BROAD AGENCY ANNOUNCEMENT

(BAA) INTRODUCTION:

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

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. 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").

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 2007 Department of Defense Multidisciplinary Research Program of the University Research Initiative

4. Research Opportunity Number

BAA 06-028

5. Response Date

White Papers: Thursday, 17 August 2006

Full Proposals: Monday, 13 November 2006

6. Research Opportunity Description

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 Fiscal Year (FY) 2007 MURI competition is for the 29 topics listed below. Detailed descriptions of the topics can be found in Section VIII 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 (11) should be submitted to the Office of Naval Research (ONR):

(1) Exploiting Nonlinear Dynamics for Novel Devices
(2) Towards Trust Management in Service Oriented Architectures
(3) Disparate Sensor Network Based Situation Understanding
(4) Underwater Acoustic Communications
(5) Radiation Belt Dynamics and Energetics
(6) Thermal Management for Advanced Electrical Systems
(7) Light Cellular Structures for Force Protection
(8) Human-Robot Interaction in Littoral and Urban Military Domains: Human-Unmanned Systems Interaction
(9) Exploiting the Documented Plasticity of the Adult Brain to Create Superior Warfighters in Fast-Paced Close Quarters Combat
(10) Reactive Material Dynamic Response & Energy Release for MOUT Applications
(11) Processing and Production Science for Next Generation Fuel Cells

White papers and full proposals addressing the following topics (12) through (19) should be submitted to the Air Force Office of Scientific Research (AFOSR):

(12) Science-Based Design of Fuel –Flexible Chemical Propulsion/Energy Conversion Systems
(13) Enterprise Health: Self-Regenerative Incorruptible Enterprise
(14) Atmospheric Neutral Density Prediction
(15) Building Bridges between Neuroscience, Cognition, and Human Decision Making
(16) Behavior of Systems with Humans and Unmanned Vehicles
(17) Biologically-Inspired Flight for Micro Air Vehicles (MAVs)
(18) Quantum Simulations of Condensed Matter Systems using Ultra-Cold Atomic Gases
(19) Bioinspired Supramolecular Enzymes

White papers and full proposals addressing the following topics (20) through (29) should be submitted to the Army Research Office (ARO):

(20) Biologically Synthesized Quantum Electronic Systems
(21) Attosecond Subwavelength Optical Pulses
(22) Designing and Prescribing an Efficient Natural-like Language for Bots
(23) Ionic Liquid Containing Polymeric Materials
(24) Self-healing Polymer Composites through Mechanochemical Transduction
(25) Engineering of Phase Transforming EMO Materials
(26) Robust and Resilient Tactical MANETs
(27) Urban Sensor Network Structure For Data Fusion
(28) Dynamic Modeling Of 3D Urban Terrain
(29) Wide-band Gap Semiconductor Based Sensing for Detection and Response to WMD Threats

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

A Research Topic Chief is identified for each specific MURI Topic. Questions of a technical nature shall be directed to the Research Topic Chief identified in Section VIII of this BAA. Questions of a policy nature shall be directed to ONR as specified below:

<u>ONR MURI Program Point of Contact:</u>
Dr. Bill Lukens MURI Program Manager
Office of Naval Research, Code 03R
875 North Randolph Street - Suite 1425
Arlington, VA 22203-1995
Telephone Number: (703) 696-4111

Facsimile Number: (703) 588-1013
E-mail Address: 363 MURI@onr.navy.mil

Questions of a business nature shall be directed to ONR's Contract and Grant Awards Division, as specified below:

ONR Business Point of Contact:
Ms. Kristin Fuller, Contract Specialist
Contract and Grant Awards Division
Office of Naval Research, Code 0251
875 North Randolph Street - Suite 1425
Arlington, VA 22203-1995
Telephone Number: (703) 696-4591
Facsimile Number: (703) 696-0066
E-mail Address: fullerk@onr.navy.mil

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

The previous MURI competition comprised ONR BAA #05-017 dated 21 June 2005 for the FY06 Multidisciplinary University Research Initiative Program.

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 base period of three

years, to be funded incrementally or as options. Two additional years of funding as an option are possible, to bring the total maximum term of the award to five years.

Total amount of funding for five years available for grants resulting from this FY06 MURI BAA is estimated to be about $130M, pending out-year appropriations. It is anticipated that the maximum award will be $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 Offerors 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.

The Canadian government, through Defense Research and Development Canada, has expressed an interest in encouraging collaboration between Canadian researchers and U.S. researchers on the MURI program in research areas of mutual interest. Canadian university researchers, since they are not eligible to receive MURI funds, will be using their own resources that, most likely, will be provided by Canadian government granting agencies. Potential Offerors are encouraged to take advantage of this opportunity to collaborate and team with Canadian researchers at no additional cost to DoD if there is suitable expertise that can enhance and strengthen the MURI project.

*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.

IV. APPLICATION AND SUBMISSION INFORMATION

1. Application and Submission Process

The proposal submission process is in two stages. Prospective Offerors are encouraged to submit white papers. The reason for requesting white papers is 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 to the proposer to encourage or discourage them to submit full proposals. White papers arriving after the deadline may not receive, and therefore may not benefit from, the informal feedback. However, all full proposals submitted under the terms and conditions cited in the BAA will be reviewed regardless of the feedback on, or lack of, a white paper.

Where to Submit: Proposals and white papers may be submitted to ARO, ONR, or AFOSR through Grants.gov or they may be submitted to those agencies by hard copy.

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.

VERY IMPORTANT – Download PureEdge Viewer: In order to download the application package, you will need to install PureEdge Viewer. This small, free program will allow you to access, complete, and submit applications electronically and securely. For a free version of the software, visit the following web site: www.grants.gov/DownloadViewer.

The due date for white papers is no later than 4:00 PM (Eastern Daylight Time) on 17 August 2006. Offerors will receive feedback on white papers on or about 11 September 2006. The due date for full proposals is no later than 4:00 PM (Eastern Standard Time) on 13 November 2006. Notification of recommendation for award will be announced on or about 09 February 2007.

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. Offerors are expected to appropriately mark each page of their submission that contains proprietary information. Grants awarded under this announcement will be unclassified.

Grants.gov White Paper Submission: Contents 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 four of this announcement) and the funding opportunity number (BAA 06-XXX), 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. Follow the prompts to download the application package. NOTE: You will not be able to download the Application Package unless you have installed PureEdge Viewer (See: http://www.grants.gov/DownloadViewer).

SF424 (R&R) – 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). Mark Field #1 as "pre-application" and attach the white paper file at Field #20. 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 offerors 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.

Hard Copy White Paper Submission: Content and Format of Applications

If submitting by hard copy instead of electronically through Grants.gov, please complete the Grants.gov form as described, print it out, and mail to the attention of the responsible Research Topic Chief at the agency specified for the topic using the address

provided in Section IV.5. Hard copy submission of 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 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 four of this announcement) and the funding opportunity number (BAA 06-XXX), 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. NOTE: You will not be able to download the Application Package unless you have installed PureEdge Viewer (See: http://www.grants.gov/DownloadViewer).

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."

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 (20) 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, Offerors 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 3 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)

If you need to elaborate on your responses to questions 1-5 on the "Other Project Information" document, **provide the information in field 7 as part of your project narrative. Do not attach a file in field 11.**

FORM: Research & Related Budget
Complete the Research and Related Budget form in accordance with the instructions on the form (activate Help Mode to see instructions) and the following instructions. 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. Options must be separately priced. The form will generate a cumulative budget for the total project period. You must complete all the mandatory information on the form before the NEXT PERIOD button is activated. You may request funds under any of the categories listed as long as the item and amount are necessary to perform the proposed work and meet all the criteria for allowability under the applicable Federal cost principles. 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 May 2007. For the three-year base grant, the cost should be broken down to reflect funding increment periods of:

(1) Five months (01 May 07 to 30 Sep 07),
(2) Twelve months (01 Oct 07 to 30 Sep 08),
(3) Twelve months (01 Oct 08 to 30 Sep 09), and
(4) Seven months (01 Oct 09 to 30 Apr 10).

Note that the budget for each of the calendar periods (e.g. 01 May 07 to 30 Sep 07) 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) Five months (01 May 10 to 30 Sep 10),
(2) Twelve months (01 Oct 10 to 30 Sep 11), and
(3) Seven months (01 Oct 11 to 30 Apr 12).

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, COM, etc. (must show base amount and rate). Justify in Field K.

- Travel - Number of trips, destination, duration, etc. Justify in Field K.

- Subcontract - A cost proposal as detailed as the offerors cost proposal will be required to be submitted by the subcontractor. Include in Research & Related Subaward Budget Attachment Form.

- 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 in Field K.

- 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 offerors procurement method to be used (competition, engineering estimate, market survey, etc.). Justify in Field K.

- 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 offerors procurement method to be used (competition, engineering estimate, market survey, etc.). Justify in Field K.

Budget Justification (Field K on the form)
Provide the required supporting information for the cost elements as shown above (see Research & Related Budget instructions) and listed as follows: indirect cost, travel, consultant, materials, and other direct costs. Provide any other information you wish to submit to justify your budget request. The Research and Related Budget Form only includes five performance periods and the MURI BAA requires reporting of seven budget periods. Attach the budget information for the last two MURI budget periods, 01 October 2010 to 30 September 2011, and 01 October 2011 to 30 April 2012, in Field K in the same format as that provided for the first five budget periods. 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 in Field K.

FORM: R&R Subaward Budget Attachment(s) Form
Budgets for Subawardees. You must provide a separate cumulative and multi-year R&R budget for each subawardee. Download the R&R Budget Attachment from the R&R SUBAWARD BUDGET ATTACHMENT(S) FORM and e-mail it to each subawardee that is required to submit a separate budget. A cost proposal as detailed as the offerors cost proposal will be required to be submitted by the subcontractor. Note: Subwardees must have installed PureEdge Viewer before they can complete the form. After the Subawardee has e-mailed its completed budget back to you, attach it to one of the fields provided on the R&R SUBAWARD BUDGET ATTACHMENT(S) FORM. Use up to 10 letters of the subawardee's name as the file name (e.g., ucla.xfd or stanford.xfd).

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."

Hard Copy Proposal Submission: Content and Format of Applications

If submitting by hard copy, please complete the Grants.gov forms as described, print them out, and mail to the addresses in Section IV.5. 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	17 August 2006	4:00 PM Eastern Daylight
Notification of Initial DoD Evaluations of White Papers	11 September 2006*	
Full Proposals Due	13 November 2006	4:00 PM Eastern Standard Time
Notification of Selection for Award	9 February 2007*	
Start Date of Grant	01 May 2007*	

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

Proposal Receipt Notices
After a 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. For white papers the e-mail is sent to the Principal Investigator and for proposals the e-mail is sent to the authorized representative for the institution. The e-mail for white papers notes that the white paper has been received and 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.

4. Submission of Late Proposals

Any 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.3, 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 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 applied 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. Offerors 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, Offerors are urged to schedule delivery to occur several days before the deadline.

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

If submitting hard copies instead of electronically through Grants.gov, send to the addresses below:

Hard copies of white papers and full proposals addressing topics (1) to (11) should be sent to the Office of Naval Research at the following address:

Office of Naval Research
For full proposals include: ATTN: ONR Code 03R/MURI
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

Hard copies of white papers and full proposals addressing topics (12) to (19) 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 07)
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 copies of white papers and full proposals addressing topics (20) to (29) should be

sent to the Army Research Office at one of the following addresses:

For delivery by ordinary First Class or Priority Mail (but not Express Mail) through the U.S. Postal Service:

U.S. Army Research Office (FY07 MURI)
P. O. Box 12211 Research Triangle
Park, NC 27709-2211

For other means of delivery (such as Express Mail, FedEx, UPS, etc.):

U.S. Army Research Office (FY07 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 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 of lesser importance than 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 employed by the government.

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 employed by the
government. Evaluation panel members are required to sign "no conflict of interest" and non-disclosure agreements (NDA) to protect proprietary and source-selection information.

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 Offerors 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 - Proposals should be accompanied by a completed certification package which can be accessed on the ONR Home Page at Contracts & Grants. The certification package for Grants is entitled, "Certifications for Grants and Agreements."

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 they need 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 offerors 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. Offerors 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 offerors 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

FY07 MURI Topic #1
Submit white papers and proposals to the Office of Naval Research

Exploiting Nonlinear Dynamics for Novel Devices

Background: Not that long ago, nonlinear equations were discovered to possess a variety of mathematically rich solutions connected to the concept of chaos and other instabilities. Once nonlinear dynamical behaviors were mathematically understood, new ideas arose on how to exploit nonlinear dynamical systems. This led to a search for these complex behaviors in real physical systems. It soon became evident that numerous devices could be driven into responses that were chaotic or exhibited other types of complex behaviors. As an example, control of chaos was achieved and applied to operating lasers at higher power levels. Nonlinear resonance was investigated for detectors optimized to noisy environments. Widely separated chaotic electrical systems were synchronized and employed in a secure communication system. Nonlinear dynamical behavior has been found in single neurons and in neural ensembles. These biological systems work on a threshold principle, possess excitatory and inhibitory responses, and operate with massively parallel connections that underlie biological computation. Nonlinear science and mathematics have only recently begun to start to match up to this neural sophistication. The time is ripe for an investigation of devices based on nonlinear dynamics.

