ONR Announcement # N00014-18-S-F006
ARO Announcement # W911NF18S0003
AFOSR Announcement # FOA-AFRL-AFOSR-2018-0001

Fiscal Year (FY) 2019 Department of Defense
Multidisciplinary Research Program of the University Research Initiative

Deadlines

White Paper Inquiries and Questions
15 June 2018 (Friday)

White Papers must be received no later than
29 June 2018 (Friday) at 11:59 PM Eastern Time

Application Inquiries and Questions
02 October 2018 (Tuesday)

Applications must be received no later than
16 October 2018 (Tuesday) at 11:59 PM Eastern Time

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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. 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 of new awards made after December 26, 2014, will include revisions to reflect DoD implementation of new OMB guidance in 2 CFR Part 200, "Uniform Administrative Requirements, Cost Principles, and Audit Requirements for Federal Awards."

Please note the following important items:

- There are no topics selected for UK collaboration this year.
- 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) 2019 Department of Defense Multidisciplinary Research Program of the University Research Initiative

3. Announcement Type

Initial Announcement

4. Funding Opportunity Number

ONR: N00014-18-S-F006
ARO: W911NF18S0003
AFOSR: FOA-AFRL-AFOSR-2018-0001

5. Catalog of Federal Domestic Assistance (CFDA) Numbers

ONR: 12.300
ARO: 12.431
AFOSR: 12.800

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

6. Key Dates

White Papers due: 29 June 2018 (Friday) at 11:59 PM Eastern Time
Applications due: 16 October 2018 (Tuesday) 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 DISCRIPTION

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 2019 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, or in different departments in the same university. By supporting multidisciplinary teams, the program is complementary to other DoD basic research programs that support university research through single-investigator awards. Proposals 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):

Topic 1: Fundamental Limits on Information Latency; Purdy

Topic 2: Molecularly Programmable Graphene Architecture (MPGA); Baatar

Topic 3: Identifying invariances for improved modeling and prediction of oceanographic phenomena; Harper

Topic 4: Self-Assembly for High Performance Organic Electronics; Armistead

Topic 5: Bio-inspired high-dimension control through models of cephalopod distributed information processing; McKenna

Topic 6: Active Perception and Knowledge Exploitation in Navigation and Spatial Awareness; Steinberg

Topic 7: Advanced Analytical and Computational Modeling of Arctic Sea Ice; Malek-Madani

Topic 8: Topology & Advanced Dynamics of Coupled Human/Machine Systems; Holm-Hansen

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

Topic 9: Clearing Your Head: The Glymphatic System and Restorative Effects of Sleep, Munson-Gregory

Topic 10: Foundations of Emergent Computation and Self-Organized Adaptation, Stanton-Baker

Topic 11: Multi-layer Network Modeling of Plant and Pollen Distribution across Space and Time, Strand-Garcia

Topic 12: Near Field Radiative Heat Energy Transfer between Nanostructured Materials, Varanasi-Ulrich

Topic 13: Networked Interactions Governing Community Dynamics, Kokoska-Garcia

Topic 14: Prediction and Control in Particulate Systems, Myers-Barzyk

Topic 15: Reactive and non-Reactive Scattering from Targeted Molecular Quantum States, Parker-Baker

Topic 16: Unified Decision Theory: From Bounded to Unbounded Rationality, Iyer-Myers

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

Topic 17: THz Electronics Based on Antiferromagnets

Topic 18: Quantum Information Concepts from Tensor Networks and the Holographic Principle

Topic 19: 2D Heterostructures for Flexible, Lightweight Electronics and Optoelectronics

Topic 20: Feedback control and sparse neural signals

Topic 21: Dissipation Engineering in Open Quantum Systems

Topic 22: Group-IV Alloy Synthesis and Materials Properties

Topic 23: Neuromorphic Networks for Multifunctional Intelligent Systems

Topic 24: Microstructurally-aware Continuum Models for Energetic Materials

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 $170 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.

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:

1. Applicants are encouraged to submit a white paper; and

2. 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: White papers may be submitted via e-mail directly to a Research Topic Chief, 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."

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 29 June 2018 (Friday) at 11:59 PM Eastern Time.

Evaluation/Notification: Initial evaluations of the white papers will be issued on, or about, 20 July 2018 (Friday).

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 16 October 2018 (Tuesday) 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 March 2019 (Friday). 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 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 (1) to (8) 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 (9) to (16) 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 (FY19 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 (FY19 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 (17) to (24) 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 three Letters of Support, describing interest in the topic area or expressing a commitment for 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 Jun 2019. 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) FY19: Twelve months (01 Jun 19 to 31 May 20): $1,500,000
(2) FY20: Twelve months (01 Jun 20 to 31 May 21): $1,500,000
(3) FY21: Twelve months (01 Jun 21 to 31 May 22): $1,500,000

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

(4) FY22: Twelve months (01 Jun 22 to 31 May 23): $1,500,000
(5) FY23: Twelve months (01 Jun 23 to 31 May 24): $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) FY19: Four months (01 Jun 19 to 30 Sep 19): $312,500
(2) FY20: Twelve months (01 Oct 19 to 30 Sep 20): $1,250,000
(3) FY21: Twelve months (01 Oct 20 to 30 Sep 21): $1,250,000
(4) FY22: Eight months (01 Oct 21 to 31 May 22): $937,500

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

(4) FY22: Four months (01 Jun 22 to 30 Sep 22): $312,500
(5) FY23: Twelve months (01 Oct 22 to 30 Sep 23): $1,250,000
(6) FY24: Eight months (01 Oct 23 to 30 Jun 24): $937,500

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

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

(1) FY19: Twelve months (01 Jun 19 to 31 May 20): $1,500,000
(2) FY20: Twelve months (01 Jun 20 to 31 May 21): $1,500,000
(3) FY21: Twelve months (01 Jun 21 to 31 May 22): $1,500,000

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

(4) FY22: Twelve months (01 Jun 22 to 31 May 23): $1,500,000
(5) FY23: Twelve months (01 Jun 23 to 31 May 24): $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.

- 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.

3. Grants.gov Application Submission and Receipt Procedures

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

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*	15 June 2018 (Friday)	
White Papers Due	29 June 2018 (Friday)	11:59 PM Eastern Time
Notification of Evaluations of White Papers	20 July 2018 (Friday)**	
Questions Regarding Proposals*	02 October 2018 (Tuesday)	
Proposals Due	16 October 2018 (Tuesday)	11:59 PM Eastern Time
Notification of Selection for Award	01 March 2019 (Friday)**	
Estimated start date of grant	01 June 2019**	

* 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

Awards under this FOA will be made to Applicants on the basis of the evaluation criteria listed below. The primary basis for selecting proposals for acceptance will be technical, importance to agency programs, and fund availability. Cost realism and reasonableness will also be considered when selecting proposals. The DoD agency reserves the right to request and require any additional information and documentation after it makes the award instrument determination. The DoD agency reserves the right to remove Applicants from award consideration when the parties fail to reach agreement on award terms, conditions, and cost/price within a reasonable time, or when the Applicants fails to timely provide requested or required additional information.

Applicants' proposals will be evaluated against the following criteria:

1. Overall scientific and technical merits of the proposal and responsiveness to the topic (i.e., the degree of innovation, soundness of technical concept, Applicant's awareness of the state of the art and understanding of the scope of the problem, significance and originality of the technical approach and effort needed to address/solve the problem, and anticipated scientific impact within the field. The following areas will also be considered: (1) the Applicant's capabilities, related experience, facilities, techniques or unique combinations of these which are integral factors for achieving the proposal objectives, (2) the qualifications, capabilities and experience of the proposed Principal Investigator (PI), team leader and key personnel who are critical to achieving the proposal objectives, and (3) the integration of students in the research.

2. Potential DoD relevance and contribution to the Department of Defense mission.

3. The availability of funds.

Criteria 1, 2, and 3 are equally important.

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)

System for Award Management (SAM): All Applicants submitting proposals or applications must:

a. Be registered in the SAM prior to submission;
b. Maintain an active SAM registration with current information at all times during which it has an active Federal award or an application under consideration by any agency; and
c. Provide its DUNS number in each application or proposal it submits to the agency.

SAM may be accessed at https://www.sam.gov

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 for all three (3) services shall be directed to ONR as specified below:

ONR MURI Program Point of Contact:

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

Mailing address:
Office of Naval Research One Liberty Center
875 North Randolph Street, Suite 1020
Arlington, VA 22203-1995

Questions of a business nature for all three (3) agencies 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 submitted after the Q&A deadline, as noted in the table in Section IV. C. 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, 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 and Cooperative Agreement awards greater than $100,000, as well as OTAs not under 10 U.S.C. 2371b, require a certification of compliance with a national policy mandate concerning lobbying. Grant applicants shall provide this certification by electronic submission of SF 424 (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 normal OTA applicant 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/en/Contracts-Grants/submit-proposal/grants-proposal by checking the "I agree" box in Field 17 and attaching the representation to Field 18 of the SF 424 (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 SF 424 (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:

1. 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).

2. Section 101(a) of the Continuing Appropriation Act, 2016 (Pub. L. 114-53) and any subsequent FY2016 appropriations act that extends to FY2016 the same restrictions as are contained in section 743 of Division E, title VII of the Consolidated and Further Continuing Appropriations Act, 2015 (Pub L. 113-235).

3. 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).

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

The prohibitions stated above do not contravene requirements applicable to Standard Form 312,

Form 4414, or any other form issued by a Federal department or agency governing the nondisclosure of classified information.

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

1. Use of Animals:

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 IACUC Approval, IACUC Approved Protocol, and most recent USDA Inspection Report) prior to award. For assistance with submission of animal research related documentation, contact the Research Topic Chief .

2. Use of Human Subjects in Research:

a. You must protect the rights and welfare of individuals who participate as human subjects in research under this award and 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 3900.39D (or its replacement), 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:

(1) 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 Federalwide Assurance (FWA#),

(2) Any claimed exemption under 32 CFR 219 101(b), including the category of exemption, supporting documentation considered by your 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.

(3) Any determinations that the proposal does not contain activities that constitute research involving human subjects, including supporting documentation considered by your 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 regarding the Human Research Protection Program should contact the Research Topic Chief. If the research is determined by the IRB to be greater than minimal risk, you 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.

d. Research involving human subjects must not be commenced under any award or modification or any subcontract or grant subaward or modification until awardee receives notification from the Grants Officer that the HRPO has approved the assurance as appropriate for the research under the award or modification and that the Human Research Protection Officer (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.

