contact, with telephone number, facsimile number, e-mail address, topic number, and topic title
- Identification of the research and issues
- Proposed technical approaches
- Potential impact on DoD capabilities
- Potential team and management plan
- Summary of estimated costs
- Curriculum vitae of key investigators

The white paper should provide sufficient information on the research being proposed (e.g., hypothesis, theories, concepts, approaches, data measurements and analysis, etc.) to allow for an assessment by a technical expert. It is not necessary for white papers to carry official institutional signatures.

White papers may be submitted via e-mail, via the United States Postal Service (USPS), via a commercial carrier or may be hand delivered to the attention of a responsible Research Topic Chief at the agency specified for the topic. For hard copy submissions, use the addresses provided in Section IV entitled, “Application and Submission Information” paragraph number 5 entitled, “Address for the Submission of Hard Copy White Papers and Full Proposals”. White papers should be stapled in the upper left hand corner; plastic covers or binders should not be used. Separate attachments, such as individual brochures or reprints, will not be accepted.

Copies – one (1) original and two (2) copies.

Grants.gov Full Proposal Submission: Content and Format of Applications

Application forms and instructions are available at Grants.gov. To access these materials, go to http://www.grants.gov, select "Apply for Grants", and then select "Download Application Package". Enter the CFDA for the respective agency to which you are directing the application (ARO – 12.431, ONR – 12.300, AFOSR – 12.800, as found on page five of this announcement) and the funding opportunity number, designated as “research opportunity number” on page two of this announcement. Each topic in this announcement has a Research Topic Chief identified from one of the participating agencies; ONR, AFOSR, or ARO. You should direct your application to the agency associated with the topic for which you are applying.

Content and Form of Application – SF 424 (R&R)

You must complete the mandatory forms and any applicable optional forms (e.g., SF-LLL Disclosure of Lobbying Activities) in accordance with the instructions on the forms and the additional instructions below**. Files that are attached to the forms must be in Adobe Portable Document Format (PDF) unless otherwise specified in this announcement.**

Form: SF 424 (R&R)

Complete this form first to populate data in other forms. Complete all the required fields in accordance with the pop-up instructions on the form. To activate the instructions, turn on the "Help Mode" (icon with the pointer and question mark at the top of the form). The list of certifications and assurances referenced in Field 18 can be found on the ONR Home Page at Contracts and Grants. The certification package for grants is entitled, "Certifications for Grants and Agreements." In Field 4, designate "MURI" and the topic number. For example, "MURI-topic 5."

Form Research & Related Other Project Information.

Complete questions 1 through 5 and attach files. The files must comply with the following instructions:

Project Summary/Abstract (Field 6 on the Form)

The project summary should be a single page that identifies the research problem, technical approaches, anticipated outcome of the research, if successful, and impact on DoD capabilities. It should identify the Principal Investigator, the university and other universities involved in the MURI team if any, the proposal title, the agency to which the proposal is submitted, the MURI topic number and the total funds requested from DoD for the 3-year base period, the 2-year option period and the 5-year total period. The project summary must not exceed 1 page when printed using standard 8.5" by 11" paper with 1" margins (top, bottom, left and right) with font Times New Roman, 12 point. To attach a Project Summary/Abstract, click "Add Attachment."

Project Narrative (Field 7 on the form)

The Following Formatting Rules Apply for Field 7

- Paper size when printed - 8.5 x 11 inch paper
- Margins - 1 inch
- Spacing -single
- Font - Times New Roman, 12 point
- Number of pages - no more than twenty-five (25) single-sided pages. The cover, table of contents, list of references, letters of support, and curriculum vitae are excluded from the page limitations. Full proposals exceeding the page limit may not be evaluated.

Include the Following in Field 7

The first page of your narrative must include the following information:

- Principal Investigator name
- Phone number, fax number and e-mail address

- Institution, Department, Division
- Institution address
- Other universities involved in the MURI team
- Current DoD Contractor or Grantee? If yes, provide Agency, point of contact; phone number
- Proposal title
- Institution proposal number
- Agency to which proposal is submitted
- Topic number and topic title

- Table of Contents: List project narrative sections and corresponding page numbers.

- Statement of Work: A Statement of Work (SOW) should clearly detail the scope and objectives of the effort and the specific research to be performed under the grant if the proposal is selected for funding. It is anticipated that the proposed SOW will be incorporated as an attachment to any resultant award instrument. To this end, this project narrative must include a severable self-standing SOW, without any proprietary restrictions, which can be attached to a grant award.

- Technical Approach: Describe in detail the basic science and/or engineering research to be undertaken. State the objective and approach, including how data will be analyzed and interpreted. Discuss the relationship of the proposed research to the state-of-the-art knowledge in the field and to related efforts in programs elsewhere. Include appropriate literature citations/references. Discuss the nature of expected results. Discuss potential applications to defense missions and requirements. Describe plans for the research training of students. Include the number of full time equivalent graduate students and undergraduates, if any, to be supported each year. Discuss the involvement of other students, if any.

- Project Schedule, Milestones and Deliverables: A summary of the schedule of events, milestones, and a detailed description of the results and products to be delivered.

- Assertion of Data Rights: A summary of any proprietary rights to pre-existing results, prototypes, or systems supporting and/or necessary for the use of the research, results, and/or prototype. Any data rights asserted in other parts of the proposal that would impact the rights in this section must be cross-referenced. If there are proprietary rights, the proposer must explain how these affect its ability to deliver research data, subsystems and toolkits for integration. Additionally, proposers must explain how the program goals are achievable in light of these proprietary limitations. If there are no claims of proprietary rights in pre-existing data, this section shall consist of a statement to that effect.

- Management Approach: A discussion of the overall approach to the management of this effort, including brief discussions of: required facilities; relationships with any subawardees and with other organizations; availability of personnel; and planning, scheduling and control procedures.

  (a) Describe the facilities available for the accomplishment of the proposed research and related education objectives. Describe any capital equipment planned for acquisition under this program and its application to the proposed

research. If possible, budget for capital equipment should be allocated to the first budget period of the grant. Include a description of any government furnished equipment/hardware/software/information, by version and/or configuration that are required for the proposed effort.

(b) Describe in detail proposed subawards to other eligible universities or relevant collaborations (planned or in place) with government organizations, industry, or other appropriate institutions. Particularly describe how collaborations are expected to facilitate the transition of research results to applications. Descriptions of industrial collaborations should explain how the proposed research will impact the company's research and/or product development activities. If subawards to other universities are proposed, make clear the division of research activities, to be supported by detailed budgets for the proposed subawards.

(c) Designate one individual as the Principal Investigator for the award, for the purpose of technical responsibility and to serve as the primary point-of-contact with an agency's Program Topic Chief. Briefly summarize the qualifications of the Principal Investigator and other key investigators to conduct the proposed research.

(d) List the amount of funding and describe the research activities of the Principal Investigator and co-investigators in on-going and pending research projects, whether or not acting as Principal Investigator in these other projects, the time charged to each of these projects, and their relationship to the proposed effort.

(e) Describe plans to manage the interactions among members of the proposed research team.

(f) Identify other parties to whom the proposal has been, or will be sent, including agency contact information.

- List of References: List publications cited in above sections.
- Letters of Support: Up to three Letters of Support from various DoD agencies may be included.
- Curriculum Vitae: Include curriculum vitae of the Principal Investigator and key co-investigators.

All applications should be in a single PDF file. To attach a Project Narrative in Field 7, click "Add Attachment."

Bibliography & References Cited (Field 8 on the form)

This field not required.

Facilities & Other Resources (Field 9 on the form)

This field not required.

Equipment (Field 10 on the form)

This field not required.

Other Attachment (Field 11 on the form)

Attach budget proposal at field 11. You must provide a detailed cost breakdown of all costs, by cost category, by the funding periods described below, and by task/sub-task corresponding to the task number in the proposed Statement of Work which was provided in Field 7 of the Research and Related Other Project Information Form. The option must be separately priced.

. The budget should adhere to the following guidelines:

Detailed breakdown of all costs, by cost category, by the calendar periods stated below. For budget purposes, use an award start date of 01 June 2009. For the three-year base grant, the cost should be broken down to reflect funding increment periods of:

(1) Four months (01 June 09 to 30 Sep 09),
(2) Twelve months (01 Oct 09 to 30 Sep 10),
(3) Twelve months (01 Oct 10 to 30 Sep 11), and
(4) Eight months (01 Oct 11 to 31 May 12).

Note that the budget for each of the calendar periods (e.g. 01 June 09 to 30 Sep 09) should include only those costs to be expended during that calendar period.
The budget should also include an option for two additional years broken down to the following funding periods:

(1) Four months (01 June 12 to 30 Sep 12),
(2) Twelve months (01 Oct 12 to 30 Sep 13), and
(3) Eight months (01 Oct 13 to 31 May 14).

Annual budget should be driven by program requirements. Elements of the budget should include:

- Direct Labor - Individual labor category or person, with associated labor hours and unburdened direct labor rates.

- Indirect Costs - Fringe benefits, overhead, G&A, Cost of Money (COM), etc. (must show base amount and rate). Justify.

- Travel - Number of trips, destination, duration, etc. Justify.

- Subcontract - A cost proposal as detailed as the proposer's cost proposal will be required to be submitted by the subcontractor.

- Consultant - Provide consultant agreement or other document that verifies the proposed loaded daily/hourly rate. Include a description of the nature of and the need for any consultant's participation. Strong justification must be provided, and consultants are to be used only under exceptional circumstances where no equivalent expertise can be found at a participating university. Provide budget justification.

- Materials - Specifically itemized with costs or estimated costs. An explanation of any estimating factors, including their derivation and application, shall be provided. Include a brief description of the proposer's procurement method to be

used (competition, engineering estimate, market survey, etc.). Justify.

- Other Directs Costs - Particularly any proposed items of equipment or facilities. Equipment and facilities generally must be furnished by the contractor/recipient (justifications must be provided when Government funding for such items is sought). Include a brief description of the proposer's procurement method to be used (competition, engineering estimate, market survey, etc.). Justify.

Funding breakdown by task/sub-task corresponding to the task number in the proposed Statement of Work which was provided in Field 7 of the Research and Related Other Project Information Form must also be attached.

SF-LLL Disclosure of Lobbying Activities Form

If applicable, complete SF- LLL. Applicability: If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the grant/cooperative agreement, you must complete and submit Standard Form - LLL, "Disclosure Form to Report Lobbying."

Proposal Receipt Notices

After a full proposal is submitted through Grants.gov, the Authorized Organization Representative (AOR) will receive a series of three e-mails. It is extremely important that the AOR watch for and save each of the e-mails. You will know that your proposal has reached ONR, ARO or AFOSR when the AOR receives e-mail Number 3. You will need the Submission Receipt Number (e-mail Number 1) to track a submission. The three e-mails are:

Number 1 – The applicant will receive a confirmation page upon completing the submission to Grants.gov. This confirmation page is a record of the time and date stamp for the submission.

Number 2 – The applicant will receive an e-mail indicating that the proposal has been validated by Grants.gov within a few hours of submission. (This means that all of the required fields have been completed.)

Number 3 – The third notice is an acknowledgment of receipt in e-mail form from the designated agency within ten days from the proposal due date. The e-mail is sent to the authorized representative for the institution. The e-mail for proposals notes that the proposal has been received and provides the assigned tracking number. Hard copy submissions will receive only e-mail number 3.

Hard Copy Full Proposal Submission: Content and Format of Applications

If submitting a full proposal by hard copy as opposed to formally through grants.gov, please complete the Grants.gov forms as described, print them out, and submit to the address in Section IV paragraph number 5 entitled “Address for the Submission of Hard Copy White Papers and Full Proposals”. Full hard copy proposals should be stapled in the upper left hand corner; plastic covers or binders should not be used. Separate attachments, such as individual brochures, or reprints, will not be accepted.

Copies – one (1) original and five (5) hard copies.

3. Significant Dates and Times

Schedule of Events		
Event	**Date**	**Time**
White Papers Due	31 October 2008	4:00 PM Eastern Daylight Time
Notification of Initial DoD Evaluations of White Papers	10 November 2008*	
Full Proposals Due	09 January 2009	4:00 PM Eastern Standard Time
Notification of Selection for Award	24 April 2009*	
Start Date of Grant	01 June 2009*	

*** These dates are estimates as of the date of this announcement.**

4. Submission of Late Proposals

Any full proposal submitted through Grants.gov where the time and date for submission (e-mail Number #1) is after the deadline for proposal submission in Section IV entitled, “Application and Submission Information” paragraph number 3 entitled, “Significant Dates and Times” will be late and will not be evaluated unless the Grants.gov website was not operational on the due date and was unable to receive the proposal submission. If this occurs, the time specified for the receipt of proposals through Grants.gov will be extended to the same time of the day specified in this BAA on the first workday on which the Grants.gov website is operational.

For hard copy full proposal submission, any proposal, modification, or revision that is received at the designated DoD agency after the exact time specified for receipt of proposals is "late" and will not be considered unless it is received before the award is made, the contracting officer determines that accepting the late proposal would not unduly delay the acquisition, and:

(a) the proposal was sent to the address specified for the designated agency by U.S. Postal Service Express Mail three or more business days prior to the date specified for the receipt of proposals (the term "business days" excludes weekends and U.S. Federal holidays); or

(b) there is acceptable evidence to establish that it was received at the DoD agency designated for receipt of proposals and was under the Government's control prior to the time set for receipt of proposals; or

(c) it was the only proposal received.

However, a late modification of an otherwise timely and successful proposal that makes its terms more favorable to the Government will be considered at any time it is received and

may be accepted. This applies to hard copy and Grants.gov submissions.

Acceptable evidence to establish the time of receipt at the DoD agency includes the time/date stamp of that installation on the proposal wrapper, other documentary evidence of receipt maintained by the installation, or oral testimony or statements of Government personnel.

If an emergency or unanticipated event interrupts normal Government processes so that proposals cannot be received at the Government office designated for receipt of proposals by the exact time specified in the announcement, and urgent Government requirements preclude amendment of the announcement closing date, the time specified for receipt of proposals will be deemed to be extended to the same time of day specified in the announcement on the first work day on which normal Government processes resume.

Note that proposals delivered by commercial carriers are considered "hand carried" and that no exception can be made to allow such proposals to be considered if for any reason they are received after the deadline. Proposers are advised that some proposals responding to past announcements that were sent via commercial carriers were delayed during shipment and arrived after the deadlines, typically by one or two days. To decrease the probability that proposals delivered by commercial carriers will arrive after the deadline and thus be ineligible to compete, proposers are urged to schedule delivery to occur several days before the deadline.

