I. Opportunity Description

The Defense Advanced Research Projects Agency (DARPA) is issuing an Artificial Intelligence Exploration (AIE) Opportunity inviting submissions of innovative basic or applied research concepts in the technical domain of autonomous machine teaming. This AIE Opportunity is issued under the Program Announcement for AIE, DARPA-PA-19-03. All proposals in response to the technical areas described herein will be submitted to DARPA-PA-19-03-01 and, if selected, will result in an award of an Other Transaction (OT) for a prototype project. The total award value for the combined Phase 1 base and Phase 2 option is limited to $1,000,000. This total award value includes government funding and performer cost share, if required.

A. Introduction

CREATE is investigating new approaches for autonomous teaming of physically distributed groups of AI enabled systems (multi-agent systems) when there is limited opportunity for centralized coordination. Autonomy research for unmanned systems including Unmanned Aerial Vehicles (UAVs), satellites, unattended ground sensors (UGSs), and robots has primarily focused on improving the performance of individual system sensing and behaviors. However, the high level actions and integration into a larger mission or ‘team’ remains stuck in the paradigm of one or multiple humans controlling a single ‘autonomous’ system. The state-of-art in group autonomy of unmanned systems emphasize communications heavy approaches (e.g. Direct human control of many systems, contract / auction techniques, or coalition methods) which are brittle in communication constrained environments. Other efforts have explored machine teaming using swarm behaviors that emerge from simple reactive responses from each individual, but these tend to be inflexible and slow to accomplish a task. All of these approaches rely on static and pre-defined objective functions, static swarm behaviors, or other Markov Decision Processes (MDPs) that significantly limit the team’s ability to react to unexpected missions or balance competing mission objectives.

Context Reasoning is the use of implicitly given facts, relationships, and models from dynamically changing internal or external knowledge stores to enable “machine understanding” of sensing and commands to improve autonomous decision making. Where MDPs are not able to make use of domain information effectively due to their representational limitations, contextual reasoning allows autonomous agents to form hypotheses and infer relationships amongst new and stored observations enabling highly adaptable individual agent decision making, thus breaking the reliance on centralized C2 and the need for pre-planned cost function definition. Local decision making is less informed and suboptimal but is infinitely scalable, naturally applicable to heterogeneous teams, and fast.

B. Objective/Scope

Context Reasoning for Autonomous Teaming (CREATE) aims to explore the utility of Artificial Intelligence (AI) on the autonomous formation of scalable machine to machine teams capable of
reacting to and learning from unexpected missions in the absence of centralized communication and control. CREATE will develop the theoretical foundations of autonomous AI teaming to enable a system of heterogeneous, contextually-aware agents to act in a decentralized manner to satisfy multiple, simultaneous and unplanned mission goals. Agents within the team will have mechanisms for regulation to ensure (favorable) emergent behavior of the team to (1) better ensure the desired mission outcome and (2) bound the cost of unintended adverse action or ‘regret’.

The theoretical foundations of AI teaming will facilitate the scaling of autonomous systems to a large system of heterogeneous agents. An autonomous and decentralized foundation ensures system robustness to degradation of communications. Agents will be expected to understand the applicability of their own sensing and actuation modes to multiple high-level mission goals and, thereby, automatically balance their resources. The automation of contextual reasoning facilitates intelligent agent action at machine speeds. The combined foundations developed must explain the emergent behavior of the system and provide mechanisms for regulating this behavior.

**Heterogeneous contextually-aware agents.** Context allows humans and machines to form hypotheses and infer relationships to better understand observations and events. Context, appropriately understood, can help disregard the irrelevant and focus energies on the meaningful, thus improving the performance of a person or a machine. Context also enables the development of situational understanding through the use of multiple sources and features without dependence on brittle single sensor observations or poorly fused data. For the purposes of CREATE, we define ‘context reasoning’ as the use of implicitly given facts from a dynamically changing internal or external knowledge base to enable machine understanding of sensing and commands to improve autonomous decision making.

CREATE studies will explore the function and utility of encoding common knowledge (e.g. general places and things), procedural knowledge (e.g. user’s manuals and playbooks), and learned knowledge (evolving experiential, or semantically inferred information). Internal knowledge stores and any shared partial knowledge stores form the basis of an autonomous agent’s contextual awareness. A systems’ own perceptions from sensors or other inputs will be reasoned over using this context to inform autonomous actions. Of necessity, knowledge stores of embedded systems will be much smaller, more efficient, and more timely than those used in well-known commercial and military applications. CREATE will explore the utility of these smaller and distributed knowledge stores for the purpose of autonomous teaming.