3. Use of Recombinant DNA or Synthetic Nucleic Acid Molecules:

Proposals which call for experiments using recombinant or synthetic nucleic acid molecules must include documentation of compliance with NIH Guidelines for Research Involving Recombinant or Synthetic Nucleic Acid Molecules (NIH Guidelines), approval of the Institutional Biosafety Committee (IBC), and copies of the DHHS Approval of the IBC letter.

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 DoD contracts, grants, and other assistance instruments may be eligible to use HPCMP assets in support of their funded activities if the DoD Research Topic Chief 's approval is obtained and if security/screening requirements are favorably completed. Additional information and an application may be found at https://www.hpc.mil/.

9. Project Meetings and Reviews

Individual program reviews between the DoD awarding agency and the performer may be held as necessary. 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: Fundamental Limits on Information Latency; Purdy

Topic 2: Molecularly Programmable Graphene Architecture (MPGA); Baatar

Topic 3: Identifying invariances for improved modeling and prediction of oceanographic phenomena; Harper

Topic 4: Self-Assembly for High Performance Organic Electronics; Armistead

Topic 5: Bio-inspired high-dimension control through models of cephalopod distributed information processing; McKenna

Topic 6: Active Perception and Knowledge Exploitation in Navigation and Spatial Awareness; Steinberg

Topic 7: Advanced Analytical and Computational Modeling of Arctic Sea Ice; Malek-Madani

Topic 8: Topology & Advanced Dynamics of Coupled Human/Machine Systems; Holm-Hansen

ARO:

Topic 9: Clearing Your Head: The Glymphatic System and Restorative Effects of Sleep, Munson-Gregory

Topic 10: Foundations of Emergent Computation and Self-Organized Adaptation, Stanton-Baker

Topic 11: Multi-layer Network Modeling of Plant and Pollen Distribution across Space and Time, Strand-Garcia

Topic 12: Near Field Radiative Heat Energy Transfer between Nanostructured Materials, Varanasi-Ulrich

Topic 13: Networked Interactions Governing Community Dynamics, Kokoska-Garcia

Topic 14: Prediction and Control in Particulate Systems, Myers-Barzyk

Topic 15: Reactive and non-Reactive Scattering from Targeted Molecular Quantum States, Parker-Baker

Topic 16: Unified Decision Theory: From Bounded to Unbounded Rationality, Iyer-Myers

AFOSR:

Topic 17: THz Electronics Based on Antiferromagnets

Topic 18: Quantum Information Concepts from Tensor Networks and the Holographic Principle

Topic 19: 2D Heterostructures for Flexible, Lightweight Electronics and Optoelectronics

Topic 20: Feedback control and sparse neural signals

Topic 21: Dissipation Engineering in Open Quantum Systems

Topic 22: Group-IV Alloy Synthesis and Materials Properties

Topic 23: Neuromorphic Networks for Multifunctional Intelligent Systems

Topic 24: Microstructurally-aware Continuum Models for Energetic Materials

Topic 1: (ONR) Fundamental Limits on Information Latency

Background: Despite the progress made in the study of networks, both wireless and wired, especially those that operate in highly dynamic environments, a major challenge remains unresolved, namely that of tracking, controlling and optimizing information latency. In fact, the use of the term "delay-tolerant networking" by the networking community, is an admission of its inability to effectively control information latency. When the missions served by a deployed network are time-critical (e.g., mobile tactical edge mesh networks), it is clear that the issue of information latency and latency control must be given high priority. Even in the commercial world, increasingly ubiquitous connectivity to communication networks and availability of portable devices have engendered a host of applications in which sources – people, sensors, Internet of Things (IoT) – send updates of their status (e.g., news, weather reports, social media updates, vehicular status including position, velocity, acceleration) to interested recipients. These applications need status updates at one or more monitors to be as timely as possible. These new timeliness metrics related to the quality of status updates, such as the recently developed "Age of Information" (AoI), are quite different from traditional notions of delay. For example, delay monotonically increases as throughput increases, but the age of status updates initially decreases with increase in throughput and then increases at higher loads [1]. Previous attempts to address this problem have generally resulted in piecemeal solutions, with only incremental performance improvement. Furthermore, a fundamental mathematical formulation for the evaluation of information latency is still lacking.

A new "network science" is needed that comprehensively addresses all aspects of time-criticality in networked communications and networked / autonomous control systems, especially in applications that require the transmission of information about the state of a process of interest between various sources and destinations. This should include methods for controlling the transmission of information in the form of "updates" in cases where the traffic is generated from sources that observe on-going processes (as in tracking and telemetry, surveillance, monitoring, threat detection, etc.), while taking into account channel and network conditions, traffic patterns

and other-user behavior. In addition, this should also explore how timeliness relates to fundamental aspects of information of the signal at the source, as this notion clearly transcends the design of engineering systems, and draws connections to information theory, sampling theory, compressed sensing and causal signal reconstruction. Another aspect of timeliness that is not well understood is its relationship to signal uncertainty and the uncertainty principle [2]. This MURI provides a way to address these problems that are themselves timely in view of the evolving trends in communication, where the context is shifting from the mere transport of bits to serving tasks such as control, compute, infer, estimate, reconstruct, predict, and disseminate information in a timely manner, to name a few. From a practical standpoint, maintaining timeliness is a multi-faceted problem that appears in many forms including, data freshness in warehouses, data centers, web caches, fog and edge clouds [3], periodic updating of real time databases and route caches in mobile networks, freshness of channel state information, to describe a few; however, no consistent analytical methodology has emerged to evaluate, let alone optimize these applications.

Objective: (i) Experimentally and theoretically explore the "network science" of information freshness and timeliness in complex communication networks (ii) More broadly, explore the relationship between signal latency and the uncertainty principle as it relates to prediction and estimation (iii) Develop novel and definitive ways to track, control and eventually optimize of information latency in networked communications.

Research Concentration Areas: This MURI will require the broad-based expertise of researchers in fields that include (i) electrical engineering (e.g., communication and information theory, coding, signal processing) (ii) computer science (e.g., algorithms, complexity analysis, queueing theory, and security), (iii) physics (entropy, propagation), and (iii) mathematics (e.g., optimization and game theory). Additionally, large-scale simulations and demonstrations will be part of this MURI.

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 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:
Dr. Dan Purdy, ONR 301, dan.purdy@navy.mil;

Co-Topic Chief:
Dr. Waleed Barnawi, ONR 301, waleed.barnawi@navy.mil

Topic 2: (ONR) Programmable Graphene Molecular Architecture

Background: In the decade and half history of the National Nanotechnology Initiative (NNI), two of the most astounding advances in nanoscience and nanotechnology are the rise of graphene and the exquisite molecular programmability achieved in DNA nanotechnology, with the former garnering the 2010 Nobel Prize in physics (to ONR PI Andre Geim and Kostya Novoselov), while the latter was rewarded with the Kavli Prize for Nanotechnology in the same year (to another ONR PI Ned Seeman). Today graphene can be grown to meter scale in area while at the other extreme we can synthesize graphene nanoribbons (GNR) that are less than one nanometer (precisely three benzene rings) wide! Furthermore, the electronic properties of these GNRs can be tuned by designing and synthesizing molecular homo- or hetero- structures, all with atomic precision. However, we still face formidable challenges when attempting to synthesize larger and functionally diverse electronic devices and circuits. Part of the reason is that the strong carbon-carbon covalent bonds -- the very reason we have robust and reliable electronic structures that we hope to exploit to build functional devices and circuits, seem to hinder our design flexibility. The challenge in DNA nanotechnology is the opposite. To date DNA is the only molecule in which we have achieved complete structural programmability with single nucleotide precision, which enable us to build arbitrary-shaped DNA nanostructures with nanometer resolution (both in 2D and 3D). Part of the reason for this success is the enormous design flexibility afforded to us by the facile and relatively weak hydrogen bond between complimentary nucleotide base pairs – the famous Watson-Crick molecular recognition and pairing mechanism. Yet despite this unprecedented structural control and molecular programmability, it has proven extremely difficult to derive useful functionality, particularly electronic functionality, from the wide variety of DNA structural motifs thus far. This MURI is an attempt to "marry" these two iconoclastic nanomaterials, by exploiting their strengths while complementing each other for their weaknesses. Ideally one would like to build a single nanosystem in which we rely upon the strong covalent bonds, particularly through the de-localized □-electrons, in nanographene for electronic functionalities while seeking DNA-like programmability for structural control. In this fashion, we get the best of both worlds – the functional stability and reliability of the strong covalent bonds, coupled with structural flexibility and reprogrammability of the weak hydrogen bonds. Indeed, data is already starting to emerge that indicate certain nitrogen doped graphene nanoribbons (N-GNR) prefer to assemble laterally, both on metallic surfaces and in solution, presumably via the hydrogen bonding interaction brought on by the nitrogen dopants, or possibly involving the even weaker van der Waals (vdW) interaction. The key next step is to understand and clarify these interactions and find ways to control them in order to achieve programmability. Potential approaches include both surface synthesis techniques under ultra-high vacuum condition and innovative organic synthesis techniques.

Objective: To encourage innovative research in understanding and utilization of hydrogen bonds and vdW interactions in nanographene molecules in order to achieve programmable 2D molecular electronic architectures. The ultimate goal and long term vision for this research thrust is to be able

to design and synthesize graphene molecular structures, based on their desired electronic device/circuit functionalities, in a programmable fashion.

Research Concentration Areas: Areas of interest include, but are not limited to: (1) understand and clarify the hydrogen bonding and other weak interactions in nanographene based molecular structures that promote lateral self-assembly; (2). explore ways to design/synthesize novel molecular precursors that possess both reaction centers for covalent bond formation (for functional control), as well as weak interaction sites for molecular recognition and programmable assembly; (3). study and devise 2D molecular architectures that will provide novel electronic, optical and magnetic functionalities, while at the same time amenable to molecular programmability for structural control; (4). tools and capabilities to effectively image, characterize and test the final structures with atomic precision; (5). theoretical component to guide experimental efforts will be an integral part of the program.

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

Topic 3: (ONR) Identifying invariances for improved modeling and prediction of oceanographic phenomena

Background: In geophysical fluid dynamics, there are a variety of energetic flow features at the submesoscale that can impact the operational performance of platforms, sensors, and systems. In the ocean, these salient features can include currents, fronts, filaments, vortices, wakes, and internal waves, which may exist at different spatial scales. While the underlying physical principles that drive these oceanic processes may be well-known, the ability to accurately predict them with numerical models remains elusive. With sufficient spatial resolution, the models can be used to accurately simulate these features, but there is often difficulty in forecasting their evolution due to nonlinear dynamics in the physical system. In the case of large scale geophysical fluid dynamic models such as those used in meteorology or oceanography, computational limitations can often prevent the numerical solutions from accurately representing small but important structures, such as turbulent vortices. Numerical parameterizations are typically used in an attempt to capture the net effect of the subgridscale processes, often involving empirical models developed with human expertise. These problems may involve large sets of well-defined (labeled) data, but their spatial and temporal resolutions are typically inadequate to enable accurate numerical modeling.

