NASA SBIR 2021 Phase I Solicitation

H6.23 Spacecraft Autonomous Agent Cognitive Architectures for Human Exploration

Lead Center: ARC

Participating Center(s): JSC

Scope Title:

Learning and Adaptation for Space Cognitive Agents

Scope Description:

This subtopic solicits intelligent autonomous agent cognitive architectures that are open, modular, make decisions under uncertainty, and learn in a manner that the performance of the system is assured and improves over time. Cognitive agents for space applications need to adapt and learn from observation, instruction, and interaction as missions proceed. The value of preprogrammed agents that do not adapt over time will diminish in extended missions. Building upon the success of the previous solicitations, this extended scope will enable small businesses to develop both the learning technology and the necessary assurance technology within the scope of cognitive agents that forward base mission control to spacecraft and habitats, and multiply the cognitive assets available to the crew.

It should be feasible for cognitive agents based on these architectures to be certified or licensed for use on deep space missions to act as liaisons that interact both with the mission control operators, the crew, and most, if not all, of the spacecraft subsystems. With such a cognitive agent that has access to all onboard data and communications, the agent could continually integrate this dynamic information and advise the crew and mission control accordingly by multiple modes of interaction including text, speech, and animated images. This agent could respond to queries and recommend to the crew courses of action and direct activities that consider all known constraints, the state of the subsystems, available resources, risk analyses, and goal priorities.

Cognitive architectures capable of being certified for crew support on spacecraft are required to be open to NASA with interfaces open to NASA partners who develop modules that integrate with the agent, in contrast to proprietary black-box agents. A cognitive agent suitable to provide crew support on spacecraft may be suitable for a wide variety of Earth applications, but the converse is not true requiring this NASA investment.

Proposals should emphasize analysis and demonstration of the feasibility of various configurations, capabilities, and limitations of a cognitive architecture suitable for crew support on deep space missions. The software engineering of a cognitive architecture is to be documented and demonstrated by implementing a prototype goal-directed software agent that interacts as an intermediary/liaison between simulated spacecraft systems and humans.

Proposals should emphasize analysis and demonstration of the feasibility of various configurations, capabilities, and limitations, and address learning and adaptation during mission scenarios of a cognitive architecture suitable for crew support on deep space missions. The software engineering of a cognitive architecture is to be documented and demonstrated by implementing a prototype goal-directed software agent that interacts as an intermediary/liaison between simulated spacecraft systems and humans.

Expected TRL or TRL Range at completion of the Project: 2 to 4
Primary Technology Taxonomy:
Level 1: TX 10 Autonomous Systems
Level 2: TX 10.3 Collaboration and Interaction
Desired Deliverables of Phase I and Phase II:

- Research
- Analysis
- Prototype
- Software

Desired Deliverables Description:

For Phase I, a preliminary cognitive architecture, preliminary feasibility study, and a detailed plan to develop a comprehensive cognitive architecture feasibility study are expected. A preliminary demonstration prototype of the proposed cognitive architecture is highly encouraged.

For Phase II, the Phase I proposed detailed feasibility study plan is executed generating a comprehensive cognitive architecture, comprehensive feasibility study report including design artifacts such as System Modeling Language/Unified Modeling Language (SysML/UML) diagrams, a demonstration of an extended prototype of an agent that instantiates the architecture interacting with a spacecraft simulator and humans executing a plausible Human Exploration and Operations Mission Directorate (HEOMD) design reference mission beyond cislunar orbit (e.g., Human Exploration of Mars Design Reference Mission: https://www.nasa.gov/pdf/373665main_NASA-SP-2009-566.pdf), and a detailed plan to develop a comprehensive cognitive architecture feasibility study suitable for proposing to organizations interested in funding this flight capability is expected. A Phase II prototype suitable for a compelling flight experiment on the ISS is encouraged.

State of the Art and Critical Gaps:

Long-term crewed spacecraft, such as the International Space Station, are so complex that a significant portion of the crew's time is spent keeping it operational even under nominal conditions in low-Earth orbit and still require significant real-time support from Earth. Autonomous agents performing cognitive computing can provide crew support for future missions beyond cislunar by providing them robust, accurate, and timely information, and perform tasks enabling the crew more time to perform the mission science. The considerable challenge is to migrate the knowledge and capability embedded in current Earth mission control, with tens to hundreds of human specialists ready to provide instant knowledge, to onboard agents that team with flight crews to autonomously manage a space-flight mission.

The majority of Apollo missions required the timely guidance of mission control for success, typically within seconds of an off-nominal situation. Outside of cislunar space, the time delays will become untenable for Earth to manage time-critical decisions as was done for Apollo. The emerging field of cognitive computing is a vast improvement on previous information retrieval and integration technology, and is likely capable to provide this essential capability.

Investments continue to be made in a wide variety of cognitive agents. However, a critical gap that this subtopic addresses is assured learning for cognitive agents enabling it to appropriately adapt to the crew it interacts with in a manner that assures performance improves and not degrades over time mitigating risks related to learning systems.

Relevance / Science Traceability:

This subtopic is directly relevant to the HEOMD Advanced Exploration Systems (AES) domain: Foundational Systems - Autonomous Systems and Operations.

There is growing interest in NASA to support long-term human exploration missions to the Moon and eventually to Mars. Human exploration up to this point has relied on continuous communication with short delays. To enable missions with intermittent communication with long delays, new artificially intelligent technologies must be developed in order to keep the crew sizes small. Technologies developed under this subtopic are expected to be suitable for testing on Earth analogues of deep space spacecraft as well as the Deep Space Gateway envisioned by NASA.

References:

1. P. Ye, T. Wang and F. Wang, "A Survey of Cognitive Architectures in the Past 20 Years," in IEEE Transactions on Cybernetics, vol. 48, no. 12, pp. 3280-3290, Dec. 2018, doi: 10.1109/TCYB.2018.2857704.
2. COGNITIVE 2020 : The Twelfth International Conference on Advanced Cognitive Technologies and Applications: https://www.iaria.org/conferences2020/COGNITIVE20.html
3. ACC'20 - The 4th International Conference on Applied Cognitive Computing:https://americancse.org/events/csce2020/conferences/acc20
4. 2020 International Conference on Cognitive Computing: http://thecognitivecomputing.org/2020/
5. C. Gkiokas, "Cognitive agents and machine learning by example: Representation with conceptual graphs", Computational Intelligence Vol. 34 Issue 2 May 2018.

6. M. Zaharija, "Cognitive Agents and Learning Problems", International Journal of Intelligent Systems and Applications March 2017.

7. Human Exploration of Mars Design Reference Mission: https://www.nasa.gov/pdf/373665main_NASA-SP-2009-566.pdf