5. Address for the Submission of Hard Copy White Papers and Full Proposals

Submission of white papers and submission of hard copy full proposals shall be sent to the addresses below:

Hard copies of white papers and full proposals addressing topics (1) to (9) should be sent to the Office of Naval Research at the following address:

Primary

Office of Naval Research
For full proposals include: ATTN: ONR Code 03R
For white papers include: ATTN: (list name of responsible Research Topic Chief)
875 North Randolph Street - Suite W256A*
Arlington, VA 22203-1995
Point of Contact: Paula Barden
703-696-4111

Secondary

Office of Naval Research
For full proposals include: ATTN: ONR Code 03R
For white papers include: ATTN: (list name of responsible Research Topic Chief)
875 North Randolph Street - Suite 257*
Arlington, VA 22203-1995
Point of Contact: Dr. William Lukens
703-696-4668

*This is the address for hand delivery, delivery via USPS and delivery via commercial delivery

services.

If a telephone number is required, please use 703-696-4111 or 703-696-4668.

Important Notes Regarding Submission of White Papers and Proposals:

If the Offeror is using USPS, please allow an additional five (5) business days for the package to be delivered to this address due to USPS mail being sent to a central location for special processing before it is sent to this address.

Hard copy white papers and full proposals addressing topics (10) to (21) should be sent to the Air Force Office of Scientific Research at the following address:

Air Force Office of Scientific Research
For full proposals include: ATTN: Mailroom (MURI 09)
For white papers include: ATTN: (list name of responsible Research Topic Chief)
875 North Randolph Street
Suite 325, Room 3112
Arlington, VA 22203-1768
Point of Contact: Dr. Spencer Wu
703-696-7315

Hard copy white papers and full proposals addressing topics (22) to (32) should be sent to the Army Research Office at one of the following addresses:

For delivery by USPS (ordinary First Class or Priority Mail (but not Express Mail)):
U.S. Army Research Office (FY09 MURI)
P. O. Box 12211 Research Triangle Park,
NC 27709-2211

For commercial delivery (such as Express Mail, FedEx, UPS, etc.):

U.S. Army Research Office (FY09 MURI)
For full proposals include: ATTN: Dr. Larry Russell
For white papers include: ATTN: (list name of responsible Research Topic Chief)
4300 S. Miami Blvd
Durham, NC 27703-9142
919-549-4211

V. EVALUATION INFORMATION

1. Evaluation Criteria

White papers will be evaluated by the responsible Research Topic Chief to assess whether the proposed research is likely to meet the objectives of the specific topic, and thus whether to encourage the submission of a full proposal. The assessment will focus on scientific and technical merit (criterion 1, below) and relevance and potential contribution to DoD (criterion 2, below), although the other criteria may also be used in making the assessment. Full proposals responding to this BAA in each topic area will be evaluated using the following criteria. The first three evaluation factors are of equal importance:

(1) scientific and technical merits of the proposed basic science and/or engineering research;

(2) relevance and potential contributions of the proposed research to the topical research area and to DoD missions; and

(3) potential impact on the institution's ability to perform defense-relevant research and to train, through the proposed research, students in science and/or engineering (for example, by acquiring or refurbishing equipment that can support DoD research and research-related educational objectives).

The following four evaluation criteria are each of lesser importance than any of the above three, but are equal to each other:

(4) the qualifications and availability of the Principal Investigator and key co-investigators;

(5) the adequacy of current or planned facilities and equipment to accomplish the research objectives;

(6) the impact of interactions with other organizations engaged in related research and development, in particular DoD laboratories, industry, and other organizations that perform research and development for defense applications; and

(7) the realism and reasonableness of cost (cost sharing is not a factor in the evaluation).

Decisions for exercising options will be based on accomplishments during the base years and potential research advances during the option years that can impact DoD research priorities and technological capabilities.

2. Evaluation Panel

White papers will be reviewed either solely by the responsible Research Topic Chief for the specific topic or by an evaluation panel chaired by the responsible Research Topic Chief. An evaluation panel will consist of technical experts who are Government employees.

Full proposals will be evaluated by an evaluation panel chaired by the responsible Research Topic Chief for the particular topic and will consist of technical experts who are Government employees. Evaluation panel members are required to sign "no conflict of interest" statements.

3. Selection Process

Full proposals will undergo a multi-stage evaluation procedure. The respective evaluation panels will review proposals first. Findings of the evaluation panels will be forwarded to senior DoD officials who will make funding recommendations to the awarding officials.

VI. AWARD ADMINISTRATION INFORMATION

1. Administrative Requirements

- CCR - Successful proposers not already registered in the Central Contractor Registry (CCR) will be required to register in CCR prior to award of any grant, contract, cooperative agreement, or other transaction agreement. Information on CCR registration is available at http://www.onr.navy.mil/02/ccr.htm.

- Certifications - The following certification applies to each grant applicant seeking federal funds exceeding $100,000:

Certification Regarding Lobbying Activities

(1) No Federal appropriated funds have been paid or will be paid by or on behalf of the applicant, to any person for influencing or attempting to influence an officer or employee of an agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any Federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.
(2) If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the Federal contract, grant, loan, or cooperative agreement, the applicant shall complete and submit Standard Form-LLL, “Disclosure Form to Report Lobbying,” in accordance with its instructions.
(3) The applicant shall require that the language of this certification be included in the award documents for all subawards at all tiers (including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements) and that all subrecipients shall certify and disclose accordingly.
This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by Section 1352, title 31, U.S.C. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

2. Reporting

In general, for each grant award, annual reports and a final report are required summarizing the technical progress and accomplishments during the performance period, as well as any other reports as requested by the Research Topic Chief.

VII. OTHER INFORMATION

1. Government Property/Government Furnished Equipment (GFE) and Facilities

Each proposer must provide a specific description of any equipment/hardware that each participating institution needs to acquire to perform the work. This description should identify the component, nomenclature, and configuration of the equipment/hardware that it proposes to purchase for this effort. The purchase on a direct reimbursement basis of special test equipment or other equipment that is not included in a deliverable item will be evaluated for allowability on a case-by-case basis. Maximum use of Government integration, test, and experiment facilities is encouraged in each of the proposer's proposals.

Government research facilities and operational military units are available and should be considered as potential Government furnished equipment/facilities. These facilities and resources are of high value and some are in constant demand by multiple programs. It is unlikely that all facilities would be used for the MURI program. The use of these facilities and resources will be negotiated as the program unfolds. Proposers should explain which of these facilities they recommend.

2. Use of Animals and Human Subjects in Research

If animals are to be utilized in the research effort proposed, the proposer must complete a DoD Animal Use Protocol with supporting documentation (copies of AAALAC accreditation and /or NIH assurance, IACUC approval, research literature database searches, and the two most recent USDA inspection reports) prior to award. Similarly, for any proposal that involves the experimental use of human subjects, the proposer must obtain approval from the proposer's committee for protection of human subjects (normally referred to as an Institutional Review Board, (IRB)). The proposer must also provide NIH (OHRP/DHHS) documentation of a Federal Wide Assurance that covers the proposed human subjects study. If the proposer does not have a Federal Wide Assurance, a DoD Single Project Assurance for that work must be completed prior to award. Please see http://www.onr.navy.mil/02/howto.htm for further information.

3. Department of Defense High Performance Computing Program

The DoD High Performance Computing Program (HPCMP) furnishes the DoD S&T and DT&E communities with use-access to very powerful high performance computing systems. Awardees of DoD contracts, grants, and assistance instruments may be eligible to use HPCMP assets in support of their funded activities if Research Topic Chief approval is obtained and if security/screening requirements are favorably completed. Additional information and an application may be found at http://www.hpcmo.hpc.mil/.

VIII. SPECIFIC MURI TOPICS

ONR FY09 MURI TOPIC #1

Submit white papers and proposals to the Office of Naval Research

Cellular, Molecular, Genetic and Biochemical Correlates of Training

Background:
The long term goal of the Cellular, Molecular, Genetic and Biochemical Correlates of Training program is to obtain new insights into learning and memory that can be leveraged towards improved training protocols for empowering tomorrow's warfighter. Over the past several decades, the field of neuroscience has made tremendous advances in explaining brain function; however, we still lacks a complete understanding of what structural and functional changes underlie learning and memory. Hence, an ambitious, multidisciplinary basic research effort is needed in order to ascertain cellular, molecular, genetic and biochemical correlates of learning, memory acquisition, consolidation, retrieval and extinction, and to unravel the complex interactions of genes, the environment, and neural circuits involved in learning and memory.

Learning and memory is thought to be a result of changes in synaptic strength, but much remains to be discovered about factors that govern neural plasticity. Long-term potentiation (LTP) and long-term depression (LTD) have long been believed to underlie learning and memory, but a clear causative relationship between LTP/LTD and learning and memory has yet to be demonstrated. Moreover, much remains to be discovered about the role of protein transport as well as what factors modulate synaptic plasticity on short and long time scales. There is ample opportunity to capitalize on advances in transgenic models in order to further investigate the complex interaction between environmental factors and genetics involved in behavior, such as learning under stress. An example, of how this collaboration may work is recent research by Dr. Michael Posner and his colleagues who have studied genetic related attentional and executive function deficiencies in children that have been remediate using a regime of training. The genes involved modulate neurotransmitters such as serotonin, and dopamine. What remains to identify is the brain circuits involved and the interactions between training and genetics?
Finally, investigation of newly described brain circuits could lead to significant insights into learning and memory.

Objective: The Cellular, Molecular and Biochemical Correlates of Training Program will provide advances and insights into the science of learning and memory in order to improve training. The goals are to determine the cellular, molecular, and genetic and biochemical correlates of learning, memory acquisition, consolidation, retrieval and extinction, and to dissect the complex interactions of genes, the environment, and neural circuits involved in learning and memory.

Research Concentration Areas: Areas of interest include, but are not limited to the following: (**1**) New insights into long term depression/potentiation, e.g. synaptic structure, the role of specific neuropeptides or mRNA. This research will combine human behavioral research with

the use of animal's models to dissect the interactions of genes, environmental factors, and neural circuits underlying learning and memory.
(**2**) Determination of factors that regulate neural plasticity e.g. neurogenetics (longer-term), neurochemistry (shorter-term).
(**3**) Anatomical, electrophysiological, functional and behavioral analyses of newly described circuits, e.g. the retrosplenial cortex, or of newly described cell types, e.g. grid cells, in rule-based learning, working memory and behavior.
(**4**) Use of gene knockout, knock-down, knock-in and transgenic models in studying the interaction of genetics and stress on learning and retention.
(**5**) Investigation of the affect of different learning environments/techniques on gene expression associated with improved working memory.

Impact: This research has enormous potential in contributing significantly to new training techniques for the future Warfighter, and in offering new paradigms for training and learning under stress.

Research Topic Chiefs: Dr. Ray Perez, ONR, 703-696-4986, ray.perez@navy.mil
Dr. Roy Stripling, ONR, 703-696-0364, roy.stripling@navy.mil

FY09 MURI Topic #2

Submit white papers and proposals to the Office of Naval Research

Removing the Botnet Threat

Background: Malicious overlay networks are undermining the utility of the Internet by their ability to easily disrupt and corrupt legitimate Internet activity. The mainstay of these networks is the botnet – self-propagating, self-organizing, autonomous software. This malicious software lodges itself on a susceptible machine, taking supervisory control. These infected machines are organized into a command-and-control network, the botnet. Botnets are used to spread spam, engage in click fraud, launch denial-of-service attacks, and disrupt legitimate commerce but their impact could be far worse. Industry and much of academia are engaged in damage control via patch-management rather than fundamental problem solving. Without innovative approaches to removing the botnet threat, the full utility of the Internet for society will be unrealized.

Objective: Develop foundational principles for cyberspace and network applications that will minimize, if not altogether eliminate, the peril from botnets.

Research Concentration Areas: Areas of interest include, but are not limited to, the following: (1) develop a theory for the formation, propagation and discovery of botnets, particularly their command and control (C2) structures over the critical information infrastructure and cyberspace; (2) understand key weaknesses in the C2 structures that can be exploited to detect, deny, and disrupt botnets; (3) explore new strategies for authentication, accountability, ownership management, cryptographic protocols and network architectures as countermeasures; (4) construct a classification of botnets based on their C2 structure and capacity for disruption; and, (5) develop models for the epidemiology of botnets.

Impact: The risks from botnets, foreign and domestic, to the nation's critical infrastructure cannot be ignored. Recent events in Europe demonstrate the capability of unattributed botnets to massively disrupt the economy of a small nation. Larger nations may, in fact, be more susceptible to such attacks owing to their heterogeneous infrastructure and many opportunities for exploitation. Eliminating or, at a minimum, containing the botnet threat is tantamount to a cyber disarmament that would substantially remove the threat of a massive zero-day cyber attack.

Research Topic Chief: Dr. R.F. Wachter, ONR, 703-696-4304, wachter@onr.navy.mil

FY09 MURI TOPIC #3

Submit white papers and proposals to the Office of Naval Research

Machine Intelligence and Adaptive Classification for Autonomous Systems

Background: Automatic sensor processing and navigation algorithms are fundamental enabling technologies for a wide variety of deployable, autonomous systems. Although progress has been made during the past ten years, new basic research and new theory is needed to achieve significant progress towards the ultimate goal of fully automated systems. There are many open problems that need to be solved by the basic research community. For example, in sonar and other sensor processing streams, there has been research in adapting the signal processing to the environment, but environmental adaptation of classifiers is an unsolved problem. In addition, there has been work in adapting classifiers to new data, particularly in speech recognition, but these approaches typically apply after signal processing and feature extraction has already been performed. Finally, sensor signal processing is typically decoupled from system control and navigation, and at best only loosely integrated with classification. Integrating these functions has the potential to improve system-level performance as measured by classification probability, false alarm rate, and area coverage times.

Objectives:

- Fundamental advancements in machine learning theory for joint detection, classification, localization algorithms that adapt to challenging operating environments
- New theory and methods that integrate detection, classification and tracking with system deployment, navigation and adaptive search strategies – thereby adjusting operations based on observations, recognizing and responding to exceptions, and optimizing system performance in adverse, unknown, or highly variable operating environments

Research Concentration Areas: Physics-based signal processing theory, machine learning theory, clutter discrimination, feature identification (as opposed to feature selection) for automatic classification, classifier training theory (*in situ* training, large data sets, unequal-size target and clutter data sets), environmentally adaptive classification, feature-based tracking, feature-based navigation, adaptive search, and artificial intelligence and learned behavior for adapting to the environment. Bayesian methods and graphical models are of particular interest.