Objective: Design devices to exploit dynamical phenomena including chaos, bifurcations, spatiotemporal patterns, synchronizations, resonances, and instabilities that can arise in nonlinear systems. The devices should be portable, by a person or an unmanned vehicle, and have low power consumption. The focus will be on detection, classification, and control systems for use in urban combat environments. Computational architectures including dynamical logic gates could be explored for their utility in pattern recognition and decision-making. Lessons can be learned from aspects of neural ensembles governing sensory, motor and cognitive systems. Applications of highly nonlinear devices might include acoustic, magnetic and electric field detectors; autonomous controllers for low flying UAVs and other unmanned vehicles in urban areas.

Research Concentration Areas: This MURI is multidisciplinary needing physicists and mathematicians to understand the wide range of behaviors of coupled nonlinear oscillator arrays; computer scientists for novel dynamic-based computer logic gate architectures; neurobiologists and electrical engineers to reverse engineer neural systems into practical devices operating near instabilities for enhanced sensitivity.

Impact: Sensitive dynamical detectors could locate and classify weapons in an urban environment applied to perimeter defense, stairwell alarms for rooftop deployment, and crowd weapons searches. Decision-making novel nonlinear dynamical chips and circuits could be applied to land-based robots on the battlefield, and for UAVs to operate at street level in urban warfare scenarios. Chaotic transmitters placed on UAVs, could search for IED signatures.

Research Topic Chief: Dr. Michael F. Shlesinger, ONR, 703-696-4220, shlesim@onr.navy.mil

FY07 MURI Topic #2
Submit white papers and proposals to the Office of Naval Research

Towards Trust Management in Service Oriented Architectures

Background: The security of software has largely been a secondary concern in the software community compared to functionality and performance. This is beginning to change with the cost of insecurity climbing to the point where it threatens commerce and military readiness. The news is replete with stories of online identity theft, hard drives wiped out, and networks taken down. Industry has responded by adding layers of defensive software and issuing patches upon patches as flaws are discovered. This cycle is not a desirable sustainable path towards achieving trustworthy systems. Yet, industry is also moving toward service-oriented architectures (SOA), a highly dynamic, highly adaptable, heterogeneous information infrastructure. SOA offer significant advantages in robustness, flexibility, and functionality; however, those advantages greatly complicate already complex trust management. New approaches to trust management in SOA are necessary. Trust must become a formal property, mathematically explicit, computationally tractable, and managed in an SOA. Trust must address policy and compliance within, or among, different SOA.

Objective: Develop mathematical principles for ensuring trust with sufficient fidelity for trust management in SOA. These principles must also address issues of identity, provenance, and access while balancing concerns of privacy, confidentiality, transparency, resiliency, and tractability in SOA environments. Trust must be a principal system property that is continually managed in concert with other supporting components such as firmware, operating systems, compilers, applications, computer systems, protocols, and of course code.

Research Concentration Areas: Areas of interest include, but are not limited to, the following very broad areas: (1) models of trust in a SOA involving cross-disciplinary aspects of policy, economics, e-communities, security levels, and assurance; (2) mathematical foundations and semantics for trust in SOA that enable reasoning about trust; (3) epistemological reasoning in the presence of inconsistent, partial, uncertain, and dynamic information about trust for trust maintenance; (4) analysis of software/hardware components, interfaces, low-level code, protocols, and software tools relative to trust; (5) algorithms, languages and compiler technologies that support reasoning about and maintaining trust attributes; (6) architectures that enable ascertaining trust in discovery services and interoperations; (7) practical measures and metrics of trust and risk for negotiations in SOA; and (8) covert channel analysis of trust maintenance systems.

Impact: The Department of Defense (DoD) is moving towards a service-oriented architecture for its information infrastructure, known as the Global Information Grid (GIG), where trust and security are primary concerns; however, the basis and means to ensure those properties are not yet resolved. This research will be an important advance toward providing the supporting theory as a foundation for building more secure information systems.

Research Topic Chief: Dr. R.F. Wachter, ONR, 703-696-4304, wachter@onr.navy.mil
Ms Judith Froscher, NRL, 202-767-3381, froscher@itd.nrl.navy.mil

FY07 MURI Topic #3
Submit white papers and proposals to the Office of Naval Research

Disparate Sensor Network Based Situation Understanding

Background: In a variety of DoD operations, there is a need to exploit and integrate information from multiple sensors across a variety of modalities, media types including video imagery (static and dynamic), audio (speech), acoustic stimuli, radar, IR, LADAR, SAR, text, as well as signals from novel chemical and biological sensors. Much of the information available today is network based, such as that arising from the disparate sensor networks mentioned above. The purpose of this MURI is to develop mathematical approaches and tools for extracting, representing, integrating, and ultimately understanding information.

Humans display a remarkable capability to perform situation understanding despite noisy sensory signals and conflicting inputs. Humans are adept at network visualization, and at understanding subtle implications among the network connections. To date, however, human's innate ability to process and integrate information from disparate, network-based sources for situational understanding has not translated well to automated systems.

Objective: This MURI program seeks to develop novel mathematical methods and algorithms for disparate information exploitation, processing, and integration, particularly the creation of mathematical frameworks that are based upon how humans and other biological systems process information.

Research focus areas: Areas of interest include (a) Mathematical frameworks for higher-level information and knowledge representation; (b) Methods for indexing information derived from perceptive events as done by biological systems; (c) Multi-sensory cue triggered knowledge-base searching as performed by biological systems for real-time information retrieval; (d) Methods for associating, integrating and understanding/inferencing discovered knowledge from disparate sources; (e) Methods for situation understanding and inferring intentions for threat assessment from the retrieved knowledge that consists of behavioral patterns, new activities, and anticipated behavior; (f) Probabilistic and statistical methods for dealing with uncertainty for network-based information. To achieve the objectives of this topic, basic research in several disciplines is needed, such as biological systems, computational neuroscience, mathematics, computer science, machine learning, graph theory, statistics, and others.

Impact: The overall impact of this program is automated situation understanding in complex and dynamically changing, information-rich environments using disparate network-based information sources with the performance levels similar to humans that enables successful and safe completion of security/surveillance missions in GWOT.

Research topic chief: Dr. Shubha Kadambe, ONR, (703) 588-2439, kadambs@onr.navy.mil; Dr. Wendy Martinez, ONR, (703) 696-4320, martinwe@onr.navy.mil

FY07 MURI Topic #4
Submit white papers and proposals to the Office of Naval Research

Underwater Acoustic Communications

Background: In 1948, Shannon showed that it was theoretically possible to drive transmission errors to arbitrarily low levels in any channel if the proper encoding was selected (The Bell System Technical Journal, Vol. 27, pp. 379–423, 623–656, July, October, 1948). Can Shannon's Theorem 11 [*Let a discrete channel have the capacity C and a discrete source, the entropy per second H. If $H \leq C$, there exists a coding system such that the output of the source can be transmitted over the channel with an arbitrarily small frequency of errors (or an arbitrarily small equivocation)*] be applied to horizontal underwater acoustic communications (acomms) channels?

The above question captures two broad areas in acomms that are in need of basic research: 1) Channel Capacity 2) Coding Systems; however, successful research in acomms relies on knowledge and experience in a variety of fields. To fully comprehend all the complexities, a melding of elements in physics (acoustics), oceanography (environment), communications (digital signal processing), and materials science (transducer design) is required. The researchers in the field have varying degrees of breadth and depth in these sub-disciplines, so they generally rely on collaboration to improve their probability of success.

The channel capacity (or estimation) problem is the most vexing. Signals transmitted over underwater channels are spread (or extended) in time and bandwidth. The extent of this spreading in time and frequency can be captured in the *scattering function*, but the scattering function itself can vary both spatially and temporally, and in worst case scenarios, the latency of the channel is in excess of its temporal coherence.

Objective: 1) Bridge the gap between the ocean modeling community and the signal processing community in order to spur development of modeling tools suitable for the frequencies and bandwidths of acomms signals. 2) See receiver architecture improvements grow out of more insight into the physical ocean channel as characterized by the potentially time-varying, scattering function. 3) Use the scattering function as a framework for environmentally adaptive coding systems that estimate the scattering function and adjust accordingly. 4) Build a suite of benchmark channels of utility to all members of the underwater acoustic communications community, generated initially from accurate data sets and eventually from suitable models. Returning to Shannon, the goal of this MURI is to enhance our skill in determining C, maximizing H, and minimizing the frequency of errors in a wide variety of ocean environments.

Research Concentration Areas: Areas of interest include, but are not limited to: 1) Underwater channel physics, channel simulations, and measurements: Acoustic propagation models tailored to communications applications are needed. Channel characterization that captures the time variability of the channel scattering function is a necessary component of these models. 2) Diversity exploitation: Further exploitation of temporal, frequency, spatial, and bearing diversity is needed. 3) Alternative modulation strategies: Modulation techniques that either improve the capacity of a communications link or net and/or make demodulation performance easy or relatively insensitive to channel estimation errors are needed.

Impact: The frequency-shift-keyed (FSK) modulation schemes that are currently employed in applied acoustic communications are fairly robust to the time and frequency spreading of the channel, but their inefficient use of bandwidth coupled with the limited availability of bandwidth underwater makes them ill-suited for high-data-rate applications. Acomms experiments using coherent schemes (phase-shift-keyed or PSK) have demonstrated the

potential to increase data
rates by some two orders of magnitude, but thus far have been proven difficult to employ in practical applications. Understanding and closing the gaps between theoretical, developmental, and implemented acoustic communications systems will help meet the requirements of the off-board and distributed sensing strategies envisioned for the future of undersea warfare.

Research Topic Chief: Dr. Robert Headrick, ONR, 703-696-4135, headrir@onr.navy.mil

FY07 MURI Topic #5
Submit white papers and proposals to the Office of Naval Research

Radiation Belt Dynamics and Energetics

Background: The earth's radiation belts are regions of trapped energetic particles within the magnetospheric cavity. The belts contain energetic electrons, protons, and ion species found in the solar wind and in the ionosphere. The charged particles are confined by the convergence of the earth's magnetic field above the poles. Energies of the particles extend from less than one keV to hundreds of MeV. Particles within the radiation belts are thought to have both solar and ionospheric sources. In the past, detonations of nuclear devices at high altitudes have also contributed high-energy particles to the radiation belts with densities 2 orders of magnitude above natural levels. Within the belts, particles gyrate around magnetic field lines and 'bounce' between mirror points above the poles. At radiation belt altitudes the primary loss mechanism is interaction between trapped particles and low frequency electromagnetic waves (primarily Alfven and whistler waves) which alter the pitch angle of the gyrating particles. Particles that have their pitch angles scattered into the loss cone will mirror lower in the atmosphere and be removed by collisions with the neutral atmosphere.

Effects of radiation on space systems include spacecraft charging, detector malfunctions, and alteration of memory and processors. Biological systems are also at risk. Even quiet-time levels of radiation in some regions of the radiation belts would be lethal to an unprotected astronaut. To decrease the likelihood of damage, satellites are placed in orbits that avoid spending prolonged periods within the belts. However, the hazard is increased significantly at times of high solar, interplanetary wind-stream, or geomagnetic activity. Coronal mass ejections (CMEs) can dramatically increase the flux of trapped radiation and temporarily create new radiation belts in regions where they do not normally occur. High-altitude nuclear tests of 1958 and 1962 showed the significant impact of dramatically increased radiation levels on satellite systems. New physical models and technologies to specify, forecast and mitigate the hazards of the radiation belts would improve space system survivability and ensure the continuation of space-based services.

Objective: This MURI seeks proposals that will: 1. Improve the current understanding of radiation belt dynamics, particular fluxes, filling rates, and loss rates of the radiation. 2. Develop models that will increase our understanding of radiation belt phenomena and predict particle energy distributions. 3. Investigate new and innovative methods of altering pitch angles to explore the mechanisms responsible for the loss of energetic particles.

Research Concentration Areas: Studies will address both experimental and theoretical approaches to the understanding of radiation belt dynamics. Research concentration areas will include, but not be limited to: 1. Radiation belt dynamics, including fluxes, sources and sinks of radiation belt particles; 2. Novel or innovative techniques to measure radiation belt parameters; 3. Wave-particle interactions; 4. ELF-VLF generation, propagation, and amplification from the ground or in space; 5. Innovative methods of artificially modifying pitch angles to explore the mechanisms responsible for the loss of high-energy particles, for example, methods based on electrostatic and magnetostatic interactions.

