**Special Notice N00014-18-R-SN05**
**Special Program Announcement for 2018 Office of Naval Research**
**Basic Research Opportunity:**
**"Advancing Artificial Intelligence for the Naval Domain"**

## I. INTRODUCTION

This announcement describes a research thrust entitled "Advancing Artificial Intelligence for the Naval Domain" to be launched under the Fiscal Year (FY) 18 Long Range Broad Agency Announcement (BAA) for Navy and Marine Corps Science and Technology, N00014-18-S-B001, which can be found at https://www.onr.navy.mil/en/Contracts-Grants/Funding-Opportunities/Broad-Agency-Announcements

The research opportunity described in this announcement falls under the following sections of the BAA: Appendix 1 "Program Description,"

- Section I entitled "Expeditionary Maneuver Warfare & Combating Terrorism (Code 30); specific thrusts and focused research area:
  - Paragraph E. "ONR 30 Decision Support, AI, Machine Learning and Graph Analysis Program," Technology Investment area 3, entitled "Modeling/ Machine Learning/ /Artificial Intelligence"
- Section II entitled "Command, Control, Communications, Computers, Intelligence, Surveillance, and Reconnaissance (C4ISR) (Code 31); specific thrusts and focused research areas:
  - Paragraph A. Mathematics, Computers and Information Sciences, Specific scientific and technical areas entitled "Computational Methods for Decision Making" and "Machine Learning, Reasoning, and Intelligence
- Section V "Warfighter Performance (Code 34)":
  - Paragraph A entitled "Human and Bioengineered Systems", Specific thrusts and focused research: "Perception, metacognition and cognitive control" and "Representing and reasoning about uncertainty"
- Section VI entitled "Naval Air Warfare and Weapons (Code 35)"; specific thrusts and focused research areas:
  - Paragraph 5. "Intelligent autonomy for safe, reliable, and scalable control of heterogeneous unmanned air systems based on high-level mission tasking".
  - Paragraph 6. "Science of Autonomy"; clauses "b. Autonomous learning, reasoning, and decision-making in unstructured, dynamic and uncertain environments. c. Human interaction/collaboration including understanding intent and actions of human team members, adversaries, and bystanders. d. Organic perception/understanding to support decision-making, reasoning, and actions in a complex, dynamic world."

The purpose of this announcement is to (1) focus the attention of the scientific and technical community on specific areas of interest related to the advancement of artificial intelligence,

(2) encourage dialogue amongst those interested in this area with the Office of Naval Research (ONR), and (3) provide a timetable for the submission of white papers and proposals.

## II. TOPIC DESCRIPTION

ONR is interested in receiving white papers and proposals in support of advancing artificial intelligence for future naval applications. Work under this program will consist of basic research, and it will be funded under Budget Activity 1 (as defined in DoD Financial Management Regulation Vol. 2B, Ch. 5). The overall S&T effort is envisioned to be conducted at the Technology Readiness Level (TRL) 1-3 stage.

### Topic 1

### Title: Integration of Domain Knowledge and Machine Learning

**Background:** Foundational approaches to building intelligent agents may be cast into two broad categories of Knowledge Representation and Reasoning (KR) and Statistical Machine Learning (SML). These two approaches have advanced largely independently of each other, with their respective strengths and shortcomings. Despite recent breakthrough advances in SML (Deep Learning (DL) in particular), it has a number of shortcomings as it requires large annotated training sets, is unable to generalize beyond the training data and can be brittle under perturbations, and at best can only perform shallow inference. Complex concepts and tasks present even greater challenges for DL, because there are a paucity of examples (e.g., rare or unusual cases, complex activities) and the difficulties of annotating them. Hence, the current DL approach falls short of acquiring the sophisticated knowledge and reasoning necessary for building agents that can understand uncertain, unstructured, open, and dynamic environments, predict events and plan actions.

Over the past decades KR has developed a variety of techniques for building useful models for many domains. While strengths of KR models include broad applicability and logical structure enabling deep reasoning and rationality, their shortcomings include the challenge of modeling mundane concepts necessary for agents to understand every-day situations and perform tasks. Integration of knowledge and learning is needed to overcome shortcomings of both KR and DL and expedite development of versatile agents that can perform robustly and explain their actions. Indeed recent successes, such as using the knowledge of rigid motion invariances together with DL to train a robot to recognize objects from many viewpoints with fewer examples, support this combined approach. These promising advances are preliminary and ad hoc. Again, a principled framework for integrating knowledge and learning is paramount. This presents a number of fundamental challenges that stem in part from the incompatibility of representations. While domain knowledge is high-level and primarily symbolic, causal, relational, and semantic; learned representations are typically low-level, distributed and numerical. For integration of knowledge and learning, best examples derive from insights from humans who are very good at domain knowledge adaptation.

