

# Operational Environments at the Extreme Tactical Edge

**Mark J. Gerken**

FAST Labs, BAE Systems  
600 District Avenue  
Burlington, MA 01803 USA  
mark.gerken@baesystems.us

## Abstract

You can't get more "on the tactical edge" than in space. No other operational domain suffers from the combinations of distance from the operator, harsh environments, unreachable assets with aging hardware, and increadably long communications as space systems. The complexity of developing and deploying AI solutions in satellites and probes is far more difficult than deploying similar AI on Earth. This talk explores some of the considerations involved in deploying AI and machine learning (ML) in the space domain.

## Dawn of the Space Era

In early October 1957, the Soviet Union launched the first artificial satellite into low Earth orbit. With a diameter of only 22 inches and weighing in at 184 pounds, Sputnik 1 made history as it broadcast radio signals from space back to Earth. Twelve years later, on July 16<sup>th</sup>, 1969 Apollo 11 was launched from Cape Kennedy. Just under three hours later, it reignited its engines to place it in a trans-lunar orbit. Due in part to the complexity of its planned orbital maneuvers, the Apollo 11 modules included the first ever totally silicon-based computer. At the time, the Apollo Guidance Computer was a revolutionary design. It weighed about 70 pounds, ran at just over 2 MHz, and had just under 80KB of memory. In comparison, the IBM 360 introduced a few years earlier in 1964 was larger than a filing cabinet and weighed over 1700 pounds. These early missions ushered in the start of the modern space era. Today there are thousands of operational satellites (and many more defunct ones) in Earth orbit, and there have been dozens of probes sent to distant planets. Many of these satellites include AI-enabled systems and payloads. Software may still be updated even across long distances, but those updates have to live within the confines of their host's hardware configurations when launched. Further, it can take *years* before space-capable versions of new hardware is available, and years from then before a satellite incorporating that hardware can be designed and launched. But why does it take so long? What is it about the space domain that makes it so inhospitable to computer systems?

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## AI and Space

Space systems can be extremely long lived, and have long design cycles. Launched in 1977, Voyager 1 is still communicating. Over nine years of design went into the Mars Perseverance mission; launched in 2020, it took seven months to reach the planet. Perseverance itself was based on the Curiosity rover which was launched *ten years prior*. Perseverance is actively exploring the Martian surface, including using AI to support navigation and sensing. The rover includes the BAE RAD750<sup>®</sup> computer which first flew *fifteen years* earlier on the 2005 Deep Impact mission. The RAD750<sup>®</sup> is a re-engineered rad-hard version of the 1997 IBM PowerPC 750. That means that the computer being used today on Perseverance is based on a CPU introduced in the late 1990s! Any new or updated functionality has to run within the limits of that hardware.

## Communications

Due to their relatively low altitude and orbital mechanics, a ground station may have limited opportunity to upload software updates to orbiting satellites. For long-range probes such as Lucy (launched in 2021), communication spectrum usage becomes an issue as can solar occlusion. As the Earth orbits the Sun, so too do the other planets. Mars is recently in conjunction, placing it on the other side of the Sun from the Earth's perspective. For a nearly two week period of time, communications with the Red Planet were cut off as the Sun was blocking. Round-trip communication time as Mars came out of occlusions is close to 40 minutes, far too long to support direct terrestrial control of distant missions.

## Harsh Environments and Computer Hardware

Space is a shooting gallery; potentially high energy radiation including Alpha and Beta particles and Gamma and X-Rays can damage sensitive equipment. Single event effects (random, instantaneous disruptions such as flipping a memory bit) may induce software faults and dose effects can cause lasting damage to semiconductors. One way to combat these problems is through radiation hardening, but there's more to creating a rad-hard version of a CPU than wrapping it in aluminum.

Together, these conditions combine to create an extremely challenging environment, but one that AI can tackle. Together we will explore these topics during this talk.