**Decentralized decision making.** CREATE will explore the accuracy and value of decentralized machine decisions made from local observations and any available global context with an emphasis on decisions related to unplanned missions. Consider the unexpected detection of an unknown entity. An autonomous system may attempt to estimate the characteristics of the unknown entity using active or passive sensing, or it may attempt to infer the characteristics of the unknown entity using its contextual knowledge base. CREATE seeks innovative techniques that explore combined estimation and inferencing techniques to determine individual actions to unexpected missions. CREATE will compare and contrast decentralized decision-making with centralized decision-making, including factors of complexity, performance, and communication costs/requirements.
**Commander regulation.** Fully autonomous agents have the potential to take undesirable action. While ‘hard coded’ safeguards may be one possible solution, it is unlikely that commanders will anticipate all safeguards required for all possible eventualities for a team while maintaining an interesting level of autonomy. Investigators should attempt to identify the correct balance of hard coded safeguards and contextual safeguards.

Of particular interest is the exploration of mission definition that ensures favorable emergent behavior. A machine readable mission definition that defines the desired effects and does not prescribe specific solutions will enable flexibility in the autonomous system. By way of example, consider an area coverage problem where a number of autonomous systems, each with some sensing radius, must collectively sense over some area. Geographically constraining the movement of each system to remain within a fixed area will model the mission after the well-known physical diffusion problem. Just as in physical diffusion, random movement choices by each system will eventually achieve uniform coverage. Creating this favorable emergent behavior better ensures the desired state while giving the autonomous systems the freedom to attempt ‘low regret’ AI teaming techniques.

**C. Structure**

Proposals submitted to DARPA-PA-19-03-01 in response to the CREATE opportunity must be UNCLASSIFIED and must address two independent and sequential project phases, a Phase 1 Feasibility Study (base) and a Phase 2 Proof of Concept (option). The periods of performance for these phases are 6 months for the Phase 1 base effort and 12 months for the Phase 2 option effort. The Phase 1 (base) award value is limited to $350K. The Phase 2 (option) award value is limited to $650K. The total award value for the combined Phase 1 and Phase 2 is limited to $1,000,000 to include Performer cost share, if required.

Phase 1 studies will be evaluated to determine the feasibility of the approach and whether to select the option for Phase 2. The Government reserves the right to award all, some, one, or none of the options based on available funding, Phase 1 technical performance, and an assessment of the feasibility of the approach.

This solicitation is intended to fund applied research teams to explore the possibility and merit of the concepts described. Compelling research plans will show a clear structure on how some or all of these concepts will be explored and quantified. Because research teams will be asked to collaborate with other research teams in Principle Investigator (PI) meetings, proprietary solutions that would limit collaborative exploration in any way are strongly discouraged.

**D. Phase Descriptions**

**Phase 1 Feasibility Studies:** The goal of Phase 1 is to demonstrate the feasibility and value of AI to machine teaming with simulation and quantitative analysis. Feasibility simulations and analysis should identify conditions and techniques that enable a system of heterogeneous, contextually-aware agents to act autonomously, in a decentralized manner, to satisfy multiple, simultaneous mission goals and adapt to unexpected missions. CREATE is specifically focused on teaming amongst Size Weight and Power (SWaP) constrained systems (e.g. UAVs, UUVs, UGSs, Satellites, etc.). Feasibility studies should include considerations of scale, tempo, cost of information flow, and methods to manage uncertain or contradictory knowledge. Researchers will explore methods of enabling commander regulation while ensuring autonomous agent
freedom of decision. Proposals should explore a variety of regulation methods (e.g. ‘hard’ safeguards, contextual safeguards, and mission emergent behavior), define measures for ‘regret’, and explore the trade space between minimal regret and maximum autonomy.

Proposals should define specific mission simulations to help quantify the effectiveness of their proposed techniques. Proposers may use open domain standard problems (e.g. RoboCup rescue) or alternative scenarios. Scenarios must allow researchers to quantify performance metrics (even at the expense of ‘realism’) and show a plausible path to generalize observations to other scenarios.

**Phase 2 Proof of Concept Options:** The primary goal of Phase 2 is to continue to refine AI teaming techniques and algorithms started in Phase 1 and to demonstrate that the techniques identified can be hosted on one or more SWaP constrained system(s). Hosting platforms should participate in hardware in-the-loop simulation or otherwise demonstrate that the teaming techniques shown in simulation can be ported to embedded hardware systems.