Humans continuously update and refine their world models by seamless integration of their current knowledge and new experiences, thus enriching their world models and improving their skills. Even though humans exhibit a wide spectrum of learning abilities and personalities, indepth investigation of how humans reconcile these two seemingly discordant representations can reveal common processes in skill improvement and provide insights into developing a computational framework for integrating domain knowledge and machine learning. Recent advances in KR and DL, and cognitive models of learning present a timely opportunity for developing conceptual and computational approaches for building versatile agents that learn quickly and robustly, and behave predictably.

**Objective:** The main objective is to develop a principled computational framework for integrating domain knowledge and machine learning for fast and robust learning of diverse, complex concepts and tasks with light supervision. A complementary objective is to gain insights into how humans incorporate prior knowledge and learning from scant data to improve their skills and learn new concepts and tasks, and use these insights to inform the computational framework.

**Research Focus Areas:** Focus areas include the following. (1) Design of experiments based on cognitive models that elucidate how humans refine and improve their models of concepts and tasks, and learn entirely novel concepts and skills by integrating existing knowledge and new experiences. These experiments should address several classes of tasks with varying levels of complexity ranging from skill improvement to attaining expertise. (2) Investigate approaches that reconcile divergent representations encoded in KR (ranging from formal to qualitative, such as laws of physics, rules, relations, semantic descriptions) and those that emerge from DL, and develop computational methods for principled integration of knowledge and learning. (3) Develop methods for automatic learning of KR-like structured models of knowledge and reasoning about novel concepts and tasks from examples.

**Anticipated Resources:** It is anticipated that multiple awards under this topic will be no more than an average of $500K per year for four years.

**Research Topic Chiefs:**
Dr. Behzad Kamgar-Parsi, ONR 31, 703-696-5754, behzad.kamgarparsi@navy.mil;
Dr. Thomas McKenna, ONR 34, 703-696-4503, tom.mckenna@navy.mil.

**Topic 2**

**Title: Artificial Intelligence in support of Collaborative Complex Decision-Making**

**Background:** In the US military (as in many other organizations) high consequence, strategic and tactical decision-making is an interactive, team-centered activity. For example, decision-making within Combat Information Centers (CICs) involves teams of expert staff who continuously: (a) monitor multiple information streams, (b) analyze and assess the evolving situation and operating conditions, (c) formulate, evaluate, and recommend potential courses of action (COAs), and (d) inform and advise military decision-makers who must then choose among competing COAs the “right” satisficing solution to mission risks, needs, and objectives. In the near future there will be fewer supporting staff members, the demand tempo of decision-making will increase, and the volume, complexity, and dynamics of monitored mission-relevant information, the actual battlespace, and contemplated COAs, will far exceed what human staff can comprehend or manage on their own. Decision-makers and staff are in need of comprehensive decision support systems that assist in the various tasks of complex decision-making (viz., monitor, analyze, assess, inform, evaluate, and recommend) as well as track, interact, and facilitate cooperation and collaboration among decision-making teams and participants. In response to this need, ONR seeks to develop intelligent decision-support tools and data analytic, machine learning, cognitive, and artificial intelligence (AI)-based technologies that accelerate decision-making capability/tempo and enable commanders and staffs to make exceptionally high quality decisions as fast as possible.

(For a summary of challenges for Naval decision support systems/agents see: https://www.onr.navy.mil/Science-Technology/Departments/Code-34/All-Programs/human-bioengineered-systems-341/Multi-Echelon-Command-Decision-Making)

**Objective:** The objectives for this topic are: (i) to advance the scientific understanding of collaborative complex decision-making and (ii) to develop AI technologies that actively inform and assist either in individual tasks or in the overall decision-making process. Key features of the desired technologies are that they possess the ability to assess the relative meaning and task-/context-sensitive importance of new or changing information, and convey or explain the basis of their recommendations in human-understandable terms. While many different AI technologies and scientific research questions are germane to the problem domain of collaborative complex decision-making, this focus is on science and technology that address one or more of the research focus areas listed below.

