

Artificial Intelligence Exploration (AIE) Opportunity

DARPA-PA-20-02-03 Time-Aware Machine Intelligence (TAMI)

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 time-aware neural network architectures that introduce a meta-learning capability into data-driven machine learning to enable time-based machine cognition and intelligence. This AIE Opportunity is issued under the Program Announcement for AIE, DARPA-PA-20-02. All awards will be made in the form of an Other Transaction (OT) for 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 or if proposed.

To view the original DARPA Program Announcement for AIE, visit [beta.SAM.gov](https://beta.sam.gov) (formerly FedBizOps) under solicitation number DARPA-PA-20-02: https://beta.sam.gov/opp/667875ba2f464ccfa38688ea1a718fe7/view?keywords=DARPA-PA-20-02&sort=-relevance&index=opp&is_active=true&page=1

A. Introduction

The Time-Aware Machine Intelligence (TAMI) AIE Opportunity will develop new time-aware neural network architectures that introduce a meta-learning capability into machine learning. This meta-learning will enable a neural network to capture the time-dependencies of its encoded knowledge.

As a neural network learns knowledge about the world and encodes it in its internal weights, some learned weights may encode knowledge whose activation should be conditioned based on time. Examples of such time dependencies are the weights mapped to the appearance features of a person in a convolutional neural network (CNN) for object recognition or the weights mapped to the dynamic features of a person's gait in a recurrent neural network (RNN) for activity recognition – both are only valid for a finite interval of time. Current neural networks do not explicitly model the inherent time characteristics of their encoded knowledge. Consequently, state-of-the-art (SOA) machine learning does not have the expressive capability to reason with encoded knowledge using time. An inference network, for example, cannot discount activations of weights for time-conditioned knowledge as features become less relevant over time. This lack of time dimension in a network's knowledge encoding limits the "shelf life" of the systems, leading to outdated decisions and requiring frequent and costly retraining to optimize performance.

TAMI's vision is for an AI system to develop a detailed self-understanding of the time dimensions of its learned knowledge and eventually be able to "think in and about time" when exercising its learned task knowledge in task performance.

TAMI draws inspiration from ongoing research on time processing mechanisms in human brains. A large number of computational models have been introduced in computational neuroscience to explain time perception mechanisms in the brain. TAMI will go a step further from such research to develop and prototype concrete computational models. TAMI will leverage the latest research on meta-learning in neural networks. Recent neural network models with augmented memory capacities are possible starting points for investigating the meta-learning of time dependencies.

Additionally, neural network based temporal knowledge graph modeling may provide mechanisms to infer hidden temporal relations of entities.

B. Objective/Scope

TAMI seeks to develop a new class of neural network architectures that incorporate an explicit time dimension as a fundamental building block for network knowledge representation. TAMI will develop new time-modeling components into such networks and investigate learning paradigms that can simultaneously learn task knowledge and be able to develop a self-reference to the details of the time dependencies of its knowledge encoding as meta-knowledge.

As motivation for the TAMI vision, consider neural networks designed for inference. Such neural networks derive abstract task knowledge from the analysis of a large number of data samples. Each data sample exists only in a specific time. For example, features given by a vehicle data sample are associated with that specific vehicle's age (e.g., rust and dents) and, therefore, are explicitly dependent on time. Neural networks incorporate such information as static activation weights; however, using the example above, the activation of these weights should ideally be conditioned on time.

Since neural network's knowledge encoding is a composite from features of many data samples, the time properties of the encoded knowledge in a neural network are complex functions of the time properties of the data from which the knowledge was built. Simply encoding timestamps or aggregating learning data according to time duration is insufficient, as machine learning cannot know beforehand which aspects of its encoded knowledge remain time conditioned.

Furthermore, other time-related properties exist in a neural network's knowledge encoding, dependent on the type of task learned. A new learning mechanism is needed to enable a self-awareness of the complex time-conditioned property of neural networks' knowledge encoding.

TAMI's objective differs from other machine learning research on machine time perception and temporal knowledge modeling where the focus is on modeling the time properties in the source data and encoding them in the neural network model. TAMI focuses on modeling the time property of its own learning. In other words, TAMI will develop a form of meta-learning into neural networks.

C. Structure

The TAMI program will comprise two phases. The focus of Phase 1 will be a Feasibility Study, during which performers will develop theories and computational methods to answer fundamental questions regarding time cognition in machine learning. Phase 2 will shift the focus towards a Proof of Concept demonstration, during which performers are expected to prototype time-aware meta-learning methods into computational models and demonstrate whether the new model could provide novel machine intelligence capabilities that current SOA machine learning architectures cannot achieve.

Proposals submitted in response to this AIE 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. Combined Phase 1 base and Phase 2 option efforts for this AIE Opportunity should not exceed 18 months. The Phase 1 (base) award value should not exceed \$250,000. The Phase 2 (option) award value should not exceed \$750,000. As previously stated, the total award value for the combined Phase 1 and Phase 2 is limited to \$1,000,000. This total award value includes Government funding and performer

cost share, if required.

