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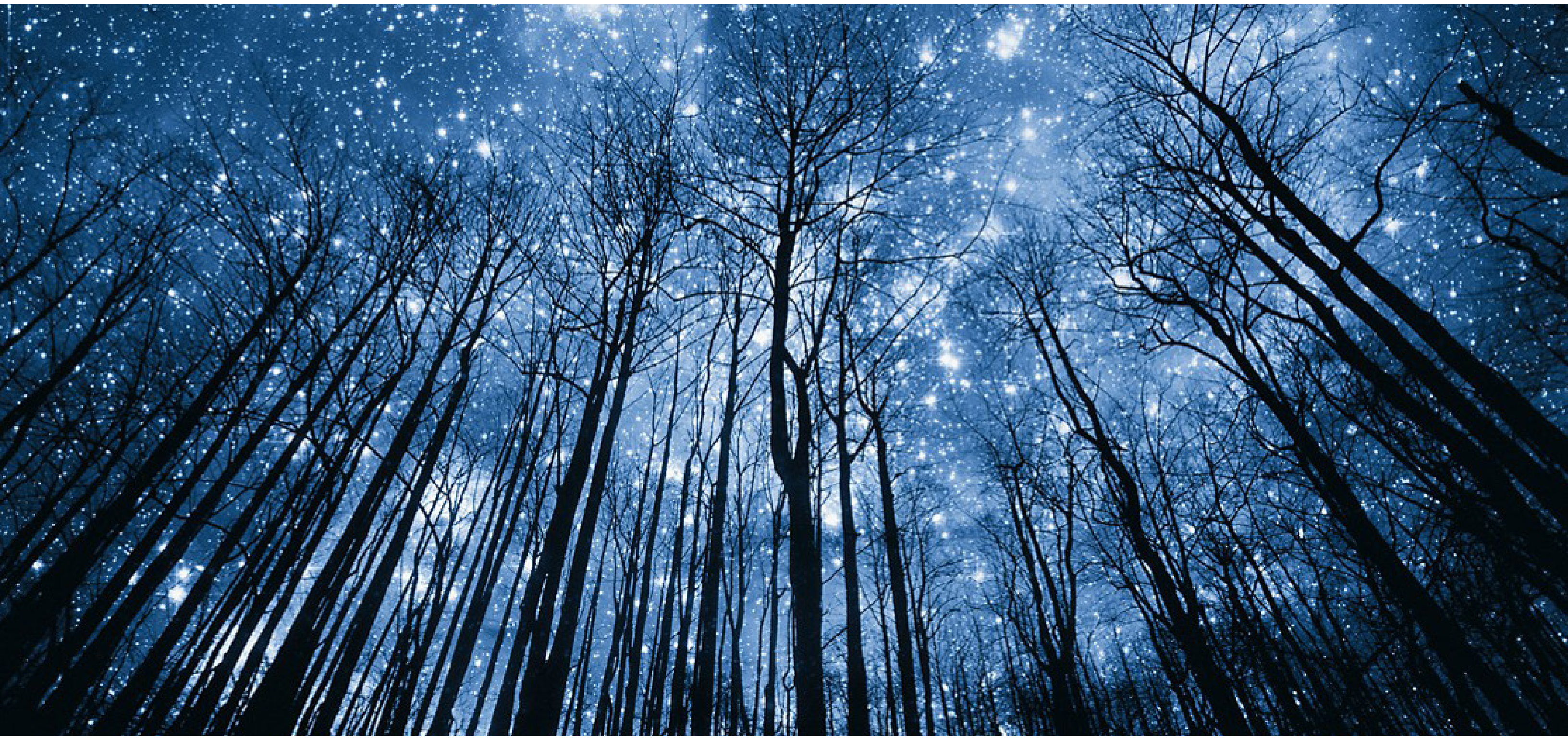

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Knowledge Sharing Article

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Abstract

The fascination with the endless outer space has persisted and been shared by all people. Humans are determined to explore the uncharted, find new planets, test the limits of our knowledge and technology, and then push even further. The innate need to investigate and test the boundaries of what we know and where we have been has benefited our society for years. Human space exploration helps to address crucial questions about the origins of our solar system and our role in the universe. By addressing the issues that are related to human space travel, we improve technology, create new markets, and encourage peaceful ties with other countries. Accepting the challenge of traveling further into space will encourage both the people of today and the generations of tomorrow to continue on this exciting journey.

The state of humanity on Earth is deteriorating year by year. Many ponder why it is necessary to spend so much money on space when there are so many resources that are already under stress due to climate change, economic instability, and viral pandemics. However, space exploration is crucial if we want to maintain that state of a dominant and progressive species. Despite not having evolved for space travel, humans nonetheless venture there. This sparked the creation of numerous technologies that benefit the economy and enhance life on Earth. We would not have GPS, precise weather forecasting, solar cells, or ultraviolet filters in eyeglasses and cameras without space missions.

Technology keeps our modern life moving forward with simple things like setting our alarm clocks for the morning to the ability to do precise surgery hundreds of kilometers distant with a 5G connection. The same is true for space exploration-related technology. Improved solar panels, implantable heart monitors, light-based cancer therapy, cordless tools, lightweight high-temperature alloys, portable water purification systems, international search and rescue systems, and biomedical technologies are among the more extensive list of technological advancements made possible by spaceflight. Also, the scientific studies made possible and accomplished by space exploration projects advance knowledge in numerous research domains. The information gained paves the way for several novel breakthroughs that benefit all of us here on Earth, including the development of innovative new materials, a better understanding of human aging, and the knowledge that is required to support human habitation and employment in deep space. We anticipate additional technical development if space exploration is conducted.

All modern spacecraft contain computers as a necessary component. They are now employed for system administration tasks, data formatting, attitude control, and guiding and navigation tasks like rendezvous, re-entry, and mid-course corrections. Mercury, the first human spaceship, was devoid of a computer, nonetheless. Without general-purpose computers on board, unmanned earth orbital and deep space missions were conducted for fifteen years. However, without computers, the manned shuttles, and the unmanned Galileo spacecraft could not operate. Both carry multiple computers, not just one. Current spacecraft are now more adaptable thanks to this transition. The ability of software to alter the capabilities of the computer in which it sits and the hardware that it commands, leads to increased versatility. It is far less expensive and quicker to use software to account for changes as missions evolve and become more sophisticated than to replace the hardware.

Data is the essence of space exploration, which is used for anything from helping with R&D initiatives to foretelling when vessels re-enter orbit. The supporting systems that manage and analyses the enormous volumes of data that is required for important operations in mission control must constantly be "on."

Most of the computers in outer space, including the control systems for satellites, space stations, and Mars rovers, are decades old. The Intel 80286SX CPUs used by the ISS were created in the late 1980s. Along with tablets and other devices, the ISS also has over a hundred laptops. They serve as remote terminals for computers that control multiplexers and demultiplexers, as well as being used for email, the Internet, and entertainment.

The volume of data that Earth satellites produce is huge. For instance, the Westminster, Colorado-based Maxar Technologies, a provider of space technology, adds more than 80 TB of data daily and has an image library that exceeds 110 petabytes in size. For the planet and other satellite startups, using data center services is crucial. Black holes and radio galaxies are two examples of objects that AI technologies are already employed to detect.

Edge computing, a method that enables sensor data to be processed by computers right where it was collected instead of having to go back to a central server for cataloging and analysis, is presently used in many space initiatives. Gartner predicted that by 2022, half of all data will be created and processed outside of a traditional centralized data center or a cloud network. Edge computing has already made a significant impact in the workplace.

Storage, processing, and movement of data have always been foundational elements in making space exploration successful. This article explores the technical aspects of space exploration starting with the history of computer technology in space programs, followed by the need for advancements in storage systems, servers, and data center technology in the modern age. The involvement of cutting-edge technical concepts such as Artificial Intelligence, Cloud Computing, and Edge Computing will also be discussed. Finally, by exploring the future scope of data center technology in space programs, readers will be able to uncover a new perspective of conducting business as a new vertical altogether. Furthermore, the article will provide insights into how this might be established in the future.

Introduction

Space technology refers to the technology used in outer space, for travel (astronautics), or other operations outside Earth's atmosphere, such as spaceflight, space exploration, and Earth observation. Space vehicles such as spacecraft, satellites, space stations, and orbital launch vehicles are examples of space technology, as are deep-space communication, in-space propulsion, and a broad range of additional technologies such as support infrastructure equipment and processes.

The space environment is so unusual that working in it frequently necessitates the development of new tools and procedures.

Many terrestrial services, such as weather forecasting, remote sensing, satellite navigation systems, satellite broadcasting, and some long-distance communications systems, rely heavily on space infrastructure. Astronomy and Earth science are two of the fields that benefit from space technology. New technologies that emerge from or are propelled by space-related initiatives are frequently used in other economic pursuits.

The fascination with the skies has been widespread and long-lasting. Humans are compelled to explore the unknown, find new planets, test the limits of science and technology, and then push even farther. For millennia, our civilization has benefited from the intangible urge to explore and question the boundaries of what we know and where we have gone.

Human space exploration contributes to the understanding of basic issues about our location in the universe and the history of our solar system. By solving the problems of human space travel, we advance technology, develop new businesses, and contribute to the peaceful coexistence of countries. Curiosity and adventure are essential to the human spirit and accepting the challenge of traveling farther into space will inspire today's citizens and future generations to participate in this thrilling trip.

When you hear the word "space exploration," the first thing that comes to mind is probably satellites. Over the years, space scientists have used satellite capabilities to gather information about what is going on in orbit. Without a doubt, space is a lesser-known topic among the general public.

Furthermore, when it comes to space, there are always a lot of unresolved questions. Satellites are often used to collect data and take images. These images are further analyzed and investigated in order to compile additional useful information.

However, the entire process of taking photographs, transporting them to space research facilities, and refining them takes a long time.

A few human-containing satellites and robots have also been to space. Though the spacecraft is outfitted with cutting-edge technology to retrieve information from orbit, processing and transmission to the audience takes time.

Because time is the most important component in space travel, specialists have begun to consider ways to lessen this time consumption. Datacenter technology has shown to be an effective means of assisting with space exploration.

How Do Computers Work in Space?

Redundancy: Computers in space prioritize redundancy. This implies that if one system fails, another steps in. Because of the 1.5-second communications latency between ground control computers and computers in orbit, systems must be able to function in real-time with minimum input from ground control.

NASA frequently builds three or four backup systems for each onboard computer operation. In the case of a crucial system failure, another system is always available to take over and prevent a crisis.

Distributed Processing: Because early spacecraft could not support the weight of modern computing systems, which might typically weigh hundreds or thousands of pounds, only lightweight computers were mounted onboard. These computers performed sophisticated calculations and returned the findings to ground-based computers. By distributing processing power over numerous systems, spaceships may reduce weight by employing lighter processors.

When it comes to unmanned spacecraft, such as space probes, distributed processing is critical. Missions such as Galileo and Voyager, which would go beyond the solar system, made extensive use of distributed processing systems.

Proven Equipment: Only proven technology is used since computers in space must be fully error-free and work with a high fault tolerance. This helps to explain why NASA was initially hesitant to employ new languages such as FORTRAN on early flights, instead of relying on machine language.

This also explains why contemporary spaceships rely on technology that is manufactured by companies such as Lenovo. Because of its rugged design and tried-and-true technology, the Lenovo ThinkPad is used throughout the space station and on manned space trips. Furthermore, the ThinkPad possesses the military-grade ruggedness that is needed for space flight.