Impact: DoD interest in the physics of the radiation belts is motivated by the desire to protect space assets from high-energy radiation. With sufficient warning of increases in the density of high-energy particles in the radiation belts, satellites could be put into safer modes to decrease damage. Ultimately, active methods could protect sensitive systems from damaging radiation on demand.

Research Topic Chief: Dr. Robert P. McCoy, ONR, 703-696-8699, mccoyr@onr.navy.mil; Maj. David Byers, AFOSR, 703 696 8411 david.byers@afosr.af.mil

FY07 MURI Topic #6
Submit white papers and proposals to the Office of Naval Research

Thermal Management for Advanced Electrical Systems

Background: The rapidly increasing use of electronics in military hardware is resulting in unprecedented thermal management needs. The cooling requirements of modern weapon, sensor, and signal processing systems significantly affect the design and operation of current ships and aircraft. It is projected that volumetric heat dissipation rates in power electronics will continue to increase by about 15% per year. Future all-electric warships and combat vehicles are envisioned to have high power electrical systems for propulsion, pulsed power weapons, and sensor arrays. A common challenge is the rejection of > 1 kW/cm^2 heat fluxes over large areas (square meters). Power requirements for electric propulsion, phased-array radar, airborne active denial, directed-energy weapons, and self-protection systems are expected to reach tens of megawatts. Isothermal conditions required for optimal operation of large solid-state laser and radar arrays produce additional challenges. Innovative thermal management systems are needed to acquire, transport and reject several megawatts of waste heat, greatly exceeding current state-of-the-art thermal technologies. Advanced phase change cooling technologies such as micro channel evaporators and spray cooling have demonstrated the potential of spot cooling in excess of 2 kW/cm^2 over small areas. However, significant challenges need to be addressed to scale such technologies into large, reliable, and affordable systems.

Objective: To develop thermal management technologies capable of rejecting large quantities of waste heat through fundamental studies of multi-phase heat transfer, fluid dynamics, and nanostructured materials. A system-level approach, incorporating elements to acquire heat at fluxes up to 1 kW/cm^2 and to transport and reject total heat loads in excess of 1 MW, should be emphasized. The system should be able to maintain isothermal operation at temperatures near 50 °C, while ultimately rejecting heat at ambient conditions. Other issues to consider are power consumption, size, weight, cost, and reliability.

Research Concentration Areas: A multidisciplinary research effort involving mechanical engineers, physicists, materials scientists, and chemical engineers is needed to address the following areas of interest: (1) evaporative cooling of high heat fluxes, (2) two-phase transport in large systems, (3) high thermal conductivity composites, (4) high-efficiency, compact heat exchangers, (5) methods of enhancing heat transfer in evaporators/condensers, (6) development and understanding of novel thermal fluids, (7) thermal storage techniques for load balancing and energy conservation, (8) system level modeling methodologies for large, coupled electrical-thermal systems including transient effects, reliability, and control.

Impact: Innovative and scalable thermal management technologies are required for the development of future high power electronic propulsion, sensor, and weapon systems for a variety of Defense systems. Improved thermal management will result in significant savings in energy consumption, as well as in increased thermal performance and reliability of electronic components. Such technologies would immediately impact phased-array radar and high energy laser systems being developed by the Navy and Air Force and hybrid electrical combat vehicle systems being developed by the Army.

Research Topic Chief: Dr. Mark S. Spector, ONR, 703-696-4449, spectom@onr.navy.mil

FY07 MURI Topic #7
Submit white papers and proposals to the Office of Naval Research

Light Cellular Structures for Force Protection

Background: The rise in global terror has led to the use of improvised explosive weapons (IEDs) that do not require physical contact, but can be activated by remote control. IEDs generate explosions that have injured, incapacitated, or killed many U.S. and coalition personnel. Personnel are injured or killed in an explosion from the primary air shock waves, penetration of fragments either directly released during the explosion or accelerated by interactions with the blast wave front, burning due to high temperature gases created during detonation, differential momentum transfer to appendages resulting in traumatic amputation, acceleration into rigid objects, or by the collapse of structural vehicle or platform components. As part of it's existing D&I program, ONR has conducted pioneering research in Cellular Materials. Current efforts have focused on advantages of cellular materials for blast resistance and have shown very promising results of these light-weight structures over solid monolithic structures. There is a need to extend the research to include blast and fragment/kinetic energy penetrator threats.

Objective: Maximize the blast resistance of cellular materials to preserve and protect the warfighter and military assets from both blast and kinetic energy threats. Develop mechanical behavior models, failure maps, etc, relating cellular material topologies to structural performance for Naval and Marine Corps force protection applications. Develop design tools, novel joining methods for cellular materials and cost-effective fabrication technologies. Structures of interest are light (~50% of those fabricated from monolithic materials) complex in geometry, cellular in nature and may consist of metallic, non-metallic, and composite cellular materials.

Research Concentration Areas: Areas of interest include, but are not limited to the following:

1) Fabrication methods for metallic or organic composite ultra-light cellular structures,
2) Blast-related failure mechanisms of periodic cellular structures,
3) Failure/ optimization maps of ultra-light structures,
4) Innovative designs for deployment of ultra-light cellular structures for force protection,
5) Mechanical behavior of cellular structures under static and high rate loading,
6) Environmental degradation mechanisms of cellular structures

The ultimate goal is development of topologies, design tools, and fabrication methodologies for ultra-light structures which can be deployed and integrated into a variety of force protection structures for Naval and Marine platforms.

Impact: Light deployable structures will enable sufficient protection for a variety of Navy and Marine Corps assets needed to protect our warfighters from IED blast effects.

Research Topic Chief: Dr. David Shifler, ONR, 703-696-0285, shifled@onr.navy.mil.

FY07 MURI Topic #8
Submit white papers and proposals to the Office of Naval Research

Human-Robot Interaction in Littoral and Urban Military Domains: Human-Unmanned Systems Interaction

Background: The Navy and Marine Corps are currently investing in a variety of naval unmanned systems to be operated from small naval host platforms or by small Marine Corps units. Examples of this include the Littoral Combat Ship, Maritime Patrol Aircraft, submarines, and unmanned systems designed for Marine Corps units at the battalion level and below. In many of these cases, there will be significant limitations on the manning available for these systems in terms of both numbers and skill types. Increasing the level of automation can have a significant impact on reducing manning requirements. However, despite many advances in autonomous control technologies, mission management often still requires a human's cognitive skills, judgment, decision-making, and tactical understanding. Further, future unmanned systems missions may require frequent user interactions with the autonomous agents to coordinate autonomous planning and execution with those of manned platforms or units in a dynamic battle space. This is particularly relevant to the rapidly changing environment of the global war on terrorism with the challenges of littoral and urban operations, the threat of chemical and biological weapons, the difficulty in differentiating enemies from neutral civilians, and the need for better force protection. In this environment, it will be critical to enable meaningful collaboration between unmanned systems and warfighters in order to take advantage of human cognitive strengths and minimize the impact of both human and autonomous system weaknesses. Humans and robots must be able to: (1) communicate clearly about their goals, abilities, plans, and achievements; (2) collaborate to solve problems, especially when situations exceed autonomous capabilities; and (3) interact via multiple modalities both locally and remotely. To achieve these goals, a number of unaddressed Human-Robot Interaction (HRI) challenges must be addressed. For effective HRI is essential that the robots have good models of the humans they are interacting with. We must have effective mechanisms for HRI and communication. Roles and responsibilities must be assigned according to the capabilities of both the human and the robot. It must be easy for the human to affect control, to assess the situation, and to assist the robot. Dialogue is particularly important because it allows the operator to review what has happened, to understand problems each robot has encountered, and to be notified when assistance is needed. For more complex missions, users will need to be supported by interfaces that integrate significant amounts of data at different levels of abstraction and guide their attention to the information that best supports the current tactical situation. At the same time, the interfaces must provide access to information in a manner that supports skilled users in managing complex, unanticipated situations. Humans and robots must coordinate their actions to function as a team, to increase task efficiency and performance.

Objective: To develop the principles and methodologies for humans and robots (autonomous systems in general) to collaborate naturally and effectively as peers. The emerging field of HRI is multidisciplinary by its very nature, including work in robotics, cognitive science, computer science, human factors and HRI. Researchers in these fields are just beginning to collaborate to address the following issues: how can robots model the human; how do we move HRI towards a human needs perspective rather than being technology driven; how can a robot's model of human cognition support both mixed initiative control as well as interactions with encountered humans; how do we create interfaces that integrate the information from multiple robots into a cohesive display and disseminate information to multiple echelons; how and when do humans easily access the lower levels of automation; how do we ensure that HRI technologies will be readily applicable to unique aspects of the naval environment such as limited and intermittent

communications of undersea vehicles, wave-induced boat motion and its mitigation, and operations with highly limited manning; reduce interactions while providing the ability to predict behavior; how is the commander's intent transferred to the robots? Who controls the change in autonomy levels as the emergent mission needs dictate? What is the collaborative behavior for the use of multiple vehicles between multiple operators who may be sharing resources and assets?

Research Concentration Areas: HRI in autonomous operations; computational cognitive models as reasoning agents; affective computing to support social regulation; multi-modal and mixed-initiative interaction; human-guided learning; HRI metrics and evaluation principles; dynamic autonomy; principles of team collaboration; HRI for heterogeneous teams; joint human-robot manipulation and mobility; and other relevant areas. Advanced embedded vision supporting HRI, including tracking, gesture and activity recognition. Human understanding or mental models of intelligent agents. Natural language interaction for high-level human control of robotic agents. Integrated computational theories of HRI.

Impact: This MURI will develop the underlying principles and technology that will enable autonomous vehicles and robots to work with people as capable partners. The human's understanding and mental model of the autonomous agent's plans and behaviors will affect the level of trust, and thus can greatly limit the ways in which future autonomous systems are used. The types of cognitive models researched under this effort can improve user understanding of autonomous system plans and behaviors while also generating behavior that is more unpredictable to an enemy. By developing the ability for humans and robots to work as peers, we will gain an effective mechanism for gaining new means of providing the most relevant, timely information to the warfighter, and the ability to gain the advantage in what has become asymmetrical warfare.

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

FY07 MURI Topic #9
Submit white papers and proposals to the Office of Naval Research

Exploiting the Documented Plasticity of the Adult Brain to Create Superior Warfighters in Fast-Paced Close Quarters Combat

Background: Recent findings in Cognitive and Neural Science are revolutionizing our understanding of brain and behavioral plasticity in adult humans. With a few hours of practice on a fast-paced video game, young adults demonstrate substantial increases in the spatial breadth and resolution of visual attention, in the speed with which attention can be redirected to resolve unpredictable visual events, and in the ability to effectively process multiple simultaneous tasks. Significantly, these skill improvements transfer across a broad range of task settings and thereby represent fundamental changes in information process capacity. This discovery is potentially of great military importance because it exhibits a generic change in information processing capability along perceptual/cognitive dimensions closely related to combat performance, and it is obtained with military aged adults. Brain imaging techniques such as fMRI and fNIR are beginning to suggest possible neural bases for these findings, for example showing increases in the size of brain regions sub serving training-related performance improvements.

Objective: Create a fundamental understanding of the mechanisms underlying the recently uncovered plasticity in adult brain and behavior, and exploit this understanding to develop revolutionary training techniques and methods that are optimally configured to enhance combat-relevant sensory and cognitive information processing capabilities in young adults. This agenda can be achieved only through an integrated program of basic multidisciplinary research incorporating empirical and theoretical work extending across the cognitive, perceptual, neural, and learning sciences.

Research Concentration Areas: Areas of interest include, but are not limited to: (1) Behavioral studies to determine the range and extent of the basic perceptual and cognitive capacities that can be enhanced through brief training experiences; (2) Neurobiological and behavioral studies of the relation between measured changes in brain structure/function and changes in the information processing performance; (3) Behavioral/neurobiological studies to trace the changes in (e.g., decay of) performance enhancements and changed brain morphology across time following cessation of training; (4) Behavioral research to determine the training strategies most effective in creating changes in the variety of cognitive and perceptual capacities investigated; (5) Transfer of training studies to determine the relation between training-induced changes in perceptual/cognitive skill and performance in warfighting exercises; and (6) Application of computational modeling to characterize our understanding of the effects of training on brain structure and function.

Impact: New training strategies that emerge from the proposed program of research on perceptual learning and brain plasticity have enormous potential for increasing the combat superiority of our warfighters.

