ONR Announcement # N00014-20-S-F003
ARO Announcement # W911NF-20-S-0009
AFOSR Announcement # FOA-AFRL-AFOSR-2020-0002

Fiscal Year (FY) 2021 Department of Defense Multidisciplinary Research Program of the University Research Initiative

Deadlines

White Paper Inquiries and Questions
18 May 2020 (Monday)

White Papers must be received no later than
01 June 2020 (Monday) at 11:59 PM Eastern Time

Application Inquiries and Questions
31 August 2020 (Monday)

Applications must be received no later than
14 September 2020 (Monday) at 11:59 PM Eastern Time

SPECIAL NOTE: Applications must be 'VALIDATED' by Grants.gov by the application deadline, which can take up to 48 hours after successful submission. See Timely Receipt Requirements and Proof of Timely Submission

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I. INTRODUCTION

This publication constitutes a Funding Opportunity Announcement (FOA) as contemplated in the Department of Defense Grants and Agreements Regulations (DoDGARS) 32 CFR 22.315(a). A formal Request for Proposals (RFP), solicitation, and/or additional information regarding this announcement will not be issued.

The Department of Defense (DoD) Multidisciplinary University Research Initiative (MURI), one element of the University Research Initiative (URI), is sponsored by the DoD research offices. Those offices include 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").

DOD's MURI program addresses high-risk basic research and attempts to understand or achieve something that has never been done before. The program was initiated over 25 years ago and it has regularly produced significant scientific breakthroughs with far reaching consequences to the fields of science, economic growth, and revolutionary new military technologies. Key to the program's success is the close management of the MURI projects by Service program officers and their active role in providing research guidance.

The DoD agencies will not issue paper copies of this announcement. The DoD agencies involved in this program reserve the right to select for award all, some or none of the proposals submitted in response to this announcement. The 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 FOA will not be returned. It is the policy of the DoD agencies to treat all proposals as competition sensitive information and to disclose their contents only for the purposes of evaluation.

Awards will take the form of grants. FOR ARMY SUBMISSIONS ONLY, awards will take the form of grants and/or cooperative agreements. Any assistance instrument awarded under this announcement will be governed by the award terms and conditions that conform to DoD's implementation of the Office of Management and Budget (OMB) circulars applicable to financial assistance. Terms and conditions will reflect DoD implementation of OMB guidance in 2 CFR Part 200, "Uniform Administrative Requirements, Cost Principles, and Audit Requirements for Federal Awards."

Please note the following important items:

- Topic 27: (OSD) "Advanced Modeling of Evolutionary Cyber Eco-Systems with Autonomous Intelligence" has been added by OSD. Whitepapers and proposals for this topic should be submitted as for AFOSR Topics.
- Topic 12: Opportunities to attract Australian funding for proposals with Australian collaborators in Topic12 are described at http://www.business.gov.au/ausmuri
- Applicants should be alert for any amendments that may modify the announcement. Amendments to the original funding opportunity announcement (FOA) will be posted to the Grants.gov Webpage: https://www.grants.gov/
- A project abstract is required with the application and must be publically releasable as specified in the following section of this FOA: Section II. D. 2. b.(2)

- Responses to the Certifications and Representations indicated in Section II. H., 2 thru 4 of this FOA are required with the application.

- The notice that advisors external to the U.S. government may be used as subject-matter-expert technical consultants in the evaluation of the proposals after signing non-disclosure statements is contained in Section II. E. 4.

A. OVERVIEW

1. Federal Awarding Agency Names

Office of Naval Research
One Liberty Center
875 N. Randolph Street
Arlington, VA 22203-1995

Army Research Office
800 Park Office Drive
Research Triangle Park, NC 27709

Air Force Office of Scientific Research
875 North Randolph Street
Arlington, VA 22203

2. Funding Opportunity Title

Fiscal Year (FY) 2021 Department of Defense Multidisciplinary Research Program of the University Research Initiative

3. Announcement Type

Initial Announcement

4. Funding Opportunity Number

ONR: N00014-20-S-F003
ARO: W911NF-20-S-0009
AFOSR: FOA-AFRL-AFOSR-2020-0002

5. Catalog of Federal Domestic Assistance (CFDA) Numbers

ONR: 12.300
ARO: 12.431
AFOSR: 12.800

NOTE: The correct CFDA Number must be used in proposal submission to avoid misrouting.

6. Key Dates

White Papers due: 01 June 2020 (Monday) at 11:59 PM Eastern Time
Applications due: 14 September 2020 (Monday) at 11:59 PM Eastern Time

For a full Table of Events, see Section II. D. 4. "Significant Dates and Times"

II. DETAILED INFORMATION ABOUT THE RESEARCH OPPORTUNITY

A. PROGRAM DESCRIPTION

The MURI program supports basic research in science and engineering at U.S. institutions of higher education (hereafter referred to as "universities") that is of potential interest to DoD. The program is focused on multidisciplinary research efforts where more than one traditional discipline interacts to provide rapid advances in scientific areas of interest to the DoD. As defined in the DoD Financial Management Regulation:

> Basic research is systematic study directed toward greater knowledge or understanding of the fundamental aspects of phenomena and of observable facts without specific applications towards processes or products in mind. It includes all scientific study and experimentation directed toward increasing fundamental knowledge and understanding in those fields of the physical, engineering, environmental, and life sciences related to long-term national security needs. It is farsighted high payoff research that provides the basis for technological progress (DoD 7000.14-R, vol. 2B, chap. 5, para. 050201.B).

DoD's basic research program invests broadly in many fields to ensure that it has early cognizance of new scientific knowledge.

The FY 2021 MURI competition is for the topics listed below.

Detailed descriptions of the topics and the Topic Chief for each can be found in Section II. I, entitled, "SPECIFIC MURI TOPICS," The detailed descriptions are intended to provide the applicant 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.

Proposals from a team of university investigators are warranted when the necessary expertise in addressing the multiple facets of the topics may reside in different universities. By supporting multidisciplinary teams, the program is complementary to other DoD basic research programs that support university research through single-investigator awards. Proposals shall name one Principal Investigator (PI) as the responsible technical point of contact. Similarly, one institution shall be the primary awardee for the purpose of award execution. The PI shall come from the primary institution. The relationship among participating institutions and their respective roles, as well as the apportionment of funds including sub-awards, if any, shall be described in both the proposal text and the budget.

White papers and proposals addressing the following topics should be submitted to the Office of Naval Research (ONR):

ONR:

Topic 1: Molecular Qubits for Synthetic Electronics

Topic 2: A Brain-based Compositional Framework for Robust Computer Vision

Topic 3: Littoral Ocean Dynamics off Rocky Coasts and Shorelines

Topic 4: Fog and Turbulence

Topic 5: Dynamic Tuning of Thermal Transport

Topic 6: Chemically and Thermally Insensitive Super/Ultra-Hard Materials

Topic 7: Narrative, Moral and Social Foundations of Social Cyber-Attack in Social Media

Topic 8: A Dynamics and Control Theory of Safe, Cognitive and Learning Systems

Topic 9: Understanding Turbulence-Chemistry Interactions in Non-Equilibrium, High-Speed Flows

Topic 10: Predicting Organic Molecular Decomposition

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

ARO:

Topic 11: Anomalous Dipole Textures in Engineered Ferroelectric Materials

Topic 12: Cyber Autonomy through Robust Learning and Effective Human/Bot Teaming

Topic 13: Highly Heterogeneous Meta-macrostructures Created via Fine-particle Interactions

Topic 14: Non-Silica Inorganic Material Phases Synthesized from Genetically Modified Diatoms

Topic 15: Novel Mechanisms of Neuro-Glio Bio-Computation and Reinforcement Learning

Topic 16: Quantum Network Science

Topic 17: The Same is Different: Integrating Multiple Phenomena in Single Materials

Topic 18: Tunable Dilute Anion III-Nitride Nanostructures for Stable Photocatalysis

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

AFOSR:

Topic 19: Mechanisms of Novel Reactivity in Aqueous Microdroplets

Topic 20: Topological Plasma Electromagnetics

Topic 21: Interfacial Engineering of Superconductors

Topic 22: Targeted Optical Stimulation of Individual Retinal Photoreceptors

Topic 23: Quantum Random Access Memory

Topic 24: Metasurface Edge Sensing, Processing and Computing

Topic 25: Non-Hermitian Programmable Materials at Exceptional Points

Topic 26: Mathematical Foundations for Enabling Robust Optimal Design of Hypersonic Systems

White papers and proposals addressing the following OSD topic should be submitted to the Air Force Office of Scientific Research (AFOSR):

OSD:

Topic 27: Advanced Modeling of Evolutionary Cyber Eco-Systems with Autonomous Intelligence

B. FEDERAL AWARD INFORMATION

1. Period of Performance

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

2. Award Amount

The total amount of funding for the five years available for grants resulting from this MURI FOA is estimated to be approximately $190 million dollars pending out-year appropriations. MURI awards are contingent on availability of funds, the specific topic, and the scope of the proposed work. Typical annual funding per grant is in the $1.25M to $1.5M range. The amount of the award and the number of supported researchers should generally not exceed the limit specified for the individual topics in Section II. I.

It is strongly recommended that applicants communicate with the Research Topic Chiefs 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.

C. ELIGIBILITY INFORMATION

This MURI competition is open only to, and proposals are to be submitted only by, U.S. institutions of higher education (universities) with degree-granting programs in science and/or engineering, including DoD institutions of higher education. To the extent that it is a part of a U.S. institution of higher education and is not designated as a Federally Funded Research and

Development Center (FFRDC), a University Affiliated Research Center (UARC) or other University Affiliated Laboratory (UAL) is eligible to submit a proposal to this MURI competition and/or receive MURI funds. Ineligible organizations (e.g., industry, DoD laboratories, FFRDCs, and foreign entities) may collaborate on the research but may not receive MURI funds directly or via subaward.

To assess risk posed by applicants, we review your application, proposal, and Office of Management and Budget (OMB) designated repositories of government-wide public and non-public data, including comments you have made, as required by 31 U.S.C. 3321 and 41 U.S.C. 2313 and described in 2 CFR 200.205 and 32 CFR 22.410 to confirm you are qualified, responsible, and eligible to receive an award.

When additional funding for an ineligible organization is necessary to make the proposed collaboration possible, such funds may be identified via a separate proposal from that organization. This supplemental proposal shall be attached to the primary MURI proposal and will be evaluated in accordance with the MURI review criteria by the responsible Research Topic Chief. If approved, the supplemental proposal may be funded using non-MURI or non-Government funds.

D. APPLICATION AND SUBMISSION INFORMATION

1. Application and Submission Process

Regardless of whether or not a non-MURI funded collaboration is included in the proposal, the same submission process for white papers and proposals will be followed.

The proposal submission process has two stages:

- Applicants are encouraged to submit a white paper; and
- Applicants must submit a proposal through Grants.gov.

Prospective awardees are encouraged to submit white papers to minimize the labor and cost associated with the production of detailed proposals that have very little chance of being selected for funding. Based on an assessment of the white papers, the responsible Research Topic Chief will provide informal feedback notification to the prospective awardees to encourage or discourage submission of proposals. The Research Topic Chief may also, on occasion, provide feedback encouraging re-teaming to strengthen a proposal.

Submission of White Papers:

ARO and ONR White Paper Submissions: White Papers to ARO and ONR may be submitted via e-mail directly to the Research Topic Chief, or via the United States Postal Service (USPS), or via a commercial carrier to the agency specified for the topic. For hard copy submissions, use the addresses provided in Section II. D. 2. a, entitled, "Address for Submission of Hard Copy White Papers."

AFOSR White Paper Submission: White papers to AFOSR Research Topic Chiefs should be

submitted electronically via https://afosr.gov1.qualtrics.com/jfe/form/SV_6E8xfwSxoGWisS1. Detailed instructions are included on the submission page. For support, please contact Ms. Katie Wisecarver at 703-696-9544 or MURI@us.af.mil.

Hard copy 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. **Do NOT email ZIP files and/or password protected files.**

White Paper Deadline: The due date and time for receipt of white papers is no later than 01 June 2020 (Monday) at 11:59 PM Eastern Time

Evaluation/Notification: Initial evaluations of the white papers will be issued on, or about, 22 June 2020 (Monday).

Submission of Proposal: Any applicant may submit a proposal even if its white paper was not identified as being of "particular value" to the Government or if no white paper was submitted. However, the initial evaluation of the white papers should give the prospective awardee some indication of whether a proposal would likely result in an award.

Proposal Deadline: Proposals must be submitted and received electronically through Grants.gov not later than 14 September 2020 (Monday) at 11:59 PM Eastern Time to be considered for selection. This is the final due date.

Applicants are responsible for making sure the application is submitted, received, and validated by Grants.gov before the application deadline. Late applications are ineligible for consideration.

Award Notification: It is anticipated that final selections for award will be made on or about, 01 February 2021 (Monday). See Section II. D. 4. for "Significant Dates and Times."

2. Content and Format of White Papers/Applications

The white papers and proposals submitted under this FOA are expected to address unclassified basic research. White papers and proposals will be protected from unauthorized disclosure in accordance with applicable laws and DoD regulations.

Applicants are expected to appropriately mark each page of their submission that contains proprietary information.

For proposals containing data that the applicant does not want disclosed to the public for any reason, or used by the Government except for evaluation purposes, the applicant shall mark the title page with the following legend:

"This proposal includes data that shall not be disclosed outside the Government and shall not be duplicated, used, or disclosed--in whole or in part--for any purpose other than to evaluate the proposal or for program coordination. If, however, a grant is awarded to this applicant as a result of--or in connection with-- the submission of this data, the Government shall have the right to

duplicate, use, or disclose the data to the extent provided in the resulting award. This restriction does not limit the Government's right to use information contained in this data if it is obtained from another source without restriction. The data subject to this restriction is contained in (insert numbers or other identification of sheets)."

Also, mark each sheet of data that the applicant wishes to restrict with the following legend: "Use or disclosure of data contained on this sheet is subject to the restriction on the title page of this proposal."

Titles given to the White Papers/Proposals should be descriptive of the basic research they cover and not be merely a copy of the topic title.

Use of Principal Investigator (PI) Over Multiple Proposals/Topics:

Applicants contemplating the use of an individual as Principal Investigator (PI) for more than one proposal and/or topic are strongly encouraged to contact the Topic Chief(s) prior to white paper submission to determine if the Topic Chief(s) support PI participation in multiple proposals and/or topics. Support of the use of a PI over multiple proposals and/or topics is at the discretion of the Topic Chief(s).

PI participation in multiple proposals and/or topics shall be identified in all white paper submissions where the PI is proposed. The white paper should also document the amount of time the PI is available for the project(s) and how the PI will manage their time given the possibility of multiple awards.

Applicants that do not submit white papers, but wish to submit a proposal, shall document PI participation in multiple proposals and/or topics in all proposals where the PI is proposed. The proposal should also document the amount of time the PI is available for the project(s) and how the PI will manage their time given the possibility of multiple awards.

a. White Papers

White paper format shall be as follows:

- Paper Size - 8.5 x 11 inch paper
- Margins - 1 inch
- Spacing – single spaced
- Font - Times New Roman, 12 point
- Number of Pages - no more than four (4) single-sided pages (excluding cover letter, cover page, and curriculum vitae). White paper pages beyond the 4-page limit may not be evaluated or read.
- Copies - For Hard Copy Submissions please provide one (1) original and two (2) copies.

White Paper content shall be as follows:

- A cover letter (optional – one page)
- A cover page, labeled "PROPOSAL WHITE PAPER," that includes the FOA number,

proposed title, and proposer's technical point of contact, with telephone number, facsimile number, e-mail address, topic number, and topic title
- Identification of the research and issues
- Proposed technical approaches
- Potential impact on DoD capabilities
- Potential team and management plan
- Summary of estimated costs
- Curriculum vitae of key investigators (see Use of Principal Investigator (PI) Over Multiple Proposals/Topics)
- Identification of any Organizational Conflict(s) of Interest (if any) – See Section II. H. 5 for more details.
- Identification of anticipated human or animal subject research

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.

Address for Submission of Hard Copy White Papers

Each topic in this announcement has one or more Research Topic Chief(s) identified from one of the participating agencies; ONR, ARO, or AFOSR. Prospective applicants shall submit the white paper to one of the Research Topic Chiefs at the agency to which they are applying.

Submission of hard copy white papers shall be sent to the addresses below.
Important Notes Regarding Submission of Hard Copy White Papers: If the Applicant is using USPS, please allow an additional five (5) business days for the package to be delivered due to USPS mail being sent to a central location for special processing before it is sent to the addresses below.

Office of Naval Research:
Hard copies of white papers topics (X) through (XX) should be sent to the Office of Naval Research at the following address: (For those topics with multiple topic chiefs, send the white paper to the first topic chief listed.)

Primary:
Office of Naval Research
ATTN: (list name of responsible Research Topic Chief)
875 North Randolph Street - Suite W256A
Arlington, VA 22203-1995
Point of Contact: Paula Barden
Email: paula.barden.ctr@navy.mil
703-696-4111

Secondary:
Office of Naval Research
ATTN: (list name of responsible Research Topic Chief)
875 North Randolph Street - Suite 1020

Arlington, VA 22203-1995
Point of Contact:-Dr. Ellen Livingston
Email: ellen.s.livingston@navy.mil
Phone: 703-696-4668

U.S. Army Research Office:
Hard copy white papers addressing topics (XX) through (XX) should be sent to the U.S. Army Research Office at one of the following addresses:

For delivery by USPS use:
U.S. Army Research Office (FY21 MURI)
P. O. Box 12211
Research Triangle Park, NC 27709-2211

For commercial delivery (such as FedEx, UPS, etc.) use:
U.S. Army Research Office (FY21 MURI)
For white papers include:
ATTN: (list name of responsible Research Topic Chief)
800 Park Office Drive, Suite 4229
Research Triangle Park, NC 27709
919-549-4211

Air Force Office of Scientific Research:
Hard copy white papers addressing topics (XX) through (XX) should be sent to the Air Force Office of Scientific Research at the following address:

Air Force Office of Scientific Research
ATTN: (list name of responsible Research Topic Chief)
875 North Randolph Street, Suite 325, Room 3112
Arlington, VA 22203-1768
Reference phone # 703-696-9544
Email: MURI@us.af.mil

b. Application Package

NOTE: Proposals must be submitted electronically through Grants.gov.

Before you start: Identify the SPECIFIC MURI TOPICS to which you are proposing and obtain the associated agency and Topic Chief for your topic. You will find the topics with the associated agency and Topic Chief listed in Section II. I, entitled "SPECIFIC MURI TOPICS". This information is needed for the grants.gov Agency Routing Identifier and the CFDA number.

Content and Form of Application:

Prospective applicants submitting an application must complete the mandatory forms in accordance with the instructions provided 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.

Required Forms

(1) SF 424 Form (RESEARCH & RELATED) (Mandatory)

The SF 424 (R&R) form must be used as the cover page for all proposals. Complete all required fields in accordance with the "pop-up" instructions on the form and the following instructions for specific fields. Please complete the SF 424 first, as some fields on the SF 424 are used to auto-populate fields on other forms.

The completion of most fields is self-explanatory with the exception of the following special instructions:

- Field 3 - Date Received by State: The Date Received by State and the State Application Identifier are not applicable to research. Leave blank.

- Field 4a - Federal Identifier:
  For ONR, enter "N00014"
  For ARO, enter "W36QYT"
  For AFOSR, enter "FA9550"

- Field 4b - Agency Routing Number:

  For ONR, enter the three (3) digit Research Topic Chief's Code and the Research Topic Chief's name (last name first) in brackets (e.g., 331 [Smith, John]).
  For ARO, enter the name of the Research Topic Chief.
  For AFOSR, enter the Research Topic Chief's Topic Number (#) and Research Topic Chief's name (last name first) in brackets (e.g., 12 [Smith, John]).

Applicants who fail to provide an Agency Routing Number may receive a notice that their proposal is rejected.

- Field 4c - Previous Grants.gov Tracking ID: If this submission is for a Changed/Corrected Application, enter the Grants.gov tracking number of the previous proposal submission; otherwise, leave blank.

- Field 7 - Type of Applicant: Complete as indicated. If the organization is a Minority Institution, select "Other" and under "Other (Specify)" note that the institution is a Minority Institution (MI).

- Field 9 - Name of Federal Agency: List the appropriate agency (i.e., ONR, AFOSR, or ARO) as the reviewing agency. This field is usually pre-populated in Grants.gov.

- Field 16 - Is Application Subject to Review by State Executive Order 12372 Process? Choose "No". Check "Program is Not Covered by Executive Order 12372."