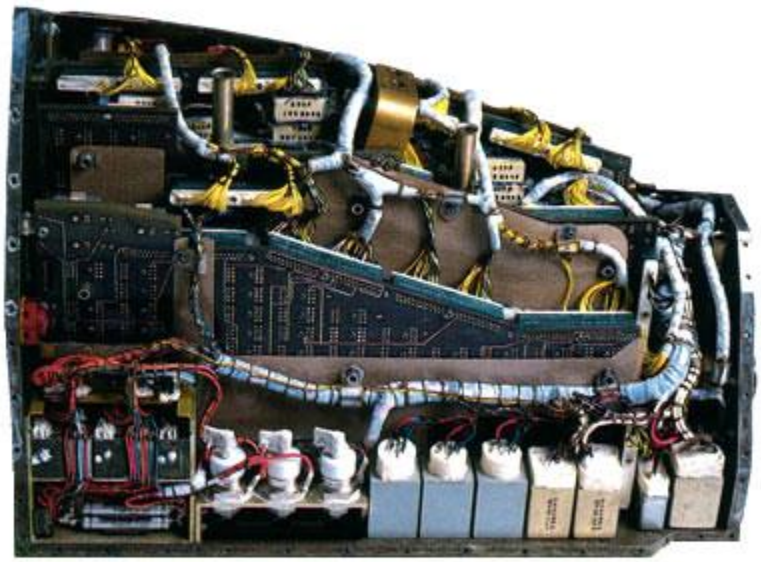
Brief History of Computing Technology in Early Space Missions

Gemini - The First Computer in Space: Following Project Mercury, the United States' first man-in-space attempt, it became evident that having an onboard computer would be critical to the success of future missions. Prelaunch, ascent, rendezvous, and re-entry calculations might be aided by an onboard computer. Furthermore, a computer would offer the astronauts more time to do experiments without having to worry about piloting the ship.

The Gemini mission was the first to include a digital computer on board. The Gemini computer was designed solely for NASA's specifications by none other than IBM. Starting in 1962, IBM put its best engineers on the front lines to construct the Gemini computer, and by 1965, they had completed it.

The Gemini was an engineering wonder at the time, but it lacked the redundancy and fail-safes of subsequent space-bound computers. As a result, it was less than ideal for fully automating space travel, and to compensate, humans on board could step in and take control when the computer made an error.

Using a special kind of memory that is known as "Ferrite Core Memory," the Gemini Computer could store small quantities of data and conduct rudimentary computations. Furthermore, the CPU operated in a serial mode, which meant that it only processed one bit at a time. By today's standards, this is a snail's pace, yet creative engineering has made it incredibly capable.



The Gemini Computer
Image Source

Early Software in Space: In addition to becoming the first vessel to launch a digital computer into space, the Gemini project introduced software advances. IBM's ongoing software development for the Gemini project gave rise to principles that are being employed today. Error detection and integrated diagnostics are already standard in technology, and we can credit Gemini's digital computer for this.

Early software applications were sometimes not fully comprehended. The program development was haphazard and unorganized due to a complete lack of software techniques. Because NASA needed to employ established technology, emerging languages like FORTRAN were discouraged. Although FORTRAN is considered one of the first programming languages, it was in its infancy at the time and could not be trusted by NASA engineers. Machine language, sometimes known as "assembly" language today, was the alternative.

Furthermore, the dependability of early software was a challenge for usage in spacecraft. NASA promptly attempted to improve on this. A magnetic tape drive was the most often used format for loading software packages. Although tape drives were not the most dependable format, NASA improved on the conventional design and deployed its own "hardened" version. NASA tape drives were evaluated for their ability to survive extreme vibration and radiation.

Computers On the Apollo Mission: Early achievements in the Gemini project gave the Apollo project a lead start. The Apollo project, well renowned for sending man to the moon, already had a solid hardware and software base. It was not simple to navigate to the moon. It became evident that NASA's computer equipment needed to be upgraded for the upcoming mission.

The computer onboard the Apollo missions was dubbed the "fourth crew member" because it played an important role in spacecraft navigation. NASA commissioned MIT to develop the technology in order to create the most durable system. MIT formally began developing the computer systems for the Apollo mission in 1961.

The mission's hardware and software development was fraught with failures and problems. Because needs were continually changing, each Apollo mission from 1961 to the Moon Landing in 1969 employed a more powerful system than the previous one. The onboard computers from the first missions were unrecognizable by the time the iconic Apollo 11 mission arrived.

In addition, the onboard computers performed various functions. The Apollo computer made excellent use of relatively poor hardware, with 4K of RAM and 32 K of storage space. Although computers nowadays are far more powerful, the Apollo computer could perform a range of tasks despite its restricted hardware. Even more astounding is the fact that the onboard computer operated the Saturn booster, aiming, altitude control, autopilot, and all velocity change controls with minimal human input.

Apollo Guidance Computer
Image Source

Today's Computers in Space

Computers are becoming more important than ever in space exploration. In the future, the primary focus will be on developing more economical computers capable of doing more sophisticated calculations. Historically, developing spaceship computer systems has been expensive. Reduced development and operating costs are critical to assuring continuing progress in space exploration.

Companies such as SpaceX and Blue Origin are capitalizing on NASA engineers' decades of study. Aside from lowering costs and enhancing computing efficiency, computers can assist humans in a few essential areas.

Satellites: Satellite technology is one area where space computers are advancing. Communication satellites have been in operation for decades, but with developments in satellite technology, their full potential is now becoming a reality.

Supercomputers on Earth can employ satellites to expand our understanding of our planet by leveraging developments in artificial intelligence and machine learning. Satellites can help with mineral deposit exploitation, agricultural development, and disaster relief. Satellites also aid in the collection of meteorological and climate data for study and simulation.

Telescopes: In the 1970s, telescopes were launched into space for the first time to examine our universe. These telescopes could not maneuver, interpret photos, or communicate with ground control without computers.

The onboard computer of many space telescopes functions similarly to that of any unmanned spacecraft, with a few notable exceptions. Telescopes have additional software for calibrating the mirror and image-processing gear. Furthermore, the onboard computers save photographs and send them back to Earth.

Planetary Rovers: Rovers have been used by planetary scientists to examine the moon and planets since the early lunar missions. Rovers are remote-controlled robots with numerous onboard computer systems that assist the rover in operating autonomously.

In 2012, the Curiosity Rover studied the surface of Mars with the assistance of a specifically constructed onboard computer: the PowerPC RAD750 CPU. It is far slower than a regular desktop PC. This computer, on the other hand, can resist the intense heat and radiation present on Mars' surface. Future planetary rovers will be more powerful.

The ambition to inhabit Mars is driving the future. Companies like SpaceX, led by Elon Musk, are at the forefront of Mars colonization efforts. If history is any guide, we may anticipate computers to play a critical part in human expansion into the universe.

Now More Than Ever, Space Exploration Is Critical

Mankind has been confronted with difficulties since its inception. Humans have had to devise answers to everyday challenges throughout history. These are the pillars that have enabled individuals to broaden their perspectives. Curiosity is the seed that grows into all sciences; without it, there would be no biology, medicine, chemistry, physics, or any other discipline of study. We would be locked in the Stone Age if it did not exist. Humanity is at the pinnacle of technological achievement, but the search does not and must not end there. Humans have an innate desire to explore the unknown. Exploration of the cosmos beyond our planet is the pinnacle of human curiosity, making it the most difficult undertaking humanity has ever faced.

This marks the start of a new age in space exploration, with space exploration groups that are pushed to create the systems and skills that are needed to explore beyond low-Earth orbit, including destinations such as translunar space, near-Earth asteroids, and, eventually, Mars.

The International Space Station is used as a testing ground and stepping stone for organizations as they embark on the difficult trip ahead. We prepare astronauts for the rigors of long-duration flight and the permanent expansion of human exploration beyond where we have gone before by building on what we learn there. Near-Earth asteroids may be visited by explorers, providing answers to questions that humanity has long had. Visiting an asteroid will give vital mission experience and will prepare us for the following stages, which might include being the first people to set foot on Mars.

Robotic exploration continues to provide fundamental insights about our Universe by traveling to remote locations, conducting reconnaissance, and gathering scientific data. We will employ technology and our senses to improve our capacity to observe, adapt, and discover new information by merging human and robotic exploration approaches.

Year each year, humanity's plight on Earth worsens. Why invest all this money on space when climate change, economic uncertainty, and viral pandemics are straining the world's resources? It is simple to see why this argument arises: there are significant issues to be solved on Earth, and flying to space is prohibitively expensive. This oversimplification misses the character of mankind, the desire that has propelled us to the top of the food chain. Space exploration is critical if we are to remain that way. Here are several compelling reasons why we should be up there.

New Technologies and Research: Humans did not develop to travel to space, but we do it nonetheless. As a result, several technologies that feed back into the economy and improve our lives on Earth have been developed. Without space missions, we would not have GPS, accurate weather forecasting, solar cells, or UV filters in sunglasses and cameras. There is also medical research going on in space right now that might heal illnesses and extend human lives, which cannot be done on Earth. Space exploration has the potential to save your life.

Nitinol, a flexible yet robust alloy that was created to allow satellites to spring open after being packed inside a rocket, is another less well-known but useful breakthrough. Orthodontists now provide patients with braces composed of the material.

Asteroids Do not Care About Us: Speaking of saving lives, space exploration has the potential to save all of ours. The solar system has settled down since the early eons, but there are still an unknown number of large asteroids and comets out there that may collide with Earth and make the COVID-19 epidemic look like a distant memory. The question is not whether another massive asteroid will strike Earth, but when. A strong space program is our sole hope of deflecting such an asteroid. If we do not work toward that aim, mankind will become extinct. NASA is now planning to launch a spacecraft into an asteroid to test one technique of protecting Earth from such a collision.

If we do not want to end up like the dinosaurs, we must protect ourselves against being hit by a large asteroid. According to NASA, a stony or iron asteroid the size of a football field may collide with our planet's surface once every 10,000 years, perhaps causing tidal waves large enough to inundate coastal areas.

But it is the true monsters, asteroids 100 meters (328 feet) or larger, that we should be concerned about. Such a collision would create a firestorm of hot debris and flood the sky with sun-blocking dust, wiping out forests and farm fields and starving any human or animal life that survived.

That is why it is critical to devise a method to neutralize such a danger to Earth. NASA's Double Asteroid Redirection Test, which is scheduled to launch in late September 2022, will be the first mission to test asteroid deflection using kinetic impactor technology. In order to demonstrate that it is feasible to slightly modify the route of an asteroid, a robotic spacecraft will be smashed into the binary asteroid system Didymos. This would allow NASA to divert possible dangers away from Earth.

Colonization Is the Ultimate Backup: There are presently about eight billion people on Earth, which is a large number. On this planet we are all packed together. If something occurred to Earth, our species may go extinct. Consider the previously mentioned asteroid strike. Colonizing other worlds in the solar system (or constructing our own orbital colonies) is a method of creating a "backup" of mankind that will endure whatever happens to Earth. Future people will be Martians who will never visit Earth. The technology to enable this and maintain humans independently of Earth will not evolve on its own.

Already, our capacity to launch satellites into orbit is assisting us in monitoring and combating urgent issues on Earth. Some examples are forest fires and oil spills, as well as the depletion of aquifers on which people rely for drinking water.

However, our growing population, excessive greed, and disregard for environmental implications have already caused significant damage to our world. According to a 2012 poll, most experts believe that the Earth's carrying capacity is between 8 and 16 billion people - we now have a population of about 8 billion. As a result, some futurists say that humanity should be planning to colonies another planet soon. It might be the difference between your life and the lives of your descendants.

Space Mining Could Save the World: As the world's population continues to rise inexorably, so does the burden on our natural resources. The mining of rich minerals has caused a slew of issues, including environmental devastation and human exploitation, yet there is an abundance of precious elements in space. Startups like AstroForge plan to mine asteroids instead of Earth, which would provide a limitless supply of rare raw minerals.

