National Aeronautics and
Space Administration

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Subcommittee on Space Science, and Competitiveness

Committee on Commerce, Science and Transportation

United States Senate

Statement by:
Dr. Steve A. Chien
Technical Group Supervisor
Artificial Intelligence Group
Jet Propulsion Laboratory

114th Congress

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Chairman Cruz, Ranking Member Peters, and Members of the Committee, thank you for the opportunity to speak to you on this topic of Artificial Intelligence (AI), and specifically it's relation to space exploration.

For the record, I am here as an employee of NASA's Jet Propulsion Laboratory, which is a Federally Funded Research & Development Center, managed by the California Institute of Technology for NASA.

As a Senior Research Scientist specializing in Autonomous Systems at JPL, I work on the development and application of Artificial Intelligence to NASA missions. I have had the privilege to lead the deployment of AI software to NASA's Earth Observing One and Mars Exploration Rovers missions, as well as for European Space Agency's Rosetta mission. Separately, The Artificial Intelligence Group has deployed additional AI software to the Mars Exploration Rovers and Mars Science Laboratory missions, as well as to NASA's Deep Space Network. In my group and related groups at JPL, we focus on using AI to improve the performance of space exploration assets: to conduct more science, improve response to track science phenomena and natural hazards, and increase the efficiency of operations.

I know of no better introduction to this topic than to point out that as we speak, a spacecraft, Earth Observing One, weighing 500 kg, flying at about 7.5 km/s, at about 700km altitude, is operating under the control of Artificial Intelligence software called "The Autonomous Sciencecraft". This software, which has parts both on the spacecraft and in the ground system, has been the primary operations system for this mission for over a dozen years. In this time, the spacecraft has acquired over 60,000 images and issued over 2.6 million commands.

This AI software has improved the efficiency of spacecraft operations using AI constraint-based scheduling technology, enabling direct tasking by end users such as scientists and natural hazard institutions. Additionally, onboard smarts (including AI/Machine Learning classification techniques) are used to detect and track volcanic activity, wildfires, and flooding to enable rapid generation of alerts and summary products. The most advanced of this software uses imaging spectroscopy to discriminate between different substances in images – these techniques have wide applications to environmental monitoring.

Furthermore, in a range of collaborations, this spacecraft has been networked together (via the ground and internet) in a sensorweb with other spacecraft and ground sensor networks to provide a unique capability to track volcanism, wildfires, and flooding worldwide, with linkages to Thailand, Iceland, Hawaii, Sicily, Namibia, and even Antarctica to name a few. This AI multi-agent system enables detections from one part of the system to automatically trigger targeted observations from another part of the system, as well as enabling autonomous retrieval, analysis, and delivery of relevant data to interested parties.

On Mars, the autonomous navigation software used on all of the Mars rovers has at its core AI-based search software. AI and computer vision software form the core of the Autonomous Exploration for Gathering Increased Science (AEGIS) system, now in operational use on both the Mars Exploration Rover and Mars Science Laboratory Rovers. AEGIS enables the rovers to autonomously target science measurements based on general science criteria such as texture, size, shape, and color without the ground in the loop, thereby improving rover science productivity.

Machine Learning also has significant impact in dealing with the enormous datasets generated in science observatories. Just a few examples follow:

- In the Very Long Baseline Array (VLBA) Fast Radio Transients Experiment (V-FASTR), Machine Learning is used to identify millisecond duration radio transients and reject radio frequency interference in the VLBA. This Machine Learning enables fast triage of order of 10^3 transient candidates daily to 10's of candidates for human review.
- In the Intermediate Palomar Transient Factory (i-PTF), Machine Learning is applied to visual imagery to identify candidate point source (e.g. supernovae) and streaking (e.g. near Earth Asteroids) transients for daily fast triage from order of 10^6 candidates to 10's of candidates for human review.