- Field 17 – Certification: All awards require some form of certifications of compliance with national policy requirements. By checking the "I agree" box in field 17, and attaching the representation to Field 18 of the SF424 (R&R) as part of the electronic proposal submitted via Grants.gov, the Grant Applicant is providing the certification on lobbying required by 32 CFR Part 28 and representation regarding an unpaid delinquent tax liability or a felony conviction under any federal law – DoD appropriations.

(2) R&R Form: Project Abstract Form (Mandatory)

The project summary/abstract must identify the research problem and objectives, technical approaches, anticipated outcome of the research, if successful, and impact on DoD capabilities. Use only characters available on a standard QWERTY keyboard. Spell out all Greek letters, other non-English letters, and symbols. Graphics are not allowed and there is a 4,000 character limit including spaces.

Do not include proprietary or confidential information. The project summary abstract must be marked by the applicant as "Approved for Public Release". Abstracts of all funded research projects will be posted on the public DTIC website: https://dodgrantawards.dtic.mil/grants

(3) R&R Form: Research and Related Other Project Information (Mandatory)

- Fields 1 and 1a - Human Subject Use: Each proposal must address human subject involvement in the research by completing Fields 1 and 1a of the R&R Other Project Information form. For proposals containing activities that include or may include "research involving human subjects" as defined in DoDI 3216.02, prior to award, the Applicant must submit the documentation under "Use of Human Subjects in Research" (Section II. H. 6.).

- Fields 2 and 2a – Vertebrae Animal Use: Each proposal must address animal use protocols by completing Fields 2 and 2a of the R&R Other Project Information form. If animals are to be utilized in the research effort proposed, the Applicant must submit the documents described under "Use of Animals" (Section II. H. 6.).

- Fields 4a through 4d - Environmental Compliance: Address these fields and briefly indicate whether the intended research will result in environmental impacts outside the laboratory, and how the applicant will ensure compliance with environmental statutes and regulations.

  Federal agencies making grant or cooperative agreement awards and recipients of such awards must comply with various environmental requirements. The National Environmental Policy Act of 1969 (NEPA), 42 U.S.C. Sections 4321-4370 (a), requires that agencies consider the environmental impact of "major Federal actions" prior to any final agency decision. With respect to those awards which constitute "major Federal actions," as defined in 40 CFR 1508.18, federal agencies may be required to comply with NEPA and prepare an environmental impact statement (EIS), even if the agency does no more than provide grant funds to the recipient. Questions regarding NEPA

compliance should be referred to the Research Topic Chief.

- Field 7 – Project Abstract: Leave Field 7 blank; complete Form SF 424, Project Abstract.

- Field 8 – Project Narrative: Describe clearly the research, including the objective and approach to be performed, keeping in mind the evaluation criteria. Attach the entire proposal narrative to R&R Other Project Information form in Field 8. To attach a Project Narrative in Field 8 click on "Add Attachment" and attach the technical proposal as a single PDF file. (Save the file as "Technical Proposal," as typing in the box is prohibited).

The Following Formatting Rules Apply for Field 8

- Paper size when printed - 8.5 x 11-inch paper
- Margins - 1 inch
- Spacing - single
- Font - Times New Roman, 12 point
- Number of pages in Field 8 - no more than twenty-five (25) single-sided pages. The cover page, table of contents, list of references, letters of support, curriculum vitae and list of on-going and pending research support are excluded from the page limitations. The pages of proposals exceeding the page limit may not be included in the evaluation.

Requirements for Field 8

The first page (cover page) of the narrative must include the following information:

- Principal Investigator (PI) name
- Phone number, fax number and e-mail address
- Institution, Department, Division
- Institution address
- Other universities involved in the MURI team
- Is the PI a current DoD Contractor or Grantee?
- If yes, provide Agency, point of contact; and 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.

Technical Approach: Describe in detail the basic research in science and/or engineering 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, and discuss potential scientific breakthroughs. Include appropriate literature citations/references. Discuss the nature of

expected results. Describe plans for the research training of students. Include the number of time equivalent graduate students and undergraduates, if any, to be supported each year. Discuss the involvement of other students, if any.

Project Schedule: A summary of the schedule of events and a detailed description of the expected results.

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.

• 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, that are required for the proposed effort.

• Describe in detail proposed subawards to other eligible universities or with other eligible institutions. If subawards to other universities are proposed, make clear the division of research activities, to be supported by detailed budgets for the proposed subawards.

• 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 Research Topic Chief. Briefly summarize the qualifications of the Principal Investigator and other key investigators who will conduct the proposed research. Details can be included in the individual CVs.

• Briefly describe the research activities of the Principal Investigator (PI) and co-investigators in on-going and pending research projects, the time charged to each of these projects, and their relationship to the proposed effort. Details should be included in the individual CVs. Provide the percentage of the PI's time which will be allotted to this research project by year and the percentage of his time which is specifically committed or obligated to other activities (e.g. teaching, other grants, contracts, consultancies).

• Describe plans to manage the interactions among members of the proposed research team.

• 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 five Letters of Support, describing interest in the topic area expressing a commitment for funding support may be included.

Curriculum Vitae: Include curriculum vitae of the Principal Investigator and key co-investigators. List the amount of funding and describe the research activities of the Principal Investigator and key co-investigators in on-going and pending research projects, whether or not acting as Principal Investigator in these other projects.

(4) R&R Form: Research & Related Budget

The applicant must use the Grants.gov forms from the application package template associated with the FOA on the Grants.gov web site located at https://www.grants.gov/.

A separate Adobe .pdf document should be included in the application that provides appropriate justification and/or supporting documentation for each element of cost proposed. This document shall be attached under Section K. "Budget Justification" of the Research and Related Budget form. Click "Add Attachment" to attach.

Budget format should be as follows:

- Paper Size – 8.5 x 11-inch paper
- Margins – 1 inch
- Spacing – single spaced
- Font – Times New Roman, 12 point
- There are no page limitations to the Budget.

NOTE: The electronic file name for all documents submitted under this FOA must not exceed 68 characters in length, including the file name extension.

The budget shall adhere to the following guidelines.

There should be a detailed breakdown of all costs, by cost category, and by the calendar periods stated below. For budget purposes, use an award start date of 01 May 2021. Note that the budget for each of the calendar periods below should include only those costs to be expended during that calendar period. The budget should also include an option for two additional years

For proposals to **ONR topics**, the Recommended Funding Profile is:

(1) FY21: Twelve months (01 May 21 to 30 Apr 22): $1,500,000
(2) FY22: Twelve months (01 May 22 to 30 Apr 23): $1,500,000
(3) FY23: Twelve months (01 May 23 to 30 Apr 24): $1,500,000

Three-year base subtotal: $4,500,000

(4) FY24: Twelve months (01 May 24 to 30 Apr 25): $1,500,000
(5) FY25: Twelve months (01 May 25 to 30 Apr 26): $1,500,000

Two-year option subtotal: $3,000,000
Five-year total: $7,500,000

For proposals to **ARO topics**, the Recommended Funding Profile is:

(1) FY21: Five months (01 May 21 to 30 Sep 21): $520,833
(2) FY22: Twelve months (01 Oct 21 to 30 Sep 22): $1,250,000
(3) FY23: Twelve months (01 Oct 22 to 30 Sep 23): $1,250,000
(4) FY24: Seven months (01 Oct 23 to 30 Apr 24): $729,167

Three-year base subtotal: $3,750,000

(4) FY24: Five months (01 May 24 to 30 Sep 24): $520,833
(5) FY25: Twelve months (01 Oct 24 to 30 Sep 25): $1,250,000
(6) FY26: Seven months (01 Oct 25 to 30 Apr 26): $729,167

Two-year option subtotal: $2,500,000
Five-year total: $6,250,000

For proposals to **AFOSR and OSD topics**, the Recommended Funding Profile is:

(1) FY21: Twelve months (01 May 21 to 30 Apr 22): $1,500,000
(2) FY22: Twelve months (01 May 22 to 30 Apr 23): $1,500,000
(3) FY23: Twelve months (01 May 23 to 30 Apr 24): $1,500,000

Three-year base subtotal: $4,500,000

(4) FY24: Twelve months (01 May 24 to 30 Apr 25): $1,500,000
(5) FY25: Twelve months (01 May 25 to 30 Apr 26): $1,500,000

Two-year option subtotal: $3,000,000
Five-year total: $7,500,000

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

- Direct Labor – Individual labor categories or persons, with associated labor hours and unburdened direct labor rates. Provide any escalation rates for out years.

- Administrative and Clerical Labor – Salaries of administrative and clerical staff are normally indirect costs (and included in an indirect cost rate). Direct charging of these costs may be appropriate when a major project requires an extensive amount of administrative or clerical support significantly greater than normal and routine levels of support. Budgets proposing direct charging of administrative or clerical salaries must be supported with a budget justification which adequately describes the major project and the administrative and/or clerical work to be performed.

- Fringe Benefits and Indirect Costs (F&A, Overhead, G&A, etc.) – The proposal should show the rates and calculation of the costs for each rate category. If the rates have been approved/negotiated by a Government agency, provide a copy of the memorandum/agreement. If the rates have not been approved/ negotiated, provide sufficient detail to enable a determination of allowability, allocability and reasonableness of the allocation bases, and how the rates are calculated. Additional information may be

requested, if needed. If composite rates are used, provide the calculations used in deriving the composite rates.

- Travel – The proposed travel cost should include the following for each trip: the purpose of the trip, origin and destination if known, approximate duration, the number of travelers, and the estimated cost per trip must be justified based on the organizations historical average cost per trip or other reasonable basis for estimation. Such estimates and the resultant costs claimed must conform to the applicable Federal cost principals. Proposed travel should include funds for the OSD Review and other project requirements (see II. H. 9. Project Meetings and Reviews).

- Subawards/Subcontracts – Provide a description of the work to be performed by the subrecipient/ subcontractor. For each subaward, a detailed cost proposal is required to be submitted by the subrecipient(s). A proposal and supporting documentation must be received and reviewed before the Government can complete its cost analysis of the proposal and enter negotiations. The preferred method of receiving subcontract information is for this information to be included with the Prime's proposal; however, a subcontractor's cost proposal can be provided in a sealed envelope with the recipient's cost proposal or via e-mail directly to the Program Officer at the same time the prime proposal is submitted. The e-mail should identify the proposal title, the prime Applicant, and that the attached proposal is a subcontract. Fee/Profit guidance is noted below.

- Consultants – Provide a breakdown of the consultant's hours, the hourly rate proposed, any other proposed consultant costs, a copy of the signed Consulting Agreement or other documentation supporting the proposed consultant rate/cost, and a copy of the consultant's proposed statement of work, if it is not already separately identified in the prime awardee's proposal.

- Materials & Supplies – Provide an itemized list of all proposed materials and supplies including quantities, unit prices, and the basis for the estimate (e.g., quotes, prior purchases, catalog price lists)

- Recipient Acquired Equipment or Facilities – Equipment and/or facilities are normally furnished by the Recipient. If acquisition of equipment and/or facilities is proposed, a justification for the purchase of the items must be provided. Provide an itemized list of all equipment and/ or facilities costs and the basis for the estimate (e.g., quotes, prior purchases, catalog price lists). Allowable items normally would be limited to research equipment not already available for the project. General purpose equipment (i.e., equipment not used exclusively for research, scientific or other technical activities, such as personal computers, laptops, office equipment) should not be requested unless they will be used primarily or exclusively for the project. For computer/laptop purchases and other general purpose equipment, if proposed, include a statement indicating how each item of equipment will be integrated into the program or used as an integral part of the research effort.

- Other Direct Costs – Provide an itemized list of all remaining proposed other direct costs, such as Graduate Assistant tuition, laboratory fees, report and publication costs, and the

basis for the estimate (e.g., quotes, prior purchases, catalog price lists).

- Fee Profit – Fee/profit is unallowable under assistance agreements at either the prime or subaward level but may be permitted on subcontracts issued by the prime awardee.

(5) R&R Form: Research & Related Personal Data (Mandatory)

This form will be used by DoD as the source of demographic information, such as gender, race, ethnicity, and disability information for the Project Director/Principal Investigator and all other persons identified as Co-Project Director(s)/Co-Principal Investigator(s). Each application must include this form with the name fields of the Project Director/Principal Investigator and any Co-Project Director(s)/Co-Principal Investigator(s) completed; however, provision of the demographic information in the form is voluntary. If completing the form for multiple individuals, each Co-Director/Co-Principal Investigator can be added by selecting the "Next Person" button. Up to five key individuals should be entered. The demographic information, if provided, will be used for statistical purposes only and will not be made available to merit reviewers. Applicants who do not wish to provide some or all of the information should check or select the "Do not wish to provide" option.

NOTE: The Government Accountability Office, in its report GAO-16-14, WOMEN IN STEM RESEARCH: Better Data and Information Sharing Could Improve Oversight of Federal Grant-making and Title IX Compliance, December 3, 2015, recommended that the Department of Defense collect certain demographic and career information to be able to assess the success rates of women who are proposed for key roles in applications in science, technology, engineering, or mathematics disciplines.

3. Grants.gov Application Submission and Receipt Procedures

NOTE: White Papers must **not** be submitted through the Grants.gov application process.

Advance Preparation for Electronic Submission through Grants.gov

Your proposal must be submitted electronically through Grants.gov. Your organization must complete several one-time actions before electronic submission. Registration with Grants.gov may take up to twenty-one (21) days.

(1) You should verify that the person authorized to submit proposals for your organization has completed registration well in advance of the submission deadline. Grants.gov electronic proposal submissions cannot be accomplished before your organization is fully registered.

(2) A Grants.gov getting started checklist is available at: https://www.grants.gov/web/grants/learn-grants/grants-101/getting-started-checklist.html.

(3) Guidance for registering with Grants.gov as an organization may be found at: http://www.grants.gov/web/grants/applicants/organization-registration.html.

(4) Questions relating to the Grants.gov registration process, system requirements, how an application works, or the proposal submittal process can be answered by email at

support@grants.gov, telephone at (800) 518-4726 or (606) 545-5035, or at http://www.grants.gov/web/grants/support.html.

(5) An active System for Award Management (SAM) registration and an active Dun & Bradstreet Data Universal Numbering System (DUNS) number are required to register through Grants.gov.

How to Register to Apply through Grants.gov

a. *Instructions:* Applicants should read the registration instructions carefully and prepare the information requested before beginning the registration process. Reviewing and assembling the required information before beginning the registration process will alleviate last-minute searches for required information.

The registration process can take up to four weeks to complete. Therefore, registration should be done in sufficient time to ensure it does not impact your ability to meet required application submission deadlines.

If individual applicants are eligible to apply for this grant funding opportunity, refer to: https://www.grants.gov/web/grants/applicants/registration.html

Organization applicants can find complete instructions here: https://www.grants.gov/web/grants/applicants/organization-registration.html

(1) *Obtain a DUNS Number*: All entities applying for funding, including renewal funding, must have a Data Universal Numbering System (DUNS) number from Dun & Bradstreet (D&B). Applicants must enter the DUNS number in the data entry field labeled "Organizational DUNS" on the SF 424 form.

For more detailed instructions for obtaining a DUNS number, refer to: https://www.grants.gov/web/grants/applicants/organization-registration/step-1-obtain-duns-number.html

(2) *Register with SAM*: In addition to having a DUNS number, organizations applying online through Grants.gov must register with the System for Award Management (SAM). All organizations must register with SAM in order to apply online. Failure to register with SAM will prevent your organization from applying through Grants.gov.

For more detailed instructions for registering with SAM, refer to: https://www.grants.gov/web/grants/applicants/organization-registration/step-2-register-with-sam.html

(3) *Create a Grants.gov Account*: The next step in the registration process is to create an account with Grants.gov. Applicants must know their organization's DUNS number to complete this process. Completing this process automatically triggers an email request for applicant roles to the organization's E-Business Point of Contact (EBiz POC) for review. The EBiz POC is a representative from your organization who is the contact listed for SAM. To apply for grants on behalf of your organization, you will need the Authorized Organizational Representative (AOR) role.

For more detailed instructions about creating a profile on Grants.gov, refer to: https://www.grants.gov/web/grants/applicants/registration/add-profile.html

(4) *Authorize Grants.gov Roles*: After creating an account on Grants.gov, the EBiz POC receives an email notifying them of your registration and request for roles. The EBiz POC will then log in to Grants.gov and authorize the appropriate roles, which may include the AOR role, thereby giving you permission to complete and submit applications on behalf of the organization. You will be able to submit your application online any time after you have been approved as an AOR.

For more detailed instructions about creating a profile on Grants.gov, refer to: https://www.grants.gov/web/grants/applicants/registration/authorize-roles.html

5) *Track Role Status*: To track your role request, refer to: https://www.grants.gov/web/grants/applicants/registration/track-role-status.html

b. *Electronic Signature*: When applications are submitted through Grants.gov, the name of the organization's AOR that submitted the application is inserted into the signature line of the application, serving as the electronic signature. The EBiz POC **must** authorize individuals who are able to make legally binding commitments on behalf of the organization as an AOR; **this step is often missed and it is crucial for valid and timely submissions.**

How to Submit an Application to ONR, ARO, or AFOSR via Grants.gov

Grants.gov applicants can apply online using Workspace. Workspace is a shared, online environment where members of a grant team may simultaneously access and edit different webforms within an application. For each funding opportunity announcement (FOA), you can create individual instances of a workspace.

Below is an overview of applying on Grants.gov. For access to complete instructions on how to apply for opportunities, refer to: https://www.grants.gov/web/grants/applicants/apply-for-grants.html

a. *Create a Workspace*: Creating a workspace allows you to complete it online and route it through your organization for review before submitting.

b. *Complete a Workspace*: Add participants to the workspace, complete all the required forms, and check for errors before submission.

1. *Adobe Reader*: If you decide not to apply by filling out web forms you can download individual PDF forms in Workspace so that they will appear similar to other Standard forms. The individual PDF forms can be downloaded and saved to your local device storage, network drive(s), or external drives, then accessed through Adobe Reader.

NOTE: Visit the Adobe Software Compatibility page on Grants.gov to download the appropriate version of the software at: https://www.grants.gov/web/grants/applicants/adobe-software-compatibility.html

2. *Mandatory Fields in Forms:* In the forms, you will note fields marked with an asterisk and a different background color. These fields are mandatory fields that must be completed to successfully submit your application.

3. *Complete SF 424 Fields First*: The forms are designed to fill in common required fields across other forms, such as the applicant name, address, and DUNS number. To trigger this feature, an applicant must complete the SF 424 information first. Once it is completed, the information will transfer to the other forms.

c. *Submit a Workspace*: An application may be submitted through workspace by clicking the Sign and Submit button on the Manage Workspace page, under the Forms tab. Grants.gov recommends submitting your application package at least 24-48 hours prior to the close date to provide you with time to correct any potential technical issues that may disrupt the application submission.

d. *Track a Workspace*: After successfully submitting a workspace package, a Grants.gov Tracking Number (GRANTXXXXXXXX) is automatically assigned to the package. The number will be listed on the Confirmation page that is generated after submission.

For additional training resources, including video tutorials, refer to:
https://www.grants.gov/web/grants/applicants/applicant-training.html

Applicant Support: Grants.gov provides applicants 24/7 support via the toll-free number 1-800-518-4726 and email at support@grants.gov. For questions related to the specific grant opportunity, contact the number listed in the application package of the grant you are applying for.

If you are experiencing difficulties with your submission, it is best to call the Grants.gov Support Center and get a ticket number. The Support Center ticket number will assist the DoD agency with tracking your issue and understanding background information on the issue.

Timely Receipt Requirements and Proof of Timely Submission

a. *Online Submission.* All applications must be received by 11:59 pm Eastern time on the due date established. Proof of timely submission is automatically recorded by Grants.gov. An electronic date/time stamp is generated within the system when the application is successfully received by Grants.gov. The applicant AOR will receive an acknowledgement of receipt and a tracking number (GRANTXXXXXXXX) from Grants.gov with the successful transmission of their application. Applicant AORs will also receive the official date/time stamp and Grants.gov Tracking number in an email serving as proof of their timely submission.

When the DoD agency successfully retrieves the application from Grants.gov, and acknowledges the download of submissions, Grants.gov will provide an electronic acknowledgment of receipt of the application to the email address of the applicant with the AOR role. Again, proof of timely submission shall be the official date and time that Grants.gov receives your application. Applications received by Grants.gov after the established due date for the program will be considered late and will not be considered for funding by the DoD agency.

Applicants using slow internet, such as dial-up connections, should be aware that transmission can take some time before Grants.gov receives your application. Again, Grants.gov will provide either an error or a successfully received transmission in the form of an email sent to the applicant with

the AOR role. The Grants.gov Support Center reports that some applicants end the transmission because they think that nothing is occurring during the transmission process. Please be patient and give the system time to process the application.

b. *Proposal Receipt Notices*. After a proposal is submitted through Grants.gov, the Authorized Organization Representative (AOR) will receive a series of three emails. It is extremely important that the AOR watch for and save each of the emails. You will know that your proposal has reached the DoD agency when the AOR receives email Number 3. You will need the Submission Receipt Number (email Number 1) to track a submission. The three emails 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 that is used to determine whether the proposal was submitted.