Impact: This work is motivated by underwater applications – acoustic mine detection and classification and anti-submarine warfare. As such, it will directly impact Navy MCM and ASW operations using fixed or mobile autonomous systems. However, algorithms developed under this program will generally be applicable to all types of unmanned platforms, including UAV and UGV systems performing autonomous search. This effort will lead to truly autonomous systems that are able to operate in unknown or varying environments, adapt to their surroundings, and deal with exceptions that would cause a rule-based controller to fail or perform poorly.

Research Topic Chief: Dr. John A. Tague, ONR, 703-696-4399, john.a.tague@navy.mil

FY09 MURI Topic #4

Submit white papers and proposals to the Office of Naval Research

Highly Decentralized Autonomous Systems for Force Protection and Damage Control

Background: In recent years, there has been a variety of research examining distributed autonomous systems with large numbers of elements. This has required new approaches as many centralized and distributed optimization formulations become combinatorially intractable as the number of elements increase, and also require infeasible amounts of communication. One approach towards achieving greater simplicity has been the idea of emergent behaviors where the system's behavior is not dependent on any individual system element, but rather a global outcome of the interactions among elements composing the system. Some work has been done in this area examining lessons from physics, biology, engineered systems, and the social sciences. However, many of these approaches have made assumptions that limit their use. For example, much research in this area has focused on surveillance and reconnaissance. The assumptions inherent in this type of problem may not support future application to a problem such as force protection with distributed unmanned systems and damage control with distributed machinery on large manned platforms. These types of problems brings new research challenges in areas such as safe operation in close proximity to manned platforms or units, rapid adaptation and responsiveness to deal with novel threats, close collaboration with humans, and the need for a high degree of trust and reliability in such a critical usage. It also may involve collaboration between mobile vehicle systems and static systems on-board large platforms despite limited communications. Further, there is currently little understanding of the relationship between simplifying individual element intelligence and global behaviors and of how to create global representations from each element's diverse, disjoint understanding of the world in order to support human collaboration. There is also not good understanding of how such behaviors may be defeated or disrupted.

Objective: To develop new principles, methodologies, and formulations for the simplified control of large numbers of decentralized autonomous systems for force protection and damage control. This shall include a mix of experimentation and theoretical development and support understanding of how humans can collaborate with and operate around such decentralized systems and how such systems could potentially be disrupted or defeated.

Research Concentration Areas: This topic includes collaboration between the disciplines of physics, mathematics, control systems, artificial intelligence, network science, robotics, psychology, social sciences, and biology. Research focus areas include: Formulations for simplified control of distributed autonomous systems; The relationship between individual element simplicity and global behavior; Human collaboration with large numbers of decentralized autonomous systems; Performance, Robustness, and Sensitivity analysis of decentralized systems; Analytic approaches towards understanding, predicting, and disrupting the behavior of emergent systems including by an intelligent adversary; Fundamental bounds in system performance.

Impact: There are many important applications of distributed decision-making capabilities in large-scale autonomous systems, such as force protection and the use of distributed machinery on large platforms such as ships. In addition, an understanding of such systems may be of value in disrupting such systems that are utilized by an adversary.

Research Topic Chiefs: Robert Brizzolara, ONR, 703-696-2597, robert.brizzolara@navy.mil, Mark Steinberg, ONR, 703-696-5115, marc.steinberg@navy.mil.

FY09 MURI Topic #5

Submit white papers and proposals to the Office of Naval Research

Bio-inspired Autonomous Agile Sensing and Exploitation of Regions of Interest within Wide Complex Scenes

Background: Military surveillance systems exhibit an inherent tradeoff between area of coverage and degree of resolution for regions of interest. For example wide area coverage of harbors, or urban terrain, with networks of ground or UAV mounted EO/IR sensors is conducted at low or medium resolution due to sensor, signal processing and communications limitations. Low resolution tracking may be sufficient to detect and track watercraft and vehicles, but in order to obtain full identification or characterize a potential threat, for example persons bearing weapons or burying IEDs, high resolution imagery is necessary, typically obtained by pointing a high resolution sensor at the target. However, directional pointing typically requires constant vigilance by human operators. A desired agile sensing system would provide adaptive very high resolution "foveas" within wide area sensor coverage (e.g. provided from overlapping megapixel or single gigapixel sensor imagery), that track multiple possible threats and "zoom" to provide detailed imagery for further characterization, all in a fully automated manner and maintaining minimal communication needs.

Biological systems provide a number of examples of similar capabilities worth emulating. One such is provided by primate vision, in which the foveas are directed to salient points in a visual scene with purposive eye movements, while also being able to process the contextual content in the periphery. The image features sufficient for directing visual attention have been well characterized and visual filter models have successfully emulated the bottom up component of visual saliency computation. However, humans modify their eye scan patterns depending on task, instruction, and context and this top down mechanism of visual attention saliency has resisted complete analysis and modeling, but is essential for performance in high clutter and for intentional, semantically guided searches. A further complication is that humans and animals successfully search for visual targets during locomotion, but the full mechanisms by which anticipatory head and eye movements are directed for visual search while moving have not been characterized or modeled. Integrated sensory systems that combine visual, auditory and vestibular sensing at multiple levels, for example multimodal interactions at the level of the superior colliculus that lead to crossmodal, cueing, and high level cortical integration of sensory representations into unitary percepts of the space of action. A hallmark of animal sensing is the exploitation of movement in active sensing, combining eye movements, use of motion parallax and obtaining multiple looks and viewpoints. Animals approach scene understanding and purposive search through a sensorimotor action strategy that leads to agile sensing.

Objective

To support basic research leading to determination of the principles by which humans and animals accomplish agile sensing (1) to place sensory and computational resources on the most salient and task relevant areas of complex scenes, (2) to provide situational awareness without "tunnel vision", and (3) to promote the development of novel bio-inspired strategies, algorithms and architectures to enable agile search within large complex scenes, whether conducted by autonomous sensor networks, autonomous sensing vehicles or teams of vehicles.

Research Concentration Areas: 1) Multidisciplinary research in visual and visuomotor brain-inspired models and mechanisms to develop principles, algorithms and system concepts for context-dependent "foveal" searches guided by scene features (bottom up) and task (top down) for multiple moving targets from still or moving platforms. 2) Multimodal systems that combine

information from acoustic, visual and motion planning and sensing to direct sensor “foveas” to regions of interest from still or moving platforms. Regions of interest could be defined by targets, or potentially threatening activities. 3) Automated exploration of large scenes (from high resolution wide angle sensors, multiple overlapping sensors, or rapidly scanning sensors on a moving platform) and autonomous dwell or track of regions of interest and “zoom” for characterization and identification of threats, targets or activities. 4) Autonomous vehicle (USV, UGV or UAV) and sensor tasking and maneuver to acquire higher resolution, multi-aspect views of regions of interest sufficient to fully characterize a potentially threatening activity. Extensions of these approaches to night and atmospheric turbulence conditions are also of interest. 5) Cognitive and computational neuroscience analysis of optimal strategies for adjudicating between continued search and covert attention vs. foveated detailed examination of regions of interest and optimal scan patterns (head and eye movements) for different tasks and environments, and exploitation of both auditory and visual spatial attention.

Impact: New strategies, principles, algorithms and architectures to autonomously adjudicate between wide area exploration and dynamic region of interest exploitation within autonomous sensing systems, whether consisting of sensor networks, sensing from autonomous vehicles or systems of autonomous vehicles.

Research Topic Chief: Dr. Thomas McKenna, ONR, 703-696-4503, mckennt@onr.navy.mil

FY09 MURI Topic #6

Submit white papers and proposals to the Office of Naval Research

Computational Intelligence for Decentralized Teams of Autonomous Agents

Background: A critical enabler of autonomy is intelligence. While we can design agents, and teams of agents (cyber and physical), to do fairly complex tasks in tightly constrained domains without much supervision, the agents have not yet approached the level of intelligence that would allow satisfactory performance in uncontrolled environments without close human supervision, or the level of intelligence that would enable high-level interactions with humans. The main characteristics of uncontrolled environments, that make them difficult for agents, are: (i) Information uncertainty, i.e., information may be imprecise, incomplete, contradictory, or irrelevant; (ii) Open world, i.e., the numbers and types of objects/agents/people are unrestricted, and that the truth-value of statements cannot be determined; and (iii) Unpredictability, i.e., agents/people may be non-cooperative or hostile with unpredictable adversarial behaviors. Examples of tasks in uncontrolled environments are persistent surveillance of Maritime Domain with a collaborative team of stationary and mobile sensor platforms, or surveillance of information networks with teams of agents to detect cyber attacks and mitigate the damage. Advances along several directions are needed to achieve our goal of building teams of distributed intelligent autonomous agents. We need to develop principles for decentralized coordination and decision making. Integration of basic modules, with mutually incompatible knowledge representations, for perception and decision making in real time remains a challenging problem. Current approaches to developing basic elements of intelligence, such as reasoning, planning, learning, etc., generally become intractable for real world problems.

Objective: Develop principles, computational methods, and architectures for enhancing the intelligence needed for perception and decision-making by single agents and teams of agents to enable them to perform in uncontrolled environments without constant human supervision. Develop new approaches that take advantage of uncertainty to reduce computations through bundling cases, unlike the approaches that when applied to uncertain domains become more costly as they expand the search to examine every single possibility. Moreover, methods should be analyzable and provide confidence estimates for performance of individual modules, agents, and teams of agents.

Research Concentration Areas: (a) Qualitative or common-sense reasoning for robust and rapid reasoning with uncertain information. (b) Planning in the real world, where we have limited time, incomplete information about the environment, and multiple goals that are only approximately modeled; also methods for plan/intention recognition; and decentralized planning and coordination. (c) Methods for learning complex tasks and concepts; transfer learning; life-long learning, particularly learning from combining domain knowledge and examples. (d) Methods for acquiring, and refining, knowledge from many sources that may have partial or contradictory information, particularly methods that integrate logic-based and probability-based representations. (e) Architectures that allow efficient and seamless integration of reasoning, planning, and other processes, for real time perception and decision-making, and learning. (f) Design of appropriate experiments to validate theoretical developments.

Impact: This research topic will advance the intelligence necessary for building agents performing autonomously in uncontrolled environments without constant supervision. In particular, this research is aimed at enabling Persistent, Adaptive Surveillance for Maritime

Domain Awareness. Other impact is in workload and manpower reduction. Moreover, systems that can adapt are less costly to build and maintain, even for well-constrained environments.

Research Topic Chief: Dr. Behzad Kamgar-Parsi, ONR 311, 703-696-5754, kamgarb@onr.navy.mil

FY09 MURI Topic #7

Submit white papers and proposals to the Office of Naval Research

Dynamic Biological Adaptations to the Undersea Light Field

Background: Active camouflage differs from traditional approaches to camouflage in that the object of concealment produces a structured light field that mimics the background or fills in shadows rather than simply reflecting the illuminating light field. Traditional camouflage is static whereas an active camouflage can be dynamic, producing a time-dependent light field that blends in with an ever-changing background. An object on the bottom of a shallow pool, so cloaked, would produce a time-dependent pattern of light and dark features that would look like the wave-refracted, down-welling light field reflected from the surrounding bottom. Nature has figured out how to apply concepts of active camouflage in a number of ways. Some species of fish and squid have light-producing organs on their underside that act to fill in their shadow or counter-illuminate, rendering them less visible to predators lurking deeper in the water column. Octopus and cuttlefish are able to change color quickly to blend into their surroundings even when the spectral, polarimetric, and spatial characteristics of the surrounding environment are complex. Cuttlefish are able to dynamically change their surface appearance to mimic a rapidly changing ambient light field, both in spectra and polarization. Small amounts of supported, e.g., ONR, DARPA, ARMU and Air Force sources, have been directed at understanding the neurological and physiological adaptive processes in marine biological systems. However, there are many perplexing problems that simply have not been addressed. How, for example, do various marine organisms capable of dynamic camouflage sense and process information about a dynamic ambient light field? What are the primary physiological differences between organisms with a static appearance, those that change their appearance slowly, and those that react rapidly? Is the sensing and processing handled centrally, i.e., through an eye wired to a brain, or do organisms posses distributed sensing and processing capabilities such that changes in the appearance at a specific part of the body are the result of local sensing and decision making? The purpose of this MURI topic is to develop a better understanding of how organisms sense and react to a dynamically changing subsurface light field and to begin expressing existing and new knowledge in the context of physical and predictive numerical models. A successful program will result in a wealth of new observations and emerging predictive capabilities with application to defense problems of camouflage and optical communication.

Objective: The MURI project will investigate adaptive strategies of marine biological systems to dynamic light fields, both passive and active, and develop predictive mathematical models and rudimentary physical models of biological systems that may be applied to analogous problems of cloaking underwater objects using, for example, active light production and manipulation of the local underwater light field.

Research Concentration Areas: The primary focus of this MURI project would be on understanding the physiological response of biological systems to the dynamic, undersea light field with emphases on field observations and the development of predictive, interdisciplinary models of biological systems and working towards a physical model of one or more biological systems. From a technological viewpoint, the world of optical sources and transmitters is rapidly progressing, fueled by the growing demand for small, energy efficient display devices. Light emitting diodes (LED) are readily available for much of the optical spectrum and organic LED technology is rapidly advancing. Thin, flexible displays, perhaps as thin as heavy paper stock, have been demonstrated and continue to evolve. Efficient, time-dependent radiative

transfer models coupled with the ever increasing CPU speeds of micro computers and advances in optical sources and sensors is making it possible to realistically start working towards dynamic, physical models of adaptive structures based on improved knowledge of marine biological systems. Success of this MURI project would require a well-coordinated, interdisciplinary team working in the areas of marine biology, hydrologic optics, optical engineering, computer nanotechnology, and human perception.

Impact: Progress in this MURI project will likely lead to significant advances on the ability to conceal submerged objects in shallow water, permitting more effective covert operations in denied littoral environments. Results are expected to translate readily to terrestrial and atmospheric applications, addressing the obvious problems of national defense, e.g., concealing in-theater ground and airborne assets, as well as providing value to non-defense issues, such as rendering cell phone towers and wind turbines less visually intrusive. A second potential area of impact is in optical communications. Some marine animals, for example, are able to modulate their polarimetric appearance while maintaining a nearly constant spectral appearance and brightness. Other animals, such as predators, incapable of sensing polarized light would not detect a signal sent with modulated polarization.