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FY07 MURI Topic #10
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Reactive Material Dynamic Response & Energy Release for MOUT Applications

Background: Reactive Materials (RM) represent a technology of enormous importance to the DoD which provides revolutionary enhancements to munitions lethality, effectiveness, safety, and survivability for broad applicability in weapons, particularly in military operations in urban terrain (MOUT). RM are non-explosive solid ingredients (such as metals and/or metal oxides and/or polymers) which are not detonable, but can release large amounts of chemical energy very rapidly. These materials provide energy exceeding those of conventional explosives by greater than 2x and when used to replace kinetic energy projectiles, provide new mechanisms for defeat of specific targets and minimizing collateral damage. However, a fundamental understanding of the microscopic and mesoscopic processes that control how RM respond to mechanical stimulation and energy release amounts and rates is not understood. This understanding is essential so that RM properties can be tailored to influence macroscopic responses.

Objective: The objective of this effort is to develop a fundamental understanding of the processes and mechanisms that control energy release for reactive material systems subject to dynamic stimulation. A multidisciplinary research initiative capitalizing on recent breakthroughs is proposed, focusing on mechanics, materials science, physics, chemistry, modeling, and numerical simulations to identify and characterize these processes, and develop the capability to predict the response of macroscopic events based upon these microscopic processes. The goal is to exploit this understanding to achieve maximum performance characteristics in ordnance systems while maintaining the capability to survive gun or explosive launch.

Research concentration areas: Research will focus on the development and application of theoretical and experimental chemistry, physics, mechanics, materials science, modeling, and simulation methods to determine the mechanisms at the appropriate time and length scales that control RM dynamic response and energy release. This includes investigations to characterize (1) fundamental material, constitutive, and failure properties of selected RM ingredients and formulations in the appropriate strain rate regimes and time/length scales, as a function of metal type, particle size, and polymer properties; (2) the effects of intrinsic and constitutive properties, defect size and concentration to control phenomena such as shear banding, localized heating, diffusion, mixing, and onset of failure; (3) fundamental physics and chemistry leading to energy release; and (4) how these and other phenomena control energy release rates and partition into thermal and mechanical energy. Simulation of multicomponent reactive systems using real micro-mechanical parameters and chemistry will be conducted. Experimental techniques will be developed and applied to determine parameters and coefficients required to calibrate required models at the appropriate length scales.

Impact: RM have shown the potential capacity to create significant impulse and overpressure effects, thereby improving the damage over the KE-only effects normally found in current inert metal fragments and projectiles. Weapons systems employing reactive materials warheads are projected to provide the Marine Corps and Army the ability to perform within the constraints of urban and complex terrain, without sacrificing their effectiveness on less restrictive terrain. They can provide enhanced wall breaching and obstacle reduction that will enable the Force to maintain operational and tactical momentum, with minimal exposure to enemy fires. Minimum safe distances will be significantly reduced, which allow for their employment within close proximity to dismounted forces. These weapons may be smaller which will allow forces to move lighter

and more rapidly during the conduct of operations. The integration of reactive materials warheads will permit scalable and tailorable penetration, blast, and fragmentation when used in urban environments. In addition, RM have the potential to double catastrophic kill radius in other applications such as for ship and air self-defense applications and provide improvements in recognizable kill of surface targets. A science-based understanding of these phenomena will enable development of design tools to tailor RM properties to optimize performance for specific applications and at significantly reduced time and cost. The results of this effort will be transitioned to the technology development programs for validation and exploitation.

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FY07 MURI Topic #11
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Processing and Production Science for Next Generation Fuel Cells

Background and Description: Advances in manufacturing technologies are enabling the production of next generation components and devices, such as fuel cells, that are smaller, faster, lighter, and energy efficient. Fuel cells offer the advantage of operating over a much longer period of time compared to electrochemical batteries. It could power mobile electronic devices that are rugged, lightweight, and portable, such as laptop computers and cell phones. However, their wider use has been constrained by factors such as ready availability of fuel, material durability, affordable manufacturability, and capital cost. For the next generation fuel cell, fabrication processes will be needed for favorable electrode, electrolyte, and catalyst configurations with slim dimensions and component assemblies with significant design flexibility. Thin film deposition techniques such as atomic layer deposition can be exploited to produce nanostructurally-tailored thin films and membranes for enhanced power density. Freeform fabrication with its digital rendering capability will enable new conformable designs custom-tailored for specific applications with significant cost benefits. While considerable research is being performed in developing fuels and materials, there is very little research performed in molecular-level fabrication and affordable manufacturing.

Objectives: Develop design architectures and material combinations from first principles for high power density, portable fuel cells. Develop molecular-scale processes that provide nanometer-scale control of features and material compositions in customizable components. Develop direct or digital manufacturing to fabricate the fuel cell as an integrated whole, without assembly and with embedded components.

Research Concentration Areas: Areas of interest include, but are not limited to, the following: (1) Quantum mechanical computations and Monte Carlo simulations to obtain atomistic insight into diffusion and charge transfer processes; (2) Doping and other strategies for increased catalyst, electrode and electrolyte performance efficiency; (3) Thermal management modeling to determine performance; (4) Analytical study of interfaces between nanostructured electrolyte, membranes and electrodes to determine long-term reliability; (5) Optimum architectures and embedded sensor capability for performance monitoring; (6) Scalable processing routes with quantifiable and controllable kinetics for molecular-level processes and lithographic etching; (7) Freeform fabrication or direct manufacture for rapid production of optimized fuel cell geometry in unit form and with component embedding capability; (8) Application-specific, hybrid manufacturing methodologies involving integration of two or more fabrication techniques; (9) Manufacturing challenges such as defect management, repeatability, affordability and high throughput.

Impact: Affordable manufacturing of rugged, lightweight, high energy density fuel cells will revolutionize technologies used in expeditionary and autonomous vehicle operations, particularly for surveillance, robotics, smart weaponry, sensors, portable electronics and optical communication. Reduced weight from fuel cell-powered devices will greatly benefit rapid response ground forces. For the Navy, Marine Corps, and Coast Guard, high performance fuel cells offer significant benefits through reduction of emissions, improved sustainability, reduced dependence on fossil fuels and a move towards regenerative power supplies.

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FY07 MURI Topic #12
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Science-Based Design of Fuel-flexible Chemical Propulsion/Energy Conversion Systems

Background: Recent events have shown dramatically our national vulnerability to variations in the supply of petroleum. In 2002 U.S. energy consumption exceeded production by 53% and continues to grow. In FY05 the Air Force spent $4.8B for fuel, an increase of 60% over the previous year. The recent hurricane-related damage to domestic production capability and the attendant jump in energy costs further emphasized our weakness to petroleum supply threats. Fortunately, the U.S. is rich in non-petroleum energy resources, and the recent success of the DoD-DoE program to produce alternate fuels from these sources through the Fischer-Tropsch process offers significant hope for future energy security. Furthermore, the composition and performance of Fischer-Tropsch fuels demonstrated advantages with respect to petroleum-based fuels with respect to emissions, thermal stability, etc. Unfortunately, in the near term it will be necessary to process fuels from non-petroleum sources to be much like current fuels to meet the needs of our large inventory of legacy aerospace vehicles and weapons, so that the full advantages of the alternate fuels may not be realized. For the long term, the proposed initiative seeks to provide fuel-flexible energy conversion design capability in order to achieve true optimization of ***energy utilization*** – the combination of fuel production and energy conversion. This concept has not been addressed previously and would be a fundamental shift in our managing our national energy use.

Objective: To create a new modeling and simulation capability that will incorporate the chemical and transport properties of fuels in order to perform predictive design studies of chemical energy conversion systems.

Research Concentration Areas: Research will include four multidisciplinary areas: (1) chemistry to characterize fuels through surrogates that are chemically less complex yet simulate the primary chemical and transport behavior of the fuels; (2) compilation of a library of properties of component species that comprise the surrogate fuels that can be assembled to reproduce the behavior of different surrogate fuels including the physics for novel spectroscopic analysis techniques; (3) generation of detailed chemical kinetic mechanisms for surrogate fuel combustion over the full thermodynamic parameter space to serve as a database for the reduced models to be incorporated in design models; and (4) applied mathematical creation of chemical kinetic mechanism reductions and property representations that can meet the computational constraints imposed by future design models. Particular novelties in this research will be consideration of higher molecular weight hydrocarbons (> C10) and definition of mixing rules for hydrocarbon surrogates. Specific Air Force research to be addressed will include the role of fuels in altitude relight, high-speed propulsion, augmentor performance, and high-pressure gas turbine environments.

Impact: The payoff for successful research would represent a major change in the paradigm for national energy use. The products of the research would be the long-term complement to the current emphasis on energy production from non-petroleum sources. The resulting design capability will be a primary decision making tool to define not only future energy conversion technology but also the production approaches for future fuels. The opportunity will exist to achieve an overall optimization on a national scale of energy utilization with respect to criteria such as cost, efficiency, and environmental impact.

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FY07 MURI Topic #13
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Enterprise Health: Self-Regenerative Incorruptible Enterprise

Background: Existing approaches to information system security and survivability consist of preventing, detecting and containing unintentional errors and/or cyber attacks. These systems use static means to survive, but are unable to adapt, learn, tolerate and/or reconstitute dynamically in response to unforeseen errors and/or unknown cyber attacks. These systems simply fail miserably when subjected to previously unknown events. Recent research has demonstrated the ability to tolerate errors and/or attacks and gracefully degrade with respect to user (mission critical) requirements. The Organically Assured and Survivable Information System (OASIS) program funded by DARPA in partnership with AFRL/IF is one such research program. The OASIS program was a cross-disciplinary program that combined fault tolerance and Information Assurance (IA) technologies to build information systems that detect, contain and operate through cyber attacks. The problem with this approach is that regardless of how well systems are protected or how well they tolerate errors and/or attacks; they will eventually fail over time unless they have the ability to self-regenerate. On the positive side, systems that tolerate attacks by gracefully degrading service buy time for learning the root cause of errors and attacks, providing valuable knowledge to the self-regeneration process. What is needed are information systems that can adapt, learn, tolerate and/or reconstitute dynamically in response to unforeseen errors and/or unknown cyber attacks.

Objective: The objective of this Self Regenerative Incorruptible Enterprise topic is to develop new algorithms that will enable information systems to learn, regenerate themselves in response to unforeseen errors and/or attacks, and automatically improve their ability to deliver critical services. If successful, self-regenerative systems will reconstitute the information systems back to its initial operating capability while decreasing their vulnerability to an ever-increasing number of attacks.

Research Concentration Areas: Persistent information systems and data are hard to disable or remove. Robust software may be easier to regenerate. Biologically inspired diversity may inspire dynamically immune components. Information systems must automatically recognize and learn about novel cyber and service attacks. Information systems and data must have redundancy and the ability to regenerate required functionality with increased error/attack immunity, and without negatively affecting the whole system during regeneration. Areas of interest include but are not limited to the following: (1) Persistent applications and data (2) Reconstitution of data and state (3) Dynamically recognize, characterize and understand novel cyber attacks and service anomalies (understand root cause) (4) New approaches to software development (model based, specification based, component based, flow based, etc) (5) Dynamic synthetic diversity (machine generated correct, immune, and composable functionally equivalent software components) (6) Synchronize repair activities without interrupting ongoing mission priorities (7) Self optimization with respect to achieving incorruptibility (restore initial operating capacity while reducing vulnerabilities to errors and attacks)

Impact: Success in this area will result in a game changing capability that will allow information systems to persist and dynamically generate code to self-heal, thereby dramatically shortening the response time to recover from cyber attacks by taking the human out of the loop

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FY07 MURI Topic #14
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Atmospheric Neutral Density Prediction

Background: With current advances in satellite and communications technology increasing our recognition of the importance of space situational awareness, it has become increasingly important to be able to accurately locate satellites and to predict their positions in the future. The need for this information for all objects in earth orbit leads to the requirement to understand the physics of the neutral atmosphere that enables the accurate prediction of thermospheric densities at satellite altitudes. The scope of this MURI topic is the elucidation of those physical concepts and predictable key indicators of energy inputs to the atmosphere that will update and calibrate current operational satellite drag models and lead to the accurate prediction of thermospheric densities and, hence, a precise prediction of the locations of satellites. The development of large thermospheric models is being done elsewhere under other sponsorship. The intent of this MURI is to developed fundamental concepts that will eventually be included in the large models. The two areas covered by this MURI include (1) specification of the boundary values needed for physics-based global models; (2) theoretical or numerical treatments of the physical processes involved in modification of the neutral densities.

Objective: This research will develop the physics and chemistry concepts and processes required to accurately and reliably determine current and future neutral density of the thermosphere at satellites altitudes. Specifically, this initiative is intended to conduct critical basic research toward a near-real-time, accurate and interoperable capability to locate, track, identify, and estimate future locations of satellites.