Number 2 – The applicant will receive an email indicating that the proposal has been **validated** by Grants.gov within two days of submission (This means that all of the required fields have been completed). After an institution submits an application, Grants.gov generates a submission receipt via email and also sets the application status to "Received." This receipt verifies the Application has been successfully delivered to the Grants.gov system. Next, Grants.gov verifies the submission is valid by ensuring it does not contain viruses, the opportunity is still open, and the applicant login and applicant DUNS number match. If the submission is valid, Grants.gov generates a submission validation receipt via email and sets the application status to "Validated." If the application is not validated, the application status is set to "Rejected." The system sends a rejection email notification to the institution, and the institution must resubmit the application package. Applicants can track the status of their application by logging in to Grants.gov.

Number 3 – The third notice is an acknowledgment of receipt in email form from ONR within ten days from the proposal due date, if applicable. The email is sent to the authorized representative for the institution. The email for proposals notes that the proposal has been received and provides the assigned tracking number.

4. Significant Dates and Times

Schedule of Events		
Event	**Date**	**Time**
Questions Regarding white papers*	18 May 2020 (Monday)	
White Papers Due	01 June 2020 (Monday)	11:59 PM Eastern Time
Notification of Evaluations of White Papers	22 June 2020 (Monday) **	
Questions Regarding Proposals*	31 August 2020 (Monday)	
Proposals Due	14 September 2020 (Monday)	11:59 PM Eastern Time

Notification of Selection for Award	01 February 2021 **	
Estimated start date of grant	01 May 2021 **	

* Questions submitted after the Q&A deadline as noted in the table above may not be answered. The due date for submission of the white paper and/or application will not be extended.

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

Note: Due to changes in security procedures since September 11, 2001, the time required for hard-copy written materials to be received at any of the DoD Agencies has increased. Materials submitted through the U.S. Postal Service, for example, may take five days or more to be received, even when sent by Express Mail. Thus, any hard-copy white papers should be submitted in advance of the deadline established in the solicitation so that it will not be received late and thus be ineligible for consideration.

E. APPLICATION REVIEW INFORMATION

1. Evaluation Criteria

Basic Research: The MURI Program is funded by a basic research appropriation. White papers and proposals, in order to be considered for funding, are therefore required to be of a basic, rather than applied or advanced technological, nature.

Note that basic research includes "scientific study and experimentation directed toward increasing fundamental knowledge and understanding" while applied research deals with the development of "useful materials, devices, and systems or methods" and "the design, development, and improvement of prototypes and new processes to meet general mission area requirements." The full definitions of these terms are contained in document: (DoD 7000.14-R, vol. 2B, chap. 5, para. 050201.B)

White papers will be evaluated 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 proposal. The assessment of the white papers will primarily focus on scientific and technical merits, potential for the research to significantly advance fundamental understanding in the topic area, and potential DoD interest.

Proposals responding to this FOA in each topic area will be evaluated using the following criteria:

- Scientific and technical merits of the proposed basic science and/or engineering research;
- Potential for the research, if successful, to significantly advance fundamental understanding in the topic area;
- Potential DoD relevance and contribution to the Department of Defense mission;
- Qualifications and availability of the Principal Investigator and other investigators;
- Adequacy of current or planned facilities and equipment to accomplish the research objectives;
- 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
- Realism and reasonableness of cost (cost sharing is not a factor in the evaluation)

The Government will evaluate options for award purposes by adding the total cost for all options to the total cost for the basic requirement. Evaluation of options will not obligate the Government to exercise the options during grant performance.

2. Review and Selection Process

The ultimate recommendation for award of proposals is made by the DoD's scientific/technical community. Recommended proposals will then be forwarded to ONR, AFOSR, or ARO Contracts and Grant Awards Management office. Any notification received from the DoD agency that indicates that the Applicant's proposal has been recommended does not ultimately guarantee an award will be made. This notice indicates that the proposal has been selected in accordance with the evaluation criteria stated above and has been sent to the Grants Department to conduct cost analysis, determine the Applicant's responsibility, to confirm whether funds are available, and to take other relevant steps necessary prior to commencing negotiations with the applicant.

3. Options

The Government will evaluate options for award purposes by adding the total cost for all options to the total cost for the basic requirement. Evaluation of options will not obligate the Government to exercise the options during grant performance.

4. Evaluation Panel

White paper submissions will be reviewed either solely by the responsible Research Topic Chief for the specific topic or by an evaluation panel chaired by the responsible Research Topic Chief. An evaluation panel will consist of technical experts who are Government employees or who are detailed under the Intergovernmental Personnel Act (IPA). Restrictive notices notwithstanding, one or more support contractors or advisors external to the US Government may be utilized as subject-matter-expert technical consultants. These individuals will sign a conflict of interest statement and a non-disclosure agreement prior to receiving proposal information.

Proposals will undergo a multi-stage evaluation procedure. The Research Topic Chief and other Government scientific experts will perform the evaluation of technical proposals first. Cost proposals will be evaluated by Government business professionals. Restrictive notices notwithstanding, one or more support contractors or advisors external to the US Government may be utilized as subject-matter-expert technical consultants. However, proposal selection and award decisions are solely the responsibility of Government personnel. Support contractor employees and advisors external to the US Government having access to technical and cost proposals submitted in response to this FOA will be required to sign a non-disclosure and a conflict of interest statement prior to receipt of any proposal submission. Findings of the evaluation panels will be forwarded to senior DoD officials who will make funding recommendations to the awarding officials.

Due to the nature of the MURI program, the evaluation panels and reviewing officials may on occasion recommend that less than an entire MURI proposal be selected for funding. This may

be due to several causes, such as insufficient funds, research overlap among proposals received, or potential synergies among proposals under a research topic. In such cases, proposal adjustments will be agreed to by the Principal Investigator and the Government prior to final award.

5. General Information Regarding the Review and Selection Process

In accordance with Office of Management and Budget (OMB) guidance in parts 180 and 200 of Title 2, CFR, it is DoD policy that DoD Components must report and use integrity and performance information in the Federal Awardee Performance and Integrity Information System (FAPIIS), or any successor system designated by OMB, concerning grants, cooperative agreements, and TIA's as follows:

If the total Federal share will be greater than the simplified acquisition threshold on and Federal award under a notice of funding opportunity (see 2 CFR 200.88 Simplified Acquisition Threshold):

a. The Federal awarding agency, prior to making a Federal award with a total amount of Federal share greater than the simplified acquisition threshold, will review and consider any information about the applicant that is in the designated integrity and performance system accessible through SAM (currently FAPIIS)(see 41 U.S.C. 2313);

b. An applicant, at its option, may review information in the designated integrity and performance systems accessible through SAM and comment on any information about itself that a Federal awarding agency previously entered and is currently in the designated integrity and performance system accessible through SAM;

c. The Federal awarding agency will consider any comments by the applicant, in addition to the other information in the designated integrity and performance system, in making a judgment about the applicant's integrity, business ethics, and record of performance under Federal awards when completing the review of risk posed by applicants as described in 2 CFR 200.205 Federal awarding agency review of risk posed by applicants.

F. FEDERAL AWARD ADMINISTRATION INFORMATION

1. Unique Entity Identifier and System for Award Management (SAM) Registration Required

a. 2 CFR 25.110 requires that all applicants, unless exempted, must:

Be registered in SAM.gov before submitting an application;
Provide a valid DUNS unique identifier; and,
Continue to maintain an active SAM registration with current information at all times during which any applicant has an active Federal award or an application under consideration by a Federal awarding agency.

b. A Commercial and Government Entity (CAGE) code is obtained or specified as part of the SAM registration process. A CAGE code is required.

c. SAM exemption or exceptions not available under this announcement. We will not issue an Agency level exemption to SAM registration under 2 CFR 25.110(d)(1) for applicants under this announcement. You must comply with SAM registration requirements and include a DUNS and CAGE code on your application.

d. For questions about SAM registration and updates you can get questions about SAM registration and entity updates answered by live chat at https://www.fsd.gov/fsd-gov/home.do and telephone at (866) 606-8220 or (324) 206-7828. Top help topics for SAM.gov are available at https://www.fsd.gov/fsd-gov/learning-center-system.do?sysparm_system=SAM.

e. Consequences of Non-Compliance with SAM Registration Requirements:

We cannot make an award to you unless you comply with SAM requirements. If you are non-compliant, we may determine you are not qualified to receive an award, and use that determination to make an award to someone else as authorized by 2 CFR 25.205(b). You cannot receive payments without an active SAM record and CAGE code.

2. Federal Award Notices

Applicants whose proposals are recommended for award may be contacted by a Contract or Grant specialist to discuss additional information required for award. This may include representations and certifications, revised budgets or budget explanations, certificate of current cost or pricing data, subcontracting plan for small businesses, and/or other information as applicable to the proposed award.

The notification e-mail must not be regarded as an authorization to commit or expend funds. The Government is not obligated to provide any funding until a Government Contracting Officer or Grants Officer, as applicable, signs the award document.

The award document signed by the Contracting Officer or Grants Officer is the official and authorizing award instrument.

For **ARO**: ARO emails their awards/ modification documents to the awardees.

For **AFOSR**: AFOSR emails their awards/ modification documents to the awardees.

For **ONR**: ONR award/modification documents are only available via the Department of Defense (DoD) Electronic Document Access System (EDA) within the Wide Area WorkFlow e-Business Suite (https://wawf.eb.mil/). EDA is a Web-based system that provides secure online access, storage and retrieval of awards and modifications to DoD employees and vendors.

ONR creates an award notification profile for every award.

For grants, the notification profile will use the email addresses from the Application for Federal Assistance, SF424, to notify the recipient of an award. ONR recommends that organizations provide a global business address for their entity in Field 5 (Application

Information) of the SF424. ONR is using the following three email addresses entered by the grantee on the SF424 application to create the EDA notification profile:

i. Applicant Information (Field 5 - Email)
ii. Project Director / Principal Investigator (Field 14 - Email)
iii. Authorized Representative (Field 19 - Email)

For all other awards, the notification profile will use the email address from the Business Point of Contact to notify the recipient of an award.

***IMPORTANT*:** In some cases, EDA notifications are appearing in recipients' Junk Email folder. If you are experiencing issues receiving EDA notifications, please check your junk email. If found, please mark EDA notifications as "not junk."

If you do not currently have access to EDA, you may complete a self-registration request as a "Vendor" via https://wawf.eb.mil/ following the steps below:

1. Click "Accept"
2. Click "Register" (top right)
3. Click "Agree"
4. In the "What type of user are you?" drop down, select "Vendor"
5. Select the systems you would like to access (iRAPT at a minimum)
6. Complete the User Profile and follow the site instructions

Allow five business days for your registration to be processed. EDA will notify you by email when your account is approved.

To access awards after your registration has been approved, log into https://wawf.eb.mil/, select "EDA", select either EDA location, Select "Contracts", select your search preference, enter the Contract Number (or, if applicable, enter the Grant Number in the Contract Number field), and select "View".

Registration questions may be directed to the EDA help desk toll free at 866-618-5988, commercial at 801-605-7095, or via email at disa.ogden.esd.mbx.cscassig@mail.mil (Subject: EDA Assistance).

3. Reporting

If the Federal share of any Federal award may include more than $500,000 over the period of performance, the post award reporting requirements, Award Term and Condition for Recipient Integrity and Performance Matters (2 U.S.C. 200 Appendix XII), is applicable as follows:

a. Reporting of Matters Related to Recipient Integrity and Performance

(1) General Reporting Requirement. If the total value of your currently active grants, cooperative agreements, and procurement contracts from all Federal awarding agencies exceeds $10,000,000 for any period of time during the period of performance of this Federal

award, then you as the recipient during that period of time must maintain the currency of information reported to the System for Award Management (SAM) that is made available in the designated integrity and performance system (currently the Federal Awardee Performance and Integrity Information System (FAPIIS)) about civil, criminal, or administrative proceedings described in paragraph 2 of this award term and condition. This is a statutory requirement under section 872 of Public Law 110-417, as amended (41 U.S.C. 2313). As required by section 3010 of Public Law 111-212, all information posted in the designated integrity and performance system on or after April 15, 2011, except past performance reviews required for Federal procurement contracts, will be publicly available.

(2) Proceedings About Which You Must Report. Submit the information required about each proceeding that:

a. Is in connection with the award or performance of a grant, cooperative agreement, or procurement contract from the Federal Government;

b. Reached its final disposition during the most recent five-year period; and

c. Is one of the following:

(i) A criminal proceeding that resulted in a conviction, as defined in paragraph 5 of this award term and condition;

(ii) A civil proceeding that resulted in a finding of fault and liability and payment of a monetary fine, penalty, reimbursement, restitution, or damages of $5,000 or more;

(iii) An administrative proceeding, as defined in paragraph 5. of this award term and condition, that resulted in a finding of fault and liability and your payment of either a monetary fine or penalty of $5,000 or more or reimbursement, restitution, or damages in excess of $100,000; or

(iv) Any other criminal, civil, or administrative proceeding if:

(a) It could have led to an outcome described in paragraph 2.c.(i), (ii), or (b) of this award term and condition;

(c) It had a different disposition arrived at by consent or compromise with an acknowledgment of fault on your part; and

(d) The requirement in this award term and condition to disclose information about the proceeding does not conflict with applicable laws and regulations.

(3) Reporting Procedures. Enter in the SAM Entity Management area the information that SAM requires about each proceeding described in paragraph 2 of this award term and condition. You do not need to submit the information a second time under assistance awards that you received if you already provided the information through SAM because you were required to do so under Federal procurement contracts that you were awarded.

(4) Reporting Frequency. During any period of time when you are subject to the requirement in paragraph 1 of this award term and condition, you must report proceedings information through SAM for the most recent five-year period, either to report new information about any proceeding(s) that you have not reported previously or affirm that there is no new information to report. Recipients that have Federal contract, grant, and cooperative agreement awards with a cumulative total value greater than $10,000,000 must disclose semiannually any information about the criminal, civil, and administrative proceedings.

(5) Definitions. For purposes of this award term and condition:

a. Administrative proceeding means a non-judicial process that is adjudicatory in nature in order to make a determination of fault or liability (e.g., Securities and Exchange Commission Administrative proceedings, Civilian Board of Contract Appeals proceedings, and Armed Services Board of Contract Appeals proceedings). This includes proceedings at the Federal and State level but only in connection with performance of a Federal contract or grant. It does not include audits, site visits, corrective plans, or inspection of deliverables.

b. Conviction, for purposes of this award term and condition, means a judgment or conviction of a criminal offense by any court of competent jurisdiction, whether entered upon a verdict or a plea, and includes a conviction entered upon a plea of nolo contendere.

c. Total value of currently active grants, cooperative agreements, and procurement contracts includes:

(i) Only the Federal share of the funding under any Federal award with a recipient cost share or match; and

(ii) The value of all expected funding increments under a Federal award and options, even if not yet exercised.

G. FEDERAL AWARDING AGENCY CONTACTS

One or more Research Topic Chiefs are identified for each SPECIFIC MURI TOPIC. Questions of a technical nature on a specific topic shall be directed to one of the Research Topic Chiefs identified in Section II. I entitled "SPECIFIC MURI TOPICS" of this FOA.

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

MURI Program Points of Contact:

Office of Naval Research
Dr. Ellen Livingston
Email: ellen.s.livingston@navy.mil

Army Research Office
DR. LARRY RUSSELL, JR.
Email: usarmy.rtp.ccdc-arl.mbx.aro-muri@mail.mil

Air Force Office of Scientific Research
MS. KATIE WISECARVER
Email: MURI@us.af.mil

DoD Liaison (for OSD topic)
Dr. Jennifer Becker
Email: jennifer.j.becker.civ@mail.mil

Questions of a business nature for ONR contact:
David Broadwell
Grants Officer,
Code 255 Office of Naval Research
875 North Randolph Street
Arlington, VA 22203-1995
Email: david.broadwell@navy.mil

Questions of a business nature for ARO contact:
Kia Mccormick
USARMY RDECOM ARO (USA)
Email: kia.s.mccormick.civ@mail.mil

Questions of a business nature for AFOSR contact:
Laura Plati
USAF AFMC AFOSR/RP
Email: laura.plati@us.af.mil

Questions submitted after the Q&A deadline, as noted in the table in Section II. D. 4 of this FOA, may not be answered.

FOA amendments, if any, will be posted on the Grants.gov webpage https://www.grants.gov/ under the agency's specific MURI announcement.

H. OTHER INFORMATION

1. Federal Funding Accountability and Transparency Act of 2006

The Federal Funding Accountability and Transparency Act of 2006 (Public Law 109-282), as amended by Section 6202 of Public Law 110-252, and expanded by the Digital Accountability and Transparency Act of 2014 (Public Law 113-101), requires that all agencies establish requirements for recipients reporting information on subawards and executive total compensation as codified in 2 CFR Part 170. Any company, non-profit agency or university that applies for financial assistance as either a prime or sub-recipient under this FOA must provide information in its proposal that describes the necessary processes and systems in place to comply with the reporting

requirements identified in 2 CFR Part 170 Appendix A. Entities are required to meet reporting requirements unless an exception or exemption applies. Refer to 2 CFR Part 170, including Appendix A, for a detailed explanation of the requirements, exceptions, and exemptions.

2. Certification regarding Restrictions on Lobbying

Grant, Cooperative Agreement, and Technology Investment Agreement (TIA) awards greater than $100,000 require a certification of compliance with a national policy mandate concerning lobbying. Grant applicants shall provide this certification by electronic submission of SF424 (R&R) as a part of the electronic proposal submitted via Grants.gov (complete Block 17). The following certification applies likewise to each Cooperative Agreement and TIA seeking federal assistance funds exceeding $100,000:

a. No Federal appropriated funds have been paid or will be paid by or on behalf of the applicant, to any person for influencing or attempting to influence an officer or employee of an agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the awarding of any Federal contract, the making of any Federal grant, the making of any Federal loan, the entering into of any cooperative agreement, and the extension, continuation, renewal, amendment, or modification of any Federal contract, grant, loan, or cooperative agreement.

b. If any funds other than Federal appropriated funds have been paid or will be paid to any person for influencing or attempting to influence an officer or employee of any agency, a Member of Congress, an officer or employee of Congress, or an employee of a Member of Congress in connection with the Federal contract, grant, loan, or cooperative agreement, the applicant shall complete and submit Standard Form-LLL, “Disclosure Form to Report Lobbying,” in accordance with its instructions.

c. The applicant shall require that the language of this certification be included in the award documents for all subawards at all tiers (including subcontracts, subgrants, and contracts under grants, loans, and cooperative agreements) and that all subrecipients shall certify and disclose accordingly.

This certification is a material representation of fact upon which reliance was placed when this transaction was made or entered into. Submission of this certification is a prerequisite for making or entering into this transaction imposed by Section 1352, title 31, U.S.C. Any person who fails to file the required certification shall be subject to a civil penalty of not less than $10,000 and not more than $100,000 for each such failure.

3. Representation Regarding an Unpaid Delinquent Tax Liability or a Felony Conviction Under any Federal Law - DoD Appropriations

All grant applicants are **required to complete** the "Representation on Tax Delinquency and Felony Conviction" found at https://www.onr.navy.mil/Contracts-Grants/submit-proposal/grants-proposal.aspx by checking the "I agree" box in Field 17 and attaching the representation to Field 18 of the SF424 (R&R) as part of the electronic proposal submitted via Grants.gov. The representation reads as follows:

a. The applicant represents that it **____ is/ is not ____** a corporation that has any unpaid Federal tax liability that has been assessed, for which all judicial and administrative remedies have been exhausted or have lapsed, and that is not being paid in timely manner pursuant to an agreement with the authority responsible for collecting the tax liability.

b. The applicant represents that it **____ is/ is not ____** a corporation that was convicted of a felony criminal violation under any Federal law within the preceding 24 months. NOTE: If an applicant responds in the affirmative to either of the above representations, the applicant is ineligible to receive an award unless the agency suspension and debarment official (SDO) has considered suspension or debarment and determined that further action is not required to protect the Government's interests. The applicant therefore must provide information about its tax liability or conviction to the agency's SDO as soon as it can do so, to facilitate completion of the required consideration before award decisions are made.

4. Representation Regarding the Prohibition on Using Funds with Entities that Require Certain Internal Confidentiality Agreements

Agreement with the representation below will be affirmed by checking the "I agree" box in Field 17 of the SF424 (R&R) as part of the electronic proposal submitted via Grants.gov. The representation reads as follows:

By submission of its proposal or application, the applicant represents that it does not require any of its employees, contractors, or subrecipients seeking to report fraud, waste, or abuse to sign or comply with internal confidentiality agreements or statements prohibiting or otherwise restricting those employees, contractors, subrecipients from lawfully reporting that waste, fraud, or abuse to a designated investigative or law enforcement representative of a Federal department or agency authorized to receive such information.