Research Topic Chief: Dr. Steven Ackleson, ONR, 703-696-4732, steve.ackleson@navy.mil; and Dr. James Eckman, ONR, 703-696-4590, jim.eckman@navy.mil.

FY09 MURI Topic #8

Submit white papers and proposals to the Office of Naval Research

Grounding Language Understanding in Cognitive Architecture

Background: As intelligent information systems become a ubiquitous part of our warfighting capability, the individual warrior will need to interact with computational devices more than ever before. To facilitate these interactions, systems must be equipped with the capacity to communicate in the most natural way possible – through the use of dialogue and gesture. Certain undesirable features of natural dialogue are pervasive, with upward of 80% of utterances being ungrammatical and thus unable to be parsed using state of the art parsers. Natural dialogue is also rife with ambiguities resulting from the unmet requirement to apply pragmatic principles to parsing. Advances in automated abduction are paving the way for intelligent systems capable of computing over the ill-formed problems that we've described by combining probabilistic inference with rich relational representations, including those required for expressing pragmatic and other semantic information (i.e. the assumed intentions of the speaker) that is otherwise implicit in dialogue. One promising avenue for the simultaneous representation of these aspects of dialogue participation is embodiment in computational cognitive architectures. Cognitive architectures comprise computational theories of the mental representations and processes that humans employ when thinking about different domains such as space, time, categories, action, uncertainty, and beliefs/desires/intentions. A cognitive-architectural approach to dialogue through the implementation of robust mechanisms for abductive inference appears to be natural fit for building a new generation of dialogue-capable military systems, and helps to avoid overly-specific engineering solutions for highly constrained domains of discourse.

Objective: Investigate and implement cognitively plausible algorithms for understanding dialogue within a cognitive-architectural framework.

Research Concentration Areas: Development of a dialogue processing capability requires multidisciplinary advances in a variety of research areas. To test and evaluate dialogue systems, it will be crucial to develop corpora that incorporate rich semantic and pragmatic tagging of utterances. Advances in cognitive architecture to enable dialogue understanding should include but are not limited to: (I) A capability for reasoning about the of mental states of dialogue participants as dynamic constraints on interpretation, (II) the capacity to make abductive inferences about ambiguous information, and (III) an ability to integrate syntactic, semantic, and pragmatic knowledge within the same architectural framework. Multidisciplinary teams consisting of any combination of cognitive/social/developmental psychologists, cognitive scientists, artificial intelligence researchers, psycholinguists and computational linguists are preferred, given that cognitive architecture development/extension is highly constrained by the human sciences.

Impact: The space of intelligent systems to which dialogue-capable architectures could contribute to is enormous and includes: natural interfaces for the control of multiple unmanned vehicles**,** dialogue-capable intelligent tutoring systems, virtual adversaries/teammates for low-cost immersive training environments, seamless interaction between human operators and robotic counterparts, and intelligent query-processors for databases to enable individually-tailored information retrieval.

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FY09 MURI Topic #9

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Tailoring Electronic Bandgap of Nanostructured Graphene

Background: Graphene is a single atomic layer of carbon atoms arranged into a two-dimensional (2D) hexagonal lattice. Since its discovery in 2004 by physicists, single layer graphene has been produced by several methods and sample quality has steadily improved. Among the many fascinating properties of graphene that are of particular interest to nanoscale electronics are: (1). Strong ambipolar electric field effect: despite being a semi-metal with zero energy gap, graphene differs from conventional metals in that its charge carrier density can be continuously tuned from n-type (i.e. carriers are electrons) to p-type (i.e. carriers are holes) simply by applying an electric field; (2). Linear dispersion: in the vicinity of the charge-neutrality point (known as Dirac point), both electrons and holes obey linear energy-momentum dispersion relations (like photons), rather than the familiar quadratic form $E = {P^2}/{2M}$. Indeed, at low temperature, the velocity of these particles is about 1/300th of the speed of light. (3). Ultra-high mobility: at room temperature, the carrier mobility in suspended graphene exceeds ***all*** known semiconductors (~100,000 cm^2/Vs); (4). Bandgap: while a large 2D graphene sheet has zero bandgap, a finite gap can be created in graphene by cutting the graphene sheet into narrow strips and the bandgap is expected to depend on both the strip width and its orientation. All these properties stem from the true 2D nature of graphene that were hitherto unavailable to researchers, and have thus far been studied primarily by solid state physicists. Now it is time to broaden the scope and formulate a multidisciplinary research project, in which chemists, material scientists and device engineers can work alongside physicists, toward realizing the vision of devising an ultra-fast (> 1THz in comparison to today's GHz silicon technology) integrated circuit, where devices and circuits are built not by integrating multiple disparate materials rather by simply tailoring various sub-10nm 2D shapes and structures in a single sheet of graphene.

Objective: This MURI program will establish a coherent research project that focuses on *nanostructured* graphene at sub-10nm scale, understand its electronic properties, and seek ways to tailor innovative device functionalities and circuits using these structures.

Research focus areas: Areas of interest include, but are not limited to: (1) Develop physical understanding that is capable of accurately describing properties and functionalities of arbitrary shaped graphene nanostructures. (2) Develop effective experimental tools and techniques to control and engineer bandgap in graphene nanostructures; (3) Clarify the role of edges and defects that are affecting the electrical properties of graphene nanostructures and develop means to control or utilize these effects. (4) Devise and demonstrate novel devices and circuits that take advantage of the unique properties of graphene with clear advantages over current state of the art.

Impact: High mobility ballistic transport could lead to ultra-fast (>THz) electronics with high on-off ratio and low power consumption. Bandgap control in both single and bi-layer graphene could lead to multi-spectral and tunable IR sensors. The parity between electron and hole in 2D graphene could enable true complementary highly linear and efficient microwave and millimeter wave amplification and lead to significant positive impacts on the performance of various DoD electromagnetic systems.

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FY09 MURI Topic #10

Submit white papers and proposals to the Air Force Office of Scientific Research

Neurological System-Inspired Multifunctional Materials Design for Autonomous State Awareness against Exogenous Threats

Background: System state awareness through autonomous sensing, recognition and response is a crucial capability for any aerospace vehicle facing exogenous threats (thermal, mechanical, chemical, or electro-magnetic). However, the current design for autonomous state awareness of aerospace structures is primitive compared to complex biological systems that depend on the neurological system's effectiveness to autonomously sense and recognize external stimuli, threats or environmental changes and to adjust the physiological state in response. Neurological systems consist of millions of neurons networked for sensing and actuation along with locally distributed and centralized signal processing units. Sensing information is conveyed through electrical impulses (digital signal) from one neuron to another, which release neurotransmitter chemicals (analog input) through the synapses. One aspect of this signal transduction process is that cognition and decision-making are determined by a relative level of cumulative signal strength with respect to the synapses threshold values. In view of such complex biological capabilities, a major paradigm change is clearly needed to introduce autonomous state awareness for future aerospace vehicles. Intelligent multifunctional materials inspired by the neurological system should be developed to satisfy the demand on critical state self-awareness. One promising example is a highly damage-tolerant thin structure of reconfigurable sensor network consisting of an array of electromagnetic, acoustic, and optical sensor systems. Each sensor node encompasses a processor, memory and appropriately developed predictive/diagnostic algorithms which could be embedded in structures to perform sensing and self-diagnosis of threats and resultant system failure. The parasitic approach involving embedded sensor network can be avoided by using nano-functionalized fibers that have desirable sensing and actuation properties that are an intrinsic part of the material systems.

Objectives: (a) To design multifunctional material systems of highest degree of autonomous state awareness by incorporating distributed sensors, actuators, nano-functionalized fibers for sensing/actuation, processors, and memories to mimic the neurological network present in biological systems, and thereby (b) to establish new capabilities for aerospace vehicles to sense and recognize exogenous threats, the changes of environment or incipient system failure, and to initiate in real time the proper reaction and adaptation.

Research Concentration Areas: Suggested research areas are as follows: (1) Theoretical and experimental understanding of autonomous operation of neurological system; (2) Analysis of the interaction between exogenous threats, environment, structures, structural materials, and the sensory networks under study; (3) Synthesis and processing of the intelligent multifunctional material systems in the form of finely distributed sensory networks; (4) Development of multifunctional design criteria to endow the sensory network with optimum capabilities to sense and recognize exogenous threats and to initiate proper reaction, while maintaining structural requirements; (5) Demonstration of self-reconfiguration and other adaptation capabilities of the sensory networks against local material damage; (6) Development of autonomous self-learning process and technology in data mining, artificial intelligence, advanced algorithms for the formulated multifunctional material systems to continuously improve their autonomous state awareness capability throughout their usage life; (7) Validation, implementation and integration of newly proposed multifunctional material systems capable of

autonomous state awareness into load-bearing structures.

Impact: The proposed establishment of intelligent multifunctional material systems capable of autonomous state awareness will have a large impact on the performance of aerospace vehicles as follows: (1) increased reliability and responsiveness with longer flight time and reduced chance for unexpected failure, (2) greater chance for self-operation and self-control of unmanned system with minimal or no scheduled maintenance, and (3) enhanced state of self-awareness to improve agility and survivability in response to rapid changing environments and uncertainties during combat situation.

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FY09 MURI Topic #11

Submit white papers and proposals to the Air Force Office of Scientific Research

Chemical Energy Enhancement by Nonequilibrium Plasma Species

Background: This topic responds to the 2009 MURI solicitation topic on alternative fuels and energy sources. Recent Air Force basic research has provided strong indications of significant improvements to the initiation and sustainment of chemical energy conversion through coupling with weakly ionized plasma species, including a 2/3 reduction in ignition delay time and a 60% increase in laminar flame speed. Such improvements, if applicable, represent potentially enabling capability for systems including scramjets, pulse detonation engines, and high-altitude uninhabited air vehicles (UAV's) and provide a means of stable operation with alternative fuels. The next step that is needed for technological exploitation of these beneficial effects is the creation of a knowledge base and derivative modeling tools to incorporate plasma-based approaches into the design of optimized chemical energy conversion systems. The key question that needs to be addressed and is not being addressed in current research is scaling – the understanding of the relationship between plasma behavior and the associated thermodynamic-chemical-fluid dynamic environment.

Objective: The objective is to perform experimental and theoretical studies needed to understand the primary physical and chemical processes associated with plasma-enhanced chemical energy conversion and to use the results of these studies to produce engineering tools to optimize the design of chemical energy conversion systems.

Research Concentration Areas: Research will require the coordinated efforts of physicists, chemists, and electrical and aerospace engineers. The focus will be on the creation of nonequilibrium, nonthermal plasma that can be well characterized to produce ions and excited state chemical species to initiate subsequent exothermic chemical reactions. Diagnostics for both the plasma and the chemical species will be a particular challenge because of the geometrical complexity and transient nature of the plasma, the unknown spectroscopic nature of the ions and excited state species, and the harsh electromagnetic environment in which the measurements must be made. Theoretical physics and chemistry will be employed to understand the alteration of pathways for chemical energy release caused by the ions and excited state species. Finally, models for reduced chemistry will be formulated and incorporated in computational models for energy conversion, including turbulent fluid transport processes.

Impact: Scramjets, pulse detonation engines, and gas turbines are primary energy conversion devices whose performances have been limited, or, in some cases, not achieved because of technological deficiencies in stable ignition and low-loss flameholding in combustors. These deficiencies also limit the potential of these devices to utilize alternative fuels with properties that deviate from currently used fuels. Plasma-based approaches already have attracted joint Air Force-Navy attention to remediate these difficulties for pulse detonation engines and are receiving substantial basic and applied Air Force research support for the scramjet application. Plasmas also may be an enabling technology for lean-combustion gas turbine engines for high-altitude UAV's. This technology may have a significant impact for civilian applications as well, including energy efficiency, fuel flexibility, and pollution reduction. In summary, the proposed research offers potentially revolutionary short-term breakthroughs for energy conversion systems.

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FY09 MURI Topic #12

Submit white papers and proposals to the Air Force Office of Scientific Research

Ultracold Molecules

Background: The discovery of laser cooling and trapping techniques for atoms has revolutionized atomic physics. It has led to Bose-Einstein Condensation (BEC) of atomic gases, atom interferometry, quantum simulation of condensed-matter systems with cold atoms in optical lattices, and quantum-degenerate Fermi gases. Many applications have benefited from these advances, including precision inertial navigation, atomic clocks, and quantum computing. The remarkable successes of cold and ultracold atom physics have opened the doors to a new field of cold and ultracold molecules, which could potentially deliver more spectacular science and technology in areas including chemistry, precision spectroscopy, sensing and metrology, and quantum information processing. Molecules are more complex than atoms and have properties that cannot be found in atoms, promising richer physics and new applications. For example, the presence of closely spaced internal levels in molecules offers a wider range of coexisting frequencies than in atoms, presenting new possibilities for precision measurement applications and tests of fundamental symmetries in nature. One of the most significant differences is that polar molecules have an electric dipole that provides a long-range tunable anisotropic interaction between the molecules, a property that is not found in atoms. Controlling and manipulating the dipole-dipole interaction is expected to lead to many novel and exciting phenomena, including new phases of matter, quantum chemistry, and quantum computation with molecules. In the realm of physical chemistry, it may be possible to control chemical reactions with external fields in the ultracold regime. This will allow production of desired species selectively, and a better understanding of the underlying mechanisms for chemical reactions of interest. The major technical challenge lies in achieving sufficiently low temperatures and high molecule densities that are required to investigate the areas discussed above. The complex molecular internal level structure precludes a simple extension of atomic laser cooling techniques to molecules, hence novel methods are needed.

Objective: The goal of this topic is two-fold: (1) development of cooling, trapping, manipulation, and detection techniques for cold and ultracold molecules that will then enable (2) investigation of a variety of scientific problems and areas outlined below, some of which are a true *terra incognita* and cannot be accessed in any other way (e.g., ultracold chemistry, and new phases of matter), whereas other areas are expected to be advanced significantly over existing solutions.

Research Concentration Areas: Areas of interest include, but are not limited to, the following: (1) development of cooling, trapping, and detection techniques for molecules for achieving dense molecular clouds in the ultracold (sub-mK) regime; (2) quantum degenerate molecular gases and new phases of matter; (3) ultracold chemistry; (4) tests of invariance principles and fundamental symmetries in nature; and (5) robust quantum information processing.

Impact: This multidisciplinary effort will advance several fields of science, including quantum information science and quantum chemistry. It will impact military and civilian applications including sensing and metrology, advanced computing, and chemical synthesis.