There is gold in the universe, as well as silver, platinum, and other precious elements. A private-sector initiative that anticipates mining operations on asteroids has received a lot of attention, but space miners would not have to go that far to obtain riches.

The moon, for example, is a potentially profitable supply of helium-3, which is used in some MRIs and might be used as a fuel source for nuclear power reactors. The moon is also thought to be a possible source of rare earth elements like europium and tantalum, which are in great demand for usage in electronics, solar panels, and other cutting-edge technology.

It Will Be Good for Your Health: The International Space Station alone has produced a slew of medical innovations with practical applications on Earth. Some unique applications are, a method for delivering cancer-fighting medication directly to tumors, ultrasound equipment that a nurse can hold and transmit the results to a doctor thousands of miles away, and a robotic arm that can perform delicate surgery inside an MRI machine.

NASA scientists assisted a pharmaceutical firm in testing Prolia, a medicine that now helps prevent older people from osteoporosis, to keep astronauts from losing bone and muscle in the weightless environment of space. Although mice and humans do not have identical physiology or biology, it made sense to test this drug on mice in space. This is because astronauts lose around 1.5 percent of their bone mineral density each month in microgravity, which corresponds to an elderly woman on Earth losing 1.5 percent of her bone density due to osteoporosis.

Nations Can Work Together Peacefully: We already discussed the grim prospect of international combat in space. However, as proven by the collaboration of various nations on the International Space Station, this does not have to be the case. A US space program might also encourage other countries, great and small, to participate in their exploration endeavors.

NASA published a report in 2018 highlighting the benefits of international cooperation. For one thing, the high expenditures may be shared. For another, it might assist strengthening diplomatic connections between countries such as the United States and India, and create employment in both countries.

When flights to the moon restart in the 2020s, NASA will give the first contracts to four businesses to gather modest amounts of lunar regolith, the loose rock, and dust that rests above the surface. It might be the initial step toward lunar raw material mining. Space resources will be the fuel that propels America and humanity to the stars.

It Could Help Answer a Really Big Question: According to a 2021 Pew Research Center study, over two-thirds of Americans (about 65 percent) think intelligent life exists on other worlds. The general people do not consider UFOs to be a big threat to the country. When questioned about UFOs and national security, 51 percent of Americans feel they pose no harm, while 36 percent believe they pose a moderate concern.

However, thus far, sweeps of the sky using Earth-based telescopes for signals that may represent beacons from extraterrestrial civilizations have been unproductive, possibly due to interference from the Earth's atmosphere. That is why alien civilization hunters are eager for the deployment of more orbital observatories like the James Webb Space Telescope. This satellite, which will be launched on Christmas Day 2021, will be able to look for chemical evidence of life in the atmospheres of distant planets outside our solar system. That is a start, but a more active space-based search for alien evidence might finally help us answer the issue of whether we have company out there.

Space Exploration Is Inspirational: If we want our children to want to be great scientists and engineers rather than reality show presenters, rappers, or Wall Street financial tycoons, we need a great enterprise to attract and inspire them.

Neil deGrasse Tyson, an astronomer, author, and lecturer, remarked on National Public Radio in 2012, "'Who wants to be an aeronautical engineer so you can build an airplane that is 20% more fuel-efficient than the one your parents flew?' I could ask eighth-graders. That generally does not work. But if I ask, 'Who wants to be an aeronautical engineer to build the plane that will fly through Mars' rarefied atmosphere?' I get the greatest pupils in the class." This is still true, and motivating children will always be critical to future space exploration.

It is Important for National Security: The United States must identify and prevent hostile nations or terrorist organizations from launching space-based weapons or targeting its navigation, communications, and surveillance satellites. While it and other big countries such as Russia and China are parties to a 1967 convention that prohibits governments from claiming territory in space, it is not difficult to think of earlier accords that were ignored when someone perceived a profit in doing so.

Even if the United States privatize most of the space exploration, it still wants to assure that firms may harvest the moon or asteroids without fear of being usurped or having their products that are stolen. That is why it is critical to support diplomacy with a NASA space faring capability that can be turned to military use if necessary. In 2019, Congress enacted legislation with bipartisan support to establish the United States Space Force, a new branch of the United States armed forces focused on preserving the country's interests in space.

We Are Explorers: There are many practical reasons for space exploration, but one of the most important is that we are explorers. That is why humans number in the billions – we have strived to understand more about the world around us since our first upright steps, and this has allowed us to establish a planet-spanning civilization. Exploring space provides an opportunity not only to explore new worlds and develop sophisticated technology, but also to collaborate on a greater purpose regardless of nationality, ethnicity, or gender. We cease to be human when we cease to explore.

Our forefathers moved from East Africa to the rest of the world, and we have never stopped migrating since. We are running out of new territory on Earth, so the only way to satisfy this primordial yearning is to find somewhere new to go - whether that is taking quick trips to the moon as tourists or signing up for a multigenerational interplanetary adventure.

Former NASA administrator Michael Griffin distinguished between "acceptable reasons" and "genuine reasons" for space exploration in a speech to the Bay Area Houston Economic Partnership. Reasons such as economic gain and national security would be acceptable. However, genuine causes include themes like curiosity, competition, and monument-building.

"Who among us has not experienced the wonder, mystery, amazement, and enchantment of witnessing something that has never been seen before, even on TV, an experience delivered back to us by a robotic space mission?" Griffin went on to say that "when we do things for true reasons rather than acceptable ones, we attain our finest successes."

How Technology Is Facilitating Space Exploration

When Neil Armstrong first set foot on the moon in 1969 and said the now-famous words -"One small step for man, one giant leap for mankind" - He rightly foresaw the significance of space flight. The race to discover, map, and conquer continues to attract and excite people of all ages. But, since the 1960s, contemporary space flight has gone a long way. NASA has stated that its first journey to the sun will launch by the end of 2018, and private investors are eager to sponsor commercial human expeditions to Mars.

The space industry is a hive of activity. We may now travel deeper into the galaxy to explore undiscovered regions and possibly discover new phenomena, thanks to enormous advances in technology. With increased investment in government space projects and the rise of sustainable private space flight, our hopes and achievements are beginning to exceed what we saw in movies.

So, what enables these fresh discoveries and accomplishments?

Data is at the core of space flight, which is utilized for everything from research and development to predicting when vessels will re-enter orbit. Vast volumes of data are essential for important tasks in mission control, thus the supporting systems that look after and process this information must constantly be "on."

The amazing technical breakthrough that helped put the first American in space decades ago was IBM's 7090 mainframe computer, but today's supercomputers are even more important for processing data and moving space exploration forward. Supercomputers are a critical component of IT systems that enable current space initiatives to go above and beyond, from NASA to the ESA (and all the commercial efforts in between).

Supercomputing systems, which take up miles of physical space, are capable of processing massive quantities of data in a millisecond, guaranteeing scientists get the knowledge that they need, when they need it. This information is frequently time-critical and must be delivered in near-real time from rockets and space stations hundreds of kilometers away to scientists, engineers, and mathematicians, and vice versa. Finally, such powerful devices, which are filled with cutting-edge storage technology, assure the safety and security of space shuttles and their passengers. As the need for technology that aid in space exploration grows, data must be prioritized and placed at the center of design and development.

Artificial intelligence (AI) is already widely employed by individuals at the forefront of research and technology in various space enterprises. A NASA AI software detected a new planet 2545 light-years from Earth using only data from the Kepler Space Telescope.

Kepler-90i, a hot and rocky planet, was identified using machine learning technologies that trained to detect planets by analyzing recorded signals from exoplanets, or planets outside our solar system. One of the most significant advantages of machine learning in space research is that programs can filter through accessible data more quickly than people, increasing the likelihood of discovering planets just by looking at datasets.

It is even speculated that AI might aid in the discovery of extraterrestrial life. Rovers can resist the severe circumstances of the solar system - employing AI, the rovers can explore cold rivers and scorching caverns, withstanding more unfavorable conditions than a person could.

The Mars 2020 mission will also be AI-driven: the rovers that explore the planet can drive independently and even self-prioritize their to-do lists to ensure they are maximizing their proficiency. The rovers' systems will also employ AI to run tests to guarantee no information is overlooked while they study and explore Mars. Although scientists must supervise the rovers, AI allows engineers to step back and let the machines acquire and evaluate data on their own, without requiring too much human intervention.

Without computers, space flight would be impossible. Furthermore, advances in computing technology and the space race have traditionally gone hand in hand, with one discipline boosting the success of the other. But how did we go from gigantic mainframe computers in the 1950s and 1960s to the little computers we currently have in space? At the time of NASA's inception, the most prevalent computer was the UNIVAC, a massive piece of equipment that required a team of people to maintain. We progressed from room-sized computers like the UNIVAC to single microscopic computers in a matter of decades.

Computers are increasingly essential for all types of spacecraft. Computers play an important part in system administration, data formatting, and altitude control in both manned and unmanned flights. Computers also perform essential system operations like navigation and mid-course adjustments. Let us look at how we got from earth-bound computers like the UNIVAC to the computers we have today in space.

As investment in new technologies and artificial intelligence develops, so will our ability to explore more of our solar system. Technology adoption has grown by leaps and bounds. Whereas there used to be stages such as early adopters or laggards, those designations no longer exist in the same sense. Technology is not only being adopted at a quicker rate, but it is also being broadly accepted sooner. As a result of the fast development and adoption of technology, the period between key space milestones like as the moon landing, the first space station, or the voyager mission will only shorten. If technological advancement continues at its current rate, it is not unreasonable to believe that humans will soon be living among the stars rather than staring up at them.

Challenges for Computing Systems in Space

When it comes to computers in space, there are various challenges that cause them to behave differently. While computers on Earth can function with the user sitting in front of them, controlling everything and instructing the program, computers in space are not the same. The difficulty with computers in space is that people cannot constantly be there to write instructions or control software.

Furthermore, computers in space must work in "real-time" rather than "batch" mode. While our terrestrial computers normally analyze data in blocks or batches as it is loaded into memory, space computers cannot. Batch processing would be disastrous in sophisticated computing situations such as landing a space shuttle or altering course mid-flight. The situation may have altered dramatically by the time a batch of information is aggregated and processed. As a result, real-time processing is extremely important.

Because the user may not always be able to operate the computer onboard a spaceship, the hardware and software must be "failure-proof." A computer malfunction aboard a manned spaceship might be disastrous. Engineers at NASA work around this by creating as many duplicate systems as feasible. In other words, if one system fails, another replaces it.

High-performance, low-cost, programmable computer systems are essentially a commodity on Earth. However, space presents a new set of environmental difficulties for computer systems:

- **Radiation**. Electronics in space require resilience since they are sensitive to radiation, which can cause operational problems.
- **Extreme temperatures** are a fundamental constraint on both architecture and materials.
- **Maintenance** is nearly impossible since electronic parts must meet stringent standards for robustness, redundancy, and longevity.

And now comes the hard part. The smaller the electronics and the more fragile it is to the hostile space environment, the more advanced your computer requires. On one side, there are providers of radiation-resistant, programmable, Earth-grade integrated computers.

Areas in Space Technology to Keep an Eye On

New sectors, services, and use cases emerge from Internet services, IoT, image processing, and big data analysis. There are other prospects for those interested in space tourism or mining. There are three major areas to focus on:

- Downstream Data (AI, Big Data, Machine Learning/Deep Learning)
- Space Computing (Storage, Cyber, Cloud, Telecommunication, and so on)
- Life-supporting systems (Agritech, Biomed, Energy, Complex Materials)

AI is one of the most widely used terms in space technology as it has immense capability to play a critical role in various fields, including in-orbit management, system manufacture, and application value addition. Earth Observation (EO), for example, is a traditional—if not the most classic—use of satellite deployments; images that are captured from above may be used for various purposes, ranging from studying the consequences of natural catastrophes to espionage. AI in space opens a new chapter in EO by introducing scale, automated image labeling, and map correlations—all of which may be used to create new applications, such as assessing the economic health of a third-world country.