Note that, as applicable, the bases for this representation are the prohibition(s) as follow:

a. Section 743 of the Financial Services and General Government Appropriation Act, 2015 (Division E of the Consolidated and Further Continuing Appropriations Act, 2015, Pub. L. 113-235)

b. Pub. L. 114-53, Continuing Appropriation Act, 2016, or any other Act that extends to fiscal year 2016 funds the same prohibitions as contained in section 743 of Division E, title VII of the Consolidated and Further Continuing Appropriations Act, 2015 (Pub. L. 113-235) and the Consolidated Appropriations Act, 2016 (Pub. L. 114-113).

c. Pub. L. 114-223, Continuing Appropriations Act, 2017, or any other Act that extends to fiscal year 2017 funds the same prohibitions as contained in section 743, Division E, title VII, of the Consolidated Appropriations Act, 2016 (Pub. L. 114-113) and the Consolidated Appropriations Act, 2017 (Pub. L. 115-31)

d. Pub. L. 115-56, Continuing Appropriations Act, 2018 and Supplemental Appropriations for Disaster Relief Requirements Act, 2017, or any other Act that extends to fiscal year 2018 funds the same prohibitions as contained in Section 743, Division E, title VII, of the Consolidated Appropriations Act, 2017 (Pub. L. 115-31) and the Consolidated Appropriations Act, 2018 (Pub. L. 115-141)

e. Pub. L. 115-245, Department of Defense and Labor, Health and Human Services, and Education Appropriations Act, 2019 and Continuing Appropriations Act, 2019, or any other Act that extends to fiscal year 2018 funds the same prohibitions as contained in Section 743, Division E, title VII, of the Consolidated Appropriations Act, 2018 (Pub. L. 115-41)

f. Any successor provision of law on making funds available through grants and cooperative agreements to entities with certain internal confidentiality agreements or statements.

5. Code of Conduct

Applicants for grants, cooperative agreements, or other transaction agreements as applicable are required to comply with 2 CFR 200.318(c), Codes of Conduct, to prevent real or apparent conflicts of interest in the award and administration of any contracts supported by federal funds. This provision will be incorporated into all assistance instruments awarded under this FOA.

6. Requirements Concerning Live Organisms

Use of Animals:

The DoD policies and requirements for the use of animals in DoD-supported research are described in DoD Instruction 3216.01, *Use Of Animals In Dod Conducted And Supported Research And Training*, and SECNAVINST 3900.38C, *The Care and Use of Laboratory Animals in DOD Programs*. If animals are to be utilized in the research effort proposed, the Applicant must submit a Full Appendix or Abbreviated Appendix with supporting documentation (copies of Institutional Animal Care and Use Committee (IACUC) Approval, IACUC Approved Protocol, and most recent United States Department of Agriculture (USDA) Inspection Report) prior to award. For assistance with submission of animal research related documentation, contact the ONR Animal Use Administrator at (703) 696-4046. Guidance: https://www.onr.navy.mil/About-ONR/compliance-protections/Research-Protections/animal-use

Use of Human Subjects in Research:

a. Applicants must protect the rights and welfare of individuals who participate as human subjects in research awarded pursuant to this FOA and must comply with the requirements of the Common Rule at 32 CFR part 219 and applicable provisions of DoD Instruction 3216.02, *Protection of Human Subjects and Adherence to Ethical Standards in DoD-Supported Research* (2011), the DON implementation of the human research protection program contained in SECNAVINST 3900.39E, Change 1,(or their replacements), 10 USC 980 "Limitation on Use of Humans as Experimental Subjects," and when applicable, Food and Drug Administration (FDA) and other federal and state law and regulations.

b. For proposals containing activities that include or may include "research involving human subjects" as defined in DoDI 3216.02, prior to award, the Applicant must submit documentation of:

(i) Approval from an Institutional Review Board (IRB) (IRB-approved research protocol, IRB- approved informed consent document, and other material they considered); proof of completed human research training (e.g., training certificate or institutional verification of training for the principal investigator, co-investigators); and the Applicant's Department of Health and Human Services (DHHS)-issued Federal Wide Assurance (FWA), including notifications of any suspensions or terminations to the FWA),

(ii) Any claimed exemption under 32 CFR 219 104, including the category of exemption, supporting documentation considered by the Applicant's institution in making the determination (e.g., protocol, data collection tools, advertisements, etc.). The documentation shall include a short rationale supporting the exemption determination. This documentation should be signed by the IRB Chair or IRB vice Chair, designated IRB administrator or official of the human research protection program.

(iii) Any determinations that the proposal does not contain activities that constitute research involving human subjects, including supporting documentation considered by the Applicant's institution in making the determination. This documentation should be issued by the IRB Chair or IRB vice Chair, designated IRB administrator or official of the human research protection program.

c. Documentation must be submitted to the ONR Human Research Protection Official (HRPO), by way of the ONR Program Officer. If the research is determined by the IRB to be greater than minimal risk, the Applicant also must provide the name and contact information for the independent research monitor and a written summary of the monitors' duties, authorities, and responsibilities as approved by the IRB. For assistance with submission of human subject research related documentation, contact the ONR Human Research Protection Official (HRPO) at (703) 696-4046.

d. Research involving human subjects must not be commenced under any contract award or modification or any subcontract or grant subaward or modification until awardee receives notification from the Contracting or Grants Officer that the HRPO has approved the assurance as appropriate for the research under the award or modification and that the HRPO has reviewed the protocol and accepted the IRB approval or determination for compliance with Federal, DoD and DON research protection requirements. See, DFARS 252.235-7004. Guidance: http://www.onr.navy.mil/About-ONR/compliance-protections/Research-Protections/Human-Subject-Research.aspx

Biosafety and Biosecurity Requirements:

Applicants must comply with applicable provisions of DOD 6055.18-M, Change 2, *Safety Standards for Microbiological and Biomedical Laboratories*, including ensuring compliance with standards meeting at least the minimum applicable requirements of the current edition of Centers

for Disease Control and Prevention, "Biosafety in Microbiological and Biomedical Laboratories (BMBL)," and National Institutes of Health, "The NIH Guidelines for Research Involving Recombinant or Synthetic Nucleic Acid Molecules (NIH Guidelines)."

Research Involving Recombinant or Synthetic Nucleic Acid Molecules.

Applicants must not begin performance of research within the scope of "The NIH Guidelines for Research Involving Recombinant or Synthetic Nucleic Acid Molecules (NIH Guidelines)" until receiving notice from the Contracting or Grants Officer that ONR has reviewed and accepted the Applicant's documentation. In order for ONR to accomplish that review, an Applicant must provide the Contracting or Grants Officer, generally as part of an original proposal prior to award, sufficient documentation to enable the review, including:

a. A written statement that the Applicant is in compliance with NIH Guidelines. This statement should be made by an official of the institution other than the Principal Investigator and should be on university or company letterhead.

b. Evidence demonstrating that the proposed research protocol has been approved by an Institutional Biosafety Committee (IBC); and a copy of the Department of Health and Human Services (DHHS) Letter of Approval of the IBC, or the most recent letter from DHHS stating the IBC is in compliance with the NIH Guidelines.
Guidance: https://www.onr.navy.mil/About-ONR/compliance-protections/Research-Protections/Animal-Recombinant-DNA.aspx

7. Institutional Dual Use Research of Concern

As of September 24, 2015, all institutions and United States Government (USG) funding agencies subject to the United States Government Policy for Institutional Oversight of Life Sciences Dual Use Research of Concern must comply with all the requirements listed therein. If your research proposal directly involves certain biological agents or toxins, contact the cognizant Technical Point of Contact. U.S. Government Science, Safety, Security (S3) guidance may be found at https://www.phe.gov/s3/dualuse.

8. Department of Defense High Performance Computing Program

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

9. Project Meetings and Reviews

Individual program reviews between the DoD awarding agency and the performer may be held as necessary. Additionally, each year OSD organizes a review of the MURI projects resulting from the FOA issued 2 fiscal years prior. The Principal Investigators or appropriate representatives for

these projects are required to present at this review in the National Capital Region (Washington, DC area). The fourth and fifth year options for any project will not be exercised until its review is complete. Program status reviews may also be held to provide a forum for reviews of the latest results from experiments and any other incremental progress towards the major demonstrations. These meetings will typically be held at the Applicant's research facility. Interim meetings are likely, but these will be accomplished via video telephone conferences, telephone conferences, or via web-based collaboration tools.

I. SPECIFIC MURI TOPICS

ONR:

Topic 1: Molecular Qubits for Synthetic Electronics

Topic 2: A Brain-based Compositional Framework for Robust Computer Vision

Topic 3: Littoral Ocean Dynamics off Rocky Coasts and Shorelines

Topic 4: Fog and Turbulence

Topic 5: Dynamic Tuning of Thermal Transport

Topic 6: Chemically and Thermally Insensitive Super/Ultra-Hard Materials

Topic 7: Narrative, Moral and Social Foundations of Social Cyber-Attack in Social Media

Topic 8: A Dynamics and Control Theory of Safe, Cognitive and Learning Systems

Topic 9: Understanding Turbulence-Chemistry Interactions in Non-Equilibrium, High-Speed Flows

Topic 10: Predicting Organic Molecular Decomposition

ARO:

Topic 11: Anomalous Dipole Textures in Engineered Ferroelectric Materials

Topic 12: Cyber Autonomy through Robust Learning and Effective Human/Bot Teaming

Topic 13: Highly Heterogeneous Meta-macrostructures Created via Fine-particle Interactions

Topic 14: Non-Silica Inorganic Material Phases Synthesized from Genetically Modified Diatoms

Topic 15: Novel Mechanisms of Neuro-Glio Bio-Computation and Reinforcement Learning

Topic 16: Quantum Network Science

Topic 17: The Same is Different: Integrating Multiple Phenomena in Single Materials

Topic 18: Tunable Dilute Anion III-Nitride Nanostructures for Stable Photocatalysis

AFOSR:

Topic 19: Mechanisms of Novel Reactivity in Aqueous Microdroplets

Topic 20: Topological Plasma Electromagnetics

Topic 21: Interfacial Engineering of Superconductors

Topic 22: Targeted Optical Stimulation of Individual Retinal Photoreceptors

Topic 23: Quantum Random Access Memory

Topic 24: Metasurface Edge Sensing, Processing and Computing

Topic 25: Non-Hermitian Programmable Materials at Exceptional Points

Topic 26: Mathematical Foundations for Enabling Robust Optimal Design of Hypersonic Systems

OSD:

Topic 27: Advanced Modeling of Evolutionary Cyber Eco-Systems with Autonomous Intelligence

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Topic 1: (ONR) Molecular Qubits for Synthetic Electronics

Background: Synthetic Electronics is a nascent new research field, where electronic devices and circuitry will be rationally designed and chemically synthesized, by exploiting the rich functionalities of various planar polycyclic aromatic hydrocarbon (PAH) molecules (aka nanographene) and their derivatives. It represents an entirely new paradigm that relies on bottom-up chemical synthesis techniques, as opposed to top-down lithography, to assemble electronic circuitry. Over the last decade enormous success has been made in synthetic electronics, particularly terms of structural control at atomic scale, exemplified by various atomically precise graphene nanoribbons (GNRs) and their heterostructures. More recent research efforts attempt to advance this atomic precision engineering approach further towards deterministic structural programmability, by borrowing concepts from the recent success in structural DNA nanotechnology. On the functionality side, a variety of GNR heterostructures and single GNR transistors have been successfully designed, synthesized and characterized. This MURI is based on the belief that synthetic electronics platform provides a unique opportunity for building a solid-state quantum technology based on molecular qubits with unmatched spatial precision and is potentially scalable. Individual molecular units that contain

PAH motifs and constitute high-quality qubits (and qudits), with decoherence time up to 1 μs at room temperature, have already been demonstrated, and prototypical quantum algorithms such as Grover's search algorithm have been implemented. In addition, low temperature STM based electron spin resonance (ESR) experiments have demonstrated coherent manipulation of single Ti atom spin states, as well as spin interaction between two Ti atoms, in 20ns timescale. These type of systems and many others seem eminently amenable to synthetic electronics paradigm to go beyond single or two-qubit limits and make it scalable eventually. Some of the distinct advantages of molecule based synthetic quantum technology, in comparison with other leading solid-state platforms, are: (1). Extreme scalability, down to single molecules or single atoms as functioning qubits (< 1 nm2). In contrast superconducting qubits occupy area on the order of 1 μm2. (2). Ability to control and fine tune qubit distances (i.e. interactions) deterministically and with ~Å precision. This compares favorably with other atomic-scale qubits, such as those based on nuclear spins of atomic defects in solids, where qubit-placement precision is limited to ~10 nm and/or nondeterministic. (3). Ease of integration of heterogeneous quantum components. Qubits with different frequencies can be implemented using different molecules or through slight modification of the same molecule, brought together within atomic distances using chemical synthesis techniques. Despite these promises, at present molecular quantum technology is still very much in its infancy and there are many scientific challenges that remain before the vision of synthetic quantum electronics can be realized. The time is ripe to strengthen investments in this highly promising new area of science, largely spurred by DoD's long-term support and nurture.

Objective: To foster and encourage fundamental research towards the first step in realizing a molecular quantum technology based on synthetic electronics paradigm. The ultimate goal and long-term vision for this research thrust is to design and synthesize large arrays of 2D coherent molecular qubit systems, with their placements and separations designed and controlled with atomic precision.

Research Concentration Areas: Areas of interest include, but are not limited to: (1) Synthesis and integration of molecular qubits, both existing and newly discovered, with synthetic electronics structural motifs. (2). Carry out quantum characterization, in particular coherence and entanglement properties, of molecular qubits within the synthetic electronics platform. In the initial phase of the program, quantum characterization using atomic-scale scanning probe techniques will be acceptable. (3). Innovative approaches to longer-term, scalable quantum gate operations and readout schemes within synthetic electronics environment, are encouraged. (4). A theoretical component that is well-integrated with experimental/synthetic efforts is desirable.

Anticipated Resources: It is anticipated that awards under this topic will be no more than $1.5M per year for 5 years (3 years + 2 option years), supporting no more than 7 faculty researchers as (co-) principal investigators. Exceptions warranted by specific proposal

approaches should be discussed with the topic chief during the white paper phase of the solicitation.

Research Topic Chief: Chagaan Baatar, ONR 312, (703)-696-0483, chagaan.baatar@navy.mil

Topic 2: (ONR) A Brain-based Compositional Framework for Robust Computer Vision

Background: Computer vision (CV) systems based on convolutional neural networks are highly effective for object recognition under relatively benign conditions. However, these systems have significant shortcomings, attributable to their inability to generalize beyond the labeled image sets they have been trained on. To overcome lack of generalizability and robustness, they must be trained on extremely large labeled image sets, which are unavailable for many operational domains. Moreover, they perform poorly for partially occluded objects, or when exposed to untrained poses, scales, and levels of ambient illumination. In contrast, biological vision exhibits high levels of generalizability and robustness across a wide range of viewing conditions. Neuroscientific investigations in recent decades have uncovered a number of features of the circuitry and receptive field properties in the visual brain that are believed to be responsible for these unique capabilities. Most notably, they are the following. (a) A fundamental structural property of the visual system is its compositional circuitry: representations at each stage of processing are composed of building blocks drawn from earlier stages. Such a compositional representation is thought to be essential for dealing with the combinatorial complexity of the world, as well as providing the basis for the crucially important ability to judge and exploit visual similarity. (b) Inputs at all stages are represented by patterns of activity in populations of neurons, rather than single neuron activities, which confers robustness against occlusions. (c) Object recognition neurons are broadly tuned, hence robust with respect to variations in pose, scale, and illumination. (d) Interconnections among regions of the visual brain are bidirectional, with top-down projections as numerous as bottom-up. Much is now known about the circuitry, representational schemes and mechanisms of action in the visual brain, including the foregoing highlights. However, current understanding has not yet translated into creation of executable CV systems that approach the robustness of biological vision. Better understanding of visual information representation and processing in the brain will provide a principled framework for building robust vision systems.

Objective: Elucidate the computational role of the visual brain mechanisms, and exploit this understanding to create executable CV systems that deliver performance approaching that of biological vision. The mechanistic understanding sought in this MURI requires a multidisciplinary program of research involving the integrated contributions of systems, developmental and molecular neuroscientists, computational scientists, and cognitive scientists, as well as investigations involving model organisms that include both humans and non-human systems.

Research Concentration Areas: To build robust and versatile CV systems based on compositional neural networks, we need to investigate and model (a) the brain's visual information processing architecture; (b) visual primitives and rules for composition of representations at the various levels of the visual system; (c) learning mechanisms underlying visual representation and inference; and (d) the information content and role of top-down feedback. Specific questions that may be addressed include the following. By what mechanisms are neural representations at each level in the processing hierarchy composed into those at succeeding levels? By what mechanisms and circuitry is information maintained about the spatial relations among object parts and among objects forming a scene? Most fundamentally, what is the computational basis of the generalization capability of the brain's representation of the visual world? What roles are played in this by the broad tuning of neural elements; by population coding of inputs; and by the context or expectation-based constraints imposed by means of top-down projections? A major component of this MURI will be development, demonstration and comparative evaluation of a Compositional Network-based CV system that incorporates empirically informed answers to the above questions. Comparative evaluations should entail contrasting performance of state-of-the-art vision systems with that of the compositional solution developed as part of this MURI. Network comparisons should include a focus on challenging conditions such as occlusion and variations in pose, illumination, scale and context.

Anticipated Resources: It is anticipated that awards will be no more than an average of $1.5M per year for 5 years, supporting no more than 6 funded faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with topic chiefs during the white paper phase.

Topic Chiefs: Dr. Behzad Kamgar-Parsi, ONR 311, 703.696.5754; behzad.kamgarparsi@navy.mil; Dr. Harold Hawkins, ONR 341, 703.696.4323; harold.hawkins@navy.mil

Participants: Dr. Tom McKenna and LCDR Peter Walker, ONR 341; Dr. Marc Steinberg, ONR 351; Dr. Lisa Troyer, ARO; Dr. Hal Greenwald, AFOSR; Dr. Greg Trafton, NRL

Topic 3: (ONR) Littoral Ocean Dynamics off Rocky Coasts and Shorelines

Background: About 75% of the world's coastlines are rocky; however, nearly all littoral research focuses on the dynamics of the ocean, material transport and seabed change on sandy coastlines. Existing nearshore models are highly skillful in reproducing the ocean dynamics off sandy coastlines, the result of calibration based on comprehensive field experiments. New observing technologies including high-resolution synthetic aperture radar remote sensing, sophisticated floats and unmanned surface vehicles permit safe, effective field study of rocky coastlines, and in turn, now allow testing of rocky coast model predictions. Rocky coasts are morphologically diverse and the dynamics of the ocean in their vicinity is typically unknown

and often dangerous. Rocky coast environments include steep cliffs, wave-cut terraces, promontories, offshore stacks and arches, rocky beaches, and calm sheltered coves, among other forms. Given similar offshore wave forcing, the dynamics of coastal waters can vary greatly between sandy and rocky shorelines. Sandy coasts may have wide swash zones, surf zones, sandbars, and cuspate shorelines whereas on rough rocky coasts the dynamics, transport and energy balances are not clear. Consequently, the life-threatening longshore and cross-shore (rip) currents that are common on sandy beaches may operate differently on rocky coasts, or not at all. Infragravity motion (wave periods of 20-1000 s) generated by wave breaking on sandy beaches can drive large runup excursions. Do such processes operate on rocky shorelines? Will shore-trapped infragravity waves dissipate or reflect as they propagate from a sandy coast to a rocky one? Do internal waves propagating along density interfaces from the deep ocean behave differently as they encounter rocky versus sandy coasts? Will the community models from sandy coastline formulations produce robust solutions for temperature, salinity, bottom drag and flow, so that such derivative applications as acoustic transmission/loss are possible, or will new formulations be required? Comprehensive field studies and state-of-the-art model evaluation are needed to quantify our understanding of the 75% of littoral ocean dynamics that have yet to be investigated.

Objective: This MURI will develop a fundamental understanding of the littoral ocean dynamics off rocky coasts and shorelines to enable skillful numerical modeling, simulation, and prediction for these regions. Proposed efforts should include observational data collection from multiple representative shorelines; comparisons and contrasts with well-understood sandy coasts and beaches; and advancement of models and/or theory if those available are insufficient. These advancements should improve or extend community models (e.g., the Regional Ocean Modeling System (ROMS) and Delft-Flexible Mesh) and be robust enough for such derivative applications as underwater acoustic transmission loss and safety of navigation, among others.