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FY09 MURI Topic #13

Submit white papers and proposals to the Air Force Office of Scientific Research

Search for New Superconductors for Energy and Power Applications

Background: The discovery of superconductivity (SC) above 77K over 20 years ago in rare earth cuprates motivated a worldwide effort in materials science and engineering to fabricate bulk material, wires, tapes and thin films that could become key components in smaller magnets, motors and generators, as well as in communications systems and sensors with superior characteristics. Although there has been significant progress, the resulting products are generally too expensive, resulting in a limited commercial market. In the past 15 years there has been no discovery of any cuprate (or any other type of) higher-temperature SCs. If a more economical, manufacturable SC material can be found, it would have immediate application to more compact, more efficient energy and power management systems. The time is ripe to take advantage of discoveries made since Jan 2008 of new classes of SCs that include rare earth oxides mated with iron arsenates (T_c = 52K as of 4/1/08), and metallic H alloys (T_c = 17K at 96 GPa). There is great enthusiasm for an aggressive search as a result of a June 2007 workshop: "The Road to Room Temperature SC (RTS)," where over 20 lecturers predicted a higher T_c in 10 years.

Objective: The goal of this topic is to discover new classes of SCs that either will be useful at higher temperatures and magnetic fields, or that can be operated in the currently obtainable range (roughly 77K), but which will be less expensive and more useful because of reduced anisotropy and/or fewer non-SC components in practical magnets and power systems.

Research Concentration Areas: This topic will require close coupling between theorists and experimentalists, chemists and physicists, with assistance from materials scientists and electrical engineers. Theorists may be able to utilize supercomputers to design promising molecular structures, as well as to find materials systems that maximize electron-phonon interaction or to find a new mechanism to produce SC that relies on some other basic interaction. Ideas abound, e.g., Hubbard model, negative U centers, nano-clusters, organics and heavy Fermions. There is a large parameter space of both known SC compounds and potential ones, with numerous multi-component SC classes. In some cases, SC may exist only at interfaces between dissimilar materials. A broad systematic approach is required, and collaborations with scientists elsewhere, including foreign ones, are encouraged. Experimentalists may apply an Edisonian approach, which has been the basis of most SC discoveries. Additionally, when a promising compound is made, it may be desirable to engineer material specimens that exhibit a gradient of constituent components, and then construct a scanning instrument that can detect nanogram quantities of SC diamagnetic behavior. Any other promising approach will be considered.

Impact: Discovery of isotropic SC useful at 77K or operable at higher temperatures would impact most DoD power generation, storage and conditioning systems. It could be employed to launch rockets and satellites, eliminating most liquid and solid propellants, and it would greatly reduce the size of MHD systems. SC almost lossless bearings would enable more efficient energy storage via flywheels. It would be applicable to the AF's airborne active denial systems (that can be used by ground forces as well), whose generators would be 1/3 the size and weight of conventional generators. The Navy could install HTS motors in its fleet; the Army could do the same for its land vehicles. Success also would have a great impact on the nation's electrical utility industry. Important commercial applications are motors and generators, magnetic energy

storage, transformers, fault current limiters (FCLs), uninterruptable power supplies (UPSs) and high-power transmission lines. FCLs and UPSs are essential for maintenance of sensitive electronic systems and hence will have a major impact on information assurance for the DoD and industry. Another major application would be the introduction of more efficient and discriminating SC antennas and filters in both military and civilian communications systems.

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FY09 MURI Topic #14

Submit white papers and proposals to the Air Force Office of Scientific Research

Complex Nonperiodic Nanophotonics

Background: The development of nanophotonics is leading to unprecedented capabilities for controlling light, and has profound impacts in areas such as communication, computing, imaging, sensing, lighting, and energy harvesting that is of critical importance for future military systems. In general, the capabilities of nanophotonics arise from the unique optical properties of individual sub-wavelength objects, as well as the controlled interference between them. Notable examples that have been extensively explored include photonic crystals and meta-materials, both typically involving arrays that are largely periodic. On the other hand, with nano-fabrication capabilities there are enormous degrees of freedom in creating aperiodic and complex geometries, such as patterns that are quasi-periodic, fractal, or seemingly random. Moreover, it has been noted that such complex geometries, when appropriately designed, can lead to superior performance far beyond what is capable in simpler or periodic systems. For example, the use of multilayer structures with designed but seemingly random variation of layer thickness can lead to very compact spectral demultiplexers for wavelength division multiplexing systems. The use of quasi-periodic patterns can lead to light emitting diodes with enhanced power, spectral and angular performance, as well as filters with very complex transfer functions. The use of fractal metallic structures, which funnel energy from a large area into selected nano-scale hot spots, can enhance optical switching, detection and microscopy. In general, however, creating a framework that allows one to systematically understand the properties of such complex structures and to exploit them to achieve advanced functionalities represents a great challenge in analysis, design and fabrication.

Objective: Develop a basic understanding of the potentials and limitations of complex nanophotonic structures, and create a framework that allows systematic design, optimization, fabrication, characterization and exploitation of complex nanophotonic structures and devices, motivated by challenges in one or more practical application areas such as chip-scale optical information processing, computing, sensing, and imaging.

Research Concentration Area: Suggested research may include but is not limited to: (1) advanced computational electromagnetic techniques for efficient simulations of complex nano-photonic structures; (2) design and optimization strategy for nanophotonics; (3) analytic theoretical understanding of the performance and the limitations of complex nanophotonic structures; (4) ultra-compact devices for use in on-chip wavelength division multiplexing systems; (5) nano-scale optical passive and active components (sensors, emitters, waveguides, modulators, etc); (6) optical antennas; (7) ultra-low power optical switches; (8) non-periodic plasmonics; (9) physics and application of quasicrystals; and (10) nonlinear nanophotonics.

Impact: The creation of ultra-compact optical devices reduces size, weight and power consumption, and enhances the capability, dependability, and survivability of future military platforms. The general knowledge gained in understanding complex and non-periodic nanophotonic structures will also have broad implications for all technological areas where manipulation of light plays an essential role, including information, energy and sensing technologies. The area will exploit novel concepts and applications in photonics and require solving challenges in theory, design, simulation, fabrication, materials, and devices.

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FY09 MURI Topic #15

Submit white papers and proposals to the Air Force Office of Scientific Research

Multi-Scale Fusion of Information for Uncertainty Quantification and Management in Large-Scale Simulations

Background: Many physical systems, devices and processes of importance to the Air Force are poorly understood or controlled due to uncertainty in physical models and their parameters, material properties across length scales, the operating environment, or measurements. In an environment where critical decisions are made based on simulations, it is critical that the uncertainties in simulation predictions be credibly characterized and managed. Proper handling of simulation uncertainties, whether due to physical, analytical or numerical modeling errors, may require innovations in areas such as stochastic modeling, numerical error analysis, numerical algorithm development, and optimization. A rigorous end-to-end management of uncertainty in modeling and numerical simulation tools and their application to design, control and other decision-making situations for these processes present a tremendous challenge that can only be overcome by multi-disciplinary teams whose expertise, besides subject matters, span areas such as probability and statistics, applied analysis, computational mathematics, experiments and modeling, high-performance computing, and optimal design/control. What is needed are efficient and accurate analytical and computational tools combined with experimental data to identify and synthesize uncertainties from various sources to make uncertainty prediction a fundamental part of high-fidelity predictive tools for these complex multi-disciplinary, multi-physics and multi-scale systems. Current areas of technological importance where information fusion across multiple length and time scales coupled with performance assurance (analysis, control and design) is essential include random heterogeneous media; heterogeneous material systems; roughness and scattering in electromagnetics and acoustics; fluid-structure interaction and others.

Objective: To develop the mathematical and algorithmic fundamentals for addressing uncertainty quantification, propagation and management in the analysis and design of multiscale continuum systems of importance to the Air Force. While applicability and impact should be demonstrated with at least one area of critical importance, the proposed mathematical developments should not be driven with any specific application in mind. Thus, independent, modular, and flexible developments are needed that can have an immediate and simultaneous impact to a variety of applications critical to the Air Force's mission.

Research Concentration Areas: Areas of interest include, but are not limited to, the following: 1)Describing the stochastic nature of data using very large data sets or very small (gappy) experimental data sets, 2) Developing a mathematically rigorous information-theoretic framework for quantifying random information at different scales, 3) Developing efficient and accurate algorithms for propagating uncertainties in stochastic models, 4) Advanced mathematical techniques that address curse-of-dimensionality issues in stochastic continuum systems, including adaptive and reduced-order models for Stochastic Partial Differential Equations, 5) Managing uncertainties by quantifying numerical errors, model refinement and new data assimilation and data acquisition algorithms suitable for uncertain data, 6) Managing uncertainty representations among a range of processes that operate on common data sets but with disparate goals, 7) Designing with uncertainty and predicting reliability based on high-fidelity but uncertain numerical simulations.

Impact: Methodology for the quantification of uncertainties in modeling and simulation is a

critical enabler for the development of autonomous weapon systems which are integrating technologies over an increasingly wide range of length scales and physical processes. By linking these elements together with methods that account for real-world uncertainties and manage errors in the associated models, new systems across the capability spectrum can be designed, certified, and fielded at a faster pace to maintain dominance over new and varied threats, with an expectation of reliable operation.

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FY09 MURI Topic #16

Submit white papers and proposals to the Air Force Office of Scientific Research

Learning Decision Architectures for Intelligent Cooperative Control of Autonomous Systems

Background: In the ever evolving structure of battlefield architecture, unmanned vehicles (air, land and sea) are quickly moving toward the forefront of DoD research interests. If used efficiently, unmanned vehicles will save the military precious resources, including lives, while improving mission performance. During the last decade, extensive research efforts have been directed at cooperative control for teams of unmanned vehicles. Although great progress has been made in cooperative autonomous control for task execution, such as in formation flying, cooperative decision-making and mission management in the presence of uncertainty, unforeseen changes to the mission topology and operator interaction with autonomous systems and other information systems are much more difficult to address. Even task assignment algorithms for relatively small collections of unmanned vehicles (about 15) become numerically difficult. It is clear that both intelligent control, which allows a system to react to previously un-encountered situations in ways that maximize objective functions, and cooperative control, which merges local objectives and team objectives in an efficient manner, are important to future battlefield operations. Investigating the basic science behind these two areas and leveraging those ideas to form a unified theory is of utmost importance for autonomous systems research. One definition of an intelligent control system is one which perceives its environment and modifies control actions to maximize its system performance. Key characteristics include learning, memory, and the ability to modify decisions based on learned information. Additionally, the system should be able to adapt and expand the space of actions available to the team beyond a limited set of pre-defined “plays”. The characteristics of the “plant” to be learned could include an unmanned aerial vehicle (UAV), a team of UAVs, including their communication and sensor capabilities and operator, and the entire battlespace with which the UAVs must interact. Confidence levels in shared information are a critical factor and the way by which the confidence levels can be factored into decisions and how they can be improved should be considered.

Objective: To develop the fundamental theory, analyses, insight and tools: i) to fuse learning with cooperative control and decision making algorithms; ii) to improve performance over time as related to networked cooperative teams; iii) to update strategy, model and design based on current and previous information.

Research Concentration Areas: Areas of interest include but are not limited to: 1) rigorous mathematical models and provable performance of intelligent cooperative control systems; 2) novel methods for achieving intelligent strategies; 3) analysis of learning rates and training requirements; 4) concepts for learning in environments with only partial and potentially corrupted information.

Impact: The ability to autonomously adapt cooperative control and decision making strategies to account for new information in an intelligent manner is critical to the long term Air Force vision of heterogeneous unmanned systems operating in a coordinated fashion. With an intelligent fleet of unmanned vehicles, a human operator will be better able to achieve mission objectives in an efficient and adaptable manner. The fundamental theory and understanding provided by this topic will impact existing research programs in cooperative unmanned systems and directly supports the Collaborative System Control Strategic Technology Thrust.

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FY09 MURI Topic #17

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Information Dynamics in Networks

Background: Management approaches of conventional networking systems contain static assumptions about the structure of information content exchanged in a network. Examples of related scenarios include distributed routing methods and policies that do not factor in the type of information exchanged during high interference, intermittent connectivity, or network failure, compromise, and attack. These assumptions are also apparent in coding, policy, and protocol approaches that do not recognize and exploit variability and dynamics in information structure between different types of sources, users, and applications. Additionally, many network policies do not track and account for variation in traffic type, purpose, or volume, number of functioning nodes, or changing security conditions. As a result, we propose a need for network estimation, coding, and policy methods that can rapidly evaluate, track and manage dynamics both in the type of information content exchanged on networks and the resulting performance of the global network.

Objective: We wish to develop strategies for estimation of parameters of dynamic information content and exchange in networks that are computationally efficient and require low overhead. These estimation procedures should result in metrics of performance both in the exchange of information between individuals and of protocols and policies of the overall network. These metrics should then result in management approaches and policies that are provably stable and reliable under difficult conditions such as high mobility or flooding and compromise of networks. Approaches in dynamic analysis and modeling of information topological structure are of interest as well as mathematical methods drawn from diverse fields such as propagation and particle physics, stochastic decision theory, molecular biology, and behavioral analysis. The intent is to develop methods that can follow the structure of information exchanged and manage new network behavior and performance before and during its occurrence rather than pre-configuring an approach that does not adapt to variable conditions.

Research Concentration Areas: Areas of research interest include but are not limited to: (1) methods to analyze and model dynamic information structure and exchange; (2) adaptive methods for coding, estimation and decision theory in networks; (3) routing approaches for networks with highly variable connectivity, content, and user types; (4) adaptive network policy and optimization methods; (5) methods for dynamic network integrity and security analysis; (6) network management algorithms for real time distribution and allocation of network resources that are of minimum latency, overhead, and complexity. Emphasis will be placed on the ability to bound performance of these algorithms both in overall effectiveness and stability of operation of the network. Methods can exploit novel mathematical and computational approaches including those from quantum and classical dynamics, molecular quantum and classical dynamics, molecular and systems biological approaches, statistical decision theory, and social and behavioral analysis.

Impact: The impact of this program will be to enable the DOD to predict, verify, and manage the performance of its networks under highly dynamic and sometimes unstable conditions. Examples of such scenarios are: theater and tactical networks that are subject to interference and blockage due to high mobility scenarios, strategic networks with security conditions that result in mass compromise and flooding, and resource allocation situations where demands on

networks exceed the ability of the network to provide resources. Thus with a firm understanding of information dynamics in networks, we will have an approach to quantifying network behavior as it occurs and managing the response to the behavior in a predictable and stable way.