Research Concentration Areas: The successful proposal will identify key research areas as well as coupling between areas that determine neutral atmospheric density at satellite altitudes. It will include a management plan to coordinate and assimilate results. The general research area is related to an understanding of the spatial and temporal distribution, relative importance and predictive potential of solar and upward propagating energy sources of the thermosphere, and their drivers for both orbiting and reentering objects. Specific areas of interest include, but are not limited to, the following:

(a) The physics of solar and geomagnetic quiet time conditions
(b) Coupling of solar events and magnetosphere-ionosphere conditions into atmospheric effects
(c) A model of high latitude energy, including partitioning of that energy between winds and heating, and its impact on the atmosphere
(d) Determination of the effect of other thermospheric energy sources, including solar electromagnetic radiation and upward propagating tides and waves
(e) Determination of the response time from prediction or observation to a change in atmospheric density
(f) Development of physics-based energy indices to replace the proxy indices now in use
(g) An understanding of the physics of drag and precise determination of satellite drag coefficients in the 200-100 km altitude region with an orbiting object transitioning from free molecular flow to slip flow
(h) A method to validate model improvements based on results of this effort

Impact: As the mission of the Air Force becomes more oriented toward space, it is vitally important to develop the capability to know, precisely and continuously, not just where all

orbiting objects are, but where they will be in the future. Today's capabilities fall far short of this goal. This initiative fills a critical need in the development of accurate and practical models for satellite tracking and orbit prediction. The capability to forecast the impact of the earth's environment on low-earth-orbit objects will significantly enhance Space Situational Awareness and provide the required near-real-time, accurate capability to locate, track, identify, target, and estimate future locations of all resident space objects at the required precision.

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FY07 MURI Topic #15
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Building Bridges between Neuroscience, Cognition, and Human Decision Making

Background: For the past 100 years, researchers from neuroscience and cognitive science have worked independently developing separate bodies of scientific knowledge and theory. However, recent advances in neural recording and brain imaging technology in conjunction with major advancements in mathematical and computational modeling of cognition have created new and exciting possibilities for bridging the gaps between these fields and stitching together these vast bodies of research. The potential for integrating these fields has produced a surge of interest evidenced by several recent special issues appearing in major journals (*Neuron*, *Nature-Neuroscience*, *Neural networks*, *Journal of Cognitive Neuroscience*) and special funding initiatives by NSF and NIMH and DARPA. For example, diffusion models of decision making developed in cognitive science are now capable of describing both human performance as well as neural activation patterns recorded from the brain by multiple cell recording techniques. Neural network models of reinforcement learning are now capable of describing human learning as well as the dopamine response recorded in cortical - striatum neural circuits. Neural network and information processing models of cognitive control have been directly linked to electrical recording and functional magnetic resonance imaging of the anterior cingulate. In short, mathematical and computational modeling on the intersection of cognitive – neuroscience is on the cusp of outstanding and surprising theoretical scientific breakthroughs.

Objective: The general goal is to form a complete and thorough understanding of basic human decision processes ranging from neuroscience through cognition to behavior. This is to be done by building a lattice of theoretical models with bridges that span across fields studying neural recording and brain imaging in elementary decisions (simple two alternative choice tasks) to human information processing and decision making with complex dynamic tasks. For example, fine-grained, low-level models of neurophysiology need to be mapped into courser-grained neural network or connectionist models of sensory-perceptual systems and elementary information processing, which then need to be integrated into higher-level procedural models of complex human decision behavior. The main effort of this work is intended to be in the direction of new integrative theoretical developments that succeed in building these bridges using mathematical and/or computational modeling. However, this theory development must be accompanied and supported by rigorous empirical model tests and empirical model comparisons, which would require new human experimentation especially designed for this purpose.

Research Concentration Areas: The proposed research will require interdisciplinary teams composed of neuroscientists, biophysicists, mathematical biologists and mathematical psychologists, cognitive psychologists and computer scientists. The teams also need to be a mix of talented experimentalists from neuroscience and cognitive psychology working closely together with creative theoreticians. These teams will address key research issues such as: (a) what is the neural basis of decisions, (b) how does this knowledge impact and constrain higher level models of cognition, (c) how can we integrate basic neural mechanisms into information processing models, and (d) how do basic effects at the neural level scale up to influence performance on complex cognitive tasks?

Impact: Building theoretical connections between neuroscience, cognitive, and decision

behavior, would make it possible to predict in a more rigorous manner how influences of basic neural processes cascade up to impact decision performance. In particular, such theories would be capable of predicting how neural damage, physiological stress and fatigue, emotional arousal, or motivational deprivation scale up to influence human performance on complex decision tasks. Ultimately this knowledge could be used to devise treatments or decision aids to enhance military decisions under stress, and to develop autonomous agents guided by goal mechanisms similar to the emotional/motivational systems used by humans.

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FY07 MURI Topic #16
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Behavior of Systems with Humans and Unmanned Vehicles

Background: Military strategy and tactics has evolved over the last few years to include a significant and ever growing dependence on Unmanned Vehicles (UV), be they air, land, sea, or undersea. Much research is being performed on cooperative distributed decision making and coordinating tasks between multiple vehicles. However, these vehicles do not operate autonomously, but within an organizational structure of humans and a distributed network of vehicles. Key to the performance of human-vehicle organizational structures is the function of the human components. The human-automation partition is mostly ad hoc, based on trial and error, and frequently a variation of legacy systems. Poor understanding of the human component of systems with humans and semi-autonomous vehicles can lead to highly inefficient organizations and costly, even tragic, mistakes. Research programs such as the DARPA MICA program have only scratched the surface of human-vehicle understanding. New methods are needed to represent human behavior and performance in military tactical scenarios with semi-autonomous vehicles. New methods are also needed to capture the relationships between humans in organizational structures, command structures, and social structures. These imposed structural and cultural factors can, and do, dominate the human member's ability to make good decisions and perform necessary actions. Only by capturing and understanding the often complex relationships of human group dynamics in tactical situations can the full potential of semi-autonomous vehicles be realized; the optimal roles and allocations of responsibilities between man and machine can be determined; and new organizational/social structures designed so that tragic mistakes can be averted.

Objective: Develop new methods of capturing, modeling, representation, and understanding of human behavior and performance in military tactical scenarios with semi-autonomous vehicles. Also, develop new methods of representing human behavior in hierarchical command structures and social relationships. The objective is to develop a theory and concrete understanding of how to employ a human-vehicle network to accomplish tactical scenarios efficiently, make good decisions, and avoid tragic mistakes. To accomplish these objectives a multi-disciplinary team will be needed with critical expertise in cognitive psychology, social psychology, organizational behavior, semi-autonomous vehicle systems, military tactical skills, decision and control theory, operations research, computer science, and simulation.

Research Concentration Areas: Urban military tactical scenarios are emphasized, but not considered a restriction. The approach source material for the research should be an existing program scenario that has a medium to high fidelity human-in-the-loop simulation. Examples can be research projects such as the Navy Intelligent Autonomy program, DARPA HURT, ARMY Future Combat Systems, AF COUNTER project, AF LOCAAS, or various fielded semi-autonomous vehicle systems. A buildup approach can be taken with an initial 1 human, 1 vehicle; 1 human, m vehicles; and n humans, m vehicles. Emphasis in the first two would be on human cognition, and in the latter on organization and sociology. The emphasis here is on human aided autonomy or human controlled autonomy. For example, human aided target recognition, human aided search, or human aided planning and tactics. Existing studies can be exploited or human experiments can be performed with specific emphasis on conditions where humans make mistakes in cognition or judgment due to: workload, fatigue, belief systems, preconceived notions, incomplete information, inability to allow for erroneous data, inattention, boredom, training, not accepting data, arrogance, inability to consider the negative consequences of decisions, etc. For multiple humans in an organizational structure there is: cultural norms, pressure to conform, information

compartmentalization, lines of authority, lines of responsibility, punishment, social acceptance, inability to speak truth to power, etc. These lists are not exhaustive and the aim of the research is discover which of the factors make the greatest contribution to bad decisions and which factors in organizational structures can result in tragically bad decisions. The product of this research is a set of military application specific human performance models with attendant theory that can be used to synergistically exploit the strengths of humans and autonomous vehicles while simultaneously minimizing their respective weaknesses.

Impact: Increasingly complex networks of humans and autonomous vehicles are being developed without a rigorous foundation in the fundamentals of human cognition and human behavior in organizations. These human performance models are critical if tragically bad decisions are to be prevented when designing new systems and organizations, as well as for training, simulation, trade studies, and exercises. These models will also contribute to the understanding and development of adversary models, which are also critical if the full potential of autonomous vehicles is to be exploited.

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FY07 MURI Topic #17
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Biologically-Inspired Flight for Micro Air Vehicles (MAVs)

Background: Future operations in urban environments will entail weapon systems capable of operating in confined spaces with precision and unprecedented levels of real-time battlespace awareness, intelligence and responsiveness. Micro Air Vehicles (MAVs), small air vehicles with a maximal linear dimension of order 15cm or less, may provide such urban combat capability. At such small scales, traditional fixed-wing air vehicle design principles are insufficient to meet urban environment performance requirements. The flows at the MAV scale are characterized by low Reynolds number, extensive flow separation, unsteadiness and viscous interactions not typical of larger air vehicles. Lift to drag ratio and airfoil efficiency degrade due to the separation of laminar boundary layers. These flow fields may exhibit complex interactions with the lightweight structures used to construct MAVs, and traditional control surface deflection may lack adequate bandwidth and control power. To operate successfully in an urban or confined environment, MAVs must have agility, resistance to gusts and cross-winds, and the ability to hover, "perch" or dwell to survey the environment. Such wide-ranging requirements demand creative integration of traditionally disparate propulsion, aerodynamics, structures, materials, sensors and flight control disciplines. As a point of departure, this MURI effort seeks to exploit knowledge gained from the study of biological flying organisms (bats, birds and flying insects) to develop the capabilities envisioned for MAVs operating in urban environments.

Objective: This program seeks to develop the fundamental scientific foundation necessary to enable agile, autonomous MAV flight operations in an urban environment. Goals for this effort include 1) development of physically-based predictive models of propulsively effective fluid-structure interactions, and actuation patterns by integrating theoretical, numerical and experimental methods; 2) advances in lightweight, low-power, multifunctional materials suitable for actuators, sensors and highly flexible structures; and 3) advances in integrating such novel features as biology-inspired flight control sensors and methodologies, extreme changes in vehicle configuration and periodically-varying structural properties to enable gust-tolerant flight.

Research Concentration Areas: Research areas of interest include, but are not limited to: (1) flow physics of biology-inspired mechanisms that simultaneously provide lift and thrust, and enable hover; (2) interactions of unsteady aerodynamic loading with flexible structures; (3) flexible, low-power materials for large displacement actuation, such as flapping or morphing; (4) gust-tolerant flight control methodologies inspired from biology incorporating novel sensors and structural property tailoring of aeromechanical surfaces; (5) integration of theoretical, numerical and experimental analysis techniques; (6) power requirements, packaging and integration issues for MAV urban operations.

Impact: This research provides a foundation for enabling gust-tolerant MAVs to autonomously navigate, maneuver, detect and target in an urban environment. An understanding of fluid-flexible structure interactions (AFOSR POCs: Lt Col Jefferies/Dr. Giurgiutiu), integration of multifunctional materials (POC: Dr. B.L. Lee) and robust flight control techniques (AFOSR POCs: Dr. W. Larkin / Dr. F. Fahroo / Lt Col Heise) will establish new design practices for MAVs and will lead to an unprecedented capability for successfully prosecuting urban operations. These new design strategies will influence larger air vehicle design strategies incorporating flexible and/or morphing structures.

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FY07 MURI Topic #18
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Quantum Simulations of Condensed Matter Systems using Ultra-cold Atomic Gases

Background: Many advances in modern technologies are driven through discovery of new materials. The most novel and exotic new materials have properties dictated by quantum mechanics: high temperature superconductors, quantum Hall effect materials, 0- 1- and 2-D electron gasses in semiconductors, colossal magneto-resistive materials, and many others.

Currently, our understanding of these systems is impeded by the fact that most of these materials involve non-negligible many-body interactions, often strong electron-electron correlations. Such systems are still poorly understood qualitatively and difficult to treat quantitatively. Even the simplest model for describing strongly-coupled fermions, the Hubbard model, does not allow reliable analytical or numerical analysis. To avoid a trial and error approach, synthesizing and then testing a whole range of materials in the hope that one of them will have a desired property, new approaches must be developed for studying systems in the strong correlation regime.