**Research Focus Areas:**

(1) *Models of Complex Human Decision-Making:* Develop psychological/cognitive theories and executable models of complex decision-making in both individuals and teams. Models should elucidate mechanisms, biases, and abilities tied to realistic (i.e., real world) human decision-making as an on-going, cyclic, goal-directed process with both feedback and adaptation. Ideally, models and experimental/empirical studies would be compared and contrasted across individual and team decision-making contexts. Examples of what is meant by 'complex' decision-making include but are not limited to: (A) Sequential decision-making problems under uncertainty, time pressure, and resource constraints, where there is a cost to acquiring more knowledge and/or reducing uncertainty, (B) Problems involving multi-objective optimization and/or satisficing, and involving both objective and subjective tradeoffs, (C) Problems with short-term contingencies that require a rapid response as well as slower but persistent changes in the environment, mission, or available resources that require adaptation over time, (D) Problems where negative consequences are severe, and where "taking risks" is a necessary part of achieving goals, (E) Problems where no extant knowledge representation covers all relevant aspects of the problem and both metric and nonmetric valuations are of importance.

(2) *AI Methods for enabling Complex Decision-Making:* Leverage the potential contributions of multiple AI approaches to complex decision-making, considered individually or in combination. Deep learning approaches may contribute, but in their current state of development they lack satisfying ways to deal with hierarchical information structure, are not transparent, and cannot distinguish between causation and correlation—all properties that are sought. Symbolic approaches or hybrids of deep learning and symbolic approaches may hold greater promise. Regardless of the approach, or combination of approaches, the proposed work should include a careful analysis, and demonstration, of what parts of the complex decision-making problem each of the component approaches is best suited to address.

(3) *Explicit and Implicit Communication:* Interfaces/displays and dialogue systems that enhance decision-making effectiveness and human-machine teaming. This includes task-level interfaces/displays for intuitively conveying information and trade-spaces regarding factors such as uncertainty, plausible outcomes/contingencies, competing COAs and their valuations, awareness of inconsistent (contradictory or missing) information, et cetera. It also includes the application of intent recognition, task recognition, and implicit communication frameworks to team-based decision-making; in collaborative decision-making, the joint activity is an informational task not a physical task but it still involves human-human and human-machine interactions and collaborations.

(4) *Monitoring and Active Machine Learning about Task and Team:* Application of experimental/empirical, statistical, and structured learning methods to learn about the decision-making process, task, and team. For example, learning methods could be combined with a Live, Virtual, Constructive (LCV) environment to (semi-)automatically learn (a) the decision-making task, (b) the various ways it can be/is carried out, (c) the capabilities and performance characteristics of team members and teams under differing conditions, and (d) weaknesses and opportunities for intervention/improvement based on outcomes.

**Anticipated Resources:** It is anticipated that multiple awards under this topic will be no more than an average of $500K per year for four years.

**Research Topic Chiefs:**
Dr. Micah Clark, ONR 34, 703-696-4525, micah.clark@navy.mil;
Dr. Harold Hawkins, ONR 34, 703-696-4323, harold.hawkins@navy.mil

**Topic 3**

**Title: Decentralized Perception and Planning in Dynamic Environments**

**Background:** A challenging research area, with important Naval applications, is understanding (perceiving) a physical environment where large volumes of heterogeneous streaming data (e.g., video, other types of imagery, audio, tweets, blogs, etc.) are collected by a team of autonomous agents that collaborate to recognize and localize mission-relevant objects, entities, and actors in the environment, infer their functions, activities and intentions, and predict events. To achieve this, each agent must process its localized streaming data in a timely manner; represent its localized perception into a compact model to share with other agents, and plan collaboratively with other agents to collect additional data to develop a comprehensive, global, and accurate understanding of the environment. Current methods are inadequate as they record the data now and process later, treat perception and planning as two separate and independent modules leading to poor decisions, and lack tractable computational methods for decentralized collaborative planning.

The broad issues that need to be addressed are new perception and planning methods that enable rapid understanding by focusing on what is relevant and informative in complex and cluttered environments, and do so within a unified theoretical framework that does not require ad hoc decomposition and restrictive assumptions on the separation of perception and planning. Collaborative optimal decentralized planning is a hard computational problem and becomes even more complicated when agents do not have access to the data at the same time and must plan asynchronously. Further, systems are needed that can rapidly adjust their sensing plans at much higher bandwidths based on cues from more minimalistic perception methods while also having strong theoretical properties such as approximate near-optimal asynchronous solutions within provable bounds and with performance estimates for real-time planning.