The Role of Artificial Intelligence in Space Exploration

Artificial intelligence is already making our lives easier on Earth, but what about beyond our planet's borders? Is AI useful for space missions and space exploration in general? Many firms, like NASA and Google, have already deployed AI to hunt for new celestial bodies, life on other planets, and even to streamline astronauts' tasks in space. Let us look at the artificial intelligence technology that is helping space exploration.

Personal Assistants in Space: Fans of the film Interstellar may recall robot aides Tars and Case assisting Joseph Cooper (played by Matthew McCauneghey) and his team of researchers that are entrusted with discovering life on other planets. CIMON, or Crew Interactive Mobile Companion, was developed by IBM in collaboration with the German space agency DLR and Airbus. CIMON is a spherical artificial intelligence (AI) robot that can communicate with humans on the International Space Station. There are several applications for such technology. When astronauts embark on a long-duration mission, they face communication delays that prohibit mission control from providing timely assistance in the event of an emergency or in day-to-day mission-related duties.

CIMON aids in removing these obstacles by serving as a personal assistant and locating all the information for the astronauts more quickly. Assume that an astronaut is working on a project at the International Space Station and has a question about it. This would require them to stop what they are doing, float over to a laptop, find the information, and then return to the experiment station. By finding this information for the astronauts, CIMON removes all this labor. Just like you would ask Siri or Alexa a question and they would respond, CIMON will do the same.

In addition to understanding human speech, CIRI has facial recognition technology, which enables more intimate contact. Human data annotators are needed to put critical points along training dataset photos so that the algorithm can recognize all the aspects of human faces. Furthermore, because CIRI can move about through twelve internal fans, CIMON may move and spin freely in all directions. This is accomplished using LiDAR technology, which allows the robot to recognize its surroundings and necessitates some data annotation.

Processing Satellite Images: The amount of data that is generated by Earth satellites is massive. Maxar Technologies, a space technology business that is located in Westminster, Colorado, for example, has over 110 petabytes of picture storage and adds more than 80 TB of data every day. Using data center services is critical for planet and other satellite firms. AI technology is already being used to detect black holes and radio galaxies. AI algorithms are being used to examine data from the Gaia satellite observatory in order to locate new stars that may help explain the formation of our galaxy. Prior to the application of AI and machine learning tools to analyze data, astronomers could only identify roughly 100 stars. This number has been raised to 2,000 protostars as a result of improved AI technologies.

Spatial telescopes provide a large number of photographs of the Earth, which are important for gathering meteorological information, creating up-to-date online maps, and other data. Our planet's satellite imaging alone has an infinite number of applications for artificial intelligence. Without AI algorithms, individuals would have to process data on their own, which would result in less reliable information. Furthermore, in order to receive data within a fixed institution, continuous communication with the satellite is required, which is nearly impossible owing to the continual movement of the equipment in orbit. The direct usage of artificial intelligence on board the satellite eliminates the need for further communication between ground and space stations.

The value of machine learning algorithms rests in their capacity to analyze millions of photos in a matter of seconds, noting any changes in the movement of atmospheric fronts, for example. Furthermore, unlike humans, artificial intelligence does not require rest and is not prone to errors caused by a lack of attention and attentiveness. This is crucial when after natural disasters. By using AI to automate different operations, the satellite begins collecting photographs on its own if the sensors detect specific signals, such as important variations in pressure or temperature of air streams. Furthermore, such satellites may be used as part of catastrophe warning systems, as AI algorithms can calculate the possibility of an event and its course of development and repercussions.

The Role of AI in the Development of Satellites and Spacecraft: Satellites and spacecraft are tough to build. Many repeated activities requiring great accuracy are involved in the manufacturing process. Furthermore, the majority of them should be carried out in isolated rooms to minimize potential contamination of future equipment elements by microscopic living forms. Many, according to NASA, can survive in spotless environments, on cleaning chemicals, and even in space. Biological contamination on the Moon, Mars, and other celestial worlds can skew alien life study results.

As a result, firms have lately begun adopting systems based on artificial intelligence algorithms to limit touch with people when manufacturing spaceships. Artificial intelligence may drastically speed up production processes while also minimizing the possibility of biological contamination. Furthermore, AI systems review the performance of operations regularly, the findings of which aid in the optimization of various processes. Eliminating the human component is also vital for increasing manufacturing output. On assembly lines, collaborative robots, or "cobots," take over the most time-consuming and error-prone processes.

Conducting System Monitoring: Satellites and spacecraft, like any other complex system, need extensive system monitoring. The list of potential issues ranges from the most expected to the most implausible, from small faults to collisions with other objects in orbit. Scientists employ AI systems that continually examine the functioning of various sensors to check the status of artificial satellites. Such systems cannot only alert ground control of difficulties, but also address them on its own. SpaceX, for example, has outfitted their satellites with a system of sensors and motors that can detect the device's position and alter it to prevent accidents with other objects.

Spacecraft, probes, and even rovers are using artificial intelligence to navigate. Experts say the technology used to manage these gadgets is similar to the systems that assure autonomous car movement. Outside of our globe, artificial intelligence tracks many factors by combining data from a network of sensors and maps.

The High Demand for AI Products Has Increased Demand for Data Annotation: While training datasets are required for all AI technologies, computers cannot learn from raw data in its original form. As a result, raw datasets must be prepared using various data annotation approaches. Because this is a time-consuming procedure, firms developing AI products frequently outsource this work to third-party service providers, such as Mindy Support, who can annotate millions of photos and videos.

Finding all the data annotators required to do all of the job is one of the obstacles that firms face. There should also be some form of quality assurance method in place to verify that all work is completed accurately and on schedule. We must also keep in mind that data annotators require training in terms of what they must perform and how to use certain tools. One of the perks of engaging such service providers is that the firm providing data annotation services will usually be able to handle these issues.

How Datacenter Level Technologies Help Space Exploration

Computers play an important role in data collecting, management, and maintenance. Without them, storing the massive quantity of study data we have accumulated would take years. As a result, scientists can keep up to speed on knowledge. Data may also be sorted and patterns discovered by computers on their own.

Research data is so broad and massive that manual storage would take years. Computers are essential in the compilation, storage, and dissemination of this information. Computers successfully collect, organize, and retain this technological knowledge, allowing scientists to keep up to date and obtain real-time information all around the world. Different astronomical phenomena, such as black holes, quasars, and even sunspots, have distinct signals and patterns. Computers filter and sort data about these patterns on their own, making the task of space explorers easier.

"New space," which refers to the recent privatization and commercialization of the Space sector, is not a normal market evolution—it is a significant disruption to the multibillion-dollar Space business.

National governments' monopoly on space is no longer valid. Over the previous decade, and particularly in the last four years, space has grown more accessible, private, and entrepreneurial than ever before. With private players playing an increasingly crucial role in providing a new generation of creative, cost-effective solutions throughout the whole launch vehicle, payload, and launch infrastructure system—simplicity, dependability, and dramatically reduced prices are the new requirements.

New Space, New Computing Needs: Big Data is altering the game in space, just as it is in many other areas. We should turn to the stars once we have exhausted our Big Data sources on Earth. As the complexity of missions and data usages grows, so do computer requirements. These necessitate high-performance, low-power, cost-effective solutions.

Machine Learning skills running on the Edge are now necessary since whole datasets cannot be sent to Earth; software-defined capabilities allowing for the reconfiguration of an already-in-orbit satellite are also becoming essential. Consider this: the typical Geostationary Earth Orbit (GEO) satellite has a lifetime of 15 years. However, operators seldom have long-term business cases. As a result, the ability to modify a satellite's mission remotely and economically - to maneuver it into a different position or even replace its functioning—is becoming increasingly important. New computational capabilities enable these developments in satellite services.

Why cloud and edge are launching the next space race: New data transmission and computation methods are having an influence both on and off the planet.

For millennia, the vast black expanses of outer space have aroused the minds of poets and philosophers—but they may be a nightmare when attempting to put up a trustworthy communications system.

Even at the speed of light, a radio signal from Mars can take up to 24 minutes to reach Earth. Two-way communication (message and response) might take an hour.

That is why cloud and edge computing, which have been reshaping the commercial sector by reducing communication delays, will be equally vital for the further exploration and exploitation of space. If we can improve communication with our far-flung space explorers, we can learn and discover more quickly.

The ascent of cloud and edge to the exosphere is part of a bigger trend discussed earlier this week by Industrious. For decades, space program discoveries have helped accelerate corporate innovation throughout the world. Nevertheless, rocket scientists and astronauts are just as likely to turn to the business sector for the newest and best tools to push the boundaries of their profession.

Many space initiatives are now using edge computing, a method that allows sensor data to be processed by computers at the same location where it was acquired, rather than going back to a central server for cataloging and analysis. Gartner predicts that by 2022, 50% of all data will be produced and handled outside of a typical centralized data center or a cloud network.

The Impact of Edge Computing on Space Exploration

To live in the hostile space environment and make long-term adventures a reality, we need computing.

Today's digital computers have proven crucial in assisting humans in achieving their goals both on and off the planet. Their significant effect has not only enhanced practically all elements of life on Earth, but has also influenced nearly every advancement in space technology, including space mechanics, mission control, spacecraft design, and data provided by spacecraft. It is no wonder that the advancement of computer technology coincides with the expansion of space technological advancements.

We need computing to survive in space and to make long-term adventures a reality. However, one big concern is that transporting and transmitting data back to Earth takes too long. Fortunately, advances in edge and cloud computing are transforming our abilities to investigate and maintain these distant space missions.

Orbiting on the edge: Edge computing can save both time and energy in space-based systems. Because energy is more valuable in space than on Earth, reducing transmissions, whether to transfer information or perform calculations, can be critical. Critical data may be evaluated in hours rather than days using edge.

Sensor-equipped swarms of nanosatellites, such as ChipSats and CubeSats, can, for example, employ edge systems to analyze data in low-Earth orbit without activating the satellite's power-hungry radio. These satellite swarms, which fly 250 to 370 miles above the Earth's surface, may be grouped and structured to assist critical tasks such as weather research, climate science, national security, and disaster response.

On the International Space Station, the in-flight research laboratory meant to help us better grasp what it is like to live and operate in space, edge computing has enormous promise. To speed up data processing for researchers, the ISS may gather and analyze data from its numerous sensors instead of transmitting it down to Earth.

Edge devices are becoming increasingly relevant and popular in terrestrial organizations for the same reason. An autonomous automobile, for example, could be involved in an accident if it had to wait for its complicated analysis of traffic and geographical data to be processed in the cloud or on a server. And, unlike in space, server signals take milliseconds to relay rather than minutes, hours, or days.