As an alternative to the physics based numerical solutions, the use of approaches from artificial intelligence community – such as machine learning – may be explored to parsimoniously capture and extract invariances and consistencies from large, four-dimensional geophysical data sets. The automated construction of spatiotemporal relationships can be used to improve both process models and numerical predictions of submesoscale geophysical processes at a variety of spatial scales. The development and application of new approaches to capture invariances in geophysical fluid dynamic systems, where significant quantities of data from numerical models are readily available yet often under-analyzed, may prove useful for both the advancement of machine learning techniques as well as for enhanced understanding and prediction of the geophysical environment.

Objective: The primary objective of the proposed effort is to explore, characterize, and develop machine learning techniques with appropriate architecture and learning processes to enable the recognition of patterns and invariances in geophysical fluid dynamics data sets that will enable improved predictions of their time evolution. Hierarchical learning techniques such as deep neural networks are potential candidates for this effort, though they may not necessarily be the most appropriate model for application to these large-scale geophysical systems. To give some constraint to the topic, the modeling and prediction of submesoscale ocean processes should be the first large scale physics problem to be explored, and may be the primary application considered for the topic area.

Research Concentration Areas: Under this topic, research addressing the following focus areas will be considered: (1) exploration of machine learning architectures and algorithms appropriate for physical oceanographic system with its fundamental governing principles, (2) investigation of various concepts of learning processes and strategies conducive to capturing invariances and patterns in both historical observational oceanographic data sets as well as numerically generated ocean model data, and (3) development of principled methods for combining high-level model-based approaches, including laws of physics and known invariances, with data-driven machine learning-based approaches for constructing improved oceanographic models and discovering new invariances at many different spatial and temporal scales.

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 six 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:
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Behzad Kamgar-Parsi (ONR 311), behzad.kamgarparsi@navy.mil>

Topic 4: (ONR) Self-Assembly for High Performance Organic Electronics

Background: Polymer chemists have used self-assembly techniques to create morphologies based on block copolymer phase separation, dissolution, crystallization kinetics, flow and orientation, and even hydrogen bonding. However, such studies have focused on inherently flexible and soluble polymers to yield the multiphase morphologies important to structure and optical properties. Electronic polymers are typically rigid and beyond encouraging or discouraging molecular Pi stacking, little has been done to control domain sizes or interface structure. Such control could significantly increase performance in photovoltaics, thermoelectrics, sensors and other devices with heterogenous active layers and lead to very low cost large area devices and active coatings.

For example, an ideal active layer in an organic bulk heterojunction solar cell needs a specific morphology consisting of a 300-nm layer having co-continuous electron donor and acceptor domains of 20 nm breadth. For the electronic and optical properties, the donor and acceptor molecules should have complementary absorption covering the visible spectrum and having specific band gaps and frontier orbital energy offsets. The packing within the domains should yield high electron and hole mobilities for the acceptor and donor phases and the packing (relative molecular orientation) at the domain interfaces should encourage charge separation and discourage charge recombination.

Using ab initio quantum theories synthetic chemists can now design and synthesize molecules and polymers with specific electronic and optical properties needed for the donor and acceptor phases in bulk heterojunction solar cells. However, the conjugated nature of these materials renders them fairly rigid and insoluble. Short side chains can be appended to these donor or acceptor phase materials to make them solution-processable but attaining the desired two-phase bulk heterojunction morphology requires simultaneous kinetic trapping of the crystallization and/or precipitation of two distinct phases from solution to yield co-continuous domains with 20 nm breadth. The solubilizing side chains insulate and can impair the electronic properties of such molecules. Moreover, these molecules may crystallize poorly and are not fully rigid, making it difficult to predict the packing and electronic properties computationally for pure aggregates and even more difficult to determine their properties in mixed regions or at interfaces. Despite these difficulties, organic solar cells have reached 14% power conversion efficiency. An improved understanding of the device physics and the development of non-fullerene acceptors could lead to low cost, light weight, flexible, solar cells which have over 20 percent efficiency and are as robust as car paint. What is needed is for the active materials to be designed for hierarchical assembly for structure and function.

Objective: The purpose of this MURI is to explore new kinds of hierarchical self-assembly approaches for organic/polymer electronic devices in general, and specifically, organic solar cells.

This includes controlling the degree of crystallinity, packing within the unit cell, thermodynamic and kinetic approaches to controlling domain sizes and shapes, and design of grain boundaries/interfaces to optimize material function. An understanding must be developed of how the morphology affects performance while developing the self-assembly approaches. New computational approaches will be needed to predict solid phase packing, to predict dissolution and domain sizes for the donor and acceptor domains from mixed solvents. Strategies need to be developed towards broader kinetic fabrication windows or towards thermodynamic drivers. On the performance side, computation of electronic, optical, and excited state properties in aggregates/domains of low order need to be developed as well as the approaches to deal with interfaces between donor and acceptor domains. This MURI is directed towards understanding the structural and functional characteristics at different hierarchical levels such that molecular design strategies can eventually be used to ensure high charge mobility and requisite frontier orbital levels in the donor and acceptor phases, desired coupling between those phases, and thermodynamic and/or kinetic-controlled self-assembly on all levels with optimal performance.

Research Concentration Areas: A balanced, interdisciplinary program consisting of (1) Multi-scale theory and modeling including design for self-assembly, packing in domains, controlling interaction between domains; electronic and optical properties; (2) Synthesis of new materials; (3) Morphological characterization throughout active layer formation and in the completed device; (4) spectroscopic, electrical characterization

Anticipated Resources: Awards under this topic will not exceed an average of $1.5M/year for 5 years, supporting ~6 faculty researchers. Exceptions warranted by specific proposed approaches should be discussed with the topic chief during the white paper phase of the solicitation.

Research Topic Chiefs:
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Topic 5: (ONR) Bio-inspired high-dimension control through models of cephalopod distributed information processing

Background: Through hundreds of millions of years of evolution, the octopus has developed a sophisticated nervous system architecture that addresses the challenges of rapid control decisions including feature selection across a high dimensional input space, control of a body with nearly limitless degrees of freedom, and efficient learning to solve challenging sensori-motor problems. These animals have extraordinary motor capabilities, with multiple modes of mobility, and excellent manipulation skills such as being able to open the lids of jars, even when inside. Encephalopods have also developed an extraordinary visual sensorimotor system to adaptively control skin texture and color for camouflage and communication. Within each arm, there are distributed networks of sensors, neurons and muscles that can effect local control. But some actions

require coordinated use of the arms and communication with conspecifics, and octopuses have evolved unusually large brains for an invertebrate to control complex behaviors and support an efficient experiential learning.

This form of efficient learning in octopus contrasts with popular "brute-force" approaches for machine learning, but may have useful lessons for the development of emerging methods for "few shot" and unsupervised learning from small data. This unusually distributed and yet capable nervous system represents a very different solution from what is found both in humans and in the state of the art of engineered systems, and could lead to new directions in embodied intelligent systems in AI. As a result, there is the potential for a new paradigm for sensorimotor control and learning of high dimensional sensing and control systems that might be achieved through an understanding of the neural computations employed by the octopus.

By focusing on neural mechanisms of sensorimotor control in the octopus, this topic will fuel the discovery of biologically-inspired algorithms that will enable efficient and adaptive control of the future naval systems of many types that will require solving sensing, learning, locomotion, and manipulation problems. A recent revolution in the miniaturization of neural recording devices now allows for fully wireless data logging from freely moving aquatic animals and the use of hundreds of recording electrodes simultaneously. Implanting these systems within octopuses will require collaboration between engineers and neuroscientists. A second challenge resides in the analysis of the complex data that will be generated from combined behavioral and neural recording experiments in octopuses. This challenge is in the field of data-driven neuroscience and modeling and will require a team of experimentalists, computational neuroscientists, and theorists with expertise in networked feedback dynamical systems working in close collaboration. Finally, understanding motion control and sensing in the octopus as it solves complex tasks through a marine environment will require collaboration between engineering and machine learning researchers including also the ability to characterize the environment using modern flow visualization, machine vision and modeling techniques.

Objective: The objective of this MURI is to launch a new, biologically-inspired paradigm for sensorimotor control of complex systems that draws upon the unique, highly parallel information processing and non-hierarchical control executed by the nervous system of the octopus. This work will create principles for effective control algorithms for high dimensional systems from arrays of multimodal sensors to future non-rigid manipulators and human assistance devices. Additionally, through an understanding of how information is rapidly assimilated by the octopus during complex sensorimotor problem solving, this research will provide new directions for machine learning during fully automated control.

Research Concentration Areas: Multidisciplinary research that includes (1) Conducting experimental and mathematical analyses of sensorimotor control of arms and skin in octopus, in order to create a biologically-based sensorimotor control theory, (2) systems neuroscience with a

focus on sensory information processing and learning of sensorimotor tasks and the incorporation of more sophisticated mathematical theory to address the unique characteristics of this type of highly distributed system, (3) Neuro-engineering to enable electrophysiological and behavior analysis of octopus behavior and connect it with the applied mathematics and data-driven analysis, and (4) Environmental characterization and modeling of environmental interactions such as fluid dynamics and structure-fluid interactions in a way appropriate for incorporation in the proposed mathematical frameworks to understand animal biomechanics in both fluid and solid substrates. Note this topic does not concern molecular mechanisms of skin camouflage nor responses to the optical environment.

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 approximately 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:
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Topic 6: (ONR) Active Perception and Knowledge Exploitation in Navigation and Spatial Awareness

Background: Substantial progress has been made in recent years in the investigation of spatial understanding and navigation in mammals and birds including correlates of neural activity. However, these investigations have yet to yield models that can satisfactorily explain human or other animal capabilities to robustly move through complex environments. One reason for this may be the kinds of investigations that have been conducted to date. Experimental studies of perception and memory have often operated in narrow, static environments with subjects that may even have their heads and bodies immobilized. Navigation studies, on the other hand, have allowed subjects to move around, but often in simplified environments that do not include many of the characteristics of natural ones or opportunities to utilize broader types of knowledge in solving problems. In contrast, animals may leverage much richer combinations of knowledge types while at the same time moving their heads and bodies to sample their environments. This can provide advantages in resolution of ambiguities, uncovering relationships, inferring properties of obscured areas, recognition of environmental invariances and prediction of changes, and selective attention towards information of discriminating value. Further, these are precisely the kind of capabilities

crucial to engineering future systems for uncertain, unstructured, harsh, and dynamic environments. Navigation methods in robotics have progressed considerably in the past decade, but these methods can be brittle and fail dramatically outside of the particular circumstances they were hand-tailored for. Both the scientific models and engineering methods lack a cohesive theoretical foundation encompassing bottom-up navigation methods, active perception, and broader knowledge exploitation within complex environments.

