NASA SBIR 2019 Phase I Solicitation

H6.03 Spacecraft Autonomous Agent Cognitive Architectures for Human Exploration

Lead Center: ARC

Participating Center(s): JSC

Technology Area: TA4 Robotics, Telerobotics and Autonomous Systems

This subtopic solicits intelligent autonomous agent cognitive architectures that are open, modular, and make decisions under uncertainty. 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.

Future deep space human missions will place crews at long distances from Earth causing significant communication lag due to the light distance as well as occasional complete loss of communication with Earth. Novel capabilities for crews and ground staff will be required to manage spacecraft operations including spacecraft and systems health, crew health, maintenance, consumable management, payload management, as well as activities such as food production and recycling. Autonomous agents with cognitive architectures could interface directly with the crew as well as with the onboard systems reducing the cognitive loads on the crew as well as perform many of the tasks that would otherwise require scheduling crew time. In addition, this cognitive computing capability is necessary in many circumstances to respond to off-nominal events that overload the crew, particularly when the event limits crew activity, such as high-radiation events or loss of atmospheric pressure events requiring crew safety or sequestration.

In deep space, crews will be required to manage, plan, and execute the mission more autonomously than currently required on the International Space Station (ISS) due to more distant and longer latency ground support provided. NASA will migrate current operations functionality from the flight control room to the spacecraft to be performed by the crew and autonomous agents supervised by the crew, so the crew is not overburdened. Cognitive agents that can effectively communicate with the crew could perform tasks that would otherwise require crew time by providing assistance, operating systems, providing training, performing inspections, and providing crew consulting among other tasks.

Current typical computers agents can easily perform super-human memory recall and computation feats, but at the same time appear to be severely cognitively impaired in that they fail to recognize the values, implications, severity, reasonableness, and likelihood of the assertions they hold and how inferences can be applied. The consequence is that computer agents often fail to recognize what is obvious and important to humans, appear to be easily deceived, and fail to recognize and learn from mistakes. Thus, crew interface to such typical computer agents for the current state of the art can be burdensome.

This subtopic seeks proposals for effective cognitive architectures that can start to provide autonomous computer agents the common-sense humans take for granted amongst ourselves. Likely such agents would maintain some type of prioritized probabilistic belief network that they continually update based on evidence and inference in order to make decisions and respond to queries that take into account the assessed risks of the assertions they believe to be true.

Due to the complexity of such systems and the need for them to be continually updated, the architecture is required to be modular such that modules can dynamically be added, removed, and enhanced. Such a cognitive architecture is consistent with that proposed by Prof. Marvin Minsky in "The Society of Mind", 1988. The cognitive architecture is required to be capable of supporting multiple processes executing on multiple processors to be able to a meet the expected computational loads as well as be robust to processor failure.

An effective cognitive architecture would be capable of integrating a wide variety of artificial intelligence modules depending on mission requirements. The following modules provide capabilities useful for a wide variety of spacecraft cognitive agents:

- Goal manager: enables the simultaneous execution of multiple goals, e.g., keep crew safe, get tasks A and B done
- Planner/scheduler: creates and updates plans and schedules that accomplish tasks
- Smart executive: robustly executes high-level plans on schedule by coordinated commanding of multiple subsystems
- Sensor processing: separating signal from noise in sensor data, extracting and compressing useful information
- Actuator controllers: low-level commanding of subsystems that change the environment, support feed-forward control
- Skill/behavior manager: the coordination of multiple actuator controllers, e.g., manipulation activities
- Internal/external communication manager: coordinates information exchanges with humans and other agents
- Intra-spacecraft path planner/trajectory generator: develops 3D movement plans for humans and machines
- Internal/external resource manager: controls the use of resources such as memory, power, and consumables.
- Image recognition manager: manages extracting information from images
- Image generation manager: dynamically creating images to convey information to humans, e.g., charts, animations
- Declarative knowledge/rule manager: ensures that the system's declarative knowledge is consistent and updated
- Risk manager: assesses the uncertainty and severity of held assertions and the implication of actions or inaction
- Value manager: assess the importance humans place on goals, assertions, activities, etc.
- Symbol manager: create and use symbols created by humans and other agents to effectively convey information
- Script manager: create and update command sequences to reduce computation required to perform tasks
- Explanatory story manager: increase human communication effectiveness through stories and analogies
- Model manager: create and update models of itself, humans, other systems, and the environment
- System health manager: maintains overall system health, performs diagnoses and prognoses
- Crew health manager: monitors crew health, alerts crew to imminent threats, ...
- Communication signal manager: maintains health of communication paths, develops contingencies
- State estimator: maintains a consistent state of the models it manages for itself and its world
- Attention manager: manages its processing power to prevent overloading itself
- Security manager: monitors and prevents threats to itself, humans, and systems it manages
- Internal simulators: simulates plan execution under various conditions prior to actual plan execution

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.

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 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 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.

The expected Technology Readiness Level (TRL) range at completion of the project is 3-5.

References:

IBM (Watson), Apple (Siri), Microsoft (Cortana), and Amazon (Alexa) are just a few of the companies developing intelligent autonomous agents. However, they generally are proprietary and would not meet the requirements for spacecraft software that could potentially put the crew and mission at risk. There is a need to provide cognitive computing for systems like Robonaut.

A survey of cognitive architectures https://arxiv.org/pdf/1610.08602.pdf. Conferences that include cognitive architecture papers include IJCAI, AAAI, as well as the ongoing CogArch series of workshops.