**E. Schedule/Milestones**

Proposers must address the following Research Project Objectives, metrics, and deliverables, along with fixed, payable milestones in their proposals. The task structure must be consistent across the proposed schedule, Task Description Document (TDD), and the Vol. 2 - Price Volume. If selected for award negotiation, the fixed, payable milestones provided in Section 9.c of the Vol. 2 – Price Volume will be directly incorporated into Attachment 2 of the OT agreement (“Schedule of Milestones and Payments”). Please see the sample OT for Prototype provided as an attachment to DARPA-PA-19-03.

For planning and budgetary purposes, proposers should assume a program start date of November 29, 2019. Schedules will be synchronized across performers, as required, and monitored/revised, as necessary, throughout the effort. Proposals must include delivery schedules for Phase 1 and Phase 2 that include timelines for preliminary (to facilitate inspection by the Program Manager) and final (to facilitate evaluation) release of deliverables. Fixed milestones for this program should include at a minimum:

**Phase 1 Milestones:**
- Month 1: Provide a comprehensive description of the proposed context reasoning teaming and commander regulation techniques that will be explored, with in-depth support of published literature and identification of literature gaps. Include an overview and comparison of current state of the art pertaining to the proposed approach especially as it compares to centralized teaming schemes. Clearly define sample mission scenarios against which techniques will be exercised. Identify baseline comparison techniques (e.g. centralized C2) and define performance measures that capture adaptability to unplanned missions, cost of unintended adverse action or ‘regret’, and any other key performance measures necessary to characterize both the proposed and baseline techniques. Update the research plan to include details of the exploration that will be performed by Milestone 2.
- Month 3: Provide an interim report describing the maturing techniques and estimated performance against baseline techniques. This milestone should include key performance trades and insights. Progress should include simulations against the sample mission scenarios identified, as well as key theoretical foundations identified. Update the research plan to
include details of the exploration that will be performed by Milestone 3.

- Month 5: Feasibility studies final review. This milestone should present a compelling case that teaming with context reasoning offers significant performance gains over the state-of-the-art and that sufficient commander regulation can be achieved to bound regret. Evidence should be provided that the techniques developed can be deployed on SWaP constrained embedded systems. Submit Phase 1 Final Report in preparation for the Phase 2 option. Phase 1 final report should summarize the approach for phase 2 tasks.

Phase 2 Milestones:

- Month 7: Report on lessons learned, continued technique development, and continued simulations. Provide revised sample mission scenarios and performance measures consistent with updated Phase 2 plans. This milestone should include details on how performers will incorporate an embedded hardware element into continued exploration that should include, at a minimum, context reasoning algorithm development hosted on one or more embedded systems exercised with hardware-in-the-loop simulation.

- Month 9: Interim progress report describing revised sample mission simulation results with revised performance measures, and algorithm development progress. Review the embedded system and hardware-in-the-loop simulation design with the government to ensure that it will meet phase 2 exploration objectives.

- Month 11: Interim progress report on all aspects of the effort. Provide a detailed test and exploration plan to include three ‘design-build-test-learn’ cycles to mature algorithms and hardware-in-the-loop simulations. Each of the ‘design-build-test-learn’ cycles should build upon each other to advance the technology assuming success of each cycle. If a cycle is unsuccessful, performers coordinate with the DARPA to decide if the cycle should be repeated.

- Month 13: Interim progress report on all aspects of the effort. Report on progress, insights, and results of ‘design-build-test-learn’ cycle one.

- Month 15: Interim progress report on all aspects of the effort. Report on progress, insights, and results of ‘design-build-test-learn’ cycle two.

- Month 18: Proof-of-concept final review. This milestone should report on progress, insights, and results of ‘design-build-test-learn’ cycle three as well as summarize key findings achieved throughout the effort. Performers should present evidence-based recommendations on future application and research areas including a cost and schedule implementation plan. Documentation should be provided sufficient for those knowledgeable in the field but did not participate in the study to continue the research at some later date. A technical data package will be provided that includes software, firmware, and simulation code. Submit Phase 2 final report.

All proposals must include the following meetings and travel in the proposed schedule and costs:

- A joint one-day Phase 1 kick-off meeting will be planned within the first month of the award. This meeting will be held in the Washington, D.C. area.

- To foster collaboration between teams and disseminate program developments, a two-day Principal Investigator (PI) meeting will be held approximately every three months (beginning in month 3), with locations split between the East and West Coasts of the United States. For budgeting purposes, plan for six two-day meetings over the course of 18 months: three meetings in the Washington, D.C. area and three meeting in the San Francisco area.
• Regular teleconference meetings will be scheduled with the Government team for progress reporting as well as problem identification and mitigation. Proposers should also anticipate at least one site visit per phase by the DARPA Program Manager during which they will have the opportunity to demonstrate progress towards the milestones.