There is an opportunity to address this problem through a new generation of experimentation and model development that leverages advances across multiple fields. Recent neuroscience results provide insights into neural circuitry that may relate spatial navigation to other types of memory in mammals. Engineering and computer science technologies can help enable experiments to collect and analyze larger and richer data sets from free-movement subjects that are not constrained spatially. This includes leveraging closed-loop simulation capabilities, virtual and augmented reality as well as new experimental sensing, imaging, and tracking techniques. Robotics can provide testbeds to mechanize and experiment with new scientific models, and ultimately develop new bio-inspired methods for engineered systems. Advances in bringing together control theory, complex systems theory, communication/information theory, graph-theoretic approaches/networks, and computational methods can be used to model and understand feedback systems that utilize active perception and more complex knowledge representations. New directions in cognitive architectures such as strategies for the deployment of attention and incorporating non-symbolic components for perception can provide conceptual tools and appropriate principled frameworks.

Objective: Comparative studies to develop new computational models of the brain system dynamics and cognitive processes integrating active perception and exploitation of broad knowledge types with spatial understanding and navigation at different levels of capability and with different sensing modalities. Utilization of such models in the development of a new theory of navigation and active perception that can be used both to gain understanding of the properties of the resulting biological models and to inspire engineered autonomy methods in which higher level knowledge is used for resolution of ambiguities, uncovering of relationships, inferring properties of obscured areas, recognition of environmental invariances and prediction of changes, and selective attention towards information of value.

Research Concentration Areas: This topic requires collaboration among the fields of control theory, computer science, robotics, computational intelligence, machine learning, mathematics, neuroscience, cognitive psychology, and cognitive science. Suggested research areas include, but are not limited to: (1) New experimental methods to study higher-level knowledge used in navigation and active perception by mammals and birds. This may include the ability of biological systems to rapidly redirect their attention to salient stimuli and relevant internal knowledge as either the environment or their perception of the environment changes. Exploiting this to create and validate models at different levels of capability for comparative understanding including frugal models appropriate for mathematical systems frameworks. (2) New systems theoretical

frameworks that span control, active perception and knowledge rich representations including the interplay between active shifts in attention and the retrieval and use of existing knowledge from within particular structures. (3) New autonomy methods to explore the properties and characteristics of these new models and systems theory frameworks including exploiting higher level knowledge such as of categories, relationships, and properties to solve navigation and active perception problems in complex and dynamic environments. This should include integrated experimentation that spans across active perception, control, and complex knowledge representations. Multiple sensing modalities including vision and sonar are within scope.

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.

Research Topic Chief:
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Topic 7: (ONR) Advanced Analytical and Computational Modeling of Arctic Sea Ice

Background: The observational record shows that the Arctic is undergoing significant changes and the trend suggests this will continue into the future. Notably, the observed reduction in sea ice volume in the Arctic has led to significant areas of open water during summer months and a more dynamic seasonal cycle of ice melt and regrowth. The emerging dynamics of the Arctic environment are being studied, but our current numerical models of the Arctic system – involving the coupling of ocean, wave, atmosphere and sea ice components – lack the fidelity to simulate many of the critical physical processes. In particular, current models of sea ice lack the complexity to faithfully represent many important processes in sea ice formation, motion, and break-up, inhibiting our ability to predict salient features of the sea ice cover on multiple time scales and impacting the strategic and tactical use of such predictions for military operations in the Arctic. To counter this shortcoming it is imperative to develop robust predictive tools that are based on the fundamental principles that govern the evolution of sea ice.

Sea ice is a complex, heterogeneous, discontinuous medium that requires multi-scale and multi-physics considerations to model appropriately, particularly when coupled with the ocean and atmosphere. Much of the previous modeling work involving sea ice has either been at fine scales when considering the ice as a material, or on large scales when including sea ice models in climate studies. The evolution of sea ice on intermediate spatiotemporal scales, kilometers in space and hours in time, is of critical importance in the synoptic prediction of Arctic sea ice, and these scales present a host of simulation challenges that have not received sufficient attention up to now. Because of the behavioral complexity involved at these scales, a new mathematical framework is needed to predict Arctic sea ice variability, taking into account that this variability is strongly

coupled to the atmosphere and the ocean. Equally important in this development is the inclusion of observational field data to inform and improve the mathematical models. Assimilation of observed data into sea ice models is especially challenging as the data, whether remotely sensed or *in situ*, exist at vastly different spatiotemporal scales. It is highly desirable that numerical tools be constructed with rigorous and verifiable error bounds associated with their range of applicability to sea ice prediction. Previous modeling efforts, including most operational sea ice models, have typically limited the descriptions of sea ice mechanics to isotropic viscous-plastic rheologies, making explicit prediction of the details of sea ice behavior, such as opening of leads in the ice and other mechanical break-up processes, difficult to simulate. New and emerging approaches must be developed in order to accurately simulate the relevant processes and critical parameters of sea ice on intermediate scales, including the prediction of sea ice of different types, complex ice deformations, and the accurate formation of leads and ridges arising from non-isotropic ice characteristics and forcing.

Objective: To establish a mathematical framework for the development of efficient analytical and computational methods for modeling sea ice behavior. This framework may involve developing new stochastic parametrization tools to capture the formation, deformation, fracture, melting, and overall motion of sea ice throughout the seasonal cycle. It is critical that this framework be versatile enough to take advantage of the availability of observational data to improve uncertainty quantification, whether Eulerian or Lagrangian based. It is equally important to understand how to assimilate sea ice observations into these advanced models that have state-of-the-art adaptive meshes at their core.

Research Concentration Areas: Suggested research areas include but are not limited to (1) Computational Methods: Development of numerical methods for obtaining stochastic filters with the goal of explaining sea ice reemergence mechanisms. The numerical methods must be robust to the multi-scale nature of the sea ice development, especially to the correlations and the teleconnections that are the dominant features in the ocean-atmosphere-sea-ice variability. 2) Reduced Models: A Systematic development of a hierarchy of reduced order models capable of characterizing model sensitivity of ocean-atmosphere-arctic sea ice coupling. The reduced models must be adaptive to observational suppliers and data, a feature that makes this project unique in geosciences. 3) Stochastic Manifolds: Develop a mathematical framework capable of capturing the characteristic features of sea-ice dynamics by invariant measures that will lead to computing low-dimensional manifolds where the essential dynamics of sea-ice resides. It is critical for this approach to integrate observational data adaptively to quantify and reduce computational errors.

Anticipated Resources: Awards on this topic are expected to be at an average of $ 1.5M per year for 5 years.

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Topic 8: (ONR) Topology & Advanced Dynamics of Coupled Human/Machine Systems

Background: Any combination of human and machine where the closed-loop dynamics traverse both electronic and biological pathways is a cybernetic system. Distinct mechanisms for information transfer, actuation and computation exist in both the human and the machine. In general, the flow of control and communication involves these fundamental elements: 1) machine dynamics induce responses in human sensory organs; 2) sensory organs generate signals that are carried by the nervous system to the brain; 3) the brain processes the sensory signals and sends command signals to the muscles; 4) the muscles respond and drive machine controls; 5) machine sensors measure the control inputs as well as the machine dynamics; 6) a computer receives the sensor signals and computes command signals; 7) actuators receive the command signals and generate forces and moments on the machine; 8) mass, inertia and physics govern the dynamic response of the machine; 9) the machine dynamics are sensed by the human. These 9 elements close the loop in a cybernetic system.

A solution for the resulting dynamics is not within any single scientific field but rather at the nexus of mathematics, physiology and controls [1]. Current methods generally reduce the entire human down to an empirical transfer function model [2]. As cybernetic systems became increasingly important, investigators sought to develop detailed mathematical models of the human physiology. Control theory was used to model the human respiratory system with a set of differential-difference equations [3]. Other research investigated the dynamics of more general interactions between the human and the physical world [4, 5]. Researchers have developed and validated first principle models of electrical and mechanical machines. However, as cybernetic systems are pushed to higher levels of performance, complex human/machine interactions have produced adverse dynamics that current models cannot explain [6]. Knowing the dynamics of each element in the control path is necessary to understanding the dynamics of a cybernetic system, but this knowledge alone is not sufficient to fully understand the complex dynamics that can occur. In particular, it is not sufficient to model the machine and the human as self-contained systems with simple interfaces, such as a vehicle generating motion and a human perceiving and commanding motion [7]. Fully understanding the dynamics requires knowledge of how machine states such as attitude and motion are coupled to internal human states affecting the nervous system, brain and respiratory system. These coupling terms give rise to potentially adverse cybernetic modes that neither the human nor the machine possess individually. Currently, there are no models or theory to understand these complex dynamics. The proposed research seeks to explore the intersection of mathematics, physiology and controls to develop rigorous models for the coupling mechanisms between internal human states and machine states. Until these coupling mechanisms are fully

understood within a mathematical framework, the complex dynamics of cybernetic systems will continue to yield unexpected outcomes.

Objectives: Two scientific breakthroughs are sought by this MURI: 1) First principle models to capture the coupled dynamics between internal human states and machine dynamics in a cybernetic system, including the ability to predict adverse modes. 2) A mathematical basis to decompose signals from cybernetic systems and reveal signatures for incipient adverse modes.

Research Areas: Suggested areas may include, but are not limited to: 1) Physiological sensing, control and signaling. 2) Biomechanics and dynamics. 3) Non-linear multi-body dynamics and control. 4) Mathematics and signal processing.

Anticipated Resources: Awards for this topic are anticipated to be no more than an average of $1.5M per year for 5 years and support no more than 8 funded faculty researchers. Exceptions warranted by specific proposal approaches should be discussed with the topic chiefs during the white paper phase of the solicitation process.

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Topic 9: (ARO) Clearing Your Head: The Glymphatic System and Restorative Effects of Sleep

Background: The brain consumes 25% of an individual's glucose intake and 20% of respirated oxygen. These metabolic processes produce waste, which cannot be transported out of the parenchyma through the brain-blood barrier. Emerging evidence suggests that this waste removal is mediated by bulk flow of interstitial solutes along perivascular pathways. These pathways, constructed from the end-feet of glial cells, provide a mechanism analogous to the lymphatic system for peripheral tissues. Proteins involved in neurodegenerative pathologies and injury have been observed to move along glymphatic pathways. Additionally, waste clearance activity is substantially accelerated during sleep. It is hypothesized that the brain's requirement to eliminate neurotoxic waste products provides a strong biological driver for sleep. Despite the importance of such findings, the specific physical mechanisms regulating waste clearance dynamics and the specific connections to wakefulness are largely unknown.