Research Concentration Areas: Critical areas to investigate include but are not limited to: physical oceanography and wave dynamics; geometrical, geological and biological characterization of the shore and seabed including bathymetry, rugosity, and composition; the influence of local meteorology; and the full spectrum of remote sensing capabilities.

Anticipated Resources: Awards under this topic will be no more than $1.5M per year for 5 years and support no more than 6 funded faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with the topic chief during the white paper phase of the solicitation. Requests for ship-time should be noted, but not included in the $1.5M.

Research Topic Chief: Dr. Reginald Beach, ONR 322, 703-696-6723, Reginald.Beach@navy.mil

Topic 4: (ONR) Fog and Turbulence

Background: Results from recent research and field observations are providing deeper insight into poorly understood and missing numerical representation of thermodynamic and microphysical processes in fog evolution. Specifically, new insights which contradict

previously held theories of maritime fog evolution, include: 1) the observation of previously unknown bimodal water droplet distribution not represented in any model, 2) large scale cold air outbreaks over warmer water is not the primary physical driver (as previously thought), 3) turbulence and above boundary layer wind shear strongly modulate fog persistence/dissipation, 4) there exists a non-linear relationship between aerosols and turbulence that suggests a similar relationship with fog, and 5) the role of the ocean surface properties in constraining fog development is unknown, yet fundamental.

Despite the fact that maritime fog is an important contribution to global radiative, microphysical, and dynamical representations of the atmosphere and ocean, current theories are insufficient to explain the magnitude and duration of properties required to understand how fog evolves. The poor state of fog and turbulent marine atmospheric boundary layer characterization has substantial impacts in closure of the atmospheric energy budget and lowers downstream predictability via incorrect initialization of source and sink terms. An integrated theory, field observation and experimental modeling effort is needed to resolve these missing elements in understanding fog evolution in different turbulent regimes. Critical to this idea is an interdisciplinary approach toward integrating multiscale and physical effects. A fundamental advance is needed to contextualize the properties missing in understanding maritime fog evolution and those aspects resolvable for efficient computational modeling.

Objective: The objective of this MURI is to understand how the combination of atmospheric boundary layer turbulence, synoptic to mesoscale scale free atmosphere flow, microphysical interactions between particulates and water vapor, and ocean fluxes interact to affect the onset, duration, and cessation of fog over water using improved theory to focus efforts on measuring new field data and refining numerical modeling to simulate and understand that theory and data.

Research Concentration Areas: Suggested research areas include but are not limited to: (1) Exploration of the mechanisms that modulate the distribution of water droplet size and quantities, 2) Measurement and modeling of the time and vertical tendencies of large scale wind shear and turbulence as it relates to fog formation, endurance, and dissipation, 3) Measurement and modeling of how the gradient in ocean surface temperature, salinity, sea spray, and drag coefficients affect the fog properties and longevity, and 4) Formulation and optimization of the bulk properties of surface and boundary layer turbulent scales that can be parameterized.

Anticipated Resources: It is anticipated that awards under this topic will be no more than an average of $1.5M per year for 5 years, supporting no more than five funded faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with the topic chief during the white paper phase of the solicitation.

Research Topic Chiefs: Daniel Eleuterio (ONR 322) daniel.eleuterio@navy.mil, Peter Morrison (ONR 351) peter.a.morrison@navy.mil, Josh Cossuth, ONR, joshua.cossuth@navy.mil, and Kate Mulreany, ONR, katherine.mulreany@navy.mil

Topic 5: (ONR) Dynamic Tuning of Thermal Transport

Background: Controlling thermal transport is a key challenge for cooling high power electronics, energy conversion systems, and materials processing. Passive thermal management approaches are limited by solid-state (conductive) components with linear, static response, acting as thermal resistors and capacitors. Dynamic control of thermal conductivity in solids would enable new thermal management strategies based on thermal switches, thermal rheostats, and thermal transistors. Beyond thermal management, active control of heat flow could enhance solid-state energy conversion and, even, enable thermal logic devices. While solid-state thermal rectification has been demonstrated, dynamic switching or tuning of materials remains a challenge. Thermal conductivity changes have been observed by manipulating the scattering rates or carrier populations via phase transitions, chemical composition modification, and applied fields. However, mechanisms based solely on scattering are typically narrow band, affecting only a small piece of the thermal carrier spectrum. New materials design strategies must be developed to generate sufficiently rapid (> 10 Hz) and pronounced (> 10:1 switching ratio) responses for application in a thermal management system.

Recent advances in low-dimensional materials, topological semimetals, and magnonic crystals have pointed to new mechanisms that could potentially be used to dynamically control thermal conductivity. Another interesting possibility is the use of polymers or other disordered materials, such as block-copolymers, colloids, liquid crystals, and organic-inorganic hybrids, where field induced changes in orientation and ordering could lead to large modulation of thermal conductivity. Traditional theoretical approaches, such as the phonon-gas model, are not adequate to describe thermal transport in disordered materials and inadequately capture the dynamic tuning possible with these materials. Recent modeling approaches based on esoteric propagating modes (eg. vibrons) have been introduced, but further *ab-initio* theoretical work supported by molecular dynamic simulations is needed to fully describe nanoscopic atomic behavior and guide material development. In addition to tuning thermal conductivity, active control of heat capacity by introducing (or removing) degrees of freedom in the atomic or molecular motion, could lead to novel methods for thermal control of electronic components.

Objective: The objective of this MURI is to develop new mechanisms for dynamically modulating thermal conductivity in materials to enable solid-state devices that operate as thermal switches over a broad temperature range. The complexity of these materials systems requires a multidisciplinary research team with expertise in physics, materials science, chemistry, and mechanical engineering to design, synthesize, characterize, and understand these materials.

Research Concentration Areas: Suggested research areas include, but are not limited to: (1) Theoretical studies of tunable thermal transport in inorganic and organic materials; (2) Design and synthesis of materials with large thermal switching ratio at near ambient temperatures (-20 to 50 C); (3) Novel methods to characterize thermal transport in such materials; (4) Concepts to exploit these materials in devices that operate as thermal diodes, transistors, and logic gates.

Anticipated Resources: It is anticipated that awards under this topic will be no more than an average of $1.5M per year for 5 years, supporting no more than six funded faculty researchers. Exception warranted by specific proposal approaches should be discussed with the topic chiefs during the white paper phase of the solicitation.

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Topic 6: (ONR) Chemically and Thermally Insensitive Super/Ultra-Hard Materials

Background: Diamond, composed of a single element, is the hardest known material and is used for a variety of industrial purposes - especially for drilling, cutting and grinding. Problematic with diamond is that it is not easy to make, reacts with iron used in many alloys of DoD interest and readily transforms to a less stable carbon allotrope at elevated temperatures. Ultra-hard compounds, i.e., those containing two or more elements, also exist and are similarly used, but they too have limitations. Answers to the following basic scientific questions are needed to advance this topic: (1) What exactly makes a material "hard"? The prevailing view is that covalent bonding dictates this, and most effort has been spent seeking compounds comprised of highly covalent light elements (a recent exception are transition metal borides). Is that assumption correct? Because the free energy of a material dictates its stability we ask what role(s) entropy (electronic, vibrational, mixing, etc.) has on hardness and if entropic considerations, akin, perhaps, to high entropy alloys, can influence both hardness and inertness. (2) Because a compound's phase dictates its performance we ask: How can one quickly determine a compound's phase diagram? Experimental approaches are tedious and computational methods like CALPHAD are becoming popular, but, those methods currently make too many assumptions or approximations to provide exacting phase diagrams, especially for high throughput work. (3) How can one explore chemical space efficiently in a search for new materials having the desired properties? Existing computational approaches using informatics-based cluster expansion methods relegate the search to the lattice for which the method was developed; off-lattice methods are needed. And, related to this, (4) How can one quickly determine the fate of an ultra-hard material for a given use, e.g., what chemistries would take place for, say, a cutting tool made of that material as it undergoes wear and chemical changes that are induced by reacting with an alloy or a ceramic? (5) Can those predicted materials be made (expediently)?

Objectives: This MURI ultimately seeks design rules for making insensitive (thermally stable, chemically inert), super/ultra-hard (Vickers hardness exceeding 40 GPa) compounds for multiple applications where "hard" matters. The selected research team is expected to: (a) answer the above fundamental scientific questions; (b) prepare a computationally designed set of new super- or ultra-hard materials for testing; (c) validate the hardness and inertness of that material for a given application where "hardness" is relevant; (d) provide foundational rules a

technologist could someday use to design an ultra-hard material that is both thermally and chemically inert for a given application.

Research Concentration Areas: A balanced, interdisciplinary program consisting of (1) Theory/Informatics; (2) Computational Materials Science/Physics/Chemistry; (2) Synthesis; (4) Chemical and Materials Analysis.

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Topic 7: (ONR) Narrative, Moral and Social Foundations of Social Cyber-Attack in Social Media

Background: Crowd manipulation, social hysteria propagation and group polarization are critical concerns across the globe. Online agitation is a key component in terrorist incidents, civil unrest, riots and violent attacks in recent years. Disinformation is just one of many techniques for manipulating audiences online; there are other, more subtle techniques and campaigns that target the moral psychology of the audience, manipulate social structure of online communities, and undertake a variety of social engineering measures to achieve strategic effects. The use of trolls, bot-armies, and "cyborgs" – humans whose influence and reach are amplified by technical means have reached epidemic proportions on social media platforms.

There has been some research investment in disinformation and "fake news," but relatively little investment in studying the social psychology of suasion online that leads to the tendency of audiences, as individuals and as groups, to accept, consume and prefer such content. Current research shows that trolls and bots control discourses in conversation by a number of different means. They target and overwhelm individuals and groups. They seek to quell some discourses and amplify others. They form echo chambers and attempt to influence key figures within the community. In anti-Western discourses, they frequently use moral arguments, stories, and images to herd the crowd towards a desired stance. Narrative and narrative frames play an important role in these information campaigns. Stories, images, videos and memes create compelling content that seeks to strike emotional chords in the audience. Narrative framing usually involves trying to find the right "fit" of the frame to the right audience at the right time, in order to achieve maximum strategic effect. In information campaigns designed to impact an audience's moral / emotional stance, the storyteller and the story must strike the right chord in the audience.

Psychology provides several theoretical stances for addressing how online audiences are manipulated by covert actors. Moral psychology provides a set of foundational matrices for understanding suasion across multiple dimensions. Social psychology provides a number of concepts for exploring confirmation bias, cognitive dissonance, illusory truth and other phenomena. Cialdini's studies of persuasion provide somewhat different frameworks for

understanding persuasion. How well do these theoretical and empirical frameworks explain anti-Western discourses online? What types of experimental processes and methods need to be undertaken in order to explore the persuasive aspects of anti-Western discourses to audiences outside of the U.S.? How do bots, cyborgs – and troll armies – matter in information conflicts? What are the most effective means of blunting their impact? How can social cyber communities develop improved resilience against infiltration, subversion and social cyber-attack? How can authorities improve their social trust with audiences before, after, and during information conflicts?

The online information environment introduces a second problem of scale. Millions of messages are delivered to target audiences over social media; audiences often spend significant fractions of their free time engaged in social media discourses. This introduces new problems of perception as audiences are surrounded by information, stories, pictures, and memes that are designed to deceive audiences with an artificial "generalized other" -- "Everybody knows that so-and-so is unreliable (or corrupt). Information science, computer science and machine learning techniques to uncover these campaigns and investigate their life cycles and evolutions – as well as to discover their weaknesses and vulnerabilities – are needed. How does volume and velocity of messages impact audience perceptions and sensibilities?

The current state of the art is in its very early stages. Previous work on online discourses have largely focused on countering violent extremism, fake news (disinformation) and bot detection. Much of the most recent work, such as the efforts of NATO Strategic Communications Center of Excellence or robotrolling or Oxford University's research on elections, has been primarily applied efforts focused on discovering bot activity and on characterizing misinformation and disinformation, generally. This effort would look at audience vulnerability to suasory discourses, as delivered by a variety of authentic and inauthentic actors and at methods to improve audience resilience to malign and deceptive information attacks.

The research envisioned would examine anti-Western, anti-authority (such as anti-vaxxer) or anti-US propaganda that are in some ways artificial (bot-pushed) and deceptive to uncover the moral psychology, social psychology and socio-technical aspects of online propaganda. Multidisciplinary research is needed due to the huge scale of messaging, stories, memes, and stories that need to be considered – and the enormous scale of the targeted audiences. Some cyber-social forensics would be needed to discern manipulated discourses and to identify the bots, trolls and cyborgs serving as cover actors and instigators. Ethnographic, experimental and/or computational social science modeling would be appropriate approaches to the exploration of this topic. Media studies research combined with social psychology or anthropology would also be considered.

Objectives: The main objectives are: (1) to develop new theoretical understandings of the techniques of propaganda, disinformation, and influence drawn from moral psychology, social psychology, and the social sciences; (2) to develop and test new models of cyber-social influence that would lead to improved understanding of how to help audiences become more resilient against social-cyber attack from malign actors; (3) to develop the science needed for authorities to more effectively protect their reputations, message audiences appropriately, and improve social trust with audiences.

Research Concentration Areas: Social sciences, especially moral psychology, anthropology, sociology, computational social science, and social psychology. Media studies and communications theory specialists are highly recommended. Information science and computer science might be usefully included to help develop cyber-social forensics to detect fraudulent and malign information actors.

Anticipated Resources: It is anticipated that awards under this topic will be no more than $1.5M per year for 5 years which will support no more than 6 funded researchers. Exceptions warranted by specific proposal approaches should be discussed with the topic chiefs during the white paper phase of the solicitation.

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Topic 8: (ONR) A Dynamics and Control Theory of Safe, Cognitive and Learning Systems

Background: A major recent advance in control theory has been the integration of increasingly complex computational methods into online control loops to solve problems that are both difficult to model and do not have an easy closed form analytic solution, while still providing some theoretical guarantees. However, this has been limited to a narrow group of computational methods, such as convex optimization solvers, that have well established properties in terms of their ability to calculate a feasible solution with convergence and performance guarantees. There is a great need to extend this to Artificial Intelligence and Machine Learning methods increasingly being considered for use in complex, feedback systems with substantial safety or other risk implications. To achieve this will require not only advances in control theory, but also appropriately rethinking AI methods to become an integral part of control loops, and not just a foreign entity in need of strict bounding, run-time monitoring, and correction as the only path to safety. An important problem is how to capture the benefits of extremely complex AI methods in a more frugal mathematical form (in terms of architecture, memory, and computation) that takes dynamics and control considerations into account from the start, but may involve different types of provable properties from the kinds of computational elements currently best understood. For the control field, AI may provide a way to improve control of difficult to model systems that might otherwise have risks of highly suboptimal performance or catastrophic failures. For the AI field, there is significant evidence from psychology, biology, and neuroscience, that regulatory mechanisms play a much more important role in natural learning than they do in the artificial version. Considering learning from a dynamic systems framework may enable faster learning of near globally optimal solutions with better generalization, effective learning of complex interactions with uncertain environments, and regulatory mechanisms against undesirable learning.

Objective: To develop a dynamics and control theory of artificially intelligent systems that enables rich use of online computational AI methods under guarantees on safety, performance, and robustness. To create fast, safe, and effective regulatory mechanisms for machine learning within and around AI methods inspired by computational models of human and other animal intelligence.

Research Concentration Areas: This topic encourages teaming across control theory, physics/nonlinear dynamics, AI/machine learning, psychology, neuroscience, and cognitive science on 4 core classes of problems: (1) Control theoretic methods that can incorporate a rich variety of AI methods with different underlying properties (machine learning, cognitive architectures, knowledge-based) and enable understanding and shaping of transient behavior and equilibria, (2) Understanding of what computational properties can and should be guaranteed in individual AI computational methods to enable systems level guarantees, (3) Derivation of more mathematically frugal forms of AI methods that preserve existing performance benefits while providing these guarantees, (4) Development of new feedback mechanisms inspired by models of human and other animal intelligence to enable improved generalizability, safety, robustness and resilience in, within, and around different classes of AI methods in complex systems.

Anticipated Resources: It is anticipated that awards under this topic will be no more than an average of $1.5M per year for 5 years, supporting no more than 8 funded faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with the topic chief during the white paper phase of the solicitation.

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Naval Research Laboratory Participants: Laura Hiatt, Signe Redfield

Topic 9: (ONR) Understanding Turbulence-Chemistry Interactions in Non-Equilibrium, High-Speed Flows

Background: Compressible turbulence drives the behavior of many terrestrial and astrophysical systems. For instance, compressible turbulence plays a vital role in star formation and the dynamics of deep wind structures of giant gas planets. In addition, turbulent flows are encountered in most existing and envisioned DoD systems operating at supersonic and hypersonic speeds. Hypersonic vehicles experience a severe increase in skin friction, acoustic loads, and aerodynamic heating when boundary layers transition from laminar to turbulent. Ramjet and scramjet engines combust fuel under high-speed turbulent flow conditions that frequently involve shock waves, extreme gradients, thermal inhomogeneity, flow separation, and high turbulence intensity. Recent basic research has increased the fundamental understanding of incompressible turbulence using modern mathematical theories, such as the exact coherent solutions (ECS) of the Navier-Stokes equations and resolvent analysis. However, it is unclear if these theories can be extended to high-speed turbulent flows where additional physical processes such as compressibility, thermal and compositional inhomogeneity, and chemical reactions occur. In high-speed flows, the timescales for changes in the macroscopic fluid dynamics are short due to extreme mechanical and thermal gradients across shock waves and boundary layers, and thus the resulting turbulence can strongly deviate from an equilibrium cascade. Moreover, non-equilibrium effects influence high-speed chemically reacting flows because chemical reactions requiring mixing on the molecular scale can be delayed until the short scales in the velocity spectrum are energized. Multidisciplinary

research is required to improve the fundamental understanding of unique aspects of compressible turbulence such as the effects of pressure dilatation, baroclinic torque and entropy fluctuations on the turbulence dynamics.

Objectives: The main objectives of this MURI are to: (1) Gain fundamental understanding of the nature of compressible, non-equilibrium turbulent flows; (2) Develop mathematical theories and computational methods to effectively represent and predict such flows; (3) Characterize the interaction between chemistry and compressible turbulence at various scales for both exothermic and endothermic reactions; and (4) Design new experiments and perhaps new instrumentation to test the mathematical theories and numerical simulations. Experiments will provide high-quality datasets to validate models and will also serve to drive computational and analytical work in fundamentally new directions. If successful, this MURI will provide for the first time a predictive capability to analyze high-speed compressible turbulent flows with finite-rate chemical reactions.

Research Concentration Areas: Suggested concentration areas include, but are not limited to: (1) Mathematical theories to represent the turbulent energy cascade in non-equilibrium, compressible turbulence and the interaction between thermodynamics and turbulence over all relevant spatial-temporal scales; (2) Sensitivity analysis to identify the parameters that most affect the state of non-equilibrium turbulence under strong density variations; (3) Simulations and experiments using the most advanced diagnostics to characterize the multi-dimensional, time-resolved interactions between chemistry and turbulence for both exothermic and endothermic reactions over a relevant range of Damköhler numbers; and (4) Reduced-order models for non-equilibrium turbulent flows developed using high-fidelity datasets and modern model reduction approaches such as data-assimilation, machine learning, and resolvent analysis.

Anticipated Resources: It is anticipated that awards under this topic will be at an average of $1.5M per year for 5 years supporting a multi-disciplinary team of 5-7 faculty researchers.

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Topic 10: (ONR) Predicting Organic Molecular Decomposition

Background: Complex organic molecules and materials made from them decompose over time depending on intrinsic molecular stability and external influences, such as pressure, temperature, and chemical potential of adjacent materials. This phenomenon is important for material where a molecule must perform for a specified length of time and/or degradation products may negatively affect functionality. Degradation related concerns become vastly more complex when considering the wide array of environmental factors for a given application: temperature, pH, thermal/mechanical stresses, catalytic effects, electric fields/currents, solvent effects. In addition, how do the different components of a mixture or

the physical state of the system influence degradation? The current state of the art involves diagnostic chemical analysis throughout the degradation process or post-mortem to validate or invalidate proposed decomposition mechanisms for narrow subsets of organic compounds, depending on application and function. There are no comprehensive predictive approaches to treating all classes of molecular materials, whether organic, organometallic, or polymer. A superior predictive approach may now be reachable through advances in quantum-trained reactive force fields, predictive models from machine learning, and emerging theoretical constructs, such as nano-reactors for identifying unknown reaction mechanisms coupled with advanced high speed experimental diagnostics for real time chemical species identification, among others. With modern tools, it should be possible to overcome the two bottlenecks preventing the ability to predict how molecular materials degrade: (1) being able to determine all possible degradative outcomes for a selected molecule in a given environment and (2) being able to determine that molecule's stability, kinetics and lifetime in that environment. Removing the first bottleneck requires a capability to determine all degradation pathways available to the system under a specified set of stressor conditions. This may involve mapping all reaction coordinates for a molecule or a collection of molecules in a given environment by using (i) purely quantum chemical calculations, (ii) reactive force fields parameterized from extant literature or from quantum-derived machine learning techniques, (iii) heuristic approaches based on high throughput experimental screening or existing reaction databases, etc. An advantageous way to address the second bottleneck would be the derivation of a single or set of numerical chemical sensitivity/stability related parameter(s) that provide information about a molecule's rate of degradation. This could be accomplished, for example, by deriving approximate rates of reactions from knowledge of all possible transition states described in (i) above, or, by some other means. Ultimately, this knowledge would be predictive and would guide decision to make new materials, prior to synthesis and testing, based on the likelihood that molecule will persist, given its intended end-use and its storage conditions.