**Objectives:** Advances in surveillance technology have led to large volumes of increasingly complex data streams. The challenge of deriving intelligence from such massive, distributed, and diverse data sources--often providing observations without bound--is a challenging issue for the Navy. To exploit the full potential of the data, the intricate dependencies within and among the data streams must be captured. This includes development of computational methods that model various dependencies that cope with noisy and incomplete data sources, integrate information from multiple sensing modalities, and coherently propagate and output measures of uncertainty. The goal of this topic is to develop the underlying science and tractable computational methods that enable flexible and resilient approaches to learning, sharing, reasoning, and exploiting representations of the mission intent for situational awareness by a team of agents within a more rigorous closed-loop framework.

**Research Focus Areas:** (1) Task-aware Perception: Techniques for learning distributed and shared representations of complex structures and representations of the environment from diverse heterogeneous sources of data, especially streaming data, in a network of agents. Much of the data is typically irrelevant to the task, and these techniques must be able to ignore such data based on machine-understandable representations of the high-level knowledge about the task. (2) Asynchronous Decentralized Planning: Methods for distributed stochastic planning that account for mission intent and risk, the full uncertainty of the environment, potential teammate attrition, uncertain actions of other teammates in cases of degraded communications, and problem constraints, e.g., communications, computation, memory, timeliness of decisions, etc. Moreover, current methods for decentralized planning assume that all agents have the same information at the same time or make other restrictive assumptions that do not hold in the real world. Tedious handcrafted task decompositions cannot scale up to complex situations, so a general and scalable framework for asynchronous decentralized planning is needed. (3) Unified Frameworks: Representations used for perception and planning are generally incompatible, so architectures and algorithms for joint learning of unified representations are needed for perception and planning that address the following issues: What perceptual information is most important for choosing the right action in a way that is robust and efficient? How can effective planning representations be learned with only limited real-world interaction data? How can the learning process be structured so as to acquire the most general and powerful representations? (4) Resilience: A formal framework to develop resilient teams of heterogeneous agents that can exploit information from a broad range of global networks when available while being neither dependent nor vulnerable to interactions with those networks. (5) Levels of Decentralization: Develop a theoretical framework for determining the optimal level of decentralization for performing given tasks. These methods should be able to analyze and model relationships, linkages, and joint activities between multiple actors and integrate entity behaviors, including complex and dynamic linkage topologies. Architectures must be flexible for learning at the various temporal and spatial scales needed for hierarchic collaborative teams, including possible human-robot teaming.

**Anticipated Resources:** It is anticipated that multiple awards under this topic will be no more than an average of $500K per year for four years.

**Research Topic Chiefs:**
Dr. Marc Steinberg, ONR 35, 703-696-5115, marc.steinberg@navy.mil
Dr. Behzad Kamgar-Parsi, ONR 31, 703-696-5754, behzad.kamgarparsi@navy.mil

## III. NO EVENTS ARE PLANNED

## IV. WHITE PAPER SUBMISSION

Although not required, white papers are strongly encouraged for all offerors seeking funding. White Papers will be evaluated by the Government to determine whether the technology advancement proposed appears to be of particular value to the Department of the Navy. Initial Government evaluations and feedback will be issued via e-mail notification from the Technical Point of Contact. The initial white paper appraisal is intended to give entities a sense of whether or not their concepts are likely to be funded.

A detailed Full Proposal (Technical and Cost Volumes) will be subsequently encouraged from those Offerors whose proposed technologies have been identified through the above referenced email as being of "particular value" to the Government. However, any such encouragement does not assure a subsequent award. Full proposals may also be submitted by any Offeror whose white paper was not identified as being of particular value to the Government or any Offeror who did not submit a white paper.

For white papers proposing efforts that are considered of particular value to the Navy, but either exceed available budgets or contain certain tasks or applications that are not desired by the Navy, ONR may suggest a full proposal with reduced effort to fit within expected available budgets or an effort that refocuses the tasks or application of the technology to maximize the benefit to the Navy.

White papers shall not exceed 5 single-sided pages, exclusive of cover page, references, and resume(s) of principal investigator(s), and shall be in 12-point Times New Roman font with margins not less than one inch. White papers shall be in Adobe PDF format (preferred) or in Microsoft Word format compatible with MS Office 2010.

The cover page shall be labeled "WHITE PAPER" and include BAA Number N00014-18-R-SN05, proposed title, technical points of contact, telephone number, facsimile number (if available), and email address.