Increased understanding of waste clearance mechanisms may enable new intervention strategies that permit accelerated recovery from periods of extended wakefulness or chronic sleep deprivation, optimize sleep quality, and promote clearance of products resulting from brain injury. To realize such strategies, breakthroughs are required that provide transformative understanding of brain metabolism, sleep neurophysiology, and glymphatic mechano-electro-chemical processes.

This understanding should allow the development of predictive capabilities for glymphatic clearance dynamics. This will likely require novel experimentation and imaging diagnostics of unsteady, multiphase, nano/microscale flows involving in-vivo and in-vitro animal studies coupled with studies of model systems. An emphasis on causative physiological relationships among waste clearance, sleep, and cognition should be developed by the integration of novel techniques and frameworks from physiology, cell biology, neurocognition, fluid and solid mechanics, control theory and other relevant disciplines. Long-term advantages of this MURI could yield remarkable advances in solider performance and neurodegenerative disease prevention.

Objective: The goal of this effort is to develop a framework describing the interplay of small-scale multiphase flows with biochemical and neurophysiological processes to quantitatively characterize glymphatic clearance dynamics and regulation mechanisms. This framework should account for disparate scales in both length and time, such that the reciprocal impact of cellular scale processes on system level regulatory phenomena (e.g. sleep) can be described and predicted. Additionally, strategies for exogenous manipulation of waste clearance to assess the impact on neurocognitive performance (e.g. alertness, learning, and memorization) should be explored.

Research Concentration Areas: Suggested research concentrations include, but are not limited to: (1) development of advanced imaging (and other diagnostic) methodologies to track glymphatic clearance dynamics, including measurement of the movement of specific waste products within an unsteady fluid environment, (2) integration of biochemical, mechanical, and physiological descriptions of the glymphatic system to describe waste clearance regulation mechanisms, (3) effects of sleep/wakefulness on waste clearance performance and behavioral approaches to determine the subsequent impact on cognitive performance, and (4) control approaches to modulate glymphatic system behavior.

Anticipated Resources: It is anticipated that awards under this topic will be no more than an average of $1.25M per year for five years, supporting no more than six faculty researchers. Exceptions should be discussed with the topic chiefs during the whitepaper phase of the solicitation.

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Topic 10: (ARO) Foundations of Emergent Computation and Self-Organized Adaptation

Background: Self-organization is a natural phenomenon whereby unanticipated global configurations and patterns of activity emerge from highly distributed and simplistic modulation of information and energy. Physical processes akin to information processing and algorithms shape how global information is encoded within the statistics and dynamics of a system's components,

data from fine-grained massively parallel searches is persistently used and stored, and control is maintained through continual interplay between bottom-up and top-down processes. Despite the ubiquity of self-organizing systems, there is no general theory for how large-scale decentralized interactions among entities executing unsophisticated algorithms result in robust and resilient information processing and remarkable ensemble-scale achievements. Lack of a framework based on abstractions and laws inhibits future engineered systems rivaling natural systems. However, a synthesis of key enablers spanning information physics, theory of algorithms, and distributed control may revolutionize this shortcoming. Nonequilibrium information physics research has recently uncovered principles governing the energetic cost of manipulating information gradients as a driver for environmental synchronization. Already, these results have inspired new control laws for high-dimensional nonlinear stochastic systems. Linking these advances with natural algorithms research may elucidate the energetics of emergent computation and hierarchical memory. Moreover, new experimental testbeds capable of global pattern control in systems with over 10^3 primitive nanoscale and macroscale entities provide for realistic stochasticity to challenge theory while enabling unprecedented opportunities to engineer emergent computation.

Objective: This MURI has two concurrent objectives: (1) Synthesize advances in nonequilibrium information physics with natural algorithms and decentralized control to identify principles governing how local algorithms, negative and positive feedback, fluctuation amplification, and the topology of information flow lead to unanticipated patterns and information processing in natural self-organizing systems. (2) Develop novel experimental systems to challenge and extend the theory and to additionally achieve directed self-organization. That is, demonstrate guided discovery of optimal information processing patterns or reconfigurable robustness to harmful emergent phenomena (e.g. failure modes) by actively biasing the environment or by manipulating the self-organization information-energy landscape.

Research Concentration Areas: Suggested research concentrations include, but are not limited to: (1) Physical laws for the energetics of information processing, pattern formation dynamics, and scaling limits on information processing and adaptability with system size, heterogeneity, information sparsity, and uncertainty/stochasticity; (2) Biologically-guided formulation of natural algorithms underlying collective information processing and memory across scales; (3) Distributed, real-time control algorithms based on simple interaction rules and information diffusion constraints capable of realizing desired collective dynamics from a continual interplay between bottom-up (local-to-global) and top-down (global-to-local) directions; (4) Experimental platforms challenging theorists to properly model and adapt to realistic uncertainty and stochasticity while providing novel testbeds for theoretical constructs.

Anticipated Resources: It is anticipated that 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. Exceptions should be discussed with the topic chiefs during the white paper phase of the solicitation.

Research Topic Chiefs:
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Topic 11: (ARO) Multi-layer Network Modeling of Plant and Pollen Distribution across Space and Time

Background: Every plant species has a niche, an environment with appropriate moisture, temperature averages and extremes, soil pH, soil nutrients, etc., which allows the species to successfully compete enough to grow and reproduce. Global plant distribution maps have been made for many plant species, identifying environmental habitats that individual species can and do grow in. The ability of a plant species to survive and reproduce is also affected by other factors such as fire, the presence or absence of specific animals or pollinators, and human activity. Human social factors such as income, home ownership, religion, methods of transportation, political stability, types of economic subsistence, and attitudes and beliefs about plants, animals, and ecosystems all have major effects on what plants grow where. For tractability, many ecological systems have been mostly studied as disconnected from other systems. However, the stability and function of ecological systems is a function of different types of interaction not just within the system under consideration but with other ecological systems, possibly over different scales in time and space. For example, some plant species can compete successfully only in areas that are mowed infrequently. Other species only exist in disturbed areas, but will only be mature enough to produce pollen 5-10 years after the disturbance. Research is needed in developing computationally tractable mathematical models that encapsulate different types of interactions between different communities of species at different scales in time and space. For example, a multi-layer network model has been recently proposed. While a tensor formulation can be used to describe a multi-layer network, such description is not easily amenable for identification (data fitting). New techniques must be developed in order to maximize the information gained from modeling multiple layers of networked interactions in a computationally tractable manner. Sparsification, factorization and subspace methods have been successfully applied in image processing and may provide alternative ways to achieve the desired goal. This MURI seeks to go beyond mapping plant species as if humans did not exist, and instead will explore and model the effect of human social forces on plant distribution. Instead of modeling plant distribution at a global level this MURI will model plant and pollen distribution at high resolution including within cities, megacities, and urban areas. The intent is to create multi-layer high resolution models that accurately model species distribution in the Halocene epoch.

Objective: The objective of this MURI is to develop both mathematical and computational modeling approaches that will transform our ability to model and predict the distribution of plant species and pollen across space and time. These advances will create a completely new capability; the ability to accurately model and predict species distribution, with human effects fully integrated.

Research Concentration Areas: Suggested research areas include, but are not limited to: autoregressive methods, geostatistical methods based around kriging, generalized linear mixed models, generalized estimating equations, and geographically and environmentally weighted regression, and computational intelligence algorithms. The successful team will have expertise in geography, economics, sociology, anthropology, botany, and entomology as well as in mathematics, artificial intelligence, machine learning, and network science.

Anticipated Resources: It is anticipated that 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. Exceptions should be discussed with the topic chiefs during the white paper phase of the solicitation.

Research Topic Chiefs:
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Topic 12: (ARO) Near field radiative heat energy transfer between nanostructured materials

Background: Recent advances in nano-fabrication and metrology made it possible to experimentally verify decades old theories of the failure of Planck's law of thermal radiation in *near fields,* where the gap size between an emitter and an absorber is less than the wavelength of the emitted radiation. In recent near field radiative heat transfer (NFRHT) experiments, the radiative heat flux was found to be increased by several orders of magnitude due to contribution from the evanescent waves. However, the influence of materials in NFRHT is not yet completely understood. As phonon-polaritons contribute in NFRHT, a narrow band emission (instead of broadband) depending on the emitter and absorber materials can be expected. Recent theories now also predict that novel materials (two dimensional (2D) materials viz. graphene) and nano-structures (i.e. meta-surfaces or hyperbolic metamaterials) could further influence NFRHT compared to their bulk counterparts by increasing the local electromagnetic density of states. However, the influence of compositions and/or nano-structures of novel low dimensional materials in NFRHT yet to be experimentally verified. Novel concepts such as dynamic control of radiative heat transfer using 2D materials that undergo phase transformations with applied voltage, temperature, etc. are also possible with novel materials. Further, some other theoretical studies predict that persistent directional heat currents are possible with magneto-optical nanomaterials in NFRHT conditions. New theories are required to explain the observed increase in the heat flux rates by several orders of magnitude more than predicted by current theories in *extreme* NFRHT (ENFRHT) experiments (with sub nm- a few nm gap size). The paradigm of (E)NFRHT between novel engineered nano-materials/structures needs further investigations to understand the underlying mechanisms of energy transfer influenced by novel nanomaterials/structures.

Objective: Determine the mechanisms responsible for radiative heat transfer between the surfaces of nanomaterials and between meta-surfaces separated by nano-scale gap sizes in near field and extreme near field regimes and discover possible novel phenomena enabled by novel nano-materials /structures in these regimes.

Research Concentration Areas: The research concentration areas include but are not limited to: 1. Develop and validate predictive theories and models for (E)NFRHT between surfaces. 2. Develop theories responsible for radiative heat transfer between various nanomaterials, objects of arbitrary shapes and sizes, engineered meta-surfaces, hetero-structures and/or hyperbolic metamaterials for energy transfer/spectral emission control in (E)NFRHT. 3. Synthesize novel nano-materials (e.g. two dimensional materials) and theory-guided unique structures such as meta-surfaces, hyperbolic metamaterials etc. to facilitate experiments. 4. Design innovative thermal property characterization tools/platforms to measure the radiative heat transfer between nanostructured surfaces and verify the models developed for (E)NFRHT regimes. 5. Explore novel device concepts to exploit (E)NFRHT between the engineered surfaces and nanomaterials.

Anticipated Resources: It is anticipated that 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. Exceptions should be discussed with the topic chiefs during the white paper phase of the solicitation.