Objectives: The Purpose of this research is to be able to predict how any molecule-based material degrades or decomposes under any set of environmental conditions. The objective towards meeting that long-term goal is to initially focus on predicting and validating small molecule chemical decomposition. The desired outcomes are: (i) new theories, computational tools, experimental techniques and protocols that are able to predict decomposition products and rates of decomposition for any molecule under a wide range of conditions; (ii) derivation of robust, chemical sensitivity/stability related parameter(s), ideally in the form of a single or reduced set of numerical value(s) that could be used to identify the best material to consider for synthesis/testing from a list of possible molecules derived from computer-aided molecular design; (iii) a comprehensive understanding of how combinations of stressors leading to decomposition differ from a single stressor, (iv) strategies for how best to construct a nascent database/knowledgebase of molecular decompositions; (v) rules based on intrinsic thermal pathways coupled with extrinsic environmental influences such as electric, magnetic, mechanical strain fields, pH, solvent/catalytic effects, thermal cycling, vibration, and light.

Research Concentration Areas: Suggested research areas could include: (1) theoretical methods for predicting mechanistic reaction networks/rates, and labile vs. metastable species (2) experimental methods to accelerate aging and decomposition processes under a variety of conditions with associated diagnostics and chemical analysis methods to identify decomposition products; (3) informatics for developing predictive models based on experimentation and computation described in (1) above.

Anticipated Resources: Awards under this topic will not exceed an average of $1.5M/year for 5 years, supporting six faculty researchers. Exceptions warranted by specific proposed approaches should be discussed with the topic chief during the white paper phase.

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Topic 11: (ARO) Anomalous Dipole Textures in Engineered Ferroelectric Materials

Background: Recently, theoretically predicted anomalous dipole textures such as polarization vortices and polar Skyrmions (non-trivial nanometer-scale textures of electric dipoles) were experimentally demonstrated in engineered advanced ferroelectric materials. For example, polar Skyrmions of a few nanometers in size were demonstrated in interfacial strain controlled complex oxide super-lattices at room temperature. Ferroelectric bubble nano-domains were also created with an electrical field using a scanning probe tip, and erased with a small mechanical force in complex oxide hetero-structures. These anomalous dipole textures are of great interest as they exhibit emergent properties such as giant electromechanical response, chirality and large spin-orbit torque which are promising for a new paradigm of transformative technologies such as ultrafast, high density memories, logic, sensing, communications and THz sources. Polar Skyrmions offer unique advantages over magnetic Skyrmions (spin textures observed in magnetic materials) such as small size (an order of magnitude smaller in size at room temperature) and possibilities of electric-field and pressure-based manipulation. To exploit the unique features of the anomalous dipole textures for novel functional devices, fundamental knowledge of how to controllably engineer (create, transport, erase) them in materials is needed. In addition, understanding the effects of temperature and external fields on the number density, chirality and interactions with each other and with other structural defects needs to be developed. Novel characterization techniques to better understand the size, chirality of different dipole textures and their interactions are nascent or undeveloped as well (such as recent novel demonstration of utilizing nitrogen vacancy centers in diamond to characterize magnetic Skyrmions). It is also anticipated that through selection of appropriate materials and further understanding of dipole texture physics and engineering, it may be possible to discover other novel textures such as half Skyrmions (merons) or multiferroic Skyrmions that can be even more easily manipulated with both magnetic and electric fields.

Objective: To develop the theoretical understanding and to experimentally study the creation, dynamics, interactions, and annihilation of anomalous dipole textures, in advanced materials and explore novel device concepts that exploit these textures.

Research Concentration Areas: Areas of interest include, but are not limited to, the following: 1) Develop the basic theory and models to predict, help understand/interpret experimental results, and to guide the realization of anomalous dipole textures (e.g. polar Skyrmions, merons, multiferroic Skyrmions) in advanced super-lattices/hetero-structures, 2) Explore different materials synthesis routes, and compositions/structures to create and engineer the advanced materials with sufficient control to realize novel dipole textures, 3) Investigate the dynamics of anomalous dipole textures under external applied stimuli (e.g. mechanical, optical, magnetic and/or electrical field, etc.), 4) Design/adapt novel characterization techniques to study the dipole texture creation/transport/annihilation and interactions with each other, with phonons, and with other structural defects, and 5) Develop novel dipole texture-based device concepts exploiting the knowledge developed in this program.

Anticipated Resources: No more than an average of $1.25M per year for 5 years, supporting no more than 6 funded faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with topic chiefs during the white paper phase of solicitation.

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Topic 12: (ARO) Cyber Autonomy through Robust Learning and Effective Human/Bot Teaming

Background: While both cyber offence and defense are currently human driven, it is envisioned that in 10 years, many cyber tasks will be carried out by autonomous systems. The DARPA Grand Challenge (Mayhem) demonstrated initial success of cyber systems that performed self-checks to identify and patch vulnerabilities. Future Army systems, especially cyber-physical systems working side-by-side with Soldiers, need to exhibit the capabilities of introspection and self-adaptation to changing operational environments and to defend against attacks that may lead to system failures. While main stream testing and verification techniques help assure system integrity prior to deployment, few of them can support runtime risk mitigation or automatic recovery after a compromise, nor can these systems adapt in response to varying operational environments or adversarial conditions, which is inevitable for any cyber autonomous system. Ensuring trustworthiness and robustness of future systems requires a leap forward of our knowledge in key technology areas: 1) Robust Learning: Current black box, data driven learning does not provide guarantees of either correctness or security

assurance; the assumption that both training and testing data can be modelled by the same stationary independent identically distributed density functions commonly gets violated in real world. Given an ultra-high dimension data space, blind or unexplored spots missed by the training phase can be exploited by adversaries, making AI system vulnerable. Recent work on using robust statistics for learning, in conjunction with robust optimization, offer a great promise in strengthening learning resiliency against malicious manipulation. Incorporating a clear adversarial context in learning and decision making will also help certify correctness; 2) Introspection/Anti-fragility Adaptation: Traditional control theory approaches cannot be adopted directly to cyber systems since they assume that states are known a priori. To support introspection, adaptation, sustainability, and survivability for cyber bots, we need new theories to work with dynamic cyber systems that are open, and non-stationary. Recent research on anti-fragility shed lights on how large open systems like financial markets can survive severe failures like black swan events. Instead of focusing on how to avoid failures, systems operating in an anti-fragility mode will embrace errors and failures, and use lessons learnt from "what went wrong" to adapt and to improve resiliency; 3) New Team Science Concepts for Cyber Bots: While AI surpasses humans in data processing scale, speed and accuracy with fewer biases, humans excel in multi-tasking and making complex decision under varying contexts and conditions. Weaknesses and failure modes are dramatically different too. To play the strength of both, new team science concepts will facilitate optimized cognitive reasoning and decision making for joint human/cyber AI systems. The creation of a shared mental model across human/bots will play a key role in maintaining a high level of trustworthiness and driving performance optimality.

Objective: To obtain scientific understandings and establish model for trusted cyber autonomous systems that support robust learning (especially from failures), exhibit anti-fragility adaptation, and allow cyber bots teaming among themselves or with human agents, in order to achieve mission assurance under highly dynamic and adverse environments.

Research Concentration Areas: Multidisciplinary participation is expected from cognitive sciences, decision sciences, AI/ML, biological adaptation, social sciences, statistics, optimization, adversarial modeling, and cyber system verification theory to 1) explore robust learning methods that can provide correctness guarantees, and create mathematical models to quantify robustness and trustworthiness of cyber autonomy under adversarial settings; 2) create anti-fragility and proactive adaptation/evolution techniques for sustaining cyber mission; 3) techniques for introspection and maintaining awareness on system "brittleness" through leveraging advances in spatial-temporal analysis of non-stationary systems; 4) definition, models and techniques to assess risks, quantify trust levels, and verify correctness of the joint human/cyber AI systems; 5) establish human/bot common mental models for defining entity roles, capability matching, and dynamic command structures for human-like reasoning and decision making; 6) explore and understand social/cultural influence on the human/cyber AI systems, and define adversarial models for potential attackers who may adopt deception in both cyber and social spaces.

Anticipated Resources: It is anticipated that awards under this topic will be no more than an average of $1.25M per year for 5 years, supporting no more than 8 funded faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with the topic chief during the white paper phase of the solicitation.

Note: Proposals are invited that include participation from Australian (AU) academic institutions; however, AU participation is not a requirement. In the case of proposals with AU participation, there still should be a single US primary institution and one PI submitting the overall proposal. Funding for the AU participation will be allocated separately by the AU government. Opportunities for Australian funding for such collaborative proposals are described at http://www.business.gov.au/ausmuri

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Topic 13: (ARO) Highly Heterogeneous Meta-macrostructures Created via Fine-particle Interactions

Background: Particle suspensions are foundational to many established (e.g., slip casting, cements) and advanced (additive manufacturing, colloidal self-assembly) materials processing methods; thus, materials scientists have obtained considerable insight into the nature of fine-particle and colloidal interactions on the microscale. However, there remain significant knowledge gaps regarding key aspects of their thixotropic behavior on the macroscale, such as the transition point at which a suspension changes from behaving as a fluid versus a soft solid. Geoscience also faces challenges related to fine-particle interactions as micron-scale particles are a large fraction of soils and unconsolidated sediment, and the presence of these fines has been observed to significantly impact soil behavior. In both these scenarios, the combination of coarse and fine particles could be described as a heterogeneous macrostructure whose behavior is governed by both the physical structure of the coarse particles and an implicit secondary structure created by a chain of fine-particle interactions. In contrast with larger inert particles whose interactions are governed by classical mechanics, interactions among fine particles (~1 μm diameter or less) are controlled by surface chemistry. Because surface chemistry is influenced by constantly changing conditions, the structural impact of these interactions could be considered a “meta” structure whose behavior varies depending on conditions. Due to a lack of understanding of the structural impact of these fine-particle interactions on the macroscale, materials science faces challenges in creating large-scale “green” bodies from particle suspensions, as builds often slump or collapse from lack of strength. Geotechnical engineering relies on empirically based constitutive models to predict the mechanical and rheological behavior of terrain in response to stress from vehicles or construction, but these models do not accurately incorporate the influence of fine particles, resulting in erroneous predictions.

Recent developments in experimental and numerical methods enable the potential to move from empiricism to mechanistic understanding of bulk fine-particle systems. These advances include characterization methods, such as high-resolution electron microscopy to image particle interactions in high-moisture conditions, the demonstrated ability to relate interparticle potential to rheological behavior, and the development of grain-resolving direct numerical simulations of fine particles that capture interparticle forces. These methods could provide the information needed to elucidate the macroscale structural influence of fine particle interactions. This new knowledge could lead to new fundamental insights into the rheology of high-solids systems and geological phenomena such as soil liquefaction. By leveraging established knowledge in powder processing and colloidal assembly, processing methods for creating desired macrostructure states in complex particle systems may be realized. The ability to create desired macrostructure states in heterogeneous particle systems could enable additive manufacturing processes of non-metallic materials on an unprecedented scale, geotechnical engineering methods for ground mobility or disaster prevention/mitigation, and bulk resource extraction of valuable trace elements from terrain or waste material.

Objective: The objective of this MURI is to determine how fine-particle interactions create a macroscale meta-structure in systems containing a mixture of fine and inert coarser particles, accurately describe the structural influence and, from that knowledge, develop both constitutive models based on mechanistic understanding that predict the macroscale behavior of these highly heterogeneous particle systems and processing methods for the inducement of desired meta-macrostructures via rheological, electrostatic, chemical, or alternative mechanisms.

Research Concentration Areas: These include, but are not limited to: (1) Microscale characterization of fine-particle interactions under a range of timescales and conditions (e.g., pH, moisture content, salinity) and how these interactions propagate through a larger assembly of particles; (2) Frameworks that predict the structural impact of stimuli-driven (stress, pH, etc.) fine particle interactions within heterogeneous particle systems from the micron to meter scale; (3) Inducement of desired meta-macrostructure states in heterogeneous particle systems via manipulation of fine particle interactions via processing additives or methods; and (4) Structural descriptions and explanations for the implicit meta-structures generated from fine particle interactions and their macroscale (>1m) influence on bulk heterogeneous particle systems such as industrial scale powder processing or Earth surface systems.

Anticipated Resources: It is anticipated that awards under this topic will be no more than an average of $1.25M per year for 5 years, supporting no more than 6 funded faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with the topic chiefs during the white paper phase of the solicitation.

Research Topic Chiefs: Dr. Julia Barzyk, ARO, 919-549-4379, Julia.g.barzyk.civ@mail.mil; Dr. Michael Bakas, ARO, 919-549-4247, Michael.p.bakas.civ@mail.mil

Topic 14: (ARO) Non-Silica Inorganic Material Phases Synthesized from Genetically Modified Diatoms

Background: Many desirable material phases are challenging to synthesize due to the underlying thermodynamics requiring extreme conditions such as high temperatures or pressures. There is considerable interest in the development of more flexible alternative processes that can create such materials without requiring challenging processing conditions. Biology has optimized processes to achieve synthesis of refractory ceramic materials under ambient conditions, leading to intense interest in co-opting biological systems for material synthesis. For inorganic materials synthesis, diatoms display particularly impressive capabilities. Diatoms are single-celled algae that selectively import silicic acid to biomineralize ornate cell walls, termed frustules, into a hydrated silica phase that is robust and persists long after the diatom perishes. Prior efforts have explored the silica frustules as optical materials, including attempts to alter frustule 3D structure, as well as chemical modification of frustules post-formation. However, recent advances in synthetic biology and genetic engineering methods for diatoms coupled with the identification of protein motifs that selectively bind a variety of inorganic metals (e.g., Ga, Ti, Al) open up the possibility to genetically modify the chemistry of diatoms for the growth of non-silica frustules. Genetically modified diatoms could enable an entirely new path for the synthesis of inorganic phases normally requiring extremely high temperatures, pressures, or other extreme conditions.

The protein-mediated hydrolysis reaction that forms the diatom frustule is chemically similar to reactions utilized in sol-gel processing and polymer-derived ceramics. If diatoms can be genetically modified to enable transport of non-Si-based acids, this body of materials processing knowledge could be leveraged to guide computational efforts to identify viable non-silica frustule compositions. Genetically modified diatoms could synthesize frustules with specific material compositions that serve directly as the targeted material phase or act as a precursor, such as those utilized in polymer derived ceramics and sol-gel processing, that is converted into the desired material via subsequent processing or pyrolysis. The control that biology provides also raises the possibility of directing deposition of specific elements to precise frustule locations. Thus, diatoms not only provide a potential synthesis platform for material phases normally requiring high temperatures and pressures, but may also enable synthesis of nano-featured physical structures with unprecedented structural, photonic, energetic, or electronic properties.

Objective: The MURI objective is to genetically engineer diatoms to biomineralize non-silica frustule compositions computationally predicted to form stable crystalline or amorphous phases, or precursors that can be processed into target material phases. Approaches to chemically modify silica-based frustules post-formation are not of interest.

Research Concentration Areas: Suggested research areas include, but are not limited to: 1. Integrated experimental and computational efforts to elucidate mechanisms governing protein-mediated transport of inorganic acids and subsequent incorporation into frustules. 2. Computational prediction and experimental exploration to identify target material compositions and phases that are viable for synthesis by genetically modified diatoms. 3. Genetic engineering and/or directed evolution of diatoms to produce synthetic species capable of assembling non-silica frustules. 4. Characterization of non-silica frustules and conversion into stable structural materials by manipulation of growth conditions, or by creation of gels, polymers or amorphous precursors that can be converted to a target material with subsequent processing.

Anticipated Resources: It is anticipated that awards under this topic will be no more than $1.25M per year for 5 years, supporting no more than 6 funded faculty researchers.

Research Topic Chiefs: Dr. Michael Bakas, ARO, 919-549-4247, michael.p.bakas.civ@mail.mil; Dr. Stephanie McElhinny, ARO, 919-549-4240, stephanie.a.mcelhinny.civ@mail.mil

Topic 15: (ARO) Novel Mechanisms of Neuro-Glio Bio-Computation and Reinforcement Learning

Background: Reinforcement Learning (RL) is a branch of Machine Learning (ML) that focuses on determining the best course of actions to maximize reward and has deep roots in cognitive psychology and control theory; specifically dynamic programming. Research has been bolstered by the dramatic success of RL algorithms in outperforming human experts in games (chess, Go) and in controlling autonomy. However, for many problems of practical interest, computational power and training data requirements can be formidable, and its convergence may be disqualifyingly slow, if at all. In contrast, biological learning and decision making are in many ways more complex, but can be very efficient. The brain explicitly samples raw data from past memory episodes in decision making, which makes its state non-Markovian, but as a result, can reduce the dimension of the state. In contrast, most RL systems operate using Markovian states, whose dimensions in some cases may be too large to allow for efficient computations. Biological learning involves building representations of the world from a few examples, filtering out superfluous data and predicting events based on the past history. Providing similar enhancements to RL require deeper understanding of memory systems and cognitive processes in the human brain. Preliminary evidence suggests that glia play a pivotal role in learning and memory. Glial cells (specifically astrocytes) communicate with each other, release their own transmitter molecules, and can activate hundreds of neuronal synapses at once. Together, these actions can synchronize neuronal activity and activate or inhibit neuronal networks; modifying information transfer and storage on multiple temporal scales and hierarchies. Recent advances in metabolic imaging and

genetically encoded activity measurements now provide an opportunity to observe coupled activities and interactions in neurons and glia. These tools could enable development of more sophisticated models for cognitive processes in the brain. Also, recent efforts have incorporated glial inspired connections into ML networks, and shown enhanced performance as a result of this addition. Similarly, we expect that hierarchically organized feedback/feedforward functions along with newly discovered information storage and access mechanisms derived from neuro-glio systems could shed additional light in the understanding of human decision making mechanisms where past memory samples are explicitly used, and hierarchical reasoning structures are exploited. Refined model shaped by these observations could inspire novel architectures for sequential decision making in RL.

Currently, high-density multi-site recordings in active subjects can allow unprecedented descriptions of cognitive processes, with a plethora of possible measurement options whose scale could be a challenge in the design of experiments. Neuro-glial inspired RL, as envisioned by this MURI, might be used to identify strategically chosen sequences of neuroscience experiments to enhance our understanding of cognitive process dynamics displayed in these extremely large datasets. Enhanced neuro-glial inspired RL techniques could facilitate efficient choices of information gathering measurements by optimizing relevant metrics such as system entropy, or the behavior of postulated models as compared to actual measurements. Altogether, neuro-glial inspired RL can offer efficient decision making tools for neuroscience experimentation and validation to further improve models for neuro-glial systems. This, in turn, might lead to more powerful neuro-glial inspired RL architectures and algorithms.

Objective: To develop novel cognitive process models derived from the principles of information processing in neuro-glio networks in the brain, leverage these models to address challenging issues in RL, and apply enhanced RL techniques to develop deeper understanding of cognitive brain functions.

Research Concentration Areas: Suggested research areas include but are not limited to (1) innovative methods to measure neuro-glial metabolic coupling and information processing; (2) integrated behavioral experiments and modeling to describe the interactions of neuro-glio interactions with learning and memory mechanisms; (3) development of novel bio-inspired neuro-glio RL approaches and architectures; (4) analysis and modeling of non-Markovian RL systems using techniques such as fractional calculus, and (5) validation of bio-inspired RL techniques in challenging problems.

Anticipated resources: It is anticipated that awards under this topic will be no more than an average of $1.25M per year for 5 years, supporting no more than 6 funded researchers.