Decisions regarding which performers will continue to Phase 2 will be based on the results of Phase 1 and the likelihood that disruptive outcomes will result from the completion of Phase 2. Funding availability will also be a decision factor.

Phase 1 research will investigate the theoretical foundations and computational frameworks necessary to enable time-aware machine meta-learning. Proposers should describe their specific methodology concepts for time-aware meta-learning and provide theoretical or experimental evidence supporting the proposed concepts. Proposers should also describe the potential novel machine intelligence capabilities that their proposed research is expected to bring about.

In proposing their time-aware meta-learning concepts, proposers should keep in mind some fundamental questions with regard to time cognition in machine learning. These questions, summarized below in three key topic areas, include, but are not limited to:

- Representation mechanisms: When representing time properties in machine models, what aspects, scales, and structures should be included? Do different categories of machine learning need different models?
- Learning mechanisms: How can time attributes co-evolve with task learning itself? What association mechanisms should be used to represent the interactions between the time dimension and the other dimensions of the encoded knowledge? How should implicit time-dependent information not directly observable in the data be captured?
- Management mechanisms: How does the time cognition in the neural network support recall of time-conditioned properties? How do such meta-learning mechanisms manage knowledge growth over time?

Proposals do not have to address all of the questions from the above topic areas. Proposals may suggest other critical questions with regard to time cognition in machine learning. Proposers should discuss how their proposed research will contribute to the understanding of machine time cognition. The research under the TAMI program will collectively take steps towards answering these questions.

Additionally, in Phase 1, proposers will investigate the computational models needed to realize their time-aware meta-learning concepts. Performers should develop a preliminary application concept that they will use to demonstrate the novel machine intelligence capabilities based on the proposed time-aware meta-learning. By the end of Phase 1, performers should clearly describe the computational models that they will implement to validate the proposed concepts and provide a description of their prototype application development plan and experimental plan. Proposers are also expected to develop quantitative metrics as a benchmark to be used in Phase 2.

In Phase 2, performers will validate their concepts and refine proposed theories and methodologies based on their experimental results and analyses. Phase 2 will prototype time-aware meta-learning methods and demonstrate whether these time-aware meta-learning concepts can provide novel machine intelligence capabilities that current SOA machine learning architectures cannot achieve. Performers are expected to assess the metrics and compare against SOA

Examples of novel machine intelligence capabilities include, but are not limited to, AI inference systems having longer-lasting “life” without performance degradation, even when some of their

encoded knowledge is obsolete; time-based causal awareness for machine learning; transfer learning time-invariant knowledge between task models; time choreography of actions between different machine learning agents; and, “mental time travel” that enables AI to recall past experiences/actions to inform decisions at present or in the future.

D. Schedule/Milestones

Proposers must address the following 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. Proposers must complete the “Schedule of Milestones and Payments” Excel Attachment provided with this AIE Opportunity as part of submitting a complete proposal and fulfilling the requirements under Volume 2 Price Volume. If selected for award negotiation, the fixed payable milestones provided will be directly incorporated into Attachment 2 of the OT agreement (“Schedule of Milestones and Payments”). Proposers are encouraged to use the TDD template provided as an attachment to DARPA-PA-20-02, which will be Attachment 1 of the OT agreement.

Phase 1 fixed payable milestones for this program should include (proposers should provide additional detail, specific to their proposed project, as necessary):

- Month 1: Report on proposer’s initial concept, methodology, and research plan.
- Month 3: Interim report describing the theory, architectures, and algorithm designs.
- Month 6: Final Phase 1 Report summarizing the time-aware machine learning concept, architectures, algorithm designs, description of the application concept, the expected novel machine intelligence capabilities that will be demonstrated in Phase 2, and proposed Phase 2 performance evaluation metrics.

Phase 2 fixed payable milestones for this program should include (proposers should provide additional detail, specific to their proposed project, as necessary):

- Month 7: Report on Phase 2 research plan, training and test data acquisition plan, and performance evaluation plan.
- Month 9: Report on implementation of the time-aware meta-learning components, initial implementation of the application prototype, and update on evaluation plan and metrics.
- Month 12: Interim report on experimental results of application prototype demonstrating novel machine intelligence capabilities that SOA machine learning architectures cannot achieve. Initial benchmark and analysis of performance metrics.
- Month 15: Report on refinements to the theory, methodology, architectures, and algorithms.
- Month 18: Final Phase 2 Report documenting final methodologies, architectures, algorithms, experimental results and performance evaluation, comparisons to SOA, and quantification of contribution to the development of 3rd wave artificial intelligence.

For planning and budgetary purposes, proposers should assume a program start date of **December 14, 2020**. Schedules may be synchronized across performers, as required, and monitored/revised as necessary throughout the program.

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

- To foster collaboration between teams and disseminate program developments, a two-day Principal Investigator (PI) meeting will be held approximately every six months, with locations split between the East and West Coasts of the United States. For budgeting purposes, plan for three two-day meetings over the course of 18 months: two meetings in the Washington, D.C. area and one meeting in the San Francisco, CA 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 agreed-upon milestones.