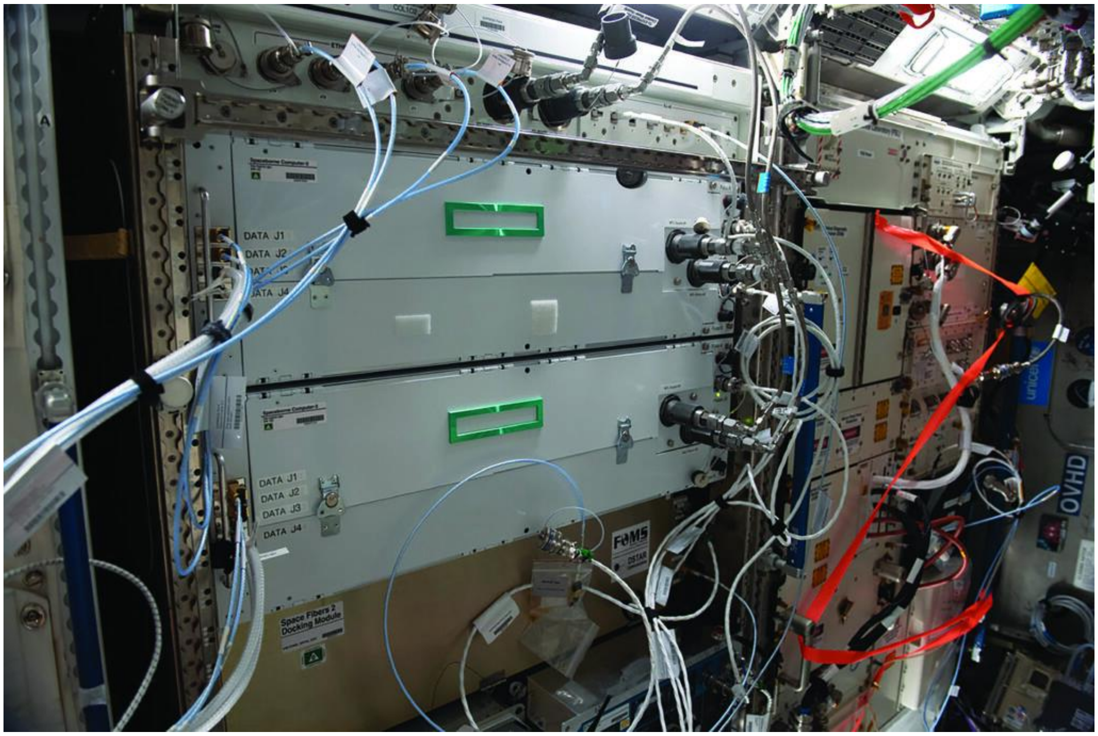
Space research and commerce are extreme examples of why edge computing is so important—enabling operational resilience, real-time decision making, and lowering data transmission costs. Edge computing enables space exploration, but more crucially, it unlocks the potential value of space.

Edge and Cloud Computing Harmony: Edge computing, a computing paradigm that moves processing and data storage closer to data sources, has the potential to save time and money. Cloud computing, which employs Internet networks of remote sensors to store, manage, and analyze data, provides on-demand access of computer system resources without the user's direct administration.

In layman's words, these computer technologies allow us to get quick access to data, which gives more knowledge, and they help us conduct space exploration more effectively by speeding up communication.

Microsoft Azure Space, in collaboration with Hewlett Packard, tested with edge and cloud computing in August 2021 to improve working procedures aboard the International Space Station to the Azure ground station and the National Institute of Health's database. The idea was to examine and process astronauts' DNA more quickly while they were in space. The experiment was a success thanks to HPE's Spaceborne Computer 2, which employs edge computing and AI processing.

While this rapid data flow keeps everyone on Earth informed, the benefits of space exploration extend well beyond productive and efficient communication. The following are a few ways that contemporary computing affects space travel and will increase our prospects of surviving in deep space.



Spaceborne Computer-2
Image Source

Research and Monitoring: Improved data processing and communication techniques have the potential to construct more productive research facilities among the stars. Ground control and spacecraft can collaborate through improved communication and share insights that provide real-time solutions. A speedier data transport can also allow for improved monitoring of the Earth. Real-time data monitoring allows astronauts to relay more specific findings of any natural catastrophes or phenomena they observe from Earth.

Such edge computing skills will help speed up research on domestic issues ranging from pandemics to climate change. Indeed, many anticipate that space will spur a slew of new technological advances, including 3D printers, onboard supercomputers, tiny satellites, servers designed for severe space conditions, and even GPS systems for space navigation.

Astronaut Healthcare: Although space flight is profound, it has a negative influence on the human body. The further astronauts fly from Earth, the more self-sufficient they must be. That implies that computer systems will have to analyze massive volumes of data locally, at the edge, in order to respond to requests and solve issues rapidly.

Among the various health concerns astronauts may confront are bone density loss and genetic alterations. Data-tech developments can assist with the discovery of health risks and solutions more quickly. It will be critical for astronaut health and longevity as we develop technologies that allow humans to dwell on Mars. Even better, biometric data that is processed by in-space computer systems may be used to track and monitor astronauts' health while in orbit or on deep space adventures.

Space Agriculture: In other ways, computing can support life in space. Data can help enhance the technique of growing food in zero gravity, which has been a difficult task for scientists. Nonetheless, its achievement would result in better meals for astronauts and fewer supplies and other baggage that is required for each mission.

NASA and other space specialists' research illustrates how artificial oxygen, more consistent temperatures and lighting, and the collecting and analysis of plant data might help people overcome the issues of food poverty in space. Astronauts may now eat fresh vegetables in space, such as lettuce. Agriculture systems may also supply natural air and water filtering for the spaceship system.

Spaceship Design: Space computing and its data can help improve combustion, water purification, and engineering breakthroughs. All the data that is gathered is continually used to create safer, cheaper, and more efficient spacecraft. The space industry would not comprehend how rockets land back on Earth or how satellite photography works without this stream of data that produces breakthroughs. The more data that we collect, the more specialists can enhance the space flight experience.

NASA's High Performing Spaceflight Computing project (HPSC) is now addressing how computing is wasteful in that its technology must be tailored around the stretch of the mission that demands the most power. While this aims for overall mission success, it results in wasteful use of resources during the operation. This project is working on technologies to increase the processing capability of spaceflight computers by a factor of 100. Operating software will be packaged with newly developed computing hardware having numerous processing cores.

Next-Generation Computing: Next-generation data computation for space travel is still in the works, so there is more possibility for innovation—especially as we concentrate more on flying around our galaxy.

Even with advancements on the horizon, astronauts' quality of life and work has substantially improved from the early days of exploration. We are creating the groundwork for computing, and it is a stepping stone that will help us stay informed, motivated, and involved in developing a stronger new-space environment so that we may thrive in the ultimate frontier.

Why Cloud Computing Is Crucial for Space Exploration

Cloud computing and technology have enormous promise in India and throughout the world today. A new analysis predicts that the worldwide cloud computing industry would expand from USD 371.4 billion in 2020 to USD 832.1 billion by 2025. Cloud computing has emerged as the favored alternative for expanding corporate infrastructure and even launching new ideas - concepts that have practically transcended time and place.

Cloud computing is being examined for improvement in space technology as it continues to evolve.

Cloud computing is a crucial tool that helps us comprehend and analyze data in real-time through video footage and satellite photos. This is especially important now that humans are beginning to make the dream of Mars and space exploration into a reality with the newly launched Perseverance Mars Rover.

According to experts, space exploration necessitates courageous human and robotized explorers who must be armed with the most vital tool: information. Data is the mechanism through which human and robotized travelers can obtain the knowledge that they require to carry out their missions to the best of their abilities. To supply Cloud data in the most efficient manner, an infrastructure that blends terrestrial and space components is required.

Though cloud computing for space appears to be in its early phases of development, we must recognize that the influence of cloud computing is inconceivable.

Let us go through this in detail.

Cloud Beyond the Clouds: Cloud computing is important in reducing communication latency. In space, like on Earth, a cloud-based ecosystem can aid in the rapid access and use of data using shared servers, frequently by using an open-source software architecture. Many data sets and AI algorithms, such as meteorological, geographic, or defense systems, cannot fit on a single server or device and must be accessible over the cloud.

It also has significant advantages in terms of increasing network coverage and delivering a new degree of cybersecurity.

Cloud computing is vital for space exploration, as we send individuals and machines further and further away from Earth, where data retrieval times are critical. Having Cloud "data centers" in lower Earth orbit will give infrastructure and application services to orbiting devices.

According to experts, the combination of compute in orbit and speedy and secure data transport, both of which are critical to business and space research, will drive an increasingly advantageous connection in the coming years.

Provides Instant Access to Data: We rely on the Internet for even the most minor explanations. Google can do everything, whether it is a novel recipe or rocket science. Astronauts in space require this knowledge to deal with far more severe scenarios. For them, a lack of information might be the difference between life and death.

Cloud computing plays a critical part in this. Cloud computing in space can provide essential insights to scientists and astronauts in real-time, allowing them to tackle and handle challenges more effectively.

These instances may entail technological issues that need restarting systems or troubleshooting suggestions. Whatever the cause, having information at your fingertips may change the game.

Offers Critical Centralized Data: Cloud computing and centralized data are inextricably linked. Cloud computing is important in giving centralized access to information. This simplifies company operations, aids in breaking down silos in the workplace, and allows for the free flow of information across departments.

That was about typical firms that we have heard of. What about physical space? The main difference between the space and a conventional business is that in an office setting, departments are separated from one another. Distance is difficult to calculate in space. On Mars, physical devices can be deployed. It might have a counterpart on Earth and another orbiting the Moon. The network that connects these physical devices will be incredibly large.

Data from these space probes and spacecraft is relayed to Earth's space stations for processing.

Data that is collected in orbit may be analyzed and made available to astronauts through the Cloud. This will aid in future research while also reducing the time it takes for data to reach Earth, be processed, and then sent back to space.

Furthermore, data is maintained in a centralized cloud repository. Space technicians can use this feature for self-service. Authorized users can obtain the necessary data without the use of intermediaries. This, once again, saves time and speeds up procedures.

Reduces Power Consumption, Improves Efficiency: Data transport and processing consume power. Solar panels in orbit generate this electricity. The more you process, the more energy you use.

The space cloud can aid in the effective storage and transport of data. In this situation, artificial intelligence that is combined with cloud computing will be beneficial.

AI cloud computing aids in the delivery of actionable insights that are based on collected data. The amount of data that is acquired by space-based equipment is massive. AI cloud computing algorithms absorb and digest this data fast. To offer solutions to research problems, AI-based algorithms undertake intelligent analysis and gather expert knowledge.

Simply said, AI combined with cloud computing eliminates the requirement for all data to be relayed back to Earth's space stations. This technology analyzes data and can generate intuitive insights that are based on it.

As a result, AI combined with cloud computing reduces power usage and delivers rapid responses to questions posed by space passengers.

Proactively Protects the Space Assets: When we think about space assets, we might think of physical ones like satellites or crucial data that is collected through a study. They are essential, regardless of their nature. They must be properly conserved and maintained.

Individuals or government entities may be unable to maintain and sustain the quality. You should also be aware that these maintenance and upgrade activities, when necessary, take a significant amount of money.

When it comes to the space cloud, the service provider has extensive expertise in preserving and improving resource quality. Space cloud service providers will be outfitted with the knowledge, tools, and technology that is needed to maintain the quality of space assets.

They will also have an in-depth understanding of future topics such as space traffic management. A collision might occur as the number of satellites in orbit increases. Though these are issues for the future, they should be considered.

From untangling and deconflicting satellite orbits to tracking orbit debris daily, the cloud's computing powers can handle it all.

Cloud computing for space exploration may be a new concept. However, as space exploration advances, there is a need to establish improved methods for optimal operations.

Cloud computing is a tried-and-true technology for enterprises of all sizes. The space cloud, while still in its early stages, has immense potential for improvisation, expansion, and the reduction of complications. As a result, focusing on the space cloud is essential for doing more in this area more effectively.

Space - The Final Frontier for Data Centers

Microsoft's ambitious undersea data center effort Project Natick made ripples in the data center business a few years ago. In earlier columns, we discussed the rising interest in so-called lights-out and self-managing data centers. However, when it comes to the network's extreme edge and lights-out computing, there is one frontier - a final frontier if you will - that continues to pique the imagination.

In the year 2021, mankind established the first conventional data center in space. The HPE Spaceborne Computer-2, a collection of HPE Edgeline Converged EL4000 Edge and HPE ProLiant workstations that are outfitted with an Nvidia T4 GPU to serve AI workloads, was launched into space in February 2021. This is the first commercially available server to be placed in space and run true production workloads.