One conceptually new avenue is to simulate strongly interacting systems using highly controllable ultra-cold atomic samples. For example, systems of cold fermions in optical lattices can provide a direct realization of the Hubbard model with controlled parameters under realistic conditions. In essence, this corresponds to realization of Feynman's pioneering idea to use one quantum system to simulate another. This would be the first practically useful analog quantum computer. By suitable control of the interactions (e.g., by varying relative field strengths, polarizations, phases, and magnetic fields) not only can the parameters of the Hubbard model be varied, but other systems can be modeled/simulated as well. As a first step we expect such quantum analog simulation to provide important insight into the nature of high temperature superconductivity, as well as providing a route toward new superconductors with still higher threshold temperatures.

Objective: The goal is to simulate a strongly interacting many-body system using cold atom ensembles, i.e. to create a simple analog quantum computer. Specifically, we anticipate that the answer to the long-standing problem of whether the Hubbard model can exhibit d-wave pairing of fermions will likely be obtained. The remarkable control that one has over cold atom systems is expected to provide insight into ways of increasing the superconducting temperature. For example, several theoretical proposals that have been made, e.g., that creating modulated systems can lead to strong enhancement of superconductivity, could be explored.

Research Concentration Areas: Design of 1-, 2-, and 3-D optical lattices with various methods to control interactions. Methods of loading lattices with both fermions and bosons, as well as mixed species loading. Investigation of controlled loading, with one or more atoms/lattice site. Simulation of: 1) the Hubbard model and its extensions (i.e. adding phonons); 2) Quantum Hall-like systems; 3) Spin chains in various dimensions (e.g. spin liquids).

Impact: Research in this field will have great implications for both the possibility to "tailor-make" materials with desired properties and for quantum information/computing. It will advance the state of knowledge in condensed-matter physics, including understanding of exotic materials and future "functional" materials with as-yet unknown properties.

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FY07 MURI Topic #19
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Bioinspired Supramolecular Enzymes

Background: The last decade has witnessed significant advances in the development of synthetic methods for preparing supramolecular compounds. Synthetic methods have been developed for preparing many types of novel structures including nano- and mesoscopic cages, cubes, tetrahedra, prisms, cylinders, rings, and rotaxanes. Although structural advances have been rapid, the realization of functional architectures for catalysis and other applications has lagged behind resulting from the lack of efficient, modular syntheses that can provide functional supramolecules in high-yields and selectivities. In addition, there has been an inability to incorporate bioinspired and biomimetic designs that allow the assemblies to change their size, shape, and function in response to either the presence of another molecular species or a change in environmental factors. This latter ability is critical to enzymatic operations. The synthetic tool kit for preparing functional architectures is in place, however before such structures can be realized, strategies must be developed to harness the potential of this synthetic methodology.

Objective: Supramolecular systems have great promise for the development of novel receptors to develop sophisticated separation systems and highly sensitive and selective detection systems for many types of analytes, including small molecules, metal ions, and many biomarkers. Moreover, they can be used to prepare catalysts that affect many chemical transformations that are important to the DoD. Finally, with recent synthetic developments, there is now the potential for preparing functional structures that are inspired by and mimic the powerful enzymatic processes that are taken for granted in biology but are extraordinarily enabling from the standpoint of recognition, catalysis, and molecular mixture separation. Powerful examples are Polymerase Chain Reaction (PCR) and Enzyme-Linked Immunosorbent Assay (ELISA), which are enzymatic amplification processes for nucleic acids and proteins. These technologies have become the cornerstone of the biotechnology industry. An important goal for supramolecular scientists is to learn how to mimic such processes using abiotic structures or harden bioderived structures with the intent of realizing powerful catalytic synthesis and detection systems that allow one to go beyond nucleic acids and proteins.

Research Concentration Areas: The specific goal of this MURI research theme is to implement functional supramolecular chemistry and allosteric control to areas of interest to the DoD. Research projects carried out under this theme will be directed towards the fundamental understanding of the principles that govern the synthesis, functionalization, and control of enzyme-like, bioinspired, activity in supramolecular assemblies, including lessons from nature on allosteric interactions in enzymes. Furthermore, they will investigate the practical application of these fundamental rules to achieve revolutionary advances in future DoD systems. Successful proposals should address the following issues: controlled synthesis of supramolecular materials, bioinspiration of enzymatic processes, broad implementation of functions via modular design, control/modulation of functions via allosteric control in multimetallic systems, computational modeling of the supramolecular systems, and development of selective catalytic properties for: materials synthesis, chemical detection, chemical neutralization,

Impact: Biomedical diagnostics, including rapid, highly specific, and highly reliable pathogen detection, coupled to environmental remediation via catalysis. DoD workplace toxic chemical detection, including volatile organic chemical (VOC) detection, coupled to practical remediation. Battle field toxic chemical detection (weapons detection) and neutralization. Environmental contaminant detection and remediation to achieve regulatory

compliance, including VOC emissions compliance and effluent evaluation/treatment for water-soluble heavy metals (e.g. corrosion products), trace aromatic, polyaromatic, and halogen-containing compounds (e.g. fuel residues, cleaning/degreasing compounds, etc.). Water-based and land-based hazardous explosive device detection, including mine and abandoned munitions detection.

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FY07 MURI Topic #20
Submit white papers and proposals to the Army Research Office

Biologically Synthesized Quantum Electronic Systems

Background: In the last several years, the potential for using biological processes in non-biological applications such as electronics has become reality. Initial efforts have been focused on using these versatile mechanisms for direct computation, non-traditional information transfer, and the assembly of nanometer scale electronic systems. The advantage that biological systems provide is the natural capability to operate on the nanometer scale for such processes as (i) high fidelity recognition of molecules, surfaces and free-standing nanostructures, (ii) precision formation of simple nanostructures, and (iii) hierarchical assembly of complex nanostructures from simpler ones. In addition, while lithographic fabrication techniques are inherently two dimensional, biology naturally operates in three dimensions. Biological assembly can make a profound impact on quantum transport properties in zero-and one-dimensional metallic and semiconducting inorganic nanostructures, as well as in more complex "quantum electronic" systems. Quantum electronic systems are characterized by transport properties that are strongly influenced by carrier-carrier interactions. As such, they are extremely sensitive to the quality and nanometer-scale structure of the system. Progress in this field is hindered by the requirement for precision assembly at or beyond the very limits of traditional fabrication technology. This is particularly true for systems that exhibit quantum transport at room temperature, for which the typical length scale is less than 5 nm. To systematically produce devices based on quantum transport requires accuracy and precision that is only achievable through biological mechanisms. Biological assembly of quantum transport structures and devices will directly address the fabrication hindrance in the experimental realm, and subsequently will provide the phenomenology to support the development of broadly applicable and analytically tractable models of quantum transport.

Objective: In anticipation of the developing capabilities of both biological assembly and quantum electronic systems, it is the goal of this MURI to (i) harness biological assembly to fabricate nanoscale inorganic structures that exhibit quantum electronic transport, (ii) use this as a basis to systematically study the effects of carrier-carrier interactions in such structures, and (iii) develop a reliable route to the biological synthesis of quantum electronic systems that operate effectively at room temperature.

Research Concentration Areas: Research must include, but is not limited to: 1) fundamental investigation of quantum transport in nanostructures and nanostructure assemblies fabricated by biological processes; 2) development of techniques for biological synthesis or high fidelity biological selection of nanostructures with nearly indistinguishable quantum electronic characteristics; 3) investigation of how defects, surfaces, environment and internal structure affect quantum transport through biologically assembled nanostructures; 4) application of directed evolution techniques or other equally effective techniques to obtain the required affinity and specificity of proteins, enzymes, DNA or other biomolecules to specific nanostructures; and 5) application of bioengineering techniques for the structural design of nanostructures at the device level.

Impact: Providing capabilities to reliably fabricate quantum electronic systems and subsequently developing a broader understanding of the phenomena of carrier-carrier interactions in nanostructures will provide the foundation for a new class of electronic and opto-electronic devices. The primary advantages that this class of device will have are ultra-low power consumption, weight and volume, and added functionality. Additionally, new environmental sensing capabilities should become possible because, e.g., (i) the electronic state of a single electron transistor is highly sensitive to the environment, and (ii)

metal-insulator transitions can result from correlated electron effects. Quantum transport systems fabricated biologically also have strong potential for ultra-low cost fabrication.

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FY07 MURI Topic #21
Submit white papers and proposals to the Army Research Office

Attosecond Subwavelength Optical Pulses

Background: The era of femtosecond laser pulses, like the previous epoch of picosecond pulses, ushered in a new generation of physics and engineering with unprecedented achievements, from precision laser surgery to quantum molecular control. Within the last year record high laser intensities have been reached (10^{22} W/cm^2). This, coupled with recent breakthroughs in chirped envelope phase control, puts us on the verge of developing attosecond (as $=10^{-18}$ s) laser pulses. In the "visible" range (1-3 eV energy photons) these subwavelength pulses will create revolutionary advances in both theory and experiment. Approaching the atomic timescale (~25 as) gives us the opportunity to, for the first time, monitor, understand, and eventually control molecular electronics underlying all physical, chemical and biological systems. Army-relevant applications range from combustion, to molecular electronics in nanoparticles (nanotubes, nanorods, quantum dots) and electronic coherence studies in solids, to building faster electronic devices. The coherence of the light pulses can be exploited for surface patterning and modification. Moreover, the vast spectrum of the Fourier decomposition of these ultrashort pulses shows that they contain components above the plasma frequency for any substance, and will therefore propagate through solid materials. This property provides the basis for a new kind of imaging, with applications ranging from weapons detection to uncovering defects in materials. Isolated sub-femtosecond optical pulses[1] and trains of such pulses [2] were first generated 2001-2002, beginning the attosecond revolution leading to the current state-of-the-art of ~100 as duration in the soft x-ray (~100 eV) range. [1] M. Hentschel, R. Kienberger, Ch. Spielmann, G. A. Reider, N. Milosevic, T. Brabec, P. Corkum, U. Heinzmann, M. Drescher and F. Krausz "Attosecond Metrology", Nature, **414**, 509 (2001). [2]P.M. Paul *et al.*, Science **292**, 1689 (2001); H.G. Muller, Appl. Phys. B **74**, S17 (2002)).

Objective: The objective of this MURI is to design and create sources of ultrashort laser pulses, down to 25 attoseconds in the visible, i.e., 1-3 eV range.

Research Concentration Areas: In order to reach ~25 as pulses, several key research areas must be addressed. One is the necessity of developing measurement techniques. Methods that were used for femtosecond pulses must be adapted so they can measure and characterize attosecond pulses. Electron re-collision physics, a fundamentally important process for attosecond production, must be developed. Another area that needs investigation is relativistic effects, particularly effects on mass of the scattered electrons and the subsequent nonlinear interactions. Generally, the shorter the time scale, the stronger the nonlinearity, but when this is pushed to the attosecond time scale several important questions arise, such as: How do electrons behave under extremely strong acceleration (radiation back reactions)? How will the collective response of electrons to strong optical fields differ from single electron response? With the advent of ultra-high intensity produced by attosecond pulses, the nonlinear optics of the vacuum can be moved into the realm of experimental capability. Once attained, attosecond pulses will open the doors to a new world of applications. Areas that this MURI should explore include: **Imaging with Attosecond Sources**, for medical applications, food screening, concealed weapons screening, time resolved electronic dynamics, coherent control of light matter interactions. The superwide spectrum of attosecond pulses presents a new potential for imaging, not only in medicine (which is based on its new quality: trans-spectral coherency provided by the coherent nature of attosecond pulses), but also with applications to weapons and mines detection. **Molecular fingerprinting and global spectroscopy:** Existing femtosecond spectroscopy allows the acquisition of characteristic molecular spectra within limited Raman bands. A light source with an order of magnitude larger coherent bandwidth will allow

simultaneous and highly-coherent excitation of multiple (molecular and electronic) bands, which may result in much more efficient and specie-specific "molecular fingerprinting." Military applications include remote time resolved chemical and biochemical sensing, analysis of strength and stress in materials, and advanced lithography.

Impact: Few developments in physics would have greater impact then the development of 25 attosecond laser pulses. For the first time electron dynamics will be measurable. Quantum control over molecular dynamics would be greatly enhanced, and an entirely new program on high resolution imaging will be created.

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FY07 MURI Topic #22
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Designing and Prescribing an Efficient Natural-like Language for Bots

Background: To cooperate and perform their myriad duties, bots (any intelligent machine) will need sufficient language for communication, representation, and decision making. In current applications and designs, bots often use minimally-structured ad hoc or formal language grammars or rudimentary natural language. However, in the near future as bots gain capacity for higher intelligence and complexity in their applications, bots will need a much richer, natural-like language than the simple formal languages or will need a language more efficient and robust (less ambiguous) than natural language. Such a language will not only allow for economical communication, but also act as a framework for the fusing of data and information from all the bot's sensors. This synthetic bot-language must not only fit into the scope of current natural language processing (i.e., speech processing, speech recognition, speech synthesis), but also constrain the infinite complexity and ambiguity of natural languages. There has been tremendous progress in understanding language construct over the past two decades. Current research shows that hierarchical models of language for real-time parsing have matured to the point of establishing a framework for understanding capacity, complexity, and processing of human's natural languages. Similarly, post-modular processing systems have developed to such an extent that computers are able to possess information and form rudimentary intelligence. Therefore, it is now possible to design and build a synthetic (yet natural-like) language with the characteristic that it is robust-enough to provide bots human-like communication, rich-enough for humans to communicate in a natural way with bots, yet constrained and minimal enough in its hierarchical framework to allow real-time processing of communication with near-future technologies. These concepts are even further enhanced in the military setting where robots and other intelligent machines will soon be playing major roles in military operations.