Research Topic Chiefs:
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Topic 13: (ARO) Networked Interactions Governing Community Dynamics

Background: In many biological systems, the dynamics of species populations are the emerging result of a suite of interactions (e.g. interactions between individuals of the same species, between species, and between the community and the supporting ecological system). The notion of community is used to refer to the structure of interactions and distribution of species populations. These communities rely on information flow and energy transfer across trophic levels within an ecosystem in order to maintain stable entropy, and to sustain, control and/or evolve community structure. Within microbial ecologies, a variety of interactions are displayed including competition, predation, environmental dominance, cooperation, cheating, and neutrality. Microbial communities exist in ecologies with fluctuating boundaries and resources that play key roles in the communication and control systems that emerge to govern group behavior. “Interactome” maps of complex microbial communities have been used by microbial ecologists to describe the underlying network structure and dynamics. However, we still lack a principled understanding of how networked interactions arise and evolve. For example, approaches linking information and biology have asserted that the assembly and evolution of a community is driven by maximum information entropy of the underlying energy flows. Still, this approach ignores the particulars of physical and mechanical interactions which have been shown to play an important role in determining the nature of embodied interactions.

Mathematical models capturing the multiple scale dynamics of heterogeneous agents may provide the basis for predicting the long-run evolution of different biological populations. Consequently, crosstalk among disciplines engaged in microbial ecology, network science, information theory, and evolutionary game theory can provide novel insights into common architectures and control features that drive the development of community structures across life scales. To the extent that higher order living community systems may exhibit analogous processes, ecological studies of these systems may thus provide a link that describes mechanistic commonalities in network design and control across a broad spectrum of living communities.

Objective: To develop and validate a computational understanding of how information transfer arises within system architectures in biological communities across nature's evolutionary space and to identify universal scaling principles from those models that are common to these various community structures.

Research Concentration Areas: Suggested research areas include but are not limited to: (1) Bioinformatic analysis and metabolic mapping of microbial communities; (2) Multi-scale ecological, mathematical and statistical modeling of microbial communities that captures dynamics, control schemes and complexity associated with colonization and growth; (3) Mathematical models of collective information processing aimed at characterizing the interplay between community structure and rates of energy-information exchange across spatiotemporal scales and the associated fundamental limits so as to measure the efficiency of information transfer. Multi-layer network models for capturing different types of interactions in biological communities across different scales in time and space (5) Theories aimed at describing community structure and interactions based upon the duality between information and entropy.

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

Research Topic Chiefs:
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Topic 14: (ARO) Prediction and Control in Particulate Systems

Background: Decades of research by geoscientists on unconsolidated earth materials have relied upon expensive collection of a large amount of data from field studies, which fail to generalize beyond the subject field sites; therefore, practitioners must gather site-specific information to make decisions using information that is not applicable beyond a specific site or conditions. In their consideration of particulate systems, physicists have relied upon simplified 2D circular contact models to demonstrate some of the phenomena observed in laboratory environments, but these

findings do not extend to heterogeneous materials in 3D. However, there is recent indication of convergence of these two approaches: In 2016, it was discovered that granular creep exists in grain beds conventionally considered to be static, giving the first indication that a simplified granular phenomena described by physicists could be resolved in earth materials. Additionally, models based on continuum theory have been developed using information for discrete particle interactions, indicating potential to move beyond reliance on on-site field testing and empirical approaches to determine earth surface material properties. Further, the advent of new experimental tools and computational approaches provide the potential to extend knowledge of grain-scale mechanics to the field scale. For example, the development of sensors small enough for insertion into samples to record information without disturbing the dynamics of the system affords the opportunity to acquire observations of micro- and macroscale behavior concurrently. Advances in x-ray computed tomography allow motion and loading to be tracked at the grain level. Optimization methods such as differential variational inequality (DVI) are recently found to challenge expensive penalty methods in efficiently and accurately enforcing frictional contact conditions.

These DVI approaches may be adapted to solve contact problems as a particular class of nonlinear constrained optimization problems. Other recent computational advances may help make these massive problems accessible, such as progress in discontinuous systems with friction and contact, hybrid finite-element-DVI frameworks, and new matrix subspace methods that may help efficiently handle unilaterally/bilaterally constrained dynamics problems. By synthesizing these approaches, new insights are sought related to both macroscale phenomena, such as landscape development and evolution, and the rheology of natural materials in general, as well as microscale phenomena, such as self-assembly and behavior of energetic materials.

Objective: Enable efficient and accurate simulation of granular systems in nature and link particulate behavior across scales to enable efficient control algorithms within these systems.

Research Concentration Areas: These include, but are not limited to: 1) Develop methods to simultaneously track grain-scale and bulk material behavior in laboratory and/or field experiments, 2) Explore and develop novel modeling and computational approaches to link micro- and macroscale, 3) Develop new experimental capabilities that will enable integration of laboratory- and field-scale data with numerical approaches, 4) Use particulate systems to test mathematical methods.

Anticipated Resources: It is anticipated that 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. Exceptions should be discussed with the topic chiefs during the white paper phase of the solicitation.

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Topic 15: Reactive and non-Reactive Scattering from Targeted Molecular Quantum States

Background: Quantum control of reactions through vibrational excitation has been an elusive dream of scientists. While some progress has been made through infrared excitation (*e.g.* methane reacting with chlorine atom), a full understanding of the role that vibrational energy plays in the course of chemical reactions is missing. The missing knowledge is directly due to rigid selection rules and also to the fact that absorption and emission occur simultaneously, severely limiting the population that can be placed into excited states. Recent advances in laser-based adiabatic passage methods have allowed one to prepare high densities of molecules ($\sim 10^{16}$ cm^{-3}) in specified vibrational (v), rotational (J), and angular momentum (M_J) states. For example, 100 % of the population of HD molecules in a supersonically expanded molecular beam was transferred from (v=0, J=0) to (v=1, J=2) and also from (v=0, J=0) to (v=4, J=0) in recent experiments using SARP (Stark-induced Adiabatic Raman Passage). SARP works by setting a controlled delay between the pump and Stokes pulses, causing unidirectional flow of population though a single avoided crossing in the Raman resonance, trapping all population in the upper state. SARP is especially powerful, in part because it relies on dynamic Stark shifting of vibrational energy levels during adiabatic passage, tolerating some frequency fluctuations in the lasers, and in part because it is an off-resonant process, allowing for a diversity in choice of excitation sources. Preparation of molecular ensembles in specified quantum states has also been accomplished using the related adiabatic passage method STIRAP (Stimulated Raman Adiabatic Passage). Via adiabatic passage methods, molecular populations are simultaneously placed into specific v, J, and M_J-states, making scattering studies from oriented molecules possible. One can now control v, J, M_J, and the translational energy simultaneously. For the first time, all thermal averaging from molecular scattering can be removed, and accurate measurement of four-vector correlations is attainable, leading to exquisitely detailed information about intermolecular potentials as a function of quantum state. Unprecedented opportunities now exist to prepare molecular populations in specified quantum states and to study their scattering dynamics.

Objective: The objective of this MURI is to prepare high densities of molecular species in selected vibrational, rotational, and angular momentum states and to study their reactive and non-reactive scattering dynamics in cold molecular beams.

Research Concentration Areas: Research is sought that will lead to a new understanding of scattering dynamics, both reactive and non-reactive, as a function of the initial molecular quantum state. Suggested research may include, but is not limited to, the following: 1.) extend adiabatic passage methods to create a large diversity of molecules in selected v, J, and M_J states, 2.) study non-reactive collisions of oriented molecules and also the role of quantum interference in molecular collisions by control of the M_J quantum number, 3.) push the limits of

adiabatic passage techniques to create molecular populations in any vibrational state, 4.) experimentally test current theoretical predictions for vibrational energy transfer rates, for barriers to reactive collisions as a function of vibrational excitation, for the geometric phase effect, and other quantum phenomena, 5.) extend molecular cooling limits to increase the diversity of polyatomic molecules available for study and exploit their state-to-state collisional dynamics in the quantum regime.

Anticipated Resources: It is anticipated that 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. Exceptions should be discussed with the topic chiefs during the white paper phase of the solicitation.

Research Topic Chiefs:
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Topic 16: (ARO) Unified Decision Theory: From bounded to unbounded rationality

Background: Traditional Decision Theory assumes unbounded rationality, that agents have unlimited time and resources while making choices that maximize their utility. Work of Kahneman and Tversky has provided ample evidence from experiments in behavioral psychology that humans tend to use bounded rationality, which are also rife with biases. Recently, in 2015, Halpern and Leung reformulated Decision Theory to account for partial observability; but much remains to be done. Inferring and using an appropriate assumption about computing resources available to an adversary (e.g., bounded rationality for lone wolf, full rationality for nation-state actors, or somewhere in between for small adversarial groups) would lead to decision making that minimizes resources while offering the same or better level of protection/utility.

While theories such as Prospect Theory provide a qualitative and correlated view of bounded rationality, a formal characterization of the underlying assumptions about human decision making are not well settled. For example, experimental game theorists and behavioral psychologists identified various inconsistencies (e.g., Ellsberg paradox, conjunction fallacy) between what classical formulation of probability theory model predicts and how humans behave while making decisions. It also has been observed that Quantum Probability Theory does help in explaining some fallacies, but not all. In particular, noncommutativity in sequential decision making, again an observed human bias, has no mathematical formalization. Lack of mathematical models of human decision making in the presence of human biases (and bounded rationality) is exacerbated in a network setting when information flows through the network, is processed and propagated in unexpected ways. To overcome these difficulties, it is necessary to build a parametrized family of mathematical structures, possibly new robust probability theories, that include as special cases traditional probability theory (unbounded

rationality), Dempster-Shafer Theory, noncommutative probability theory (along the bounded-unbounded rationality spectrum), etc., which can be employed in understanding how novel knowledge is created, team decision processes are derived, and how information is fused (with biases) and passed on. The foundational understanding sought should have a direct bearing on developing a trust calculus that can be used by decision makers to trace malleability of information as it flows from sources to the decision maker.

Objective: Create predictive models of information flow through (human) networks (with biases) through generalization of noncommutative probability theory and information theory

Research Concentration Areas: Suggested research areas include, but are not limited to **(1)** develop a theoretical noncommutative probability framework that generalizes existing probability theory framework along with computationally tractable methods; **(2)** design and carry out behavioral experiments to validate and point out insufficiency of predictive models of human behavior and behavioral game theory in a network of teams; **(3)** mathematically characterize and develop the dynamic of noncommutative information propagating through a network; **(4)** generalize decision theory to account for noncommutative probability theory to help derive predictive decision aids. This work will require expertise spanning multiple sciences, such as mathematics, computer science, physics, Social Sciences and behavioral game theory.

Anticipated Resources: It is anticipated that 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. Exceptions should be discussed with the topic chiefs during the white paper phase of the solicitation.