The commercialization of space, like the use of satellites for telecommunications, Internet access, navigation, or broadcasting, is nothing new. However, until recently, the thought of a network of data centers circling the Earth, that are powered by the Sun and cooled by the frigid vacuum, sounded more science fiction than reality. There are compelling reasons to launch 19-inch racks into space and beyond.

The "Why" Question: While SpaceX and others may have solved the issue of how to deploy data centers in orbit, answering the question of "why" is a bit more difficult. Several firms have explored prospective business models that are centered on space-based communication (to Earth) and data storage.

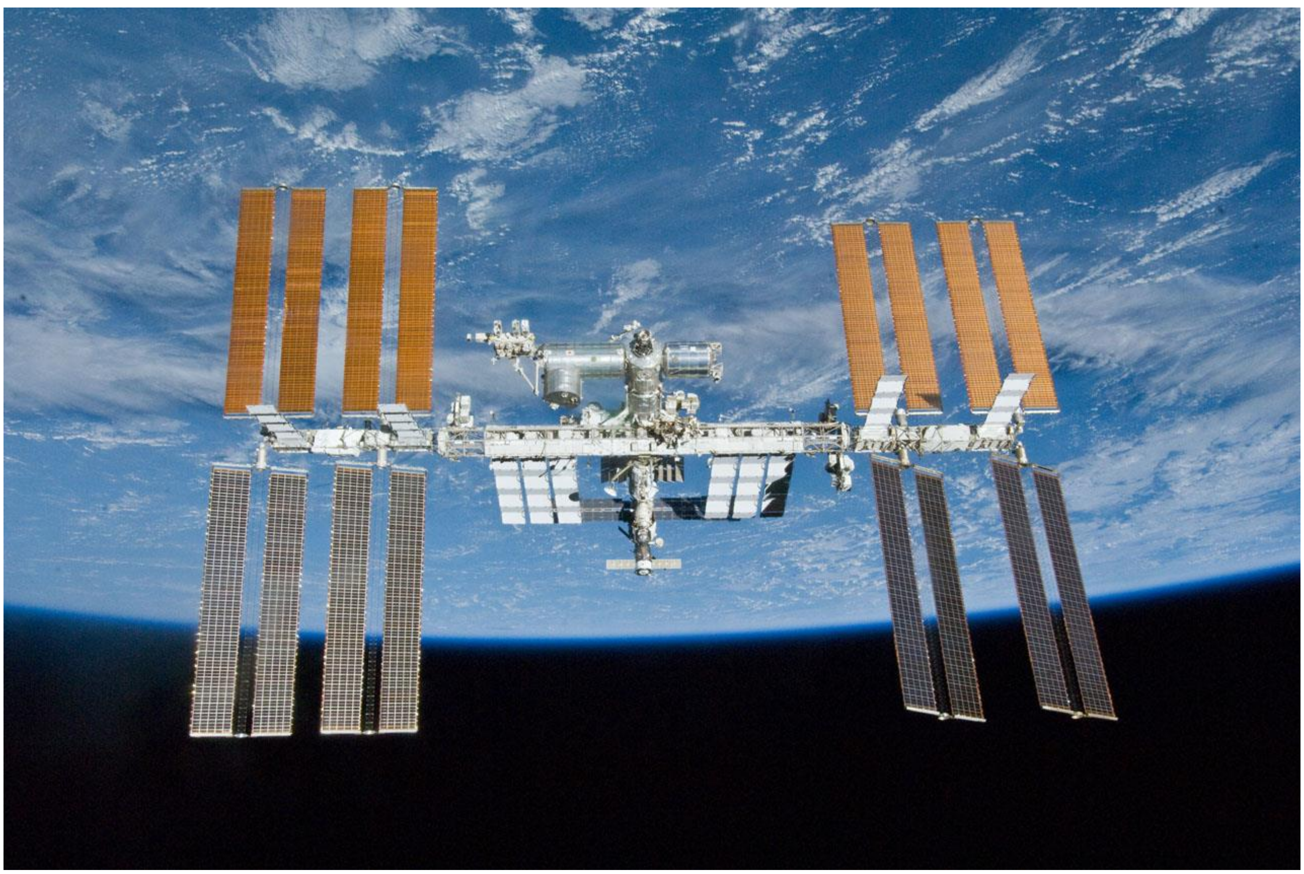
Laser Light Communications, for example, recently teamed with Equinix and intends to build a "constellation" of laser-enabled satellites. The satellites, dubbed HALO will circle the globe, forming a hybrid high-capacity network capable of providing access everywhere on the earth.

ConnectX, another company, intends to deploy a network of tiny low-Earth orbit satellites for data storage. Its primary focus is crypto-currency, with ambitions to store digital wallets off-planet, but its satellite network might have other applications.

Time for a Hardware Refresh: Most computers in space are decades old, whether on Mars landers, satellites, or space station control systems.

Today's hardened processors date from 1995 or 1996. They are not only sluggish, but it is difficult to locate developers that can create software for these devices. Furthermore, all current programs are intended to function on modern PCs.

The ISS itself is powered by Intel 80286SX CPUs from the late 1980s. There are also over a hundred computers, iPads, and other electronics on the ISS. They serve as remote terminals for multiplexer demultiplexer computers, and for email, the Internet, and pleasure.



The International Space Station
Image Source

Key systems are run on radiation-protected hardened hardware. That is, instead of the typical semiconductor wafers on chips, they employ either redundant circuits or insulating substrates.

It takes years to develop and test such a computer. Missions are also organized years ahead of time. When such a computer reaches space, it is sadly out of date.

The Spaceborne Computer-1, the first effort to place a server in space, was launched in 2017 and stayed over two years aboard the space station, despite the mission being only one year long. That mission had three objectives. First, take a computer straight off the production floor, package it to fit on a rocket, and launch it into space. Second, astronauts will be trained to install and operate it. Third, after it is up and running, how long will it keep giving you the appropriate answers?

Spaceborne Computer-1 was stored in a container on the International Space Station. The lockers are intended to be installed within a space station. HPE installed a normal 19-inch rack inside that locker. As a result, no changes to the servers were required. That initial mission had two servers that ran a set of widely recognized benchmarks 24 hours a day, seven days a week, 365 days a year.

The mission had to demonstrate its effectiveness. They intended to put the CPU, RAM, and drives through their paces. You know what the outcomes should be using the benchmarks, so after the work is over, you can see if you received the proper response. They ran 50,000 benchmarks and never encountered a mistake. On Earth, the same benchmarks were conducted on an identical machine. The servers were still operational when NASA shut them down and returned them to Earth; they wanted to inspect them.

Space Does not Like SSDs: The space-based system featured 20 solid-state drives, nine of which had failed during the voyage. Only one of the Earth-based drives had failed.

In addition, the system had five times the number of correctable mistakes in space than it did on Earth. They were, however, correctable and rectified themselves. So there was no problem. The major source of worry was solid-state drives. That is where the majority of the efforts in Spaceborne 2 was focused.

NASA also sought a system that would survive at least three years - the time it would take to go to Mars and return. So HPE doubled the gear, resulting in four servers, two in each locker.

The HPE Edgeline Converged EL4000 Edge System, a robust server that is built to function in tougher edge conditions with increased shock, vibration, and temperature levels, is in Spaceborne Computer-2. It works in tandem with the industry-standard HPE ProLiant DL360 server. The GPU of the Edgeline 4000 enables AI, machine learning, and image processing.

As of mid-December 2021, none of the new system's drives have failed. However, because the servers are not performing the same severe benchmarks as previously, the systems are not as strained. The Spaceborne 2 is now performing true production workloads.

Existing Applications: Although it is modest, the first edge computing data center in space is presently functioning.

DNA analysis is one of the tasks that it does. Previously, astronauts' DNA was checked once a month and the results were transported back to Earth for processing. The processing is now done aboard the ISS, and only the findings are relayed back to Earth. It cuts the quantity of data that must be transferred by 20,000 percent.

Now, scientists on Earth are about to consider ideas that were previously unthinkable. When data can be analyzed in 13 minutes and the findings downloaded in two seconds, astronaut health may be evaluated daily rather than monthly. On the ISS, researchers may also study the DNA of animals and plants.

Another important subject is communication research. This covers 5G and beyond communications tests and simulations, satellite-to-satellite communications, various communication protocols, various security methods, various encryption techniques, and new protocols enabling satellites to deliver data down to Earth.

Another popular use for space-based data centers is image processing. Cameras in orbit capture vast amounts of data from Earth, but the amount that can be retrieved is limited. Most of the photographs are of clouds or empty waters. People are more interested in what is changing in the visuals. Where is Houston flooded following the hurricane? Is this route still open after the flooding? You must provide information to first responders as quickly as feasible.

Simple counting is another useful example. How many vehicles are parked in the store's parking lot? What kind of construction equipment is remaining on the job site? How many cargo ships are now docked? This specific use case is still at the proof-of-concept stage, with receivers using the Spaceborne computer in tandem with their existing systems. Researchers are curious. If they receive the right response, how faster did they send it to the right people than the conventional way?

Customers recognize the importance of this type of processing on their future satellites. Building a data center on a satellite has different obstacles than building one on the ISS. The inside environment of the ISS is favorable to humans. The temperature is controlled, there is air, and human hands are present to repair anything that needs it. The requirement for air to cool the servers has already been met. Water cooled both Spaceborne 1 and Spaceborne 2.

Path to Commercialization: HPE is collaborating with a partner, OrbitsEdge, to make it all happen.

The idea is to construct a box that provides radiation protection and temperature control so that whatever is placed within it may fly and function. The OrbitsEdge satellite system is fashioned like an umbrella, with solar panels on top to collect electricity and shade the computer underneath it. Then, at the bottom, there are radiators that deflect surplus heat into space. In other words, power and cooling are free.

The first demonstration satellite will be launched before the end of 2022. Servers will eventually be found not just in satellites, the International Space Station, and future commercial space stations, but also on the Lunar Gateway space station, the moon itself, Mars, and in orbit around Mars. Imaging satellites will be the first use.

The objective is to minimize the entry barriers for pace operations and make space computing comparable to other types of edge computing. Adding computational capacity to satellites that are already slated to launch is a straightforward use case that will increase the value of those spacecraft. As launch prices fall, special-purpose constellations of satellites that are intended just for data processing can be sent into orbit to manage space-based workloads. It is expected that within five years, there will be an operational capability to analyze space data in space.

At some time, it will be feasible to increase the processing power accessible in space, either because launch prices will fall greatly or because computer equipment will be manufactured in space. At that moment, space-based data centers will be able to handle workloads for clients on Earth.

Terrestrial data centers have significant power costs and occupy precious real estate, both of which are in short supply. There are no clouds in space to come between the sun and the solar panels, thus cooling is free.

The initial expenditures of establishing and equipment for today's data centers are relatively inexpensive, but the continuing operational costs never stop. This is reversed in space. You have a big initial outlay, but your recurring expenditures are lower.

Other benefits can be obtained from space-based data centers. For example, quantum computing necessitates low temperatures. Keeping the computer in the shadow allows you to reach exceptionally low temperatures in space. There is also no vibration in space. New types of lithography, flawless crystals, and other benefits over terrestrial facilities are possible with space-based manufacturing.

NTT is another business that aims to begin early experiments of a space-based data center infrastructure in collaboration with Japan's SKY Perfect JSAT Holdings. The business intends to launch a series of satellites with processing and storage capabilities that connect to form a single data center through optical connections. The first satellites in this network are scheduled to launch in 2025. According to NTT, the on-board processing will accelerate data downloads from satellites. Second, processing power may be used to decrease the quantity of data that must be transferred by compressing it or analyzing it in space.