Objective: This multidisciplinary research initiative is both analytic – developing an understanding of computational linguistics and proper language construction and performance metrics -- and prescriptive -- designing and building the framework and architecture for such a language, developing simulations and prototype language constructs for testing and benchmarking, and ultimately developing bot language. The objectives of this research project are: 1) establish the construction and performance metrics for such a language, 2) develop bot-language requirements, model the language characteristics, and design the language elements, 3) build the framework for the linguistic processing of the language, 4) develop the rules for a classification-based vocabulary and the rule-based grammar, 5) establish a testbed with a substantial sample grammar and vocabulary, and 6) build the language. In general, this bot-language through its increased efficiency and reduced ambiguity should have lower entropy from those of current natural languages.

Research Concentration Areas: The work team should include expertise in the following areas: computational linguistics, linguistic theory (especially typology, stylistics, and discourse analysis), information theory, communications theory, formal languages, stochastic modeling, mathematics of language, simulation, and cognitive science (AI).

Impact: This research intends to build a language to be used by bots (intelligent machines) to communicate with each other and humans around the years 2015-2020. The potential value to our society of being able to communicate effectively with machines in a natural-like language is substantial.

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FY07 MURI Topic #23
Submit white papers and proposals to the Army Research Office

Ionic Liquid Containing Polymeric Materials

Background: Ionic liquids are low melting temperature salts comprised of ionic species, typically organic cations and inorganic anions. Fundamental studies dating from the 1980s to the present have shown the utility of ionic liquids in green chemistry applications, including as non-volatile bulk solvents and as media for liquid-liquid separations. Their usefulness is derived from their near-zero vapor pressure, fully tailorable solubility, and their highly polar and non-coordinating nature, which makes them ideal for catalytic reactions. In recent years, publications in this field have grown exponentially with most research focusing on synthesizing new ionic liquids, characterizing their physical properties, and using them in chemical separations and reaction processes. However relatively little research has been reported describing the use of ionic liquids as a polymerization medium, for solvating materials, or as a polymerizable monomer. Both an Army workshop on Polymer Actuators and an Army-sponsored ACS symposium on Polymers and Ionic Liquids indicate the time is right to develop a concentrated multidisciplinary program in this area to generate novel materials, such as actuators and membranes, for the Army and DoD.

Objective: This topic will bring together chemistry, materials science, process engineering, and electrical engineering to generate a fundamental understanding of how to use ionic liquids to prepare novel functional materials. The focus will be on (1) designing ionic liquids for use as a reaction medium for preparing polymeric materials, (2) using ionic liquids to solvate materials, (3) synthesizing polymers using ionic liquid polymerizable monomers, (4) using process design to prepare bulk quantities of materials, and (5) using materials science and electrical engineering to understand the effect of ionic liquids on mechanical, electrochemical, transport properties, and device (i.e., actuator) behavior.

Research Concentration Areas: Ionic Liquid Design. Research will focus on designing and preparing ionic liquids that can serve as a "green" solvent to promote polymer synthesis and as a replacement for water for polar materials. Chemistry to be explored may include free radical, ATRP, ionic, and transition metal catalyzed polymerizations. Key ionic liquid properties, such as miscibility with monomer and initiators, viscosity, reactivity, and phase behavior, are of interest. Synthesis. Synthesis will be carried out using ionic liquids as the medium and also as a polymerizable monomer. Key properties, such as reaction kinetics, degree of polymerization, MW, tacticity, temperature effects, and reactivity ratio should be characterized. New monomers may be designed that are tailored to a specific ionic liquid. Scale Up. Process engineering may be employed for bulk material preparation. The amount of material required will depend on the specific material and application, but the goal will be to prepare quantities such that bulk mechanical behavior can be evaluated with good statistical accuracy. Processing schemes, which are cognizant of scale-up issues, need to be developed such that the resultant polymers are of high purity. Bulk Property Characterization. Tensile and flexural yield strength, tensile and flexural moduli, elongation at yield, fracture toughness, actuation force, actuation frequency, conductivity, ion mobility and device performance may be characterized to understand the role of the ionic liquid in material properties and performance, particularly as they relate to actuators and polyelectrolyte membranes. Properties and performance should be characterized to elucidate the effect of ionic liquids when used for solvation vs. as a polymerizable monomer. These data will be fed back to the design stage to generate materials with targeted properties.

Impact: Potential applications for DoD and private industry include: flexible electroactive materials for adaptive structures and smart skins; smart munitions, high temperature non-

aqueous polymer electrolyte materials for power and energy applications, site-specific chemical detectors; energy absorbing materials; polymer membranes with selective transport and catalytic capability; and environmentally friendly coatings and adhesive materials.

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FY07 MURI Topic #24
Submit white papers and proposals to the Army Research Office

Self-healing Polymer Composites through Mechanochemical Transduction

Background: Polymer composites capable of self-repair or healing when damaged represent an exciting and important research goal with exceptional relevance to Army and DoD materiel, as well as civilian goods. While biological systems regularly utilize such capability, designing synthetic polymer composites to behave in such a manner represents a formidable scientific challenge. The concept of self-healing materials has been explored for many years using a variety of scientific approaches, but the vast majority of successes have been limited to laboratory experiments with model materials. Furthermore, multidisciplinary research to integrate polymer chemistry and structural composite design has not been addressed. A recent workshop on this topic sponsored by the U.S. Army Research Office explored historical accomplishments in self-healing materials in addition to emerging high potential opportunities (copies of the workshop report are available upon request). A key result from this workshop was the identification of mechanochemical transduction as a novel and particularly promising approach to enable revolutionary self-healing polymer composites. Mechanochemical phenomena, based on chemical activation initiated by the application of an external mechanical force, have long been underutilized as a basis for chemical activation. Similarly, polymer composite design has not been employed for producing, sustaining, and facilitating molecular functionality in bulk materials. The focus of this MURI is to exploit mechanochemical transduction and composite design engineering for the realization of unprecedented self-healing polymer composites. Areas where these materials could have a significant impact are far reaching and include coatings, membranes, gaskets, textiles, and electronics.

Objective: This MURI will bring chemistry, materials science, and composite engineering together to use mechanochemical transduction as a self-healing mechanism in composite materials. The goals include: (1) design molecules that activate in response to an external mechanical force, (2) incorporate these molecules into polymer composites, and (3) demonstrate self-healing using standardized fracture toughness testing. Vascular or similar delivery systems are not relevant to this topic.

Research Concentration Areas: Molecular Design: Molecular dynamic and thermodynamic theory should be extended to describe mechanochemical transduction, to develop predictive computational methodologies, and to guide the rapid design and synthesis of novel mechanophores. A multi-faceted synthetic approach is anticipated to enable the preparation of materials that exploit mechanochemical phenomena, such as small molecules, oligomers, or polymers. Design approaches may include, but are not limited to, bond cleavage (e.g., homolysis, heterolysis), addition (e.g., cycloaddition, crosslinking), coordination (e.g., metal-ligand), and network formation chemistries (e.g., H-bonding networks). Molecular design research must be adaptive to design parameters developed in complementary polymer composite design efforts. Polymer Composite Design: Polymer composite formulation, synthesis, and characterization strategies should be developed to produce, sustain and facilitate molecular functionality in bulk materials. Formulation strategies include compositions, reinforcement strategies, and multi-scale architectures. Synthesis should address controlled distribution of a wide range of potential mechanophores, in addition to polymer composite scale-up sufficient to enable standard mechanical testing of bulk material properties. Characterization should address quantitative perturbations in electronic structure, reactivity, adhesion and bond strength with the

application of mechanical force, in addition to standardized fracture toughness evaluation for both virgin and healed/repaired materials. Polymer composite design research must be adaptive to chemistries and molecular formulations developed in complementary molecular design efforts.

Impact: The potential impact of this topic on Department of Defense (DoD) and the commercial sector is tremendous, including coatings that aid in puncture repair, provide increased barrier protection, minimize tribology failure, and allow surfaces to be recoated with easily removable paints. This research could lead to more robust adhesives and also to improved gaskets and seals. Damage detection and diagnostics could also be impacted. Self-repairing materials may find application in protective materials, composite systems, implants and prosthetics, electronic, photovoltaic fibers, membranes for selective transport, and may even lead to reconfigurable "non-failing" materials that respond before failure rather than self-repairing after failure.

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FY07 MURI Topic #25
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Engineering of Phase Transforming EMO Materials

Background: Recent breakthroughs in the development of high-strain actuators demonstrate that the engineering of materials to realize highly reversible phase transformations can reap huge benefits in performance that extend well beyond mechanical actuation. In general, high-strain actuators operate by the nucleation and propagation of phase boundaries. Historically, this has resulted in large hysteresis losses that add to the switching energy requirements, complicate the control strategies, promote fatigue, and generally limit the life of the devices. Thus, the discovery that ternary and quaternary composition modifications to Ni-Ti shape memory alloys could result in a ten-fold reduction in hysteresis losses was noteworthy. This was achieved by fine tuning the compositions to provide for precise lattice parameter matches of the different stress-induced phase variants across a shared, geometrically compatible, habit plane. Similarly, recent breakthroughs in the relaxor ferroelectrics have demonstrated that frustration effects can be present near the morphotropic phase boundary that result in large strain responses with very little hysteresis. The frustration results from the interplay between short-range bonding and long-range electrostatic and elastic forces, and can effectively reduce the barriers for the transition between strain states. The extension of these principles more generally to other electronic, optical and magnetic material systems represents a new approach to developing materials with unprecedented dynamic tunability and unique physical properties. By incorporating these and other design strategies into phase transformable systems, where the two phases are engineered to have radically different electromagnetic properties, it should be possible to generate new and very interesting classes of adaptive or smart materials that offer unique behavior and revolutionary new properties.

Objective: Develop a fundamental understanding and establish the engineering expertise needed to tailor the electrical, magnetic, or optical (EMO) properties of phase transforming materials through the design and implementation of highly reversible, phase-transformations.

Research Concentration Areas: Conduct basic research in the following areas to establish the science base and infrastructure needed to enable new classes of materials that derive novel and superior performance through development of highly reversible phase transformations. Research should include, but not necessarily be limited to the following areas: 1) Exploration of different approaches to achieving highly reversible phase transformations, including such effects as engineered phase compatibility and frustration. 2) Development of a fundamental understanding of the physics and modeling tools for predicting the occurrence of states, and the range of behaviors that could be realized within engineered phase transforming materials. 3) Identify methods for enhancing the performance of phase transforming materials and stabilizing their desired phase transformations against long-term degradation. Finally, 4) demonstration of novel EMO materials and devices with application to various tunable electronic, power conversion/harvesting, adaptive optic, optical limiting, and smart systems.

Impact: To date, new strategies based on phase engineering of the materials have been successfully realized in actuation systems, e.g. in shape memory alloys and relaxor ferroelectrics. The same underlying principals should be transferable to the development of EM sensors, tunable phase shifters, adaptive optics, optical limiting and energy harvesting devices. Implementation of these concepts should also lead to reversible two-state systems for the reversible storage of hydrogen, controlled conduction of electricity or heat, and regulated emission or transmission of light. Further, these ideas could inspire a new generation of smart materials that would be capable of autonomously responding to external

stimuli and their environment to provide for optimal performance and function.

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FY07 MURI Topic #26
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Robust and Resilient Tactical MANETs

Background: Mobile *ad hoc* networks (MANETs) are a key component underpinning the Army's Future Force concept; at the tactical level, suitably employed MANETs will provide the capability to enable information dominance of net-centric warfare. This tremendous capability, coupled with the reliance that the Army will place on them, will almost certainly subject them to a wide variety of sophisticated attacks. Unfortunately, progress in addressing this issue has been affected by a fundamental lack of knowledge and understanding related to the robustness and resiliency of MANETs. The urgency of the issue is further increased because there does not appear to be any temporary or near term solution to the problem. Some specific obstacles and challenges posed by MANETs are: understanding of their underlying physical characteristics and interrelationships such as bit error, packet loss, and unreliable or intermittent connections, understanding of topological concerns and their relationship to self-organization, mobility, and decentralized control. Further complications occur because the transfer of information will be multi-hop and multi-tiered, with large variations in load, latency, bit error, and packet loss. It is only through an all out multi-disciplinary effort that real progress can be made toward developing rigorous design methods for MANETs that will provide a prescribed level of performance against intrusions and attacks. It is envisioned some of the critical elements comprising this solution will rely on the development of algorithms and protocols for resilient and robust communication, development of ability for networks to self-organize and dynamically reconfigure, and optimization methods that will help elucidate security and performance trade-offs. Additionally, employment of survivability and/or risk engineering may enable MANETs to maintain their critical services in the face of a wide variety of attacks.