Significant AI technology is used in the scheduling systems for space missions. These systems enable the operations teams to manage the incredible complexity of spacecraft and science with often thousands to tens of thousands of science and engineering activities and constraints. These systems include SPIKE for Hubble Space Telescope, Spitzer Space Telescope, as well planned use for the James Webb Space Telescope, the MAPGEN use for the Mars Exploration Rovers and LADEE Activity Scheduling System (LASS) for the Lunar Atmospheric Dust Environment Explorer (LADEE) mission. In addition, NASA's Deep Space Network, used for communications to all of the NASA missions beyond Earth Orbit, uses AI scheduling technology.

While these examples may give you the impression that AI is commonplace in space exploration, I assure you that this not the case. The above examples represent a sampling of AI success stories on a small fraction of the overall set of space missions. Because of the high-stakes nature of space exploration, adoption of disruptive technologies like AI requires an extensive track record of success as well as continuous contact with the critical stakeholders of science, operations, and engineering. However, due to both technology advances and increased stakeholder understanding of the great promise of AI, progress has accelerated dramatically in recent years. For example, instruments on the Mars 2020 rover will have unprecedented ability to recognize features and retarget to enhance science. Mars 2020 is also investigating the use of an onboard re-scheduling capability to best use available resources. The Europa Multiple-Flyby mission is studying autonomy capabilities needed to achieve science in the presence of Jovian radiation induced processor resets.

In the future, AI will likely have many applications in human spaceflight missions where astronaut time is at a premium, as well as in robotic missions where the technology may enable missions of increasing complexity and autonomy. Past efforts have placed AI in critical position for future space exploration. Sustained resources, support, and vision are needed for AI to fulfill its vast potential to revolutionize space exploration.

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Dr. Steve Chien is Technical Group Supervisor of the Artificial Intelligence Group and Senior Research Scientist in the Mission Planning and Execution Section at the Jet Propulsion Laboratory, California Institute of Technology where he leads efforts in automated planning and scheduling for space exploration. Dr. Chien is also Adjunct Faculty with the Department of Computer Science of the University of Southern California and previously was a Visiting Scholar with the Department of Computer Science of the University of California at Los Angeles. He holds a B.S. with Highest Honors in Computer Science, with minors in Mathematics and Economics, M.S., and Ph.D. degrees in Computer Science, all from the University of Illinois.

He is a founder of the International Workshops on Planning and Scheduling for Space held every other year from 1997-2013 and was the Chair of the 1997 workshop and Co-chair of the 2013 Workshop. He is former chair of the AIPS Executive Council (2000-2002), was a founding member of the ICAPS Executive Council (2002-2006), and was founding President of the ICAPS Executive Council 2002-2004. He was also a Councilor for the American Association for Artificial Intelligence (2003-2006)

Dr. Chien was a recipient of the 1995 Lew Allen Award for Excellence, JPLs highest award recognizing outstanding technical achievements by JPL personnel in the early years of their careers. In 1997, he received the NASA Exceptional Achievement Medal for his work in research and development of planning and scheduling systems for NASA. He is the Team Lead for the ASPEN Planning System , which received Honorable Mention in the 1999 Software of the Year Competition and was a contributor to the Remote Agent System which was a co-winner in the same 1999 competition. In 2000, he received the NASA Exceptional Service Medal for service and leadership in research and deployment of planning and scheduling systems for NASA. He is the Principal Investigator for the Autonomous Sciencecraft Experiment which is a co-winner of the 2005 NASA Software of the Year Award. In 2007, he received the NASA Exceptional Achievement Medal for outstanding technical accomplishments in the development of the

Autonomous Sciencecraft deployed on the Earth Observing One Mission and the development of the Earth Observing Sensorweb. In 2011 He was awarded the innaugural AIAA Intelligent Systems Award, for his contributions to Spacecraft Autonomy. In 2011, he was the team co-lead for the Sensorweb Toolbox team, which was awarded Honorable mention in the 2011 NASA Software of the Year Competition. In 2015 He was awarded a JPL Magellan Award as well as the NASA Exceptional Achievement Medal for his contributions to automated science scheduling for ESA's Rosetta mission.

Dr. Chien has presented invited seminars on machine learning, planning, scheduling, and expert systems, has authored numerous publications. in these areas, and serves as a consultant to several multinational corporations in these areas. His current research interests lie in the areas of: planning and scheduling, machine learning, operations research, and decision theory.