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Topic 17: (AFOSR) THz Electronics Based on Antiferromagnets

Background: Mutual control of charge and spin transport properties has had significant impact on information-storage technologies. Emerging phenomena such as the spin-Hall effect (SHE), spin pumping, spin-orbit torque (SOT), and spin-transfer torque (STT) allow for interconversion between charge and spin currents and generation of magnetization that could lead to faster, denser, and more-energy-efficient, memory and switching devices. Current devices rely on ferromagnetic materials (FMs) as active constituents. Manipulating the states of ferromagnets encounters limitations in terms of density and speed: frequencies are limited to GHz. In contrast to ferromagnets, for which magnetic anisotropy dominates spin dynamics, spin dynamics in antiferromagnets (AFs) are governed by interatomic exchange interaction energies, which are orders of magnitude larger than magnetic anisotropy energies, leading to potential for ultrafast

processes (to ≈10 THz) at ultralow power levels. AF insulators also exhibit much lower intrinsic damping and larger exchange coupling with adjacent nonmagnetic materials than do FMs. This vanishing magnetization makes these materials robust against external perturbations, while the absence of stray fields eliminates cross-talk and enables a higher density of circuit elements than FM-based devices can achieve. The enhanced efficiency in AFs and freedom from stray-field perturbations would alleviate the strict need in many applications of nearly perfect crystals. In addition, AF magnons have a chiral degree of freedom, which can lead to new ways of encoding and processing information. The many advantages of AF materials in electronics are balanced by significant challenges that must be addressed before AF-based devices can be realized. These include the identification of methods of detecting the rotation of the AF order parameter (the Néel vector), defined as the difference between the magnetizations of the two spin sublattices.

In all studies to date, detection has been accomplished in hybrid devices in which an AF is exchange-coupled to a FM element to allow reading of the final state of the device. In these devices, however, the AF is a passive element for which the dynamics are governed by the FM. Controlling the interaction between spin currents and the magnetic state of an AF without ferromagnetic elements is standing challenge. Experimental studies of the SHE, spin pumping, SOT, and STT effects are required to advance the fundamental understanding of high-frequency dynamics in active AF-based devices. These studies may require the development of new materials and enhancement of magnetic measurement methods to achieve sensitivity to excitations of the sublattice magnetization. Materials development, including epitaxial growth of crystalline AF insulators with controlled exchange and anisotropy energies, and control of AF/nonmagnetic interfaces, will be needed to identify suitable candidates. High-frequency spectroscopic characterization to explore the energy landscapes of these materials is required. Device design and integration will be necessary to explore the fundamental spin-charge dynamics and the potential for operations in the THz regime. Theoretical modeling, including micromagnetic simulations, is needed to understand the spin dynamics in AFs, to explore AF-based magnonic architectures, and to identify the best approaches to device realization.

Objective: The objective of this topic is to advance fundamental understanding of spin-charge dynamics in heterostructures based on AF insulators as active components toward demonstration of THz-speed spin-charge manipulation for future robust, ultrahigh-speed electronics.

Research Concentration Areas: Research subjects include: (1) growth and study of thin films; (2) nanofabrication of AF heterostructures; (3) study of nanoscale magnetic and transport properties; (4) GHz-THz spectroscopy and circuit design; (5) study of AF dynamics; and (6) theoretical modeling of ultrafast spin-charge dynamics in AF-based 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 six (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:
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Topic 18: (AFOSR) Quantum Information Concepts from Tensor Networks and the Holographic Principle

Background: Since the mid 90's, the holographic principle, in particular the correspondence between gravity in an Anti-de Sitter (AdS) space-time and a conformal field theory (CFT) on its boundary, has been driving fundamental discoveries in theoretical high-energy physics and revolutionizing our conceptual understanding of quantum gravity, quantum many-body physics, and quantum information theory. This AdS/CFT duality provides a mapping between a strongly-coupled quantum field and classical gravity, allowing for example a deeper understanding of quantum chromodynamics (QCD) in the confining (non-perturbative) regime, and the exploration of quantum many body systems in the strongly-correlated phase; both of which resisted investigation via standard theoretical and computational means. Furthermore, holographic duality has provided us with a new way to look at the fundamental nature of *information*. Quantum information fundamentally may be the relationship between geometric constructs of the bulk and the Hilbert space defined on the boundary regions. This correspondence has recently been investigated via different methods: tensor network renormalization and recovery map of noisy quantum channel. An insight into the emerging role of tensor network states, gauge theory, holographic entanglement entropy, and the bulk geometry, in the context of quantum information, is highly desirable.

Objectives: By leveraging the relationships between the holographic principle, quantum information theory, quantum error correction, and tensor networks, this MURI topic aims at developing a *comprehensive* theory and computational approaches towards discovering new and improved relationships between these domains, and designing falsifiable tests that will improve our understanding of the fundamental information in dynamic multipartite quantum systems.

Research Concentration Areas: Suggested research areas include but are not limited to: (1) Extend known results to general spacetime beyond time-slice restriction; (2) Study the relationships between the bulk geometry, gauge theory, and the operator algebras (possibly infinite dimensional) involved in the entanglement wedge reconstruction; (3) Elucidate the structures/properties of the bulk algebras in the context of gauge symmetry and approximate quantum error correction for multiple boundary regions; (4) Clarify the relationships between holographic entanglement entropy and holographic error correction; (5) Construct new families

of tensor networks as the bulk-boundary holographic maps and study their error correction properties using quantum information-theoretic or geometric formalism; (6) Can experimental manifestations of these tensor networks be used towards simulation of quantum many-body systems, or as universal resources for quantum computation?

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 (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.

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Topic 19: (AFOSR) 2D Magnetic Heterostructures for Flexible, Lightweight Electronics

Background: Lightweight materials are crucial for applications in air vehicles and satellites. New low-density and multifunctional materials are needed to realize unprecedented performance, low cost, and low energy consumption. One game-changing idea is to develop integrated two-dimensional (2D) magnets into selected matrices as smart hybrids with tailored functionalities. Such lightweight materials will have transformative applications in electromagnetic interference shielding, electrochromic devices, low-energy data storage, and ultralow-power switching. The 2017 breakthroughs in discovery of 2D magnetism in monolayer crystals and observation of layer-dependent magnetic phases open up new paradigms in fundamental science and device technologies. Monolayer semiconductors with intrinsic ferromagnetism (e.g., CrI_3) were discovered this year. These materials have enormous potential for magneto-electronics, as well as combining logic and memory for high-performance computing. Their atomically thin nature will enable unprecedented manipulation of magnetic properties (such as Curie and Néel temperatures and magnetic phases) by external control, including electric field, carrier density, and strain. It will also enable incorporation of these materials into lightweight, flexible packages. The van der Waals nature of these magnets enables arbitrary design of heterojunctions, without lattice-matching constraints, formed either between different magnets or between magnets and, e.g., spin-orbit-coupled 2D materials. An atomically sharp interface, such as these material possess, is crucial for engineering emerging interfacial physical phenomena and functionalities. For example, in heterostructures between the monolayer valley semiconductor WSe_2 and a 2D ferromagnet, the interface enables ferromagnetic control of spin and valley dynamics in WSe_2 via large magnetic proximity effect, and the demonstration of an optical analog of the giant magneto-resistance effect. Thus, the discovery of 2D magnets combined with interfacial engineering capabilities breaks new ground

in the fundamentals of magnetism, with unprecedented control and new functionality, and physical forms in data storage, sensing, and high-speed electronics.

Objective: The objective of this program is to advance the fundamental understanding of 2D magnets, their heterostructures, and composites towards demonstration of controllable magnetic phases and transitions, and to seek potential opportunities in ultrafast device applications through new methods of spin generation, manipulation, and transport.

Research Concentration Areas: Potential topics include, but are not limited, to: (1) theory-guided synthesis of new 2D magnets with magnetic anisotropy and Curie and Néel temperatures engineering; (2) new theoretical framework and nanoscale experimental probes to investigate fundamental magnetic properties unique to 2D magnets, such as stacking-order and thickness-dependent magnetic phases, vertical domain dynamics through layer-by-layer magnetization flipping, electrical and strain tunable magnetism, and ultrafast optical control of magnetization, domain dynamics, and magnons; (3) development and characterization of suitable matrices for hosting 2D magnets; (4) magnetic heterostructure engineering, interface spin structure and tunneling dynamics, novel spin-torque effects, and spin-texture engineering; and (5) new lightweight electronic composites that incorporate 2D magnets and heterostructures, for applications such as THz electronics, magnetic van der Waals tunneling transistors, spin valves and injectors, photodetectors, light emitters, and modulators.

Anticipated Resources: It is anticipated that this topic requires approximately $1.5M per year for five years, supporting approximately six funded faculty researchers. Exceptions warranted by specific proposal should be discussed with one of the topic chiefs during the white paper phase of the solicitation prior to submitting a full proposal.

Research Topic Chiefs:
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Topic 20: (AFOSR) Feedback Control with Sparse Neural Signals

Background: We are at a cusp of new inroads for achieving autonomous flight control with exceedingly efficient systems capable of adaptive learning. This is made possible by the confluence of recent advances in computational neuroscience, autonomous control, machine learning and sparse sensing. This MURI seeks to draw on this confluence to drive the next generation of smart, agile and highly adaptive autonomous systems and to probe the basic mechanisms by which animals acquire and process information from myriad distributed sensors and from multiple modalities of sensing.

The control of autonomous systems that are capable of navigation in spatially and temporally complex environments remains a significant challenge for autonomous air vehicles. Indeed, we have yet to manufacture successful autonomous robots that can match the fidelity and agility of

natural systems capable of highly complex tasks as well as systems capable of "on the fly" decision-making. As such, it remains a significant open problem in robotics and autonomous systems as well as in systems neuroscience. Recent advances in systems neuroscience have revealed two critical, and seemingly ubiquitous, phenomenon: (i) signals in high-dimensional networks of neurons are often encoded in low-dimensional patterns of dynamic neural activity [1,2], and (ii) sparsity plays a key role in encoding and decoding [3,4]. In parallel, a mathematical theory of sparsity (and compressive sensing), whereby a limited number of measurements can be used to reconstruct the full state of a system, has achieved remarkable success and impact across a broad range of engineering and scientific applications [5,6,7].

Surprisingly, few if any engineering applications involve dynamics or feedback control. In the context of sensory integration, sparsity has only recently been shown to provide a potentially transformative paradigm for decision-making tasks [8]. Such a connection between neural/sensory systems and sparse decision making, especially in equation-free architectures [9], leads naturally to the consideration of the nervous system's primary objective: to inform and/or initiate dynamic control strategies. This neural control system must bridge the gap between sparse sensory codes and the downstream motor decoding strategy [10-11]. The goal of this MURI topic is to fund basic scientific research that sheds light on integrative process and reveals principles of neural computation that may inspire a new generation of technologies.