F. Deliverables

Performers will be expected to provide, at a minimum, all reports and data required by the individual Phase 1 and Phase 2 milestones. Additionally, proposers should propose deliverables specific to the objectives of the individual efforts and milestone requirements. These may include registered reports, experimental protocols, publications, intermediate, and final versions of software libraries, code, and APIs, including documentation and user manuals, and/or a comprehensive assemblage of design documents, models, modeling data and results, model validation data, and algorithm-generated lexicons or grammar rules. Unless otherwise specified, it is desired that all deliverables be released under open-source licenses using standard best practices for versioning and usability.

II. Award Information

Selected proposals that are successfully negotiated will result in award of an OT for prototype project. See Section 3 of DARPA-PA-19-03 for information on awards that may result from proposals submitted in response to this notice.

Proposers must review the model OT for Prototype agreement provided as an attachment to DARPA-PA-19-03 prior to submitting a proposal. DARPA has provided the model OT in order to expedite the negotiation and award process and ensure DARPA achieves the goal of AIE, which is to enable DARPA to initiate a new investment in less than 90 days from idea inception. The model OT is representative of the terms and conditions that DARPA intends to award for all AIE Awards. The task description document, schedule of milestones and payments, and data rights assertions requested under Volumes 1, 2, and 3 will be included as attachments to the OT agreement upon negotiation and award.

Proposers may suggest edits to the model OT for consideration by DARPA and provide a copy of the model OT with track changes as part of their proposal package. Suggested edits may not be accepted by DARPA. The Government reserves the right to remove a proposal from award consideration should the parties fail to reach agreement on OT award terms and conditions. If edits to the model OT are not provided as part of the proposal package, DARPA assumes that the proposer has reviewed and accepted the award terms and conditions to which they may have to adhere and the sample OT agreement provided as an attachment, indicating agreement (in principle) with the listed terms and conditions applicable to the specific award instrument.

In order to ensure that DARPA achieves the AIE goal of award within 90 days from the posting date (September 3, 2019) of this announcement, DARPA reserves the right to cease negotiations when an award is not executed by both parties (DARPA and the selected organization) on or before November 29, 2019.
III. Eligibility
See Section 4 of DARPA-PA-19-03 for information on who may be eligible to respond to this notice.

IV. AIE Opportunity Responses
Responses to this AIE Opportunity must be submitted as full proposals to DARPA-PA-19-03-01 as described therein. All proposals must be unclassified.

A. Proposal Content and Format
All proposals submitted in response to this notice must comply with the content and format instructions in Section 5 of DARPA-PA-19-03. All proposals must use the templates provided as Attachments to the PA and follow the instructions therein.

Information not explicitly requested in DARPA-PA-19-03, its attachments, or this notice may not be evaluated.

B. Proposal Submission Instructions
See Section 5 of DARPA-PA-19-03 for proposal submission instructions.

C. Proposal Due Date and Time
Proposals in response to this notice are due no later than 4:00 PM on October 3, 2019. Full proposal packages as described in Section 5 of DARPA-PA-19-03 must be submitted per the instructions outlined therein and received by DARPA no later than the above time and date. Proposals received after this time and date may not be reviewed.

Proposers are warned that the proposal deadline outlined herein is in Eastern Time and will be strictly enforced. When planning a response to this notice, proposers should take into account that some parts of the submission process may take from one business day to one month to complete.

V. Proposal Evaluation and Selection
Proposals will be evaluated and selected in accordance with Section 6 of DARPA-PA-19-03. Proposers will be notified of the results of this process as described in Section 7.1 of DARPA-PA-19-03.

VI. Administrative and National Policy Requirements
Section 7.2 of DARPA-PA-19-03 provides information on Administrative and National Policy Requirements that may be applicable for proposal submission as well as performance under an award.

VII. Point of Contact Information
VIII. Frequently Asked Questions (FAQs)

All technical, contractual, and administrative questions regarding this notice must be emailed to CREATE@darpa.mil. Emails sent directly to the Program Manager or any other address may result in delayed or no response.

All questions must be in English and must include name, email address, and the telephone number of a point of contact. DARPA will attempt to answer questions publically in a timely manner; however, questions submitted within 7 days of the proposal due date listed herein may not be answered.

DARPA will post an FAQ list under the AIE Opportunity on the DARPA/STO Opportunities page at https://www.darpa.mil/work-with-us/opportunities. The list will be updated on an ongoing basis until one week prior to the proposal due date. In addition to the FAQ specific to this notice, proposers should also review the Program Announcement for AIE General FAQ list on the DARPA/DSO Opportunities page under the Program Announcement for AIE (DARPA-PA-19-03).