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FY09 MURI Topic #18

Submit white papers and proposals to the Air Force Office of Scientific Research

Synthesis, Analysis, and Prognosis of Hybrid-Material Flight Structures

Background: Combining the isotropic mechanical stiffness and strength of metals and tailorable anisotropic properties of polymeric matrix composites to build aerospace structures can lead to weight savings of 20-40% while increasing strength and durability by similar amounts. Damage tolerance of single-material flight structures is so inadequate that only a small proportion of the material strength is actually utilized. Hybrid structures made of dissimilar materials would combine damage tolerance crack-arresting characteristics of some material systems with the high strength, stiffness, ductility, and robustness properties of other material systems in an integrated structural design that makes optimal use of the best qualities in each of its constituents. High-temperature capabilities and resistance to aggressive environments would be added in only critical locations as required by the flight-regime envelope parameters. The current state-of-the-art in the design of such hybrid materials and structural systems lacks a physics-based methodology in the selection of metal/composite/ceramics combinations, design of adhesives, the orientation of anisotropic materials, and structural prognosis, which results in weight penalty because of overdesign. The analysis and prognosis of hybrid structural components, especially at the multi-material interfaces with wide coefficient of thermal expansion (CTE) mismatch under extreme environments is in its infancy and lacks even the basic definition of critical regimes and key parameters. A combination of structural mechanics, metallurgy, polymer composite technology, and chemistry is needed to understand the complicated multi-science interface issues that govern the durability and reliability of dissimilar-material structural joints and hybrid structures in general. Methods for in-situ nondestructive evaluation (NDE) and structural health monitoring (SHM) of such hybrid materials and structures are needed for remaining-life prognosis as function of actual mission profiles and environments.

Objective: Conceptualize and analyze hybrid-material structures that would synergistically combine the best attributes of metallic, composite, and ceramic components/constituents, while avoiding their inherit shortcomings. Improved strength, durability, and performance should be achieved in adverse environments. The mechanical and chemical aspects of dissimilar-material joints with wide CTE mismatch exposed to temperature cycling, environmental degradation, and dynamic/blast loading should be considered. The methodology could be validated with a baseline hybrid material such as TiGr (titanium/graphite-epoxy), but a higher-temperature system should be developed. Self-sensing materials or embedded sensor concepts that can provide a state-awareness signaling of the durability state with prognosis of remaining strength and life would greatly enhance the topic.

Research Concentration Areas: (a) basic chemical-mechanical mechanisms that enable durable predictable adhesion between dissimilar materials displaying robustness with respect to variability in manufacturing and operational parameters; (b) synthesis and analysis of hybrid flight structures with controlled durability under sustained operation, blast/impact events, and extreme environments, with joining an integral part of the design process; (c) in-situ NDE/SHM of the strength and durability of the seamless interface between dissimilar materials used in hybrid material structures; (d) prediction methodology of hybrid structure properties and durability based on hybrid material architecture (e.g., configuration, placement, location, etc.).

Impact: This research topic will enable the development of future Air Force flight platforms with

operating in a wide range of speeds in extreme environments over extensive periods of times.

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FY09 MURI Topic #19

Submit white papers and proposals to the Air Force Office of Scientific Research

Biophotonics: Optical Effects through Nature's Photonic Control

Background: Optical devices researched in natural systems have been found to have some of the fastest switching capabilities ever measured, yet operate in a very high noise or low light collection environment. These biomaterials exploit their unique capability to functionalize themselves and to self-assemble into crystalline and amorphous regions giving them the ability to alter their band gap by altering their structure dynamically. This combination would be difficult if not impossible to achieve with current systems available today. Therefore, it is important to study the basic mechanisms behind how these organisms achieve these optical capabilities with such a limited palette of materials. We want to then utilize these principles to derive new optical systems to improve DoD Intelligence, Surveillance, and Reconnaissance (ISR) capabilities. Recently, there have been several breakthroughs in biologically derived optical materials reported in the literature. One example is the isolation and sequencing of squid reflectin proteins. The biological community has only recently developed the capability to characterize the complex proteins that nature uses to control color, camouflage, etc, while simultaneously, we have seen astounding breakthroughs in nanofabrication, dip pen nanolithography, and self-assembly. This is truly a multidisciplinary topic drawing on the field expertise of biology, chemistry, physics, and optics.

Objective: Develop the knowledge necessary to use naturally-occurring optical system properties to design and construct novel optical materials including: beam steering devices, diffracting materials, filters, and structural coloration elements. For example, nature has developed novel nano and microstructures in photonic structures such as butterfly wings with iridescent coloration or reflectin structures in squid that can be turned on and off. Optical phase-array beam steering could potentially be used with both of these materials. Because these materials and structures will potentially be used with lasers at higher power levels researchers should not limit themselves to solely biomaterials but should also investigate synthetic organic and inorganic materials that can be fabricated to mimic biological structures. Recent research has demonstrated that photonic structures can be templated from butterfly wings onto alumina.

Research Concentration Areas: Suggested research areas include but are not limited to: (1) develop an understanding of the strategies and materials utilized in nature to control light; (2) perform isolation, sequence determination, expression, and structure determination of proteins with optical function; (3) develop methodologies to assemble 2 and 3-dimensional structures necessary for future optical devices; (4) perform modeling to understand the interaction between photons and bioderived and bioinspired materials and structures; (5) develop dynamic bioderived and bioinspired materials and structures; and (6) have the ability to collect light in low-light conditions.

Impact: These new materials and structures will have enhanced performance, be capable of dynamically responding to their environment, have decreased weight and cost. Biology is filled with novel optics, unusual signal processing (high noise environment), dynamic optical elements, optical effects and numerous other optical examples that can change the ISR landscape towards lighter, lower-cost, distributed optical systems to operate in extremely low light conditions.

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FY09 MURI Topic #20

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Fundamental Graphene Material Studies and Device Concepts

Background: Graphene, a 2-D sheet form of graphite, one atomic layer thick, presents a host of remarkable physical and chemical properties, many of which result from the special electronic band structure of this material. Although the valence band and conduction bands "touch" each other at the Fermi level, the density of states at the Fermi level where the bands "touch" is zero. This results in electron mobility as high as 200,000 cm^2/Vs at room temperature even when the carrier density is $10^{13}/cm^2$, thus making graphene a very attractive material for high speed THz electronic applications. As another example, the ultra-small spin-orbit coupling allows possible spintronic exploitation. Thus far, only small flakes of graphene have been fabricated revealing prospective device applications. There would appear to be a number of graphene active layer growth methods on a variety of substrates, both semiconducting and insulating, that would be amenable to possible fabrication of wafers necessary for a full-fledged study of material properties and device prospects.

Objective: The object of this prospective MURI is multifold. Members of the MURI team will:

1) Study the growth of high quality, uniform, and defect-free epitaxial graphene by a variety of methods, with an emphasis on defects with electronic impact,
2) Evaluate each method in terms of optimizing graphene properties at the nano-scale such as edge states, impact of a variety of potential insulating and conductive substrates, and atomic level passivation,
3) Characterize electron and phonon transport and bench mark potential electronic applications with specific attention to the role of grain boundaries,
4) Characterize optical, phonon and terahertz properties and develop related application concepts, such as MEMS,
5) Understand properties of heterojunctions of graphene with other materials, such as SiC, sapphire, Si, and other dielectrics, as well as the nature of the graphene-graphene interface.
6) Characterize mechanical properties and suitability for MEMS applications,
7) Identify potential chemical, pressure and biological sensing applications,
8) Characterize the thermal properties and phonon mechanics of graphene to determine power handling characteristics and related device applications.

Research Concentration Areas: In addition to a fundamental study of the application potential of graphene, the program should develop theoretical descriptions and predictions related to single and multiple layers of graphene, and investigate unusual properties as they arise during the research efforts. The broadest possible exploitation of this new technology should be explored.

Impact: At the present time, the physics and materials science of graphene resides in the academic community. The research focus is currently disjoint and generally uncoordinated with multiple redundant efforts. A MURI program is called for to provide a coordinated basis for the high level of research effort needed in this field and to provide technical leadership and focus. The goal of this MURI is to identify the properties and applications for graphene-based devices which will offer an order of magnitude improvement in performance over existing technology and/or provide electronic and photonic capabilities and opportunities which currently do not exist

and have not been anticipated.

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FY09 MURI Topic # 21

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Application Software and Data Protection for Untrusted Platforms

Background: User-level applications, running in the unprivileged mode of a processor, are the ones that ultimately handle sensitive data and hence require a secure execution environment. For example, a web browser remembers private information submitted to web sites and caches web browsing history and a media player must protect multimedia contents from unauthorized accesses. Traditionally, the operating system (OS) creates such a secure execution environment. The underlying assumption is that the OS is trustworthy, but the OS can be compromised by adversaries' exploitation of defects or vulnerabilities in the OS itself. Although a verification process can be applied to the OS in order to eliminate such vulnerabilities, a complete OS verification is well-known to be intractable due mainly to the immensity and diversity of contemporary OSs. Furthermore, since the OS runs with unlimited access to the system services and resources, there is no effective second-line of defense that the applications can resort to, in case the OS is compromised. A new system of protection that can directly protect application software and data without trusting the OS is essential.

Objective: The objective of this MURI topic is to investigate novel techniques and system architectures that can directly protect application software and data without relying on the existence of a trustworthy OS. With such a protection capability, the trustworthiness of the application (including its incorruptibility, secrecy or privacy, and security) is preserved and can be assured without any guarantee regarding the trustworthiness or state of the OS (i.e., the OS may have been compromised). To achieve this, one approach may be to separate the system privileges required to perform security/privacy functionality from that required for resource management. The provision of application/data protection may then be realized as a security module consisting of a small, simple, and easily verifiable trust base. If successful, the application/data protection system will enable a safe and straightforward distribution and deployment of DoD-sensitive application software and data to untrusted environments with less overhead and less cost.

Research Concentration Areas: The protection system requires a clear-cut threat model for this unique domain of software security. The conventional OS will be restricted to only perform resource management and scheduling. The interface that the protection system exposes must be transparent and orthogonal enough to minimize impact on existing/legacy application software. The mechanism implementing the application protection system must be small and simple enough to be fully-tested and analyzed. Solutions to this challenging problem require experts from multiple topical areas, including operating systems, databases, software engineering, computer hardware architecture, theoretical computer science and mathematics. Specifically, areas of interest to this topic include but are not limited to: (1) threat model capturing the needs of applications in an untrusted environment; (2) finer- grained privilege separation of a processor; (3) strategies for restructuring OS to adapt to the protection rules; (4) protection interface that is simple and general; (5) methods for constructing a verifiable protection enforcement system (direct hardware/virtual machine/micro kernel); (6) new approaches to secure distributed system development.

Impact: Success in this topic will result in a game-changing capability that will allow secure distribution and deployment of DoD-sensitive applications and data into possibly hostile

computing environments, thereby enabling construction of far more ambitious distributed systems with enhanced security and robustness by making the systems immune to the OS compromises.

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FY09 MURI Topic #22

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Disruptive Fibers for Flexible Armor

Background: High-strength fibers play a critical role in many DoD applications, including individual ballistic protection, vehicle armor, fabrics, gloves, and parachutes. Recently, the Army Research Office organized a workshop on flexible protective armor for the Soldier. One of the key conclusions was that new fibers could offer extraordinary advancements in both capability and performance for personnel protection. Recent scientific breakthroughs indicate that this is an opportune time for exploring disruptive fibers. These include novel approaches to controlling and enhancing molecular order within fibers, demonstration of enhanced fiber mechanical properties by tailoring molecular functionality, the design of complex inter-molecular interactions through optimization of atomic attraction potentials, and the use of molecular dynamics simulations to predict molecular repeat-unit refinements that dramatically alter chain entanglement and bulk mechanical properties. The focus of this MURI is to design and explore new fiber precursors and novel processing techniques to generate a fundamental understanding of how molecular design influences fiber properties and performance. These results will form the knowledge base needed for preparing the next generation of fibers for DoD.

Objective: This MURI will bring chemistry, materials science, and chemical engineering together to design and synthesize new fiber precursors and to process them into fibers. Fiber precursors will be designed at the molecular level that will enhance architectures and minimize defects during fiber formation. Innovative processing techniques will be used to prepare fibers, and key mechanical properties will be characterized. The results of fiber property measurements will be fed back to the molecular design stage, and be used to develop an understanding of how molecular structure and functionality impact fiber mechanical properties. Although the long-term goal is high-strength fibers for flexible armor and other DoD applications, system design and testing is not part of this topic, but may be carried out by DoD laboratories.

Research Concentration Areas: Molecular Design: Research will focus on novel strategies for designing and preparing promising fiber precursors that offer creative approaches for simultaneously achieving extraordinary tensile strength, tensile strain, lateral interactions, and elastic modulus. Approaches may include exploring polymers, inorganic fibers, or organic/inorganic hybrids. Research should include studies of how composition and functionality promote molecular interactions that lead to high-strength fibers. Molecular topology and functionality and their impact on crystallinity, alignment, and orientation are of interest as they relate to enhancing the multi-dimensional bonding of the fiber architecture. Atomic and molecular theory is needed to link desired fiber properties to molecular design, particularly for predicting key properties, such as entanglements, intermolecular interactions, thermodynamics, and the statistical mechanics of fibers. Of particular importance is the design of optimized fiber architectures that determine molecular interactions, entanglements, assembly, and fiber microstructure, such that disruptive fibers can be generated. Fiber Preparation: Processing plays a critical role in the mechanical properties of fibers. Novel approaches to processing and their impact on properties, such as tensile strength, tensile strain, elastic modulus, transverse and longitudinal stress states, and rate effects, should be explored. Of particular interest are solution processing and other innovative approaches that affect fiber alignment, orientation, crystallinity, micro/nano structure, entanglements, and the minimization of defects. The goal is to generate fibers that achieve an ultimate tensile strength of approximately 3 GPa while simultaneously maximizing ultimate tensile strain and elastic modulus, and minimizing density. Environmental stability should also be explored for the most promising fibers.

Impact: The high-strength fibers targeted in this topic are directly relevant to developing new, lightweight flexible body armor for the Soldier to increase mobility and reduce weight. It is also expected that the fundamental knowledge generated from this MURI will impact a variety of commercial and DoD applications that use fibers, including composites and fabrics.