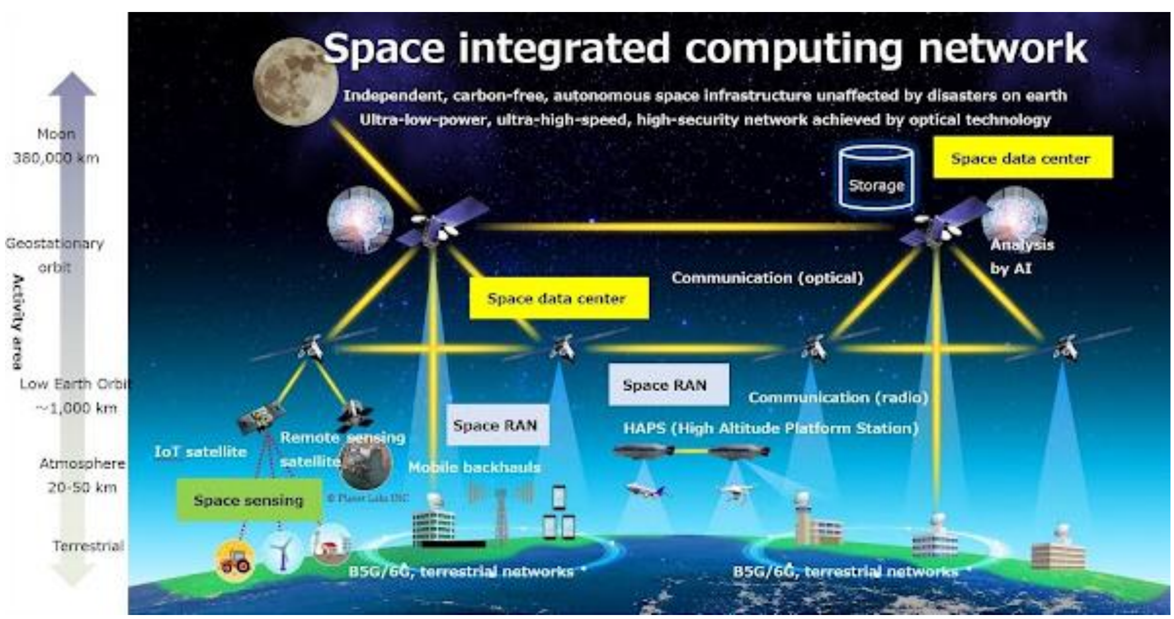
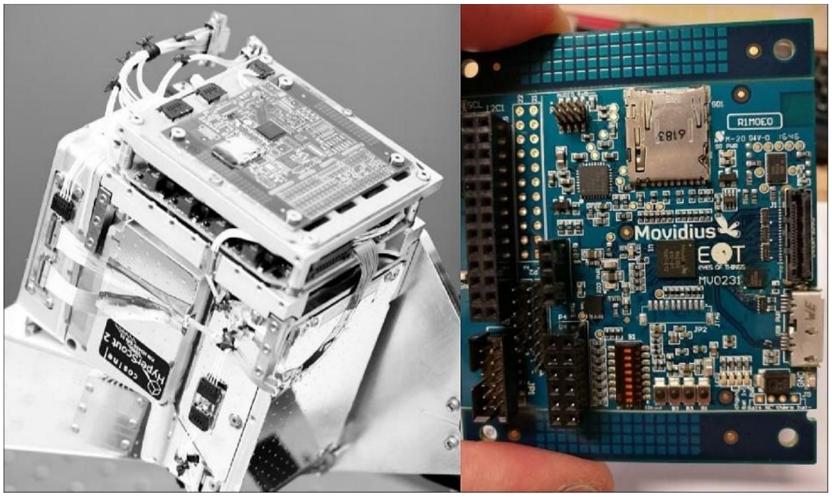


Image Source

Many more rivals with similar concepts are anticipated to emerge in the future years. The European Space Agency launched the PhiSat-1 satellite with AI processing on board last year. The PhiSat-1 is powered by Intel's Movidius Myriad 2 processor, which is not specially built for space flight. There is still more work to be done before we see a full-scale space data center sector.



Right Image: The Movidius Myriad 2 board, Left Image: integrated on the top of the HyperScout-2 electronics stack
Image Source

Lowering the Cost of Space: SpaceX is clearly not the only launch service provider out there, and its future is far from certain. However, if its reusable rocket technology can deliver on its promise of drastically lowering the cost of placing infrastructure in space, it will drive competition and open up a slew of new options for what can be sent into orbit and maintained cost-effectively. One day, this might encompass data centers.

However, prices will need to fall significantly. Based on reported SpaceX pricing of $90 million every 8000kgs (approx. $11,000 per kg, but SpaceX has stated rates as low as $2000/kg), putting a 30,000 kg, 96 kW, 12-rack container data center (including IT) into geosynchronous transfer orbit would cost roughly $330 million. That is 12 racks for roughly the price of a huge data center on the planet. A single-rack mini data center would be less expensive, costing roughly $8 million.

Although SpaceX's most recent mission was a remarkable accomplishment, it was also an incredible marketing gimmick. However, SpaceX deserves credit for pushing the bounds of conventional wisdom. When you combine that with the way Alphabet, Amazon, Microsoft, and other hyper-scalers have defied facility design dogma - from free cooling to renewables - over the last decade, space-based data centers start to sound less insane.

The AWS Lunar Region: Elon Musk is not the only tech tycoon with aspirations for space flight. Jeff Bezos is similarly devoted to space exploration with Blue Origin, but he has the benefit of being well-versed in data centers and IT. If there is any practical benefit to using space-based data centers, Bezos appears to be in a good position to make it happen.

In Space, No One Can See Your Screen: According to ConnectX, some of the satellites now in orbit are already equivalent to mini-data centers, thus the concept of space-based processing and storage is not all that far-fetched:

This is something that is already in place. Satellites are computers that process data, store it, send it, and receive it from and from Earth. ConnectX has an unfair edge in terms of space. We do not have to pay for real estate, power, cooling, personnel, or security. No one can physically access our system, and no government or institution may force the disclosure of your information.

Space-Based Resiliency: ConnectX even has its own ideas for network resiliency that are similar to the distributed resiliency solutions used by cloud platforms today:

Should a cosmic catastrophe (such as a solar flare) occur, or a satellite become inoperable, ConnectX owns the intellectual property on how the system geospatially distributes and duplicates information in the satellite constellation to avoid an outage. Another data backup is provided by a separate group of satellites flying at a higher orbital height. These backup satellite nodes will also fly into position to replace inoperable main constellation satellites.

Cloud Constellation is another space-based cloud business, with its SpaceBelt network of satellites for cloud storage that looks to be similar to what ConnectX is doing.

Cold Storage: Other data center specialists believe that space-bound data centers might be employed for non-latency dependent applications like cold storage, or to provide IT services in developing countries.

Even setting aside the enormous expenses, there are still some substantial hurdles when it comes to space-based data centers. These vary from connection concerns to maintenance to debris and radiation protection. In the short-term, one or more of these may become insurmountable.

What is obvious is that if a feasible economic case for creating and running data center capacity in orbit, then it appears possible that one day there will be firms willing to go there and make it so.

Data Center Co-location Goes to Space

A co-location facility, often known as a colo, is a data center where a company may rent space for servers and other computing devices. A colo typically offers the structure, cooling, electricity, bandwidth, and physical security, while the client provides the servers and storage.

Several space businesses are incorporating micro-data centers into their satellite designs, allowing them to analyze satellite imaging data or monitor dispersed sensors for Internet of Things (IoT) applications. Take a closer look.

As the cost of developing and launching satellites continues to fall, the next big thing is combining IT principles with satellite operations to provide data center services into Earth orbit and beyond.

Co-location of server hardware, virtually running programs in the cloud, and edge computing are all data center concepts, but the space sector wants to adapt those principles to satellite-based business models.

Satellite hardware and software were formerly intricately connected and purpose-built for a single function. Because of the development of commercial-off-the-shelf processors, open standards software, and standardized hardware, businesses may reuse orbiting satellites for multiple operations by downloading new software and sharing a single ship by hosting hardware for two or more users.

This notion of "Space as a Service" can be used to operate multi-tenant hardware in a micro-colocation model or to provide virtual server capacity for "above the clouds" computing. Several space companies are embedding micro-data centers into their designs, which will allow them to analyze satellite imaging data or monitor distributed sensors for Internet of Things (IoT) applications.

OrbitsEdge Plans Racks in Space: OrbitsEdge, located in Florida, is adopting the data center in orbit idea, employing off-the-shelf rackmount servers and mounting them on a satellite bus (the structural frame housing payloads). They are both edge computing and data centers, wanting to deploy high-performance computing infrastructure in order to process, cleanse, aggregate, and analyze data from many sources.

OrbitsEdge may interact with other satellites to gather and analyze data, and conduct overhead edge computing if a typical data center is unavailable or insufficiently close. Offloading and storing data from Earth Observation satellites, turning it into instantly usable images, and distributing the findings straight to end-users in the field are areas where the firm sees prospects. It has held conversations with the US Department of Defense, NASA, and commercial cloud providers. The conversations were about how such unconventional resources may be beneficial for various use cases on Earth, in space, and on the surfaces of other celestial bodies.

It is another site for processing data above the clouds, and there is a lot of interest in fintech, since being able to make buy/sell choices based on counting automobiles in parking lots is appealing. From space tourists to augmented reality enterprises, entertainment companies are high potential clients.

The OrbitsEdge SatFrame is the company's proprietary satellite bus, which has a standardized 19-inch server rack with space for 5U of gear. The first two SatFrame pathfinder satellites will accommodate 18-inch deep gear, with production designs capable of scaling to full-sized 36-inch deep hardware. HPE EL8000 servers will be installed on Satframe-1 and Satframe-2. Exact hardware configurations are still being finalized, with several configurations to be implemented onboard each satellite to test and verify various CPUs and other gear.

While HPE has launched a server to the International Space Station, the human-supporting environment is rather mild in comparison to what OrbitsEdge requires. SatFrame must have a big solar panel array to produce electricity, and batteries to keep the system functioning while it is in the shadow of the earth. It also requires thermal controls to dump heat from operational hardware, and protection from cosmic radiation and solar flare events in order to support off-the-shelf servers in orbit.

If successful, OrbitsEdge may expand beyond Earth orbit and launch missions to the Moon, Mars, and deep space. As distances grow, so do communication delays, and bandwidth becomes increasingly limited. For autonomous vehicle operations, vision processing, and raw data analysis, probes and people will require on-site computers.

OrbitsEdge's original aim is to begin in Low Earth Orbit and progress to Geosynchronous Earth Orbit and cis-lunar regions. Planetary surface missions where the systems are static as part of a base or housing but can also attach to a vehicle.

Loft Orbital Offers 'Space Infrastructure As A Service': The allure of sharing a satellite for cheaper operational expenses and faster time-to-market is keeping San Francisco start-up Loft Orbital busy, especially when paired with significant simplifications for clients in setup and operations. DARPA's Blackjack program, geo-data specialist Fugro, European satellite operator Eutelsat, the UAE government, and startups Orbital Sidekick and SpaceChain are among Loft Orbital's stated clients.

AWS providing computational infrastructure for others is conceptually similar to what Loft Orbital is doing for space. Loft Orbital launched its first satellite in 2021 and now has four missions in the works as a consequence of rapidly increasing client numbers.

While Loft Orbital typically hosts a client's payload onboard its satellites and controls it using its Cockpit website, in rare circumstances Loft Orbital will create or purchase the payload itself, enabling the customer to focus on their applications.

Loft Orbital is the virtualization between the data center and the hardware in the data center analogy, delivering Space Infrastructure as a Service. AWS providing computational infrastructure for others is conceptually similar to what they are doing for space.