Research Topic chiefs: Dr. Derya Cansever, 919-549-4330, derya.h.cansever.civ@mail.mil; Dr. Frederick D. Gregory, +44 01895.626517, frederick.d.gregory5.civ@mail.mil

Topic 16: (ARO) Quantum Network Science

Background: The possibility of adapting network science frameworks and protocols to quantum networks is emerging as an opportunity to enable beyond-classical capabilities. A quantum network is any network of nodes and channels between those nodes that contain quantum components capable of manipulating and distributing quantum information. Any quantum network will also contain classical components, and the necessary mix of quantum and classical elements is determined by the desired functionality of the network. Currently, quantum networks lack the robustness for large-scale, high-fidelity implementations, such as those needed to realize networks of quantum sensors, quantum communication, distributed quantum computation, networks of high-precision synchronized atomic clocks, and entanglement and teleportation enhanced long-baseline interferometry. Even so, a multidisciplinary focus on qubit physics, materials, and operation has brought us close to realizing a three node quantum network, and network components like quantum memories, repeaters, and converters are all experiencing rapid development. Network science has created a wealth of protocols to bring networks of limited reliability into robust operating regimes, and classical constructs such as percolation theory are now being applied to a variety of quantum network topologies with imperfect physical components. This percolation theory approach is evidence that a well-studied concept can help enable entanglement distribution in otherwise fragile quantum networks. However, a one-to-one application of established protocols to quantum networks isn't feasible because, for example, some protocols rely on making copies of data during processing, a process prohibited for quantum information due to the no-cloning theorem. A concerted effort pairing network scientists with quantum information scientists has the potential not only to advance our understanding of how to apply classical constructs such as percolation to quantum networks, but also to develop novel protocols rooted in quantum physics to potentially enhance network functionality. For example, we know that two quantum channels which individually have zero quantum capacity can, when combined, "superactivate" to form a joint channel with a non-zero capacity and the ability to successfully transmit information. We also know that two bits of classical information can be transmitted with only one qubit via "superdense" coding schemes that leverage superposition, entanglement, and hyper-entanglement. Further, we know that quantum correlations can preserve information in extremely noisy or contested channels, possibly enabling communication in environments in which classical communication over a fully classical network is highly degraded. Additionally, quantum algorithms exist for classical problems such as Byzantine agreement and liar detection, and these algorithms can solve some variations of the problem impossible to solve classically. One may thus envision a scheme where a quantum network is leveraged to efficiently discern faulty or untrustworthy nodes in not only quantum networks, but also in networks wholly otherwise classical. Partnerships in a new discipline of quantum network science exploring these areas are poised to greatly enhance our ability to gather, process, and share information.

Objectives: The goal of this topic is to merge theoretical and experimental concepts from network and quantum information sciences for robust distributed quantum entanglement and to explore new approaches for information gathering and processing enabled by distributed vs local entanglement. Specific objectives include but are not limited to (i) develop figures of merit for quantum networks (ii) understand the role of imperfect physical components on the figures of merit and (iii) develop novel theory, mathematics, and experiments to design, control, and improve the performance of quantum networks.

Research Concentration Areas: Suggested areas include but are not limited to: (1) The adaption and application of network science protocols such as routing, scheduling, modulation, and error correction to quantum networks with imperfect components such as repeaters, memories, and converters in order to enable the construction of robust quantum networks above the percolation threshold, which may need derivation and/or definition, when appropriate. Both wired and wireless network science protocols could be considered. (2) The discovery of new protocols that leverage quantum mechanics constructs such as superactivation, superdense coding, quantum correlations, the superposition of channels, and quantum network algorithms such as Byzantine agreement and liar detection to enhance the capacity of networks and potentially enable functioning with noisy and lossy channels. (3) The development of platforms to validate and explore the protocols developed in (1) and (2) on physical quantum networks in a laboratory, preferably with three or more nodes. (4) The exploration of new approaches for information gathering and processing enabled by distributed vs local entanglement.

Anticipated Resources: Awards under this topic will be no more than an average of $1.25M per year for five years, supporting no more than six funded faculty researchers.

Research Topic Chiefs: Dr. Sara Gamble, 919-549-4241, sara.j.gamble.civ@mail.mil; Dr. Derya Cansever, 919-549-4330, derya.h.cansever.civ@mail.mil

Topic 17: (ARO) The Same is Different: Integrating Multiple Phenomena in Single Materials

Background: Chemical incompatibility between materials with different characteristics prevents the realization of many unusual electronic functionalities that would otherwise result from the juxtaposition of those materials. Different geometric arrangements such as stacking and twisting between layers of a two dimensional (2D) material results in phenomena otherwise foreign to the material. External fields can, in some cases, turn those phenomena on or off. This presents an opportunity to achieve promising functions and devices that avoid chemical incompatibility. This MURI visualizes the realization of multiple laterally arranged electronic phases (i.e. superconductivity, magnetic, domain boundary states, etc.) resulting from stacking, twisting, and external tuning parameters within a single material to examine the

physics and electronics of their interactions. In addition to insulating, semiconducting and metallic phases, multiple groups have demonstrated superconductivity and a new form of ferromagnetism in twisted bilayer graphene, neither of which were originally expected. Though the physics results from Moiré pattern-induced flattening of electronic energy bands, a complete theoretical understanding of these emergent phenomena is still lacking. The Moiré patterning has also been shown to induce phenomena in other 2D materials. External fields can also tune electronic phases. For example, WTe2 can be tuned between superconducting and quantum spin Hall phases with an electrical bias. This MURI topic seeks to extend these concepts to other emergent phenomena in heterostructures between and among different electronic phases defined within a single material. Two monolayers of a single material can now be overlaid such that the overlap region supports a different electronic phase than the non-overlapping regions. This is a homo-heterojunction: the physical junction is made of the same material whereas the electronic junction is heterogeneous. Two dimensional materials host many symmetries that can be harnessed for functional diversity: structural, valley, spin, electron/hole and chiral (or sublattice) symmetries. This promises a host of phases and functions within a single material. Advances in the layering (vertical homo-heterojunction) and lateral arrangements (lateral homo-heterojunction) along with external fields provide the opportunity to explore electronic phases in close proximity to realize functionality not present in any single phase.

Objective: To integrate dissimilar electronic phases of matter in any individual 2D material through geometric tiling and stacking along with external fields to reveal emergent electronic, thermal and/or optical phenomena and design functional device concepts based on them.

Research Concentration Areas: Research concentration areas must include but are not limited to: 1. Theory and modeling of interactions between disparate phases to provide accurate, predictive guidance to design homo-heterojunctions, 2. Development of approaches to the precise control of inter-layer stacking, twisting and positioning of 2D materials with atom-level registry – preferably with large area – and to seamlessly integrate different regions laterally, 3. Characterization of electronic, phononic and photonic interactions through the homo-heterojunctions and among different domains hosting different phases, and 4. Design and demonstration of novel model electronic/thermal/optical device concepts within the framework of the single material.

Anticipated Resources: It is anticipated that awards under this topic will be no more than an average of $1.25M per year for 5 years, supporting no more than 6 funded faculty researchers.

Research Topic Chiefs: Dr. Marc Ulrich, ARO, (919) 549-4319 marc.d.ulrich.civ@mail.mil, Dr. Pani Varanasi, ARO, (919) 549-4325, chakrapani.v.varanasi.civ@mail.mil

Topic 18: (ARO) Tunable Dilute Anion III-Nitride Nanostructures for Stable Photocatalysis

Background: Photoelectrocatalysis using semiconductors has been hampered by a variety of challenges including: control of electron/hole recombination, inability to tune the energy bandgap and thus absorption spectrum of photoelectrocatalytic materials, and stability at the electrolyte interface. Recent advances in metal-nitrides growth, particularly the ability to grow bottom-up nanostructures of group III-nitride semiconductors, where the carrier diffusion length is greater than the nanowire dimensions, have shown extraordinary promise that are not seen in conventional oxide, arsenide, and phosphide-based semiconductor photocatalysts/electrodes. Group III-nitride semiconductors are currently used in the LED lighting and power electronics industries, and their exceptional power handling capability and stability that far surpass conventional photocatalyst materials. Additionally group-III nitride systems with continuously tunable bandgaps from UV to near infrared can be alloyed for efficient photochemistry, e.g. the bandgap of the InGaN system ranges from 0.7 eV to 3.4 eV, spanning not only the solar spectrum but also the energies of many reactions. In addition, through doping and processing to generate nanowire arrays, the Fermi levels and energy offsets can be controlled for these materials enabling enhanced charge carrier separation and extraction, surface polarity and band bending can be modified for efficient adsorption and deformation of molecules. Their surface polarity can also be controlled to achieve long-term stable operation under harsh photocatalysis conditions where photocatalysts have generally corroded. Nevertheless, it remains challenging to realize phase-stable high quality InGaN with the high indium composition (>30%) needed for efficient absorption and emission of red to green wavelengths. This problem is potentially overcome by dilute anions doping, where, up to approximately 6%, nitrogen is substituted with dilute anions such as Sb, As, or P. Dilute anion doping allows for precise band structure engineering and has been found to suppress Auger recombination, all without the need for high indium concentrations. This doping regime represents a revolutionary new opportunity to drive photoelectrochemistry with: spectrally tunable, stable, and nanostructured III-nitride systems. In addition, the combination of improved carrier mobility and controlled surface polarity and termination will allow tailoring binding sites and charge transfer (+ or -) for adsorbates in a way that may allow greater selectivity and/or minimize undesired byproducts. Combining electrochemistry, and surface and interface science, with the recent advances in growing bottom-up III-nitride nanostructures provides a unique scientific opportunity to reveal new physical and chemical phenomena at the nanoscale and the ability to drive novel photoelectrochemistry. The photoelectrocatalytic behavior of these have not been studied and both experimental and computational efforts are required. Materials/surface characterization and the interplay between processing, structure, and properties needs to be explored. In addition, understanding hot carrier dynamics, electron transfer, and subsequent electrochemistry of absorbed and solvated molecules is needed.

Objective: The objective is to develop and understand the behavior of group-III nitride semiconductor photoelectrocatalysts with tunable energy bandgap in the visible and near-infrared wavelength range and to explore their structural, surface electronic, and photocatalytic properties.

Research Concentration Areas: Areas of research may include but not limited to: (1) Theoretical efforts to calculate and model the interaction of molecules on semiconductor surfaces; (2) Synthesis of chemically uniform InGaN anion doped materials with tunable energy bandgap in the deep visible and near-infrared spectral range; (3) Controllably achieving the desired InGaN alloy, the desired doping profile, and the tailored surface morphology (esp. polarity, termination, contamination); (4) Structural, surface electronic, and photocatalytic characterization; (5) Exploration of hot carrier dynamics in nanostructured photocatalysts/photoelectrodes; and (6) Investigation of novel photoelectrochemical reactions that can be driven by these materials.

Anticipated Resources: It is anticipated that awards under this topic will be no more than an average of $1.25M per year for 5 years, supporting no more than 6 funded faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with the topic chief during the white paper phase of the solicitation.

Research Topic Chiefs: Dr. Robert Mantz, ARO, 919-549-4309, robert.a.mantz.civ@mail.mil; Dr. Michael Gerhold, ARO, 919-549-4357, michael.d.gerhold.civ@mail.mil

Topic 19: (AFOSR) Mechanisms of Novel Reactivity in Aqueous Microdroplets

Background: Recent research has shown that aqueous microdroplets (1-50 μm in diameter) present a unique environment for chemical reactions. Rates for many different types of reactions have been accelerated by, in some cases, up to six orders of magnitude in these microdroplets relative to reactions in bulk water, and reactions that are not thermodynamically favorable or not observed in bulk are seen to occur in aqueous microdroplets. This surprising and unique reactivity can be exploited for a wide range of applications including production of hydrogen from water, making nanoparticles without typical reducing agents, synthesis of high value compounds from pharmaceuticals to energetic materials, enhancing analytical methods, and even disinfecting pathogens and surfaces. These systems may also be models for the effects of confinement and self-organization on reactivity in biological systems such as cellular condensates. Yet the mechanisms that gives rise to these effects on reactivity are not at all well characterized or understood, although evidence points to the importance of reactions at or near the droplet surface. Electric fields that arise at the air/droplet interface have been implicated in these processes, but these fields have not been measured in situ. The physics that causes these fields are not well described, and as a result, the sign and magnitude of these

electric fields cannot be well modeled or predicted. The local concentration and activity of H^+ (or the actual molecular speciation of the positively charged moiety, e.g., $H3O^+$, $H5O2^+$, …) and OH^- at the droplet interface may also differ greatly from values in the bulk and play a significant role in the chemistry that occurs. Once again, these concentrations or the water ionization constant have not been measured in situ, and cannot be quantitatively calculated or predicted. Droplet size, curvature, reactant alignment (entropic effects), and ion clusters have also been discussed as playing possible roles in the unique reactivity in water microdroplets. In light of the potential importance of this reaction medium, a multidisciplinary program to study the fundamental driving forces and physicochemical effects of the processes responsible for the unique reactivity in aqueous microdroplets would be extremely timely and valuable and contribute to the wider use and exploitation of this intriguing behavior. Such a program spanning the physics of charge separation and the origin of interfacial fields in droplets, fluid mechanics, chemical and biochemical reactions, laser diagnostics, and theoretical modeling will drive the development of this area which can provide new methods for material production, decontamination/disinfection, and fuel production of interest to the DoD.

Objective: The objective of this program is to use experimental and theoretical/computational methods to advance the fundamental understanding of the unique properties of aqueous microdroplets as a medium for chemical reactions, and explore ways in which these properties can lead to new materials and methods of interest to the DoD.

Research Concentration Areas: Suggested research areas include but are not limited to: (1) In situ experimental characterization of electric fields and H^+ and OH^- ion concentrations at the surface of aqueous microdroplets having diameters less than 50 μm. Visualization of fields and ion concentrations, and molecular level information on reaction mechanisms and intermediates would also be of interest; (2) Performing modeling and simulation to predict electric field direction and magnitude at the interface between air and aqueous microdroplets, and of H^+ and OH^- concentrations at the surface of water microdroplets under various physicochemical conditions. Developing theoretical and computational models that describe the effects of the above factors on chemical reaction rates is also desired; (3) Demonstration of the effects of acceleration of reaction rates in microdroplets in a wide range of systems, and identification of systems that would particularly benefit from this approach and be of use to the DoD. Probing the effects of various properties of microdroplets and possibly external electric fields and microfluidic behavior to direct reactions would also be of interest as well as demonstration that such approaches could be scalable; (4) Demonstration of the use of microdroplet chemistry to enhance analytic methods, for example, sampling and characterizing materials and reactions at interfaces and detecting biomarkers from biological samples.

Anticipated Resources: It is anticipated that awards under this topic will be no more than an average of $1.5M per year for 5 years, supporting no more than 6 funded faculty researchers.

Exceptions warranted by specific proposal approaches should be discussed with the topic chief during the white paper phase of the solicitation.

Research Topic Chief: Dr. Michael R. Berman, AFOSR, 703-696-7781, michael.berman@us.af.mil

Topic 20: (AFOSR) Topological Plasma Electromagnetics

Background: The dispersion of electromagnetic (EM) waves in unbounded magnetized gaseous plasmas is well understood despite the generally anisotropic nature of the dielectric constant. However, when bounded by an interface, as is the case of finite-sized plasma structures, plasmas can exhibit topologically interesting behavior. The simplest example is the unique propagation of plasmon waves, i.e., surface EM waves at the planar interface between a plasma (gaseous or metallic) and vacuum (or any dielectric boundary). Topological photonics, or, more broadly, topological electromagnetics is the study of wave dispersion in heterogeneous periodic structures in (i.e., structures with interfaces and boundaries such as individual bounded plasmas or plasmas arranged into photonic crystal arrays). In the field of optics and solid-state photonics this has led to new physics such as the degenerate linear dispersion at Dirac and Weil Points in photonic crystals that results in a zero-refractive index as well as the unidirectional propagation of EM waves. Gaseous plasmas are candidates for such novel electromagnetic properties. They can be used to form topological systems when plasma structures are arranged periodically to form photonic crystals. Since plasmon waves are excited at frequencies near the plasma frequency, in gaseous plasma structures with densities typically in the range of 1011 – 1016 cm-3 these interfacial states have plasmon frequencies that are in the microwave to mm-wave region of the EM spectrum (GHz to THz). Furthermore, they overlap with resonances of appropriately-shaped metallic and dielectric structures (metamaterials) when excited by external microwave sources. These frequencies are of relevance to a broad range of commercial and military applications, many of which are of interest to the Air Force. For example, microwaves are used in beamed space power and also in driving plasma thrusters for space propulsion – technologies that further enhance the agility of space assets. Microwaves and mm-waves, are also used in communications, and novel EM devices stemming from this research might be used to protect sensitive microwave electronics or even mitigate communication black-out during vehicle re-entry. Finally, plasma devices exploiting topological features might have applications in rendering objects invisible to microwave radiation. This MURI seeks to understand the physics needed to design and construct gaseous plasma matter exploiting such features that may be relevant to future applications.

Objectives: The objective is to develop a fundamental understanding of topological electromagnetics in non-magnetized and magnetized gaseous plasma systems comprised of 1D, 2D, and 3D repeating heterogeneous structures (examples of which might be plasma

spheres and rods), including systems where these plasma structures may be integrated into metamaterials. The fundamental research objectives include studies of the methods and kinetics of forming novel plasma structures with electron densities as high as 1016 cm-3 and scales comparable to free-space wavelengths in configurations that exploit the ensuing topological properties. The subject matter is multidisciplinary and a successful program will bring together researchers with an expertise in EM wave propagation, materials, mathematical theories and computations, machine learning, plasmonics, and plasma physics. An outcome of this multidisciplinary research may be the discovery of new synergistic physics that enhance the overall EM response of topological plasma systems.

Research Concentration Areas: (1) Experiments that generate and characterize properties of gaseous topological plasmas including addressing kinetics of plasma formation and control. (2) Development of mathematical theories and predictive simulations of interactions of EM waves with topologically novel systems merging modern computational electromagnetics with emerging particle and/or continuum models for linear and non-linear plasma behavior. (3) Devise and study methods of integrating plasmas into metamaterials that have synergistic interactions and the challenges of generating plasmas in proximity to metallic or dielectric resonating structures. (4) Studies of non-linear interactions in topological plasma systems at high EM fields and of linear (or non-linear) interactions under non-ideal conditions (e.g., imperfect symmetries in periodicity and non-uniformity in plasma density and temperature). (5) Applications of machine learning to the inverse design process of optimizing the complex topological system for a desired EM response.

Anticipated Resources: It is anticipated that awards under this topic will be no more than an average of $1.5M per year for 5 years, supporting no more than 6 funded faculty researchers.

Research Topic Chiefs: Dr. Mitat A. Birkan, AFOSR, 703-696-7234, mitat.birkan@afosr.af.mil, Dr. Arje Nachman, AFOSR, arje.nachman@us.af.mil, Mr. Peter A. Morrison, ONR, 703-696-0553, peter.a.morrison@navy.mil

Topic 21: (AFOSR) Interfacial Engineering of Superconductors

Background: Interfacial engineering exhibits promise for enhancing properties of superconductors (SCs), such as transition temperature, Tc, critical current density, Jc, dissipation at high frequency, or topological nature, and for enabling new functionality. Tuning parameters available at interfaces, but not in bulk materials, include local chemical composition and structure, hybridization and proximitization between materials, control of strain, quantum confinement effects, including formation of two-dimensional electron gases, interfacial charge transfer, and electron-phonon or electron-magnon coupling. Recent achievements in producing novel SC structures can guide further advances. Atomically precise thin-film synthesis and defect quantification allow for creating wide ranges of SC-based

heterostructures. Although increases in Tc and achievement of perfect tunneling have been demonstrated, the underlying mechanisms behind the effects remain poorly understood. A coherent, multidisciplinary approach combining many-body theory, materials synthesis, heterostructure fabrication, and in situ and ex situ characterization can develop a systematic understanding of interfacial coupling in novel SC systems and utilize this theoretical understanding to achieve enhanced SC heterostructures. For example: (1) Through dissipationless coupling between a SC and a topological material, perfect Andreev reflection via Klein tunneling was recently demonstrated in YB6/SmB6 films, establishing the potential for realizing unrivaled performance in sensing and a variety of high-speed electronics. (2) Ballistic superconductivity and tunable π–junctions were produced in InSb quantum wells, providing a system for study of interplay among superconductivity, magnetism, and spin-orbit interactions. In addition, interfaces between topological, ferromagnetic, and odd-parity materials (e.g., UTe2 or Sr2RuO4) could provide a framework for exploring a variety of novel functionalities, including applications such as perfect spin-filters or in non-Abelian quantum information processing

Objective: The objectives are to create superconducting interfaces between disparate materials and to harness coupling between novel SCs and other correlated materials to create heterostructures with enhanced properties, such as increased Tc, or emergent properties.