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FY09 MURI Topic #23

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Network-based Hard/Soft Information Fusion

Background: In operations, information from "human-based sensors" (HUMINT—human intelligence, COMINT—content of intercepted messages, OSINT—open-source intelligence from newspapers/radio/TV, databases, etc.) is as valuable as information from physics-based sensors (optical, IR, electomagnetic, SAR, acoustic, etc.). (Information from physics-based and human-based sensors will be called "hard" and "soft" information, respectively.) In the past, fusion of hard information with hard information has been widely investigated. There has also been extensive work on fusion of soft information with soft information, including text understanding and database mining. Many of the frameworks suitable for fusion of hard information with hard information can conceptually be extended to fusion of soft information with hard information. However, it is not clear that soft information is best fused in these frameworks. Fusion of hard and soft information already takes place in operations—it is carried out by overloaded military intelligence officers rather than being accomplished automatically. Successful operations now require automatic fusion of information from all of the sensors, where "sensor" now has a wider definition of "any relevant physics- or human-based source."

Objective: Develop an analytical framework and accurate and efficient computational procedures consistent with this framework for network-based, distributed JDL Level 1/2 fusion of hard information from physics-based sensors with soft information from human-based sensors.

Research Concentration Areas (RCAs): Interdisciplinary research in psychology, sociology, linguistics, data mining, learning theory and sensor networks is needed in the following 8 areas: (1) Create psychology/sociology/linguistics/physics-based, mathematically consistent procedures for network-based, distributed fusion of 2 or more types of soft information with 3 or more types of hard information. Probability theory, which has been quite successful as a framework for fusion of hard information, may or may not be applicable in the wider context of hard/soft information fusion. Whatever framework is proposed (probability theory, possibility theory, evidence theory or other), the framework must be justified on the basis of its consistency with known or hypothesized principles of fusion that includes not only hard but also soft information. Justification of the framework solely on the basis of its success for hard information fusion is insufficient. (2) Determine the relation between the procedures on the one hand and the network on the other. Physics-based sensors will often be severely power- and bandwidth-limited but have low to medium latency while human-based sensors may be less power- and bandwidth-limited but have medium or greater latency. Different types of connectivity and latency for soft and hard parts of the network and need to be coordinated. Which sensors should be involved in the fusion process at which times? (3) How should the soft sensors be calibrated? (Deception by the human sensor need not be considered but error in the human sensor must be considered.) (4) Quantify the computational expense of the procedures. Scalability is required. (5) Develop or determine appropriate metrics to measure the accuracy and trustworthiness of the output of the procedures of RCA 1. It is, of course, essential to take noise and uncertainty into account. Classical approaches such as Gaussian noise, statistical confidence intervals, etc. are unlikely to be applicable. (6) In the metrics developed in RCA 5, determine robustness of the procedures and fundamental limitations on network-based hard/soft information fusion. (7) Identify or create suites of realistic, variable events on which the

procedures of RCA 1 can be tested. Verify and validate the procedures of RCA 1 on these suites. (8) Provide summary information on the advantages, qualitative and quantitative, of fusion of both hard and soft information over fusion of hard and soft information separately. Note: This topic is not about decision making but rather Level 1/2 fusion, where the input is simply wider than before (no longer just hard information).

Impact: Hard/soft fusion models are needed for operations, mission planning, training and simulation. Uses of the procedures developed by this effort in the civilian economy include emergency response, border and installation security, crowd control and traffic management.

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FY09 MURI Topic #24

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Tailored Stress-Wave Mitigation

Background: Armor is a fundamental element of military systems, representing the single largest component of battlespace survivability for the soldier. High hardness, high stiffness, high strength, and low weight are classical parameters that helped define the earliest armor systems; however, to date, a consistent set of design rules for ballistic armor materials does not exist for the armor designer. Recent advances in ballistic impact characterization and analysis offer a new opportunity to develop a self-consistent set of rules for analysis of the ballistic impact. The ballistic impact event can now be normalized to the pressure at the impact point, and stress-wave propagation can be tracked (i.e., both longitudinal and shear components) and correlated to damage initiation and growth in the material. High-speed visualization and bulk characterization results reveal the activation of multiple flaws simultaneously to produce dynamic failure, constituting vastly different behavior than what occurs during lower strain rate events. These findings point the way to a unique approach for designing materials: tailoring the deformation and failure mechanisms in the material to shape the propagation of intense stress-waves through the material in order to control and optimize energy dissipation or dispersion.

Objective: This topic seeks to develop a comprehensive understanding of the propagation of intense stress-waves in adaptive media with random, locally aeolotropic, and discontinuous properties. Novel characterization, simulation, and synthetic strategies will be necessary to demonstrate new materials exhibiting superior means of controlling and mitigating intense stress-waves. A successful proposal will provide novel insights into the convoluted inter-related physical phenomena that govern high-pressure stress-wave propagation in complex materials.

Research Concentration Areas: Theory and Characterization: Despite the tremendous maturity of modern simulations, a robust predictive tool to simulate the propagation of intense stress-waves through complex media is still a significant challenge. New research in coupled simulation and characterization efforts should address creative and innovative means to generate and optimize highly nonlinear changes in local stress distributions and loading history. These efforts must provide the necessary feature and time resolution to capture the robust material response. Further, new theory is needed to incorporate material evolution during intense stress-wave propagation. An effective research program must capture and predict the processes responsible for this evolution. This includes the statistical nature of intrinsic and extrinsic characteristics in materials, and the nucleation, coalescence and growth of small damage sites (and their distributions) during rapid loading. Additionally, research should link the stochastic stress fields to stochastic damage rules, based on initial microstructure, to provide a basis for robust design. Materials Design and Demonstration: Formulation and synthesis strategies (including controlled distributions of compositions, phases, reinforcements, and novel multi-scale architectures) must anticipate the induced evolutionary response of the material and architecture(s) during stress-wave propagation for optimized control and mitigation. Research efforts should exploit non-linear and stochastic phenomena generated during intense stress-wave propagation for novel material design. Tailored assemblies of dissimilar materials are of particular interest. Synthesis and processing must provide robust feature control with high feature densities and a wide range of distributions. Additionally, but not simultaneously, bulk materials must be fabricated for demonstration of stress-wave control and mitigation via standardized testing.

Impact: The comprehensive understanding of propagation and mitigation of high-pressure stress-waves in complex media will guide the future design and demonstration of new materials optimized for high-strain-rate ballistic performance. This will enable lightweight military hardware with dramatically enhanced survivability to serve the soldier in the battlespace of the future, in addition to new paradigms for insensitive munitions.

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FY09 MURI Topic #25

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Integrated Quantum Circuits

Background: The intrinsic features of superposition and entanglement in quantum systems enable the capability to beat classical limits in technology. Potential new capabilities include the solution of hard computational problems, ultra-secure communications, super-resolution in imaging, metrology beyond the shot noise limit, and ultrasensitive sensors. In particular, our current basis for information assurance, namely public key cryptography, could be rendered ineffective. Motivated by its potential revolutionary impact on computing and communications, quantum information processing has advanced in many ways since its effective creation in the mid 1990's. Quantum bits and logic have been demonstrated in a variety of physical systems. Sources and detectors of photons carrying quantum information, including entangled pairs, are actively being developed. Recently, experiments in remote entanglement have begun. The paramount challenge to enable applications is the contradictory requirement for precise manipulation of a quantum state on demand while maintaining strict isolation from the environment. In this regard, each physical system has its particular advantages and disadvantages. For example; trapped ion qubits have very long coherence times but logic operations are relatively slow; semiconductor qubits have fast gate operations but coherence times are short; photonic qubits are easily isolated from the environment but are difficult to store. Moreover, implementation of active and passive quantum error correction may be easier in some of these systems. Therefore, the capability to integrate different physical quantum devices into a circuit that utilizes the best characteristics of each is a very attractive idea. As importantly, such circuits could broaden the application set beyond computing and communications to imaging, metrology, and sensors, to name a few. From application and scalability considerations, chip-scale integration is needed.

Objective: The objective of this MURI is to explore, develop, and demonstrate techniques for chip scale integration of different types of physical qubits, utilizing their best characteristics for the development of quantum circuits. This will require techniques for intraconverting quantum information among different physical modalities. A broad range of applications is envisioned, going beyond computing to communications, imaging, metrology, and sensing.

Research Concentration Areas: Work should explore techniques to combine different device types advantageously in a circuit for quantum processing. The techniques developed should be scalable and suitable for chip-scale integration. Some research concentration areas for this topic are: (1) on-demand transfer of quantum states between different device types; (2) up-conversion and down-conversion to enable transmission/entanglement between different device types; (3) waveguides, transmission lines, MEMS mirrors, photonic crystals, and other components to route quantum information on-chip; (4) managing the operating temperature environment to suit the different device types; (5) theory and experiments for the optimal choice of different physical device embodiments; (6) experiments to demonstrate techniques to transfer/entangle different devices that can be implemented on-chip; (7) decoherence and error-correction in such circuits; (8) applications and algorithms; and (9) assessment of capabilities beyond classical systems. Fabrication of full-scale integrated chips is not envisaged.

Impact: Functional quantum circuits have potential revolutionary impact on a broad range of DoD applications including computing, communications, imaging, sensing, and metrology. In each case, capabilities beyond classical systems will be enabled. The impacts of this topic on

information assurance should be clear. At the underpinning of public key cryptography are two hard problems, factoring and the discrete log. Should these problems become tractable, essentially all of the currently used public-key protocols would be useless, resulting in the complete disruption of current key management infrastructures. Ultimately, secure communication for government and commerce would be undone. This is all predicated on the eventual existence of a quantum computer.

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FY09 MURI Topic #26

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Adaptive Structural Materials

Background: Most development efforts for structural materials focus on pushing the boundaries of extreme properties for a target application. Military systems, however, see continuously evolving roles and changes in tactics that are well outside the original design space leading to unexpected failures. The state of the art in the so-called adaptive materials is to embed discrete actuator components and sensor components (i.e. active fibers) into composites. With these active components, and external power and control, one can modify the net properties to exert some control over overall structural performance, but the actual mechanical properties of the material, do not change. Rigid/solid biological materials (i.e. bone) are adaptive and self-repairing, and as such can dynamically optimize themselves to fit their current operating environment. They consist of a transport system to move reagents throughout the structure, a mechanism for deposition of the load-bearing solid phase material, and a mechanism for the dissolution of the solid-phase constituent. The performance levels attainable for biological systems, however, are not acceptable for most structural applications. A system that uses these fundamental concepts from biology, with synthetic chemistry geared to produce constituents of high structural capabilities that are not possible in nature, could make composite materials that meet the needs of future military designers.

Objective: The objective of this research project is to develop concepts and fundamental understanding of a material that mimics adaptive and self-healing structural materials in biological systems, without using biological materials or organisms. Such a system must be capable of using the loading of the material, and its associated response, as both its input control signal and as part of the energy required to control the evolution of the system. The response of the material will use a dynamic balance of deposition and dissolution, as found in biological systems, to evolve. The input energy to perform the adaptation and/or morphological changes may come from either a chemical reservoir or an electrical connection.

Research Concentration Areas: The development of an adaptive metallic system as envisioned requires several research steps. Experimental: A major enabling step is the synthesis and dynamics of self-assembling soft-matter scaffolds, which must simultaneously nucleate the metallic phase and provide channels for the motion of a fluid phase throughout the system. This scaffolding must also be capable of dynamically realigning in response to fluid flow, or to applied strain. The control of any autocatalytic metal deposition reaction could involve the specific adsorption of a protective layer that will prevent deposition. This layer must be strain-responsive autonomously to allow deposition of metal in areas of high repetitive strain. A mechanism for the slow dissolution of the metallic phase under the protective layer will enable reforming of the structure. These last topics involve an experimental understanding of chemical dynamics of stressed systems, including reconstruction of surfaces and interfaces and stress-corrosion. Computational: For any structural application, the mechanics of random and time dependent systems is an important topic. Related is the transport of fluid through porous and/or random media, which must be present to provide reagents throughout the structure in a controlled, reliable rate. The strategies for maintaining an overall balance of the competitive reactions is a topic for control theory.

Impact: Technologies for a material with an adaptive microstructure would be suitable for long-

term application in military vehicles where damage tolerance and survivability are preeminent, such as for military rotorcraft.

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FY09 MURI Topic #27

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Transformation Optics

Background: The ability to create metamaterials is advancing to the state that, for the first time, the index of refraction can be varied as a function of position, potentially *to any desired profile*. Such control creates the extraordinary possibility that the path of light in such a medium can be prescribed at will. Cloaking was one of the driving forces in this developing field. Fueled by the success of creating negative index materials (NIMs), startling applications are being discovered that could transform the field of optics. One example is solar light collection. Existing systems must track the sun, but it may be possible to design the index of refraction so that, no matter where the sun is, light will be "focused" to the same spot. This eliminates moving parts and reduces the size and weight of the collector. Similar ideas may be applied to sensors, allowing for concentrated energy on the detecting element. Lenses may be made in any shape, including flat, by designing the index of refraction as a function of position. Sub-wavelength imaging is in principle possible. Utilizing metamaterials, and operating near resonance, may also allow for tunable optical elements. An example is adjusting the focus of a lens without motion or changing shape. Cloaking, mentioned above, has been demonstrated at microwave frequency. These embryonic results, buttressed by theory and simulations, seem to indicate that the world of optics is about be transformed. Fundamental issues described below, requiring research from several disciplines, can be resolved with a concerted multi-disciplinary effort. The putative applications are myriad and powerful, and while the field of transformation optics is in its infancy, the manifestations and applications can already be seen which will create a revolution in the world of optics.

Objective: The objective is to develop the physics and mathematical techniques for solving the spatially and temporally varying wave equation, solving the inverse problem, understanding the quantum optics of transformation optics, and learning how to make the required graded index materials. This program will launch the field of "Transformation Optics."

Research Concentration Areas: For each application of a transformation optical element (TOE), the inverse solution, i.e., deriving the appropriate index function, must be found. Simulations must be developed to include such things as scale change in the "unit cell," which occurs, for example, in cylindrical designs. Although simulations are currently the primary approach, analytical solutions are desirable. When metamaterials, as opposed to photonic crystals, are used, the loss from operating near resonance must be overcome or minimized. In addition, fundamental limits, such as imposed by thermodynamics (as in cloaking a radiating object) must be found – whether for the entire class of TOEs, or for each individual application. Moreover, each of the areas mentioned above should be addressed as individual research concentration areas. Another category of research involves actually making the materials. The index of refraction profiles suggested by the simulations require substantial index changes over very short spans. Although the successful development of NIMs has demonstrated the feasibility of designed index, better and more controlled index variation must be developed. While NIMs created a new tool for metamaterials, transformation optics needs the entire workbench.