E. Deliverables

Performers will be expected to provide at a minimum the following deliverables:

- Program kick-off and PI meeting presentation material and other presentation materials as requested by the Government.
- Milestone reports detailed in the Schedule/Milestones Section.
- Negotiated deliverables specific to the objectives of the individual efforts. 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, and model validation data.

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-20-02 for information on awards that may result from proposals submitted in response to this notice.

Proposers must review the sample OT for Prototype agreement provided as an attachment to DARPA-PA-20-02 prior to submitting a proposal. DARPA has provided the sample 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 sample 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 sample OT for consideration by DARPA and provide a copy of the sample 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 sample 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 goal of award within 90 days from the posting date (September 16, 2020) 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 December 14, 2020.

III. Eligibility

See Section 4 of DARPA-PA-20-02 for information on who may be eligible to respond to this notice.

IV. AIE Opportunity Responses

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-20-02. All proposals must use the templates provided as Attachments to DARPA-PA-20-02 and the “Schedule of Milestones and Payments” Excel Attachment provided with this AIE Opportunity and follow the instructions therein.

Information not explicitly requested in DARPA-PA-20-02, its Attachments, or this notice may not be evaluated.

B. Proposal Submission Instructions

Responses to DARPA-PA-20-02 shall be submitted through electronic upload to DARPA’s BAA Portal (<https://baa.darpa.mil>).

DARPA will acknowledge receipt of complete submissions via email and assign identifying numbers that should be used in all further correspondence regarding those submissions. If no confirmation is received within two business days, please contact TAMI@darpa.mil to verify receipt.

When planning a response to this AIE Opportunity, proposers should take into account the submission time zone and that some parts of the submission process may take from one business day to one month to complete (e.g., registering for a Data Universal Numbering System (DUNS) number or Tax Identification Number (TIN)).

Electronic Upload

First time users of the DARPA BAA Portal must complete a two-step account creation process. The first step consists of registering for an extranet account by going to the URL listed above and selecting the “Account Request” link. Upon completion of the online form, proposers will receive two separate emails; one will contain a user name, and the second will provide a temporary password. Once both emails have been received, the second step requires proposers to go back to the submission website and log in using that user name and password. After accessing the extranet, proposers may then create a user account for the DARPA Submission website by selecting the “Register your Organization” link at the top of the page. Once the user account is created, proposers will be able to see a list of solicitations open for submissions, view submission instructions, and upload/finalize their proposal.

Proposers who already have an account on the DARPA BAA Portal may simply log in at <https://baa.darpa.mil>, select this solicitation from the list of open DARPA solicitations, and proceed with their proposal submission. Proposals submitted through the AIE Program Announcement (DARPA-PA-20-02) as opposed to this AIE Opportunity (DARPA-PA-20-02)

may be disregarded. *Note: Proposers who have created a DARPA Submission website account to submit to another DARPA Technical Office's solicitations do not need to create a new account to submit to this solicitation.*

All full proposals submitted electronically through the DARPA Submission website must meet the following requirements: (1) uploaded as a zip file (.zip or .zipx extension); (2) only contain the document(s) requested herein; (3) only contain unclassified information; and (4) must not exceed 100 MB in size. Only one zip file will be accepted per full proposal. Full proposals not uploaded as zip files will be rejected by DARPA. Technical support for the DARPA Submission website is available during regular business hours, Monday – Friday, 9:00 a.m. – 5:00 p.m. Requests for technical support must be emailed to BAAT_Support@darpa.mil with a copy to TAMI@darpa.mil. Questions regarding submission contents, format, deadlines, etc. should be emailed to TAMI@darpa.mil. Questions/requests for support sent to any other email address may result in delayed/no response.

Since proposers may encounter heavy traffic on the web server, DARPA discourages waiting until the day proposals are due to request an account and/or upload the submission. Note: Proposers submitting a proposal via the DARPA Submission site MUST (1) click the “Finalize” button in order for the submission to upload AND (2) do so with sufficient time for the upload to complete prior to the deadline. Failure to do so will result in a late submission.

C. Proposal Due Date and Time

Proposals in response to this notice are due no later than 4:00 PM on **October, 15, 2020**. Full proposal packages as described in Section 5 of DARPA-PA-20-02 must be submitted per the instructions outlined in this AIE Opportunity *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-20-02. Proposers will be notified of the results of this process as described in Section 7.1 of DARPA-PA-20-02.

VI. Administrative and National Policy Requirements

Section 7.2 of DARPA-PA-20-02 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

Jiangying Zhou, Program Manager, DARPA/DSO, TAMI@darpa.mil.

VIII. Frequently Asked Questions (FAQs)

All technical, contractual, and administrative questions regarding this notice must be emailed to TAMI@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 publicly 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/DSO Opportunities page at <http://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-20-02).

IX. Live Question and Answer Session

This topic will feature a live question and answer session with the Program Manager in the Time-Aware Machine Learning incubator on polyplexus.com. Polyplexus is an online, professional, technical conversation between the research community and DARPA Program Managers. The live question and answer session will be held on **September 29, 2020** from 10:30AM to 12:30PM Eastern, and further details will be available on polyplexus.com.