Research Concentration Areas: Areas of research include: (1) applying simulation tools, such as all-electron density functional theory, to identify materials, crystal structures, and properties of interest; (2) employing interfacial design to create, manipulate, and enhance superconducting, electronic, or magnetic properties through coupling of novel SCs to correlated, magnetic, or topological materials, thus creating new functionalities; (3) applying advanced microscopy and spectroscopy tools to help elucidate the underlying mechanisms of enhancement. Proposed work should leverage recent developments in many-body theory and advances in epitaxial thin-film synthesis and characterization of materials, defects, and interfaces.

Anticipated Resources: This topic requires $1.5M per year for five years, supporting approximately six funded faculty researchers.

Research Topic Chiefs: Dr. Kenneth C. Goretta (Acting), AFOSR, 703-696-7349, kenneth.goretta@us.af.mil; Dr. Grace Metcalfe, AFOSR, 703-696-9740, Grace.Metcalfe@us.af.mil; Dr. Ali Sayir, AFOSR, 703-696-7236, ali.sayir.2@us.af.mil; Dr. Marc Ulrich, ARO, 919-549-4319, marc.d.ulrich.civ@mail.mil

Topic 22: (AFOSR) Targeted Optical Stimulation of Individual Retinal Photoreceptors

Background: For 150 years, it has been known that populations of retinal photoreceptors transduce photons into signals that cortical neurons convert into visual percepts. However,

because it has remained impossible to stimulate individual photoreceptors without also stimulating their neighbors, interpretations of how individual photoreceptors contribute to these percepts have been based on statistical inferences using the proportions of light that rod and cone photopigments absorb as a function of wavelength.

Advances in adaptive optics from the past 15-20 years in conjunction with retinal densitometry have made it possible to image and classify individual photoreceptors in vivo and in real time. Adaptive optics approaches also have enabled tracking techniques that produce stable images despite the presence of involuntary eye movements (i.e., microsaccades), which occur almost constantly. A logical next step is to investigate the direct relationship between photon absorption by specific photoreceptors and visual perception by using adaptive optics techniques and lasers to stimulate individual photoreceptors of known classes with photons of photopigment-matched wavelengths. This would enable functional circuits in the retina that drive visual perception to be characterized-- and ultimately leveraged-- to an extent never before possible.

The envisioned work would require multidisciplinary expertise in areas related to vision science such as visual neuroscience, psychology, optics, ophthalmology, computer vision, and computational modeling to image, track, and precisely stimulate the retina, design basic research experiments that probe retinal function, and collect, analyze, and interpret the data. Studies would investigate aspects of vision such as color and form perception and would likely start with the parafovea, where photoreceptors are larger and less densely packed than in the fovea.

Objective: This topic aims to characterize how individual photoreceptors contribute to visual perception, including sensitivity to color and form.

Research Concentration Areas: Suggested research areas include but are not limited to: (1) contributions of individual photoreceptors to normal color perception, (2) form perception based on activity in individual photoreceptors, (3) the role of lateral inhibition, (4) the spatial and temporal characteristics of retinal circuits, and (5) contributions of individual photoreceptors to anomalous color perception.

Anticipated Resources: It is anticipated that awards under this topic will be no larger than an average of $1.5M per year for five years and fund no more than six faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with the topic chiefs during the white paper phase of the solicitation.

Research Topic Chiefs: Dr. Hal S. Greenwald, AFOSR, 703-588-8441, hal.greenwald@us.af.mil; Dr. Patrick Bradshaw, AFOSR, 703-588-8492, patrick.bradshaw.3@us.af.mil

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Topic 23: (AFOSR) Quantum Random Access Memory

Background: Several algorithms that would theoretically provide a significant speed-up when performed on a quantum computer over a classical computer require random access memory (RAM). A RAM enables quick retrieval, in any order, of data stored in a memory array.

Unlike a classical RAM, the input and output registers of a quantum RAM (QRAM) use quantum bits rather than conventional bits, the memory array in a QRAM can be classical or quantum depending on the usage, and a QRAM can address a superposition of memory cells and return a superposition of the data [Hann et al., arXiv1906.11340]. No such QRAM currently exists. The availability of a QRAM would enable implementation of various quantum algorithms and herald potentially ground-breaking capabilities impossible to achieve classically.

Over the last decade, many of the building blocks for a QRAM have been demonstrated such as the storage of quantum data with long coherence times, and efficient implementations of reading from and writing to quantum memory. The development of exquisite control over interactions between matter and light has led to the achievement of quantum memories in a variety of physical platforms including neutral atoms, trapped ions, rare-earth-ion or color centers in solids, and superconducting circuits. Several research groups have also shown random access of quantum memory with multiple data cells – classical addressing as opposed to quantum addressing needed for a QRAM. Despite the impressive scientific advances in the field and clear demand for QRAMs, the realization of QRAMs is hindered partly by the input/output bottleneck and high computational cost. A dedicated effort is needed to cultivate innovative, perhaps unconventional, theoretical and experimental approaches to creating and implementing a practical QRAM. This research topic will require the collective expertise from various disciplines involving quantum mechanics, algorithms (e.g. classical, quantum or hybrid), atomic physics, photonics, materials science, engineering, electronics, information science, and computational science.

Objective: The aim of this MURI topic is to understand and create an efficient QRAM with quantum addressing of data stored in an array of memory cells. This will include close collaboration between theory and experiment to develop and implement novel protocols to perform fundamental QRAM operations with minimal computational complexity.

Research Concentration Areas: Suggested research areas through experimentation and theory include but are not limited to: (1) deterministic processes for quantum addressing of memory where the data stored can be classical or quantum, but the query and output are superposition states; (2) concepts for fundamental operations performed on a QRAM such as loading, storing, erasing and rewriting; (3) minimization of physical resources and run-time for QRAM operations; (4) investigation into the integration of QRAMs into quantum information processing systems, including novel computer architectures (such as non-von Neumann constructs) that could significantly simplify the implementation of a QRAM; (5) examination of errors and noise including but not limited to interference or cross-talk within the memory; and (6) understanding benefits of QRAMs for purposes beyond quantum computation.

Anticipated Resources: It is anticipated that awards under this topic will be no more than $1.5M per year for 5 years, supporting no more than 6 funded faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with the topic chiefs during the white-paper phase of the solicitation.

Research Topic Chiefs: Dr. Grace Metcalfe, AFOSR/RTB, 703-696-9740, grace.metcalfe@us.af.mil; Dr. Tristan Nguyen, AFOSR/RTA, (703) 696-7796, tristan.nguyen@us.af.mil

Topic 24: (AFOSR) Metasurface Edge Sensing, Processing and Computing

Background: Advanced optical sensors and imaging systems that sense and process complex information encoded in the incident optical wavefront are essential tools used in the increasingly demanding missions of the DOD. Unfortunately, current technologies do not meet the size, weight, and energy efficiency requirements needed for new wearables and aerospace applications. The development of metasurfaces has experienced impressive progress, able to achieve a variety of optical functions in a very compact, easy-to-integrate form factor. These metasurfaces are essentially flat, optical elements that can manipulate the phase front of light with a dense array of metallic or dielectric optical nanoantennas. They have already been used to create myriads of practical, passive optical elements capable of focusing or redirecting light, controlling the state of polarization, achieving multiple functions in the same physical space, and producing holograms. With these breakthroughs, one can now explore how nanophotonics and metasurface concepts can be applied effectively to sense and parse information stored in the light emerging from a scene, and process it in the analog domain at the speed of light. To this end, existing knowledge on transparent, passive metasurfaces can be leveraged to develop active photodetection metasurfaces capable of performing real-time hyperspectral imaging, spectropolarimetry, analysis of optical scene information, analog computational operations across different frequency ranges and down to the single photon level, and even solve complex mathematical problems. New knowledge is also required, as the fundamental physics of photodetection in hybrid nanophotonic structures and analog computing metasurfaces are still poorly understood and many breakthroughs are expected. By identifying new nanophotonic detection mechanisms and highly non-linear metasurface components new imaging functions can be created. If successful, these functions will enable on-chip acquisition and processing of valuable optical information about a scene that is typically not captured by the human eye or conventional sensors. Using metasurfaces as a type of front-end or edge functional surface to perform sensing and analysis tasks in the optical system can increase the capability and drastically reduce computational processing, time and power demands.

Objective: The goal of this MURI is to combine recent advances of metasurfaces and optical nanoantennas with sensing, processing and information science to probe fundamental detection limits and reveal new information processing concepts. An aim is to explore active

and non- linear metasurfaces that are capable of decoding, measuring and processing optical signals based on different intrinsic properties of light (e.g., frequency, state of polarization, orbital angular momentum, and angle of incidence). These metasurfaces should ultimately be able to achieve a variety of optical functions, including optical image and signal processing, filtering, sensing and photodetection functions across the spectrum (VIS, Near-IR/Mid-IR), extendable to more complex operations on the detected images. The research should address fundamental questions and challenges related to the ability of achieving such complex functions in an extremely compact/flat form factor.

Research Concentration Area: Areas of interest include, but are not limited to the following:
(1) new materials and optical nanoantenna concepts capable of sorting photons by their intrinsic components and at a subwavelength-scale; (2) novel photodetection and hyperspectral imaging strategies across the spectrum (VIS, Near-IR/Mid-IR); (3) metasurfaces for integration into systems for front-end processing for sensors, image processing and equation solving; (4) new computational and inverse design strategies for metasurfaces capable of performing novel detection and complex imaging functions; (5) exploration of fundamental opportunities and limitations of these concepts in terms of speed, sensitivity, energy efficiency and data size.

Anticipated Resources: It is anticipated that awards under this topic will be no more than an average of $1.5M per year for 5 years, supporting no more than 7 funded faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with the topic chief during the white paper phase of the solicitation.

Research Topic Chief: Dr. Gernot Pomrenke, AFOSR, 703-696-8426, gernot.pomrenke@us.af.mil

Topic 25: (AFOSR) Non-Hermitian Programmable Materials at Exceptional Points

Background: This topic aims to explore the parity-time symmetry concept for developing a designer's material grounded on notions from non-Hermitian physics and exceptional points. Non-Hermiticity concepts reveal nontrivial physics at exceptional points where abrupt phase transitions take place. While these effects have been demonstrated in classical systems, the full ramification of parity-time-symmetry and exceptional points in quantum domain and their effect on quantum information sciences are yet to be experimentally and theoretically explored. To bring parity symmetry concept to its quantum roots, what is needed is to develop new types of condensed matter capable of changing their state/phase in ultrashort time scales while requiring very low energy consumption by removing the over-determinacy of exceptional points (e.g., building nano- and micron-scale architectures with structurally dynamic response characteristics).

Recent studies have revealed that light-matter interactions are enhanced at exceptional points. Therefore, investigating cavity quantum electrodynamics and nonlinear processes at exceptional points may enable new quantum technologies for generating and manipulating quantum information. Furthermore, theoretical studies suggest that parity-time-symmetric qubits may be more robust against decoherence, the sudden death of entanglement can be delayed at an exceptional point, and information that has flown to environment can be retrieved in a parity-time-symmetric system. Experimental studies to validate these predictions and theoretical studies to understand the physics behind the information retrieval and universal scaling rules for decoherence may help to achieve more robust quantum information storage and quantum state transport in the presence of decoherence.

Designing new materials at exceptional points whose atomic and molecular structures can facilitate entanglement is an unchartered territory that needs to be explored with the concepts from parity-time-symmetry. Investigating the transmission of quantum states and probing quantum correlations in parity-time-symmetric systems and networks may lead to novel structures and techniques to manipulate, control and protect quantum states. This demands a multidisciplinary team of experimentalists and theorists that blend together physics, mathematics, and material science engineering to successfully accelerate scientific discovery. Fundamental studies of exceptional points may lead to a better understanding of quantum light-matter interactions, and DOD relevant applications in quantum memories and lasers with high spectral purity.

Objective: The overarching objective is to discover synthetic materials in which exceptional points emerge dynamically, and create understanding of decoherence dynamics of quantum states affected by the presence of exceptional points. Elucidate the transition from broken to unbroken parity-time-symmetric phase through an exceptional point in quantum systems and outline pertinent parity-time-symmetric universal scaling rules for decoherence.

Research Concentration Areas: (1) Design, growth, and synthesis of exceptional points-based phase change materials with desired non-Hermitian degeneracies and symmetries. (2) Experimental studies to validate theoretical predictions and theoretical studies to understand the physics behind the information retrieval and universal scaling rules for decoherence. (3) Studying nonlinear materials and processes at exceptional points to achieve efficient quantum frequency conversion for building quantum interfaces.

Anticipated Resources: It is anticipated that awards under this topic will total an average of $1.5M per year for 5 years, supporting up to 6 faculty researchers.

Research Topic Chiefs: Dr. Ali Sayir, AFOSR, 703-696-7236, ali.sayir@us.af.mil; Dr. Grace Metcalfe, AFOSR, 703-696-9740, grace.metcalfe@us.af.mil; Dr. Tristan Nguyen, AFOSR, 703-696-7796, tristan.nguyen@us.af.mil

Topic 26: (AFOSR) Mathematical Foundations for Enabling Robust Optimal Design of Hypersonic Systems

Background: Today's high-performance computing allows for unprecedented fidelity in the modeling of complex physical phenomena. For example, with modern Computational Fluid Dynamics (CFD) algorithms, one can now simulate turbulent flows free of empirical correlations, in canonical geometries using billions of grid-points and accurately predict inherent flow frequencies for separated regions. Similar advances in Computational Structural Dynamics (CSD) routinely provide similar levels of accuracy for very complex geometries. State-of-the-art embedded flight control algorithms allow the design of extremely agile, unmanned flight vehicles. Design optimization of complex systems with non-linear dynamics under uncertainty is also making rapid progress, using Bayesian techniques, multi-fidelity analysis and reduced-order modeling (ROM). This MURI seeks to further advance these developments to capture and integrate the coupled physics underlying hypersonic flight, in order to make rapid design and optimization of hypersonic vehicles possible. Hypersonic flight presents new and formidable challenges to model reduction; strong shock waves can lead to non-physical oscillations in the reduced-order solutions, even when the full-fidelity solutions remain monotone. Surface ablation and non-equilibrium flow chemistry would greatly expand the complexity of the system of equations. Transitional flows ad shock-boundary layer (BL) interactions have strong local effects, which can lead to material response, resulting in a global coupling and the general inability to causally separate sub-systems. The inherent unsteadiness of these interactions also precludes the use of lower-fidelity solutions such as Reynolds-averaged Navier-Stokes equations. New ways to efficiently exploit Direct Numerical Simulations or other high-fidelity methods such as large-eddy-simulations (LES) where applicable, may be needed to achieve practical solutions as, in a data-driven paradigm, the cost of off-line training of the reduced models far exceeds the computational capabilities for realistic designs. Finally, just as the entire vehicle and flow-material couplings must be considered together, the control system must also be included in the reducing approach, which must now handle disparate mathematical representations. This MURI therefore seeks major basic research advances in the areas of model reduction, multi-fidelity and multi-physics analysis and optimization methods that will make rapid and accurate design of hypersonic systems possible.

Objective: The objective is to develop a new mathematical framework for efficient reduced-order-modeling that can capture the couplings between physical sub-systems (e.g. fluid and material), the multiple scales of interaction, and the control algorithms for hypersonic flight conditions. The approach should be scalable to increasing levels of physical complexity (e.g. adding ablation), allow for epistemic and aleatoric uncertainty, and minimize training costs. Approaches to multi-variate, overall system optimization should be developed for both physical and algorithmic parameters.

Research Concentration Areas: The basic science challenges include but are not limited to: 1) Efficient model reduction approaches for multi-physics, multi-scale and transient dynamics for problems and conditions relevant to hypersonic flight (e.g. flows with shocks, shock-BL interactions, material deformation…); 2) Extension of model reduction to include flight control procedures and simultaneous parametrization; 3) Approaches to training cost reduction, with or without experimental and sensor data; 4) Methods for simultaneous optimization of physical and algorithmic control parameters in the presence of uncertainty; 5) Rigorous robustness and accuracy measures or bounds, and scaling.

Anticipated Resources: $1.5M per year for 5 years, supporting no more than 6 faculty researchers.

Research Topic Chiefs: Dr. Ivett Leyva, AFOSR, 703-696-8478, ivett.leyva@us.af.mil; Dr. Fariba Fahroo, AFOSR, 703-696-8429, fariba.fahroo@us.af.mil; Dr. Fred Leve, AFOSR, frederick.leve@us.af.mil; Dr. Brian Holm-Hansen, ONR, 703-588-1047, brian.holm hansen@navy.mil; Dr. Eric Marineau, ONR, eric.marineau@navy.mil

Topic 27: (OSD) Advanced Modeling of Evolutionary Cyber Eco-Systems with Autonomous Intelligence (whitepapers and proposals should be submitted to the AFOSR FOA)

Background: Cybersecurity at the level of national security can involve multiple platforms, networks, and types of actors, from lone-wolf hackers to proxy groups, and on to official government organizations tasked with the defense of critical cyber networks and cyber-physical systems (CPS). The ever growing complexity of this network makes the threat analysis difficult, providing an advantage to malicious actors whose goal is mass disruption, without regard to retaliation or global consequences. The field of cybersecurity is also evolving as a result of increased capabilities of software agents, which employ adaptive strategies to evade detection and countermeasures.

Currently, cyber operations require human operators with significant expertise, to inform the numerous decisions that must be made throughout the conduct of such operations. As a result, the ecology of cyber threats and defenses evolves relatively slowly. Future cyber operations, on the other hand, will likely evolve more rapidly due to the accelerating sophistication of machine learning (ML) technologies and, in a broader sense, artificial intelligence (AI). For example, ML-enabled approaches are very adept at creating data ("deep fakes"), and this capability is being leveraged to spread false information, increasing further the threat of foreign malign influence. AI/ML methodologies can change the nature of cybersecurity even further, moving from algorithms that detect malware to ones that predict new kinds of malware, and/or malware that can independently choose how to achieve a strategic objective. Thus, future AI/ML-enable cyber-agents could operate without having to rely on directives

from the human operator, becoming autonomous persistent threats. A nation-state that takes a leading position in developing such a capability would gain a formidable advantage. To prepare for a future in which such AI/ML-enabled cyber-agents from multiple nation states operate at scales and speeds vastly greater than current practices, we must develop sophisticated, realistic, and high-fidelity models and simulations, eventually providing a virtual environment in which this ecology of cyber-agents can interact, evolve, and be analyzed.

Objective: The intent of this topic is to explore the multiple scientific foundations that would enable the realization of a simulation framework for an entire ecosystem of advanced cyber operations, in a realistic yet practical fashion. The evolutionary dynamics of adaptive agents and networks could then be modeled to rapidly yield insights into evolving threats and vulnerabilities. While ethical and social considerations make experimentation on real-life networks difficult, if not impossible, the advanced models and simulations of the cyber ecosystem would enable in-silico experiments. When repeated at high frequency with varying parameters, these could yield highly valuable synthetic data, which is necessary to design and test cyber defense capabilities and strategies, and to evaluate the impact of tactical and strategic decisions.

Research Concentration Areas: The fundamental science behind the design of such a framework covers multiple, strongly coupled areas, making the problem extremely challenging and requiring a combination of expertise, such as computer science and machine learning, mathematics, cognitive psychology, network theory and/or game theory. Some of the specific research topics to be addressed in this undertaking include, but are not limited to, the following: 1) carefully designed abstractions for modeling: agent states, strategies, goals and objectives, and the dynamics of agent interaction; 2) human agents must also be modeled in this framework, and behavioral science could be leveraged to guide the abstract representation of human intent and belief, as well as their interactions with AI agents; 3) ML and game theory could provide a powerful combination, already demonstrated by the performance of multi-agent reinforcement learning (RL) or distributional RL. Accounting for human agents and a co-evolution of attack and defense algorithms, multiple types of games may be required, including behavioral and evolutionary, making the analysis more difficult. Furthermore, the game itself may become a dynamic variable, as rules and protocols could be broken and the strategy space redefined; 4) game-theoretical models could be blended with optimization methods for decision-making at tactical, operational and strategic levels (e.g. including resource constraints); 5) approaches to learn agent behavior from limited and noisy observations, either human or AI, would be helpful with strategy inference and attribution; 6) finally, the underlying network topology is itself variable, affected by the intelligent agents which can reconfigure it autonomously, or create fake nodes and clusters.

Anticipated Resources: $1.5M per year for 5 years, supporting no more than 6 faculty researchers.

Research Topic Chiefs: Dr. Jean-Luc Cambier, OUSD(R&E), Jeanluc.cambier.civ@mail.mil; Dr. Tristan Nguyen, AFOSR, tristan.nguyen@us.af.mil; Dr. Don Wagner, AFOSR, donald.wagner.7@us.af.mil; Dr. Fariba Fahroo, AFOSR, fariba.fahroo@us.af.mil; Dr. Cliff Wang, ARO, cliff.x.wang.civ@mail.mil