Impact: Transformation optics can revolutionize optical science. It will lead to the development of optical devices than cannot be made today, and control light in ways that are currently

impossible. The resultant technology will enable numerous advances including lightweight optical elements for military imaging and sensors, with improved resolution and sensitivity; robust non-moving imagers with variable focus; and communications. Additionally, the field will determine the viability of optical stealth technology.

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FY09 MURI Topic #28

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Emergent Phenomena at Complex Oxide Interfaces

Background: The recent observations of emergent phenomena at complex oxide interfaces strongly indicate that this material system will soon usher in a new era of technology beyond semiconductor electronics. Semiconductor technology is almost entirely based on a single degree of freedom (charge), manipulated by an electric field. Oxides, on the other hand, have multiple interactive degrees of freedom – lattice, charge, spin, and orbital – and often host strong electron correlations, resulting in remarkable quantum phenomena. While much effort has been put forth to mature multiferroics in complex oxides, a much broader family of phenomena emerge from strong correlations. The scope of these phenomena promises potentially limitless opportunities for novel functionalities. The ability to address technology-enabling phenomena converges on interfaces. Recent studies of oxide heterostructures have revealed phenomena at interfaces that are foreign to the bulk materials involved. These studies also suggest that the interface provides a mechanism to engineer the phenomena and externally control them. Examples of emergent phenomena observed at oxide interfaces include metal-insulator transitions, superconductivity, magnetically-ordered states, and the coexistence of ferromagnetism and superconductivity. Because the chemistry of oxide materials provides an immense set of possibilities, these examples represent merely a preview of what is to come. If these emergent phenomena can be tuned by materials engineering and further externally controlled, they will lead to disruptive technology both for military and civilian applications. To enable developments of this nature, a concerted effort to advance materials science, theory, and characterization will be required. Broadly categorized, required advances include developing (i) defect-free or defect-controlled interfaces; (ii) a theoretical understanding of interface-specific many-body phenomena, defects and defect clusters in complex oxides; and (iii) interface-specific characterization of transport, structure, chemistry and electronic structure.

Objective: The goal of this topic is to lay the groundwork necessary to engineer emergent phenomena at complex oxide interfaces, and develop the potential for external control of the phenomena in ways that can be exploited for novel military capabilities. Specifically, the topic seeks to (i) demonstrate correlated electron phenomena at oxide interfaces that are fundamentally distinct from bulk phenomena, (ii) determine the design rules for and demonstrate engineering of these phenomena, and (iii) determine how to control the phenomena with external fields.

Research Concentration Areas: Areas of interest include, but are not limited to, the following: (1) theory and modeling of quantum many-body phenomena at oxide interfaces; (2) oxide heteroepitaxy approaching single unit cell control and defect control; (3) interface-specific spectroscopic characterization; and (4) understanding, control and characterization of defects and their influence on emergent phenomena at the interfaces.

Impact: Understanding emergent phenomena at complex oxide interfaces will lay the foundation for disruptive military and civilian applications. Possibilities include advanced computation, sensing, and communications. Remotely interrogated passive sensors, electro-optic modulation at THz frequencies, ultra-sensitive detectors, ultra-low power electronics, and integration of disparate functionalities are foreseeable applications. These and other enabled technologies will bring needed capabilities to the US military in areas such as information-

centric warfare, situational awareness, and reduced power and energy requirements.

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FY09 MURI Topic #29

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Application of Systems Biology to Regenerative Medicine

Background: A systems biology approach toward medical research and development advocates a shift from the traditional single discipline-based, reductionist exploration of biological phenomena to an integrated view of biological system structure and dynamics. Whereas the reductionist approach has resulted in successful identification and understanding of individual biological processes, systems biology helps one to understand system properties. It involves a pluristic view of the causes and effects in biological systems through quantitative measures of multiple system components simultaneously through complex data integration using mathematical models. While tissue regeneration and restorative medicine offer great potential for improving the quality of life of many returning veterans, the complexities associated with this field of science will require establishment of new research paradigms and approaches that consider the host as a system rather than as the summation of individual organs and tissues.

Objective: The key objectives of this effort are to conduct basic research related to regenerative medicine using a systems biology approach. In particular this project should seek to understand the communicative and interactive links between host systems that can lead to novel insights into methods for large scale regeneration of tissue, organs, and limbs.

Research Concentration Areas: Areas of interest include, but are not limited to, the following: (1) Understanding dynamic processes in which behaviors of individual cells are orchestrated to assemble functional multicellular structures; (2) Development of mathematical models of stem cell interactions in culture that could lead to experimental approaches that improve outcomes of stem cell-derived organ and tissue cultures; (3) Examination of the interaction between and among molecular elements (genetic, epigenetic, mRNAs, and microRNAs) and the integration of these elements into biological networks that effect embryonic cell culture differentiation; (4) Understanding of interactions between multicomponent, biofunctional extracellular matrices and chemical and physical signal entities that control or influence stem cell proliferation, differentiation, motility and behaviors.

Impact: This objective is of critical importance because the large number of wounded military returning with devastating injuries and amputations that are never able to function fully in society as a result of these injuries. The ability to replace tissue, organs, or lost limbs would dramatically improve quality and length of life. A basic understanding of the fundamental regenerative processes is critical to realizing the potential of regenerative processes. Taking a systems biology approach that links mathematical modeling with experimental biology and considers the connection and interrelationships of multiple biological processes represents the logical extension of more traditional approaches in regenerative medicine.

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FY09 MURI Topic #30

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Mechanisms of Bacterial Spore Germination

Background: The intentional release of spores, as seen in the 2001 mail-mediated attacks, has shown *Bacillus anthracis* to be a potent and effective biowarfare agent. Bacterial spores make almost ideal bioweapons; they are metabolically dormant and resistant to heat, radiation, desiccation, pH extremes, and disinfectants. These resistances allow spores to be disseminated through a variety of methods, but most importantly via aerosols. A striking example of (unintentional) aerosol dissemination occurred from a biological weapons facility in Sverdlovsk, Russia in 1979 and resulted in over 68 pulmonary anthrax deaths in humans. Interestingly, some patients succumbed to the disease as much as 6 weeks after exposure. Some of the delay was almost certainly due to delayed spore germination. Delayed germination has been well documented in primates; in one study, dormant but viable spores were isolated from lymph nodes for at least 100 days post exposure. In another, fatal disease occurred up to 98 days after exposure. The delay in germination raises serious implications for treating potentially exposed personnel. Whereas antibiotic therapy is effective against actively growing vegetative cells (barring introduced resistances), it has no effect on spores. Therefore, the course of treatment must be lengthened due to the potential of late germinating spores.

Objective: The overall objective of this program is to determine what causes heterogeneity in germination of individual spores in a population. This objective will be approached by using a combination of wet bench experiments and iterative computer models. Whereas variability during the first hours of germination is of interest (~95% of the population), it is expected that research will focus on the remaining ~5% of spores that are further delayed in germination.

Research Concentration Areas: Areas of interest include, but are not limited to, the following: (1) Generation of experimental data to define the mechanism(s) of spore germination and to fill in data gaps for computer modeling. These could include: a) over- and under-expressing receptors and determining effects on germination heterogeneity; b) conducting proteomics on inner and outer spore membranes; c) developing electron microscopy preparation techniques to visualize receptors in spore membranes; d) conducting crystallography to determine receptor structure; e) determining the number of ligands required to bind in order to stimulate germination; f) determining if receptor complex formation is required to stimulate germination; and, g) determining the distribution of the number of receptors per spore in a spore population; and (2) Use of stochastic/mathematical analyses to develop models of spore germination.

Impact: Understanding the mechanism of spore germination heterogeneity will impact three major areas of military and civilian importance. All three depend on the fact that spores lose their resistance to a variety of stressors after germination. Decontamination of personnel and materiel is a daunting task when contaminated with spores. If germination of 100% of the spores could be induced, decontamination would be almost trivial in comparison. Likewise, antibiotic treatment of exposed personnel would be relatively straightforward if the threat of late germinating spores could be eliminated. Probably the greatest immediate impact would be on food processing. Currently high temperature and pressure are required to inactivate bacterial spores that contaminate foodstuffs. Gentler conditions could be used if the spores were induced to germinate, thus preventing loss of food quality and consistency.

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FY09 MURI Topic #31

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Opportunistic Sensing

Background: Research on autonomous sensing traditionally assumes a single sensor or a fixed number of dedicated sensors on single or multiple platforms. In the case of multiple sensor modalities, data are fused typically using a predetermined architecture. Major limitations of such conventional approaches include inadequate performance for target recognition in many important applications and inflexibility of stove-piped architectures. Opportunistic sensing refers to a paradigm for signal and information processing in which a sensing system can automatically discover and select sensor modalities and sensing platforms based on an operational scenario, determine the appropriate set of features and optimal means for data collection based on these features, obtain missing information by querying resources available, and use appropriate methods to fuse the data, resulting in an adaptive network that automatically finds scenario-dependent, objective-driven opportunities with optimized performance. The benefits of opportunistic sensing over conventional approaches include effective utilization of limited resources for multiple mission objectives, computational efficiency that only fuses necessary data, and flexible structure with robust performance adaptive to operational scenarios and environments. A principled theory of opportunistic sensing is needed for advancing autonomous sensing that not only ensures effective utilization of sensing assets but also provides robust optimal performance. The theory needs to account for a number of factors critical to future military operations such as the pervasive existence of large numbers of heterogeneous sensors (stationary, mobile, soldiers as sensors), explosive data growth, rapidly changing operating conditions, and ubiquitous computing resources connected through ad hoc wireless networking.

Objective: The objective is to develop theories and principles for opportunistic sensing that jointly addresses sensor control, sensor adaptation, and data fusion in the presence of a combination of stationary or non-stationary heterogeneous sensors in constrained environments. The proposed theories should lead to practical methodologies, algorithms and design tools with performance robust to uncertainty and adaptive to variations in dynamic operating conditions.

Research Concentration Areas: Areas of interest include, but are not limited to, the following: (1) investigation of physics-based target representation and feature extraction, particularly from electro-optical/infrared imagery and acoustic/seismic/magnetic signals, for effective target discrimination that are robust to noise, clutter, and environment. Complementarity of sensor modalities should be examined; (2) modeling and analysis of the dependency of sensor features on operational variables in sensor control, sensing platform dynamics and environment characterization to further understand effects of sensor control and adaptation; (3) development of methods for information content characterization of sensor data without full processing to enable rapid data triage; (4) investigation of innovative approaches to data and information exploitation that may include data fusion from sensor and non-sensor sources (i.e., context-relevant human intelligence or interactivity with soldiers), and data mining to capture historical contingencies in scenario-driven knowledge bases to guide sensing and fusion; (5) development of methods for sensor performance characterization, performance tradeoffs between resource utilization and information extraction, and predictive analysis. Research should evaluate the information capability of both isolated modalities and sensor suites; (6) development of theory and methods of opportunistic sensing that enable objective-driven performance improvements.

Impact: Research would advance capabilities of autonomous/aided sensing, and target recognition in persistent surveillance, sensor networks and unmanned systems. These capabilities are of particular importance to the development of Future Combat Systems and Network Centric Warfare. The military payoffs include improved situation awareness, increased lethality and survivability of advanced weapon systems, information integration for command and control, and the development of network science. Civilian applications include homeland security, facility protection, and environment monitoring.

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FY09 MURI Topic #32

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Cyber Situation Awareness

Background: The next war for the US Army to fight will likely take place both on traditional battleground and in cyber space. The adversary with sophisticated cyber offense capabilities will launch both stealth and overwhelming attacks against our information infrastructure (C4ISR). Complete situation awareness is crucial for winning the cyber battle. Cyber situation awareness (CSA) translates low level information abstracted from raw sensor data to human knowledge/intelligence for decision and action. It is a multi-level process with six aspects: 1) situation recognition (e.g., intrusion detection); 2) awareness of attack impact, e.g., damage assessment; 3) awareness on how situations evolve, a.k.a. trend (and intent) analysis; 4) awareness of the cause of the current situation, e.g., vulnerability/causality analysis; 5) awareness of response and actions, e.g., situation response; 6) estimation/prediction on the effects of a response plan. Unfortunately current theories and techniques are deficient in the following ways. First, most existing approaches only work at the low (sensor data) level. Higher level (comprehension, reasoning and determination) tasks are manually performed by analysts, which is labor-intensive, time-consuming, and error-prone. Second, there is a lack of understanding of human analysts' cognitive needs, leaving a big gap between human analysts' mental model and the lower level information model. Third, a lack of effective uncertainty management leads to distorted situation-awareness. Fourth, the six aspects of cyber situation awareness have been treated as separate problems, while a full cyber situation awareness solution requires a complete integration of the six aspects in order to support coherent functions of learning, reasoning, planning, and decision. And last, there is an urgent need of assurance quantification and benchmarking metrics to be used for system design, development, evaluation and verification.

Objective: This topic calls for the development of situation awareness theories and frameworks that support effective defense against cyber attacks. New algorithms and systems are needed to assist the automation of human analysts' cognitive situation awareness processes so that attacks can be identified and responded to in a timely and effective manner.

Research Concentration Areas: Areas of interest include, but are not limited to, the following: 1) Situation (knowledge and semantics) representation and modeling that support multi-level abstraction and transformation of data to intelligence; 2) Information fusion that can effectively combine raw and abstracted intelligence of different confident levels to support optimal response; 3) Uncertainty management and risk mitigation through probabilistic hypotheses/reasoning and sensitivity control, and using multi-level statistical analysis to manage incomplete and imperfect situation information; 4) Leveraging cognitive science understandings to automate human analysts' cognitive situation-awareness processes (to recognize and learn about evolving situations, to create automated hypothesis generation, and to reason in both pre-attack planning and post-attack response); 5) A new framework which unifies perception, comprehension, and projection functions, and integrates situation recognition, impact assessment, trend analysis, causality analysis, and situation response together; 6) Advanced mathematic models for quantitative analysis and assessment of system assurance; 7) Rapid damage assessment, repair, recovery and regeneration of critical services and functions.

Impact: Complete situation awareness leads to effective defense against cyber attacks,

especially those launched by adversaries with state sponsorship. The abilities to extract critical information, to build intelligence, and to make effective and timely decisions lead to a stronger capability in attack prevention, detection and response, and in sustaining critical functions and services. A deep understanding of assurance through modeling and analysis will advance the state of the art in building and operating resilient information systems.

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