Objective: The objective of this MURI is to launch a new paradigm for control of movement that links sparse neural representations to complex dynamics, promoting a new field of controls and revealing principles by which natural systems manage, represent, and act on high-dimensional sensory data.

Research Concentration Areas: Suggested research areas include (1) control theory, (2) systems neuroscience with a focus on sensory information processing, (3) applied mathematics and sparse sensing, and (4) robotics.

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 approximately six (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:
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Topic 21: (AFOSR) Dissipation Engineering in Open Quantum Systems

Background: All quantum systems suffer from environment-induced dissipation which can destroy quantum coherence. Even with major advances in long-lived entanglement generation and high fidelity quantum state preparation through understanding and elimination of decoherence sources in quantum systems, it remains a continuous challenge. Contrary to the convention of viewing dissipation as an encumbrance, researchers have shown (mostly theoretically) that one can use dissipation as a resource to design entangled quantum states in steady state or autonomously correct errors. By carefully embedding the quantum system in an engineered environment and applying specific driving fields, entropy can be transferred out of the quantum system and driven into a desired final quantum state or manifold of states, independent of the initial state and without active control. For example, recent experiments demonstrated that one can use engineered dissipation to deterministically produce and stabilize an entangled steady state of two trapped-ion quantum bits, independent of their initial states. The concept extends to any type of physical quantum system where the environmental coupling can be controlled. Present quantum technologies have successfully isolated systems in the laboratory to an exquisite degree such that dissipation engineering, or reservoir engineering, at a small scale has recently been realized in different platforms including trapped ions, ultracold atoms, quantum optics, and superconducting circuits. Dissipation engineering marks a major shift from standard methods of creating and controlling quantum systems. With the recent quantum technological advancements, now is the optimal time to unlock new paradigms to overcome the challenges of environmental interactions. This research area demands a multidisciplinary team of experimentalists and theorists that blend together physics, mathematics, computational science, and engineering to successfully accelerate scientific discovery.

Objective: The aim of this MURI topic is to motivate novel approaches to controlling dissipative processes to drive a quantum system into a desired manifold of quantum states, protect the quantum states from decoherence, continuously and autonomously correct errors, and manipulate the quantum states within the stabilized manifold.

Research Concentration Areas: Suggested research areas through experimentation and theory include but are not limited to: (1) Exploration of new dissipation engineering approaches to generate and protect coherent quantum states in open quantum systems; (2) Investigation of dissipation-based autonomous error correction and distillation schemes; (3) Dissipation engineering for multi-body steady state entanglement and examining multiple decoherence channels; (4) New ideas of dissipation engineering for noise-robust open quantum systems including combining dissipation engineering processes with more conventional methods; (5) Experimental validation of theoretical concepts of engineering dissipation.

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 chiefs during the white-paper phase of the solicitation.

Research Topic Chiefs:
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Topic 22: (AFOSR) Group-IV Alloy Synthesis and Materials Properties

Background: Over the past decade, Group-IV alloy systems have become viable for optoelectronic active materials by incorporating sufficient Sn into Si and Ge to create a direct band-gap semiconductor with energy transitions ranging from near to far infrared (IR) wavelengths. These alloy films are metastable, because Sn has less than 1% solubility in bulk Si and Ge. By use of non-equilibrium synthesis methods, ~20% Sn incorporation in Ge has been demonstrated and used for photodetectors and lasers. To access detection of longer wavelengths, increasing Sn composition is required. The demonstrated ability to incorporate Sn far beyond the solubility limit raises fundamental questions about the underlying science of epitaxially stabilized films, in general. Furthermore, the fundamental structural, optical, and electrical characteristics of these higher-Sn containing compounds are unknown. Both theoretical and experimental investigations are needed to produce new films and to understand and quantify the properties. Current experimentally derived properties of higher-Sn-composition alloys disagree with calculations. Because of Sn's higher atomic mass and significant spin-orbit coupling, advanced calculation techniques must be developed to accurately describe the electronic band structure. A successful project would determine the phase stability of SiGeSn alloys as a function of composition, temperature, and strain; theoretically explain and experimentally verify the electronic band structure of Si-Ge-Sn alloys; measure alloy emissivity and optical absorption; define carrier scattering mechanisms and model associated electronic transport properties; develop synthesis and processing techniques that further increase Sn composition; and characterize these new structures. The research would provide access to a new class of materials for a range of mid-wave IR (MWIR) applications with capacity for scalable integrated optoelectronic device performance.

Objective: To understand the stability of epitaxial Group-IV alloy films, to determine the extent to which high-Sn-content films can be stabilized and the resulting nanoscale features and interfaces, to theoretically predict their properties, and to measure them within the accessible range of compositions so as to evaluate the utility of this class of materials for continued development for IR optoelectronics.

Research Concentration Areas: Areas of interest include, but are not limited to, the following: (1) Investigation of the fundamental growth mechanisms, kinetics, and solubility limits for these materials; (2) Characterization of the optical, electronic, structural, mechanical, and thermal

properties of these materials, including direct/indirect bandgap, doping, strain, and defect types and concentrations and their effects; (3) Theoretical or computational evaluation of thermodynamic and kinetic stability, structural, optical, and electronic characteristics of these novel materials and interfaces. (4) Exploration of growth techniques that are scalable and relevant to a device quality manufacturing environment; and (5) Growth of films and fabrication of structures that can be used for detection of MWIR radiation.

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 seven (7) 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:
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Topic 23: (AFOSR) Neuromorphic Networks for Multifunctional Intelligent Systems

Background: Modern artificial intelligence systems, which will arguably reshape our world in the future, are now utilizing Si-based computing circuits of the von Neumann architecture. For this traditional architecture, the time and energy expended to process, memorize, and transmit signals between the logic and memory occur sequentially. They increase exponentially with the dimensions of the data, often referred to as the "curse of dimensionality" or the "von Neumann bottleneck." This situation severely limits the applications of artificial intelligence systems to handle, e.g., autonomous operation of aerospace vehicles in complex environments. In contrast, signals are processed in neurobiological networks via trillions of synapses with integrated logic and memory functions in a massively parallel mode. And the synapses are constantly modified in a parallel learning process to automatically optimize and simultaneously develop new functions in the networks. The recent innovation of synaptic resistors based on ion-doped polymer composites loaded with carbon nanotube opens a new opportunity to emulate neurobiological networks with parallel signal processing and learning capabilities. A scaled-up neuromorphic network based on such novel composite materials can circumvent the curse of dimensionality to process and learn from huge data sets with speed, power efficiency, and memory capacity exponentially superior to those of Si-based computing circuits. By integrating sensors and actuators with newly designed neuromorphic networks, we can develop multifunctional intelligent systems and thus permit efficient and effective autonomous operation of aerospace vehicles in dynamically changing environments.

Objectives: (a) To establish novel nanocomposite materials and nanoscale devices that emulate neurons and neurobiological synapses and are capable of integrated analog signal processing, memory, and learning functions; (b) to incorporate these emerging materials and devices into neuromorphic networks that mimic the critical architecture of neurobiological systems with

parallel signal processing and learning capabilities; and (c) to develop multifunctional intelligent systems for state perception, real-time learning, autonomous control and self-navigation, and self-optimization in aerospace vehicles operated in dynamically changing environments.

Research Concentration Areas: Suggested research areas are as follows: (1) Design and synthesis of novel nanocomposite materials that emulate neurons; (2) design and fabrication of nanoscale composite devices that emulate neurobiological synapses; (3) theoretical analysis and modeling of the architectures and intelligent behaviors of the neurobiological vs. neuromorphic networks; (4) microscale-to-nanoscale fabrication techniques to integrate various composite materials, sensors, actuators, synaptic devices, and neuromorphic networks in a multifunctional system; (5) VLSI Si-circuits to establish efficient interfaces between the sensors, actuators, and the neuromorphic network; and (6) demonstration and analysis of autonomous operation of multifunctional intelligence systems, such as state perception, real-time learning, autonomous control and self-driving, and self-optimization.

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 (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:
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Topic 24: (AFOSR) Microstructurally-Aware Continuum Models for Energetic Materials

Background: It is well-established within the detonation physics community that the ignition process for shock to detonation transitions in high explosives begins with an initiating shock followed by a growth to detonation. The initiating shock causes mechanical deformation, friction and other processes that localize energy at various microstructural features popularly known as "hot spots". Chemical reactions initiate at these hot spots, releasing chemical energy and heating surrounding material. Growth to detonation occurs when the surrounding material is sufficiently heated, and when there are sufficient reaction sites within the microstructure that grow and coalesce with other sites to result in a continuous reaction. Therefore, the quality, size, frequency and distribution of microstructural features is of critical importance.

High explosive formulations contain crystals of organic explosives, polymeric or adhesive binders, aluminum particles and inorganic oxidizer particles providing a diversity of microstructural variations. The crystals and particles have different particle-size distributions and lot-to-lot variability, implying a necessity for stochastic methods. Micrographs and tomography of various explosive formulations, together with ignition pressures, time to

detonation, “POP plots”, etc. could be utilized together with mesoscale modeling and Machine Learning methods to predict which features, with what distribution, feature size, etc. lead to ignition and when.

Since the detonation wave is driven by chemistry, energetic material models must include chemical energy. Initial reactions are endothermic followed by an exothermic pathway that releases energy, initiating more reactions. Detonation is sustained when energy is produced faster than quenching from energy-absorbing or energy-dissipative mechanisms. Combining microstructural features with mechanical energy localization and chemical energy release rates and utilizing AI methods such as Reinforcement Learning could result in algorithms that predict shock to detonation transition and microstructurally-aware continuum models for energetic materials.

Objective: The primary objective of this MURI topic is to transform current continuum models by incorporating microstructural features together with mechanical and chemical energetics, that are experimentally validated, to predict continuum-level shock to detonation transition in energetic materials with a range of microstructures.

Research Concentration: The selected MURI team is expected to: (i) generate transformational new continuum models that are experimentally validated, (ii) which systematically incorporates microstructural features and their distributions, (iii) together with mechanical energy localization and chemical energy release rates that lead to detonation, and (iv) accounting for uncertainty due to microstructural variation and computational methods, (v) to provide a balanced effort that culminates with hydrocode integration.

Anticipated Resources: Awards under this topic will not exceed an average of $1.5M/year for 5 years, supporting academic researchers and NNSA PI’s for model integration. Exceptions warranted by specific proposed approaches should be discussed with the topic chiefs during the white paper phase of the solicitation. This is anticipated to be a joint US-UK MURI topic.

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