The 5-page body of the white paper shall include the following information:

1. Principal Investigator(s);
2. Relevance of the proposed effort to the research areas described in Section II; relationship of the proposed work to current state of art.
3. Technical objective of the proposed effort;
4. Technical approach that will be pursued to meet the objective;
5. A summary of recent relevant technical breakthroughs; and
6. A funding plan showing requested funding per fiscal year.

Resume(s) of the principal investigator(s), not to exceed 1 page per principal investigator, shall also be included after the 5-page body of the white paper.

**White papers shall be submitted via email to tom.mckenna@navy.mil with "WHITE PAPER" in the subject line.**

White Papers shall otherwise comply with requirements of the ONR Long Range BAA, N00014-18-S-B001.

To ensure full, timely consideration for funding, white papers should be submitted **no later than 22 March 2018**. White papers received after that date will be considered as time and availability of funding permit.

The planned date for completing the review of white papers is **12 April 2018**.

## V. FULL PROPOSAL SUBMISSION AND AWARD INFORMATION

Full proposals should be submitted under the FY 18 Long Range BAA, N00014-18-S-B001, by **11 May 2018**. Full proposals received after that date will be considered as time and availability of funding permit. Full proposals shall be submitted in accordance with the requirements of the FY18 Long Range BAA, N00014-18-S-B001.

ONR anticipates that grants, contracts or other types of assistance or transactions may be issued for this effort.

Full proposals for contracts should be submitted in accordance with the instructions of the FY18 Long Range BAA. The Technical Proposal/Content shall be single spaced, with not less than 1" margins, in Times New Roman font not smaller than 12 point, single sided, and not exceed 20 pages. The cover page, resumes, bibliographies, project schedule, and table of contents are excluded in the page count.

Full proposals for grants shall be submitted via Grants.gov. The following information must be completed as follows in the SF-424 to ensure that the application is directed to the correct individual for review: Block 4a, Federal Identifier: Enter N00014; Block 4b, Agency Routing Number, Enter the three (3) digit Program Office Code and the Program Officer's name: (341 [McKenna, Thomas]). All attachments to the application should also include this identifier to ensure the proposal and its attachments are received by the appropriate Program Office.

Although ONR expects the above described program plan to be executed, ONR reserves the right to make changes.

Funding decisions should be made by **8 June 2018**. Selected projects will have an estimated award date of **15 July 2018**.

## VI. SIGNIFICANT DATES AND TIMES

| Event | Date | Time |
|---|---|---|
| | | |
| White Paper Submission | 22 March 2018 | 1400 Eastern Local Time |
| Notification of White Paper Valuation* | 12 April 2018 | |
| Full Proposal Submission | 11 May 2018 | 1400 Eastern Local Time |
| Full Proposal Selections* | 8 June 2018 | |
| Awards* | 15 July 2018 | |

Note: *These are approximate dates

## VII. POINTS OF CONTACT

In addition to the points of contact listed in N00014-18-S-B001, the specific points of contract for this announcement are listed below.

Technical Points of Contact:

Topic 1:
Dr. Behzad Kamgar-Parsi, ONR 31, 703-696-5754, behzad.kamgarparsi@navy.mil;
Dr. Thomas McKenna, ONR 34, 703-696-4503, tom.mckenna@navy.mil.

Topic 2:
Dr. Micah Clark, ONR 34, 703-696-4525, micah.clark@navy.mil;
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Topic 3:
Dr. Marc Steinberg, ONR 35, 703-696-5115, marc.steinberg@navy.mil
Dr. Behzad Kamgar-Parsi, ONR 31, 703-696-5754, behzad.kamgarparsi@navy.mil

Primary Business Point of Contact:
Michelle Parrott
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Secondary Business Point of Contact:
R. Brian Bradley
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## VIII. SUBMISSION OF QUESTIONS

Any questions regarding this announcement must be provided to the Technical Point of Contact and Business Point of Contact listed in Section VII above. All questions shall be submitted in writing by electronic mail.

Answers to questions submitted in response to this Special Notice will be addressed in the form of an Amendment and will be posted to the following web pages:

- Federal Business Opportunities (FEDBIZOPPS) Webpage
  https://www.fbo.gov/
- ONR Special Notice Webpage
  https://www.onr.navy.mil/en/Contracts-Grants/Funding-Opportunities/Special-Notices

Questions regarding White papers or Full proposals should be submitted no later than two weeks before the dates recommended for receipt of White papers and/or Full Proposals. Questions after these dates may not be answered.