Objective: Using insights from multiple disciplines in networking, engineering, mathematics, operations research, biology, statistics, cryptography, and systems theory, develop the analytical models, tools, and mathematical representations for assessing, prescribing, analyzing, and predicting the behavior of robust and resilient mobile ad hoc networks under a total threat spectrum to provide security, robustness and resilience for tactical MANETs.

Research Concentration Areas: Areas of interest include but are not limited to: 1) mathematical representations and tools for modeling and analysis of resilient and robust MANETs, 2) theories that explain the MANET layered architecture and cross layer interaction (both intentional and unintentional), 3) theories that elucidate the relationships and understanding of the trades between fragility and robustness, 4) interaction of networks, particularly, MANETs, low energy wireless sensor networks, and wired communications networks, 5) design of MANET survivability algorithms and architecture, resilient management mechanisms, threat spectrum analysis for information applications on MANETs, fault tolerant and attack resilient communication protocols, survivability requirements engineering, and security and trustworthiness in MANETs. Strategies for network control, management, attack detection and response must be devised, and must take into account the complexity of constraints between layers of system architecture and from the cross layer communication perspective. Multi-disciplined research, such as biologically inspired networks and algorithms drawn from areas of physiology, immunology and ecology, will contribute to the understanding of robust networking and the development of innovative solutions.

Impact: The results from this research will lead to a better understanding of how the tactical ad hoc and sensor networks will react in a battlefield deployment. Successful

research will provide network protocols and analysis techniques, software engineering techniques, and algorithms and architectures for attack resilient and self-healing tactical MANET. This will significantly enhance the Department of Defense's (DoD's) ability to analyze and design robust and resilient mobile wireless networks, then predict performance in a variety of challenging environments and under various level of threats/attacks. In addition, this research will lead to a larger body of knowledge in network science and a better understanding of this new science.

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FY07 MURI Topic # 27
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Urban Sensor Network Structure for Data Fusion

Background: Advances in mobile and stationary sensing technologies have significantly increased modern warfare capabilities. On the other hand there is a lack of fundamental theory and principles for the design and operation of large-scale complex sensor networks with performance predictability. The operational aspect of the design issue is traditionally formulated in terms of performance optimization with a given set of resources. This way of addressing the problem often results in limited knowledge about overall performance and subsequent system failure. Such failure is prone to unexpected events as exemplified by past network failures, for example, crashes of communication networks, large-scale blackouts of power grids, and uncertainty in recent military operations. The design aspect requires a careful topological layout of network infrastructure with optimal combinations and deployment of sensing assets to ensure predictable performance for a given mission objective. This research effort focuses on the latter to develop fundamental theory of network structure whose ultimate goal is data fusion.

There exist many different infrastructures to ensure quality of service, including traditional interconnected communication networks, distributed service delivery systems, and cellular communication structure. The choice of structure strongly influences the quality of service. Recently, research communities within the Department of Defense (DoD) and in the civilian sector have shown growing interest in network science that enables performance predictability of network-centric operations. With the increasing deployment of sensing capabilities, there is a need to address the problem of network design and operation for effectively networked sensor data fusion. Challenging issues include pervasive existence of heterogeneous sensing platforms, limited understanding of sensor performance, dynamic operational environment, line of sight constraints, communication bandwidth limitations, and power constraints.

Objective: The objective of this program is to develop fundamental theory and principles of network structure/dynamic operation for mission-oriented networked sensor data fusion that provide quantitative characterization of structural influence on performance and enable performance predictability.

Research Concentration Areas: Research should address the fundamentals of network structure as relevant to data fusion and may include, but is not limited to, the following areas: (1) For a representative set of military missions (chosen by the proposer), outline required/desired capabilities of a sensing network with limited bandwidth and constrained power, including distributed collection and delivery of information, timeliness, and reliability. Scalability is required. Operational uncertainties, disruptive events, and/or failure of individual components must be taken into account. (2) Determine optimal or a "satisfying" network structure that corresponds to these missions. This involves analyzing the information flow within the network and defining what "satisfying" means, that is, defining a performance metric or metrics. The performance metrics should be mathematically justified, practically useful and computationally feasible. These metrics should include measurement of resilience of the network structure and performance prediction. Characterization of minimal asset requirements to meet a priori given performance level is of interest. (3) In these performance metrics, make explicit the trade-offs among different

types of network structure (totally flat, hierarchical, hybrid; totally ad hoc wireless or with wired backbone) and the influence of these structures on completely distributed and hybrid (partially distributed and partially locally centralized) fusion. (4) Investigate dynamic control of network structure and sensing platforms: Networked sensor platforms need to respond to rapidly evolving commander's intent and operation scenarios, which may require spatial-temporal network analysis, target prioritization, and proactive positioning of mobile sensing assets. (5) Verify and validate the theoretical results on one or more sets of historical or military-exercise data.

Impact: This research provides advances in the effective design and operation of distributed, networked sensing assets. It assures performance predictability for large-scale sensing operations. The military payoffs are improved force situational awareness, effectiveness, and lethality. Civilian payoffs include improved effectiveness in homeland security and border control.

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FY07 MURI Topic # 28
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Dynamic Modeling of 3D Urban Terrain

Background: Urban terrain is particularly challenging to model because it has "ubiquitous" discontinuities (walls, corners) as well as planar regions and regions of slow and rapid smooth change and it has multivalent height and non-genus-0 topology (buildings, overhangs, bridges, underpasses, subways, etc.). Point-cloud data for urban terrain is becoming widely available both in databases and in real time. "Explicit" methods, that is, methods that provide an explicit representation of the surface(s) such as triangular mesh surfaces (TMSs) are often used to model urban terrain. TMSs can model corners and planar regions accurately and with high compression but not regions of smooth change. Fourier-based methods, splines and kriging have advantages for representation of slowly changing smooth regions but display Gibbs phenomena near discontinuities or rapid change. Radial basis functions do not allow sufficient compression. Wavelets are computationally expensive for point-cloud data. "Implicit" methods, that is, methods based on level-set technology, handle topological issues in natural ways but can be computationally complex. As the practical need shifts from "terrain skins" (representations of height as a univalent function of latitude and longitude) to fully 3D terrain with multivalent height and non-genus-0 topology, new methods are required.

Objective: Develop an analytical framework and accurate and efficient computational procedures that are consistent with this framework for modeling the 3D geometry and topology of large regions (1 to 10^4 km^2) of urban terrain.

Research Concentration Areas (RCAs): Interdisciplinary research in geometric modeling, approximation theory, data and information processing, nonparametric statistics, electrical engineering, computer science, learning theory and scientific computing is needed in the following 7 areas: **RCA 1**: Develop a static nonlinear model or models (explicit, implicit or hybrid) for 3D urban terrain that accurately represent the geometry and the topology of the terrain directly from highly nonuniformly distributed point-cloud data by automatic, no-human-in-the-loop procedures with raw compression ratios up to 100. (Raw compression ratio = number of degrees of freedom in data divided by number of degrees of freedom in model). Noise and uncertainty (generally with either unknown or highly non-Gaussian statistical properties) should be taken into account. New approaches are required. TMSs, Fourier-based methods, conventional splines, radial basis functions, kriging, wavelets, tensor-product representations and various other methods that have been extensively investigated over the past 20 years are not recommended. **RCA 2**: Quantify the computational expense both for generating the model and for using the model to compute items of interest (including but not limited to line of sight). Scalability is required. **RCA 3**: Develop or determine an appropriate metric or metrics to measure the accuracy of the model of RCA 1 and determine estimates of accuracy of the model(s) in those metrics. It is unlikely that conventional metrics (such as rms) will be applicable. **RCA 4**: In the metric(s) developed in RCA 3, determine tradeoffs between accuracy and compression. **RCA 5**: Develop methods for computationally efficient generation of a multiresolution sequence of models of increasing geometric and topological accuracy. These methods should be developed in the metrics of RCA 3 and in the context of (sub)optimizing the accuracy/compression tradeoff determined in RCA 4. The multiresolution sequence of models should behave "continuously" and "monotonically" as resolution is increased or decreased (that is, no surprise temporary "pop-ins/outs" or other artifacts as resolution is changed). Ad hoc multiresolution procedures not developed as part of a mathematically unified approach should not be proposed. **RCA 6**: Based on the static models of RCA 1, develop procedures for dynamically learning or re-learning 3D urban terrain as data that

supplement or replace previous data become available. **RCA 7**: Test the models and procedures of RCAs 1, 5 and 6 on large point-cloud urban data sets. For applications such as calculation of line-of-sight regions, quantitatively compare the results for the models and procedures developed under this effort with the best competing approaches.

Impact: Military, peace-keeping and humanitarian operations increasingly take place in urban regions. 3D urban terrain models are needed for simulation, training, mission planning, operational situational awareness and autonomous navigation of ground and air vehicles.

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FY07 MURI Topic # 29
Submit white papers and proposals to the Army Research Office

Wide-band Gap Semiconductor Based Sensing for Detection and Response to WMD Threats

Background: The development of compact sensor platforms for the integration of various sensing modalities is of great importance for national security. Weapons of mass destruction (WMDs) can be formed by compact aerosols of bio-agents or chemical nerve gases. Detection of such warfare agents constitutes an initial safeguard to such attacks so that areas can be evacuated and isolated for further bio-chemical analysis. Past investment in this area aimed at development of bio-agent detection systems with ultraviolet light emitting diodes (UV LEDs) and photomultiplier tubes (Defense Advanced Research Project Agency [DARPA] Semiconductor Ultraviolet Optical Sources [SUVOS]). Wide-bandgap semiconductor based transistors are also under development (DARPA Wide Bandgap Semiconductors program). Utilization of these devices for optical affinity and electric-field based sensors on one integrated platform is made possible due to the transparency of sapphire or other wide-bandgap substrates. Micro-Electro-Mechanical Systems (MEMs) based mass-resonance devices coupled with micro-fluidic delivery systems are also possibilities. A workshop based on the "On-chip detection and identification of biological and chemical molecules" was held in 2004. It targeted the synergy of the semiconductor device advancements together with the biological detection science. Optical affinity based sensors were discussed which incorporate receptor molecules on an optical microbench incorporating both UV LEDs and photodetectors on the same chip. Wide-bandgap semiconductors can be used for such device integration along with microfluidic delivery for a wet-chemistry approach as opposed to airflow based detection. Other sensing approaches can be utilized for orthogonal or combinatorial approaches which enhance probability of detection and reduce false alarms. Identification of such warfare agents may be possible in miniature sensor platforms based on statistical redundancy. Another way to improve the sensing ability of a miniaturized optical system is to look at multispectral illumination and detection. Photodetectors and sources at various wavelengths from the UV (~ 200 nm) thru the visible or near-infrared can be used to enhance the detection space and, with proper signal processing, to localize the probability of identification for a given agent. Micro-spectrometers have been developed with high resolution and small volumes to gather a much greater data set. Miniature gratings for spectral discrimination or even nanostructures such as quantum wires and quantum dots can be easily arrayed for multiple threat sensing capabilities.

Objective: This topic will develop methods and science necessary to employ wide-bandgap semi-conductors (Gallium Nitride and related alloys) as sensing devices for a multi-variate sensing approach toward the detection and identification of biomolecule or chemical based WMDs.

Research Concentration Areas: Development of III-Nitride transparent substrate wide-bandgap semiconductor science for the following sensing approaches: (i) Optical waveguide based passive sensor components, including micro-spectrometers; active devices for multispectral illumination and detection based biosensor devices; (ii) MEMs based mass resonance devices and microfluidic delivery systems based on the same materials platforms; (iii) electric-field based chemical or bio-agent sensing based on quantum confinement and/or piezoelectric effects in these materials (for example, quantum confinement based fluorescence shifts for molecular fingerprinting); and (iv) modeling of devices, device design for accurate understanding of phenomena.

Impact: The impact of this topic will be on the development of more robust integrated circuit based biological or chemical warfare agent sensors. The detection of such chemical/bio-agents in the UV-Vis-NIR with multiple sensor approaches on a single thin-film platform will enable detection and in some cases the identification of WMD threats. Portable and compact sensors with enhanced identification capabilities and reduced false alarm rates will be developed for use in homeland defense applications.

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