Loft is offering this comprehensive solution for Eutelsat's IoT service onboard its first satellite, Yet Another Mission 2 (YAM-2). Eutelsat is more accustomed to running huge, costly communications satellites than it is to creating and managing tiny spacecraft. Loft providing the infrastructure for Eutelsat's satellite IoT service makes more financial and economic sense than the firm entering the industry from scratch. The first two flights of Loft will involve proof-of-concept experiments for Eutelsat's planned IoT constellation.

Loft Orbital seeks to relieve the consumer of effort, saving the customer time, resources, and money. But there is a lot more to it than that. Loft Orbital's payload hub serves as an abstraction layer between the payload and the satellite bus, further optimizing for simplicity and speed. Traditionally, hundreds of subsystems must be modified. There are no economies of scale when building satellites and payloads in small quantities.

Loft successfully banked on a consistent stream of clients by purchasing numerous copies of a satellite bus (essentially a barebones satellite without sensors) ahead of time. This was done to obtain bulk savings and then taking out the bus and plugging in payloads when enough consumers lined up to fill it.

As a result, the customer's life may be made easier. There is no non-recurring engineering or customization that is required by leaving the bus as is. Loft puts them into orbit quicker since they do not have to perform the engineering, and we literally ordered the bus months in advance, placing not just payload and bus production schedules in parallel, but also launch procurement and mission operations timelines.

Loft also provides a software-defined payload that makes use of the software-defined radios on its satellites. Customers are already making use of the service, choosing individual antennas based on the radio frequencies necessary. Loft allows numerous clients to share use for applications such as IoT and RF spectrum surveys.

Loft will ingest data from payloads like IoT and imaging and then allow clients to use the satellite compute environment to analyze their data aboard the satellite rather than transferring it to the ground in the future.

Loft Orbital's YAM-2
Image Source

Improved Economics for Space-Powered IoT: When they can discover viable chances, cost-conscious satellite Internet of Things (IoT) start-ups like Lacuna Space and OQ Technology are embracing hosting hardware and performing virtualized functions on third-party satellites, but it is difficult to find a perfect fit for every necessity.

The primary benefit of hosting is economical. Sharing space with additional payloads is more cost effective since platforms become progressively cheaper as they grow. Last-minute offers on hosted platforms where a payload supplier is running late or canceling can be amazing prices, but they are hard to come by.

Lacuna Space collects data from IoT devices all around the world by modifying the LoRaWAN protocol. Its initial five space platforms are a combination of dedicated satellites and hosted communication packages that share space on other spacecraft. Lacuna Space will develop and launch 24 dedicated satellites in the future since sharing necessitates compromise. Platform and mission performance are not always dictated by demands alone, but by a compromise that takes into account the needs of all payloads. As the satellite constellation grows more complicated, employing hosted platforms becomes more challenging, and the logistical challenges outweigh the cost benefits.

OQ Technology used a satellite that is initially launched by the Dutch company GomSpace to undertake the first testing of its 5G-based NB-IoT service. Narrowband Internet of Things (NB-IoT) is a low-power wide-area network that connects scattered devices. By installing new software built by OQ, the satellite was reprogrammed to connect with NB-IoT devices on the ground. OQ Technology intends to give worldwide NB-IoT coverage using a combination of current satellites, hosted payloads, and its own satellites in the future.

OQ, like Lacuna Space, is making do with what is available, but there are not any ideal candidates for sharing satellites. As a result, such businesses cannot select one and must instead rely on what is available and dependable. Investors like it when you can scale up while investing less in hardware. Not every satellite has the required frequency and power, so maybe there will be enough 'constellation as a service' platforms with flexibility in the future.

Space Data Centers: A Three-Step Evolution

The construction of mega-constellations and smallsats offering a massive number of sensors in Low Earth Orbit "LEO" or Medium Earth Orbit "MEO" is increasing the need for satellite data centers. Such satellite data centers will enable these developing platforms to unleash their full potential.

We will explore how Space systems are following in the footsteps of terrestrial systems and will evolve to enable AI at the edge of space in Space-IoT satellites in a three-part series:

Stage 1 – Space data collection: With hundreds of LEO satellites collecting data in orbit, a few Space Data Centers in LEO or MEO will collect large amounts of data for AI model building. The sheer number of satellites transmitting data works as a multiplier, requiring the Data Center to take data at high speeds in a temporary buffer before committing it to long-term storage. This data is then sent to Earth for the creation of AI models.

Stage 2 – Data security and latency in space and transit: The saved data may be in the public domain or a national asset. The data in these space data centers must be safeguarded before being transferred back to Earth and, in the long term, to GEO data centers through standard RF communication systems or lasers.

Stage 3 – The ultimate space data center: The development of selectors enables True High-Density Data Centers to store data from LEO and MEO for the building of AI models in space without returning to Earth. Space becomes autonomous and self-sufficient, removing the necessity for a connection to Earth. This is critical if a comparable model is to be deployed around the Moon and Mars. There will be no way to return to Earth.

Space Data Centers – Stage 1: Space Data Collection

The major terrestrial cloud providers (Amazon Web Services - AWS, Google Cloud, and Microsoft Azure) have been collaborating with satellite constellation operators in recent years to facilitate the spread of smallsats and sensor platforms. This has enabled new entrepreneurs to launch new sensor platforms into space, which has two advantages:

- Access to terrestrial computing platforms for the creation of AI models.
- Contact point using their infrastructure, eliminating the requirement for additional specialized ground stations.

Capella Space collaborated with AWS in 2020 to begin exploiting their data centers not only as data centers, but also as ground stations (spearheading the start of the AWS Aerospace and Satellite Solutions Division). SpaceX then collaborated with Google Cloud on their Starlink LEO constellation. Microsoft Azure was then followed by SES' forthcoming 03b mPower MEO constellation and Telesat and CloudOps' future Lightspeed LEO constellation.

These collaborations have been critical in enabling the proliferation of satellite platforms and opening doors for new entrants to give the ecosystem with baby steps toward realizing Space-IoT.

For model training and data processing, the new intelligent self-aware LEO satellites with AI engines continue to rely on terrestrial systems.

The current links, which are RF links from a LEO satellite to a base station and Fiber links from the base station to the processing centers, have a lot of delay and are not as safe as they might be with certain future more secure capabilities.

The fresh start: The first generation of space data centers (Unibaps' SpaceCloud and LEOCloud) starts as processing entities (SBCs or subsystems) aboard Space IoT LEO Satellites in orbit to do some AI/ML analysis and data aggregation. Data flow is reduced in the same way as it is in terrestrial systems by compressing the data stream using sensor fusion and only transmitting and receiving altered data.

The second-generation space data centers will gather data from 100 Space IoT LEO Satellites in orbit, perform some preliminary processing, consolidate, and then deliver back to Earth through a dedicated secure link in the background. These data centers serve as aggregating locations for data that is sent and received from Earth. Data flow is reduced in the same way as it is in terrestrial systems by compressing the data stream using sensor fusion and only transmitting and receiving modified data: this is done by local processing and deleting duplicated data. Space-IoT satellites will take advantage of the tremendous advantage and performance of laser communication in space to transfer continuous sensor data to in-orbit data centers.

The advent of a high reliability Space Grade portfolio of high-density, high-performance STT-MRAMs is changing the system designs of these second-generation data centers in space. Avalanche Technology contributes to the enablement of space data centers by supplying the L4 cache of streaming links from hundreds of LEO Space IoT satellites and to terrestrial base stations. The terrestrial base stations serve as bulk storage for data analytics and ML/DL model generating computers.

In the second stage of Data Centers in Space, we will discuss the benefits of this approach in terms of security and latency and highlight the next critical component to the realization of satellite data centers: affordable and mass-volume producible laser communication terminals - Space Micro, CACI, MIT-LL, Airbus, Mynaric, BATC, GA, and SpaceX.

Space Data Centers – Stage 2: Data security and latency in space and transit

The demand for data centers to unlock the power of these new platforms is being driven by the hunger for actionable information from the deployment of thousands of sensors in LEO satellites.

In the second stage of this evolution series, we will discuss how progress toward commoditization of space laser communication technologies is allowing that vision to be achieved in a secure and unrestricted manner.

Space laser communication terminals have become vastly more compact, robust, and affordable in recent years. The terminals are progressing from novel demonstrations at the turn of the century to mass volume producible systems from companies such as Space Micro, CACI, MIT-LL, Airbus, Mynaric, BATC, GA, and SpaceX partners. The mass manufacture of these secure and low-latency devices permits the next phase in the growth of space data centers.

Why do we need Space Laser Communication Terminals?

Security: Before even adding any security protocol handshaking to the link, the resilience of a laser point-to-point communication link makes it intrinsically safe. Every time the link is attempted to be intercepted, the possible threat blocks at least a portion of the link during the intercept. This is far simpler to secure than traditional Radio Frequency (RF) communication systems. In the case of a traditional Radio Frequency, signals are disseminated over a relatively large area, making it easier to intercept by being in close vicinity, necessitating several degrees of encryption to establish a safe link.

Regulation: Because RF is a broadcast exchange, it is more prone to interference with other RF signals, making it simpler to jam or even accidentally overpower the signal from other transmitters. This has necessitated extremely "careful" RF spectrum management and licensing in order to ensure that one RF broadcast does not interfere with other RF transmissions. These required rules make it more difficult for new entrants into the fold since there are only so many spectrum bands accessible in the RF domain, each with advantages and downsides. Certain bands, such as millimeter wave (MMW), which allows ultrawideband communication in 5G infrastructure, have high speeds but a relatively restricted range that is heavily influenced by physical structures. All these spectrum bands require rigorous testing and control since, even with safety bands, interference is still possible as they move closer to one another for more communication. The most recent battle between the FAA and telecom behemoths over the development of 5G towers near airports exemplifies how, even with regulation and frequency band separation, there is no guarantee of a good ending. Because laser communication is point-to-point, there is no need for rules, and there are no chances to induce interference on other laser communication systems.

Latency: While we have all become accustomed to using the speed offered by these light-driven communication systems on terrestrial fiber networks, we are now beginning to unlock their powers in space, where they can attain even faster speeds in the vacuum of space. Satellite-to-satellite communications can now exceed 100 Gbps thanks to advancements in space laser systems. Furthermore, soon it is probable to attain those same speeds with integrated Deep Learning (DL) algorithms that modify the link in real-time to the numerous disruptions generated by the atmosphere as it travels from satellites to the ground. While such is also achievable in the RF spectrum, it is an incredibly difficult undertaking to achieve even without the extra complication of commoditizing it for space uses, not to mention the additional spectrum regulations. The spectrum and performance that can be licensed for satellite constellations is further complicated by the fact that the spectrum and performance that can be licensed depends on which way the satellite is facing. Which means that earth-facing observation satellites get a larger pipe in the RF spectrum to bring data down to the ground than space-facing/exploring satellites.

These point-to-point, ultra-high-speed, low-latency intra-satellite laser communications open the way for mega constellations to be networked and synchronized into permanent swarms of sensors giving actionable data to the globe. This is similar to what we have seen with networked sensor platforms and what they enable in Industrial IoT. These massive in-space networks, with their strong secure point-to-point laser links orbiting the planet at 17,500 mph, provide the inherent robustness necessary for ultra-secure data centers to gather and process data at the fast velocity required.

In the last step of this development, we will describe how high-density MRAM enables truly high-density data centers in space, capable of holding data from LEO, MEO, and GEO for generations of AI models without returning to Earth. Space becomes autonomous and self-sufficient, removing the necessity for a connection to Earth. This is critical if a comparable model is to be deployed around the Moon and Mars.

Space Data Centers – Stage 3: The ultimate space data center

We previously saw how medium density MRAM modules operate as a buffer or level 4 cache. This enables Data Storage Satellites to gather data from hundreds of LEO satellites without a real-time connectivity to Earth in the first stage of this evolution. Such systems, which use MRAM modules with capacities ranging from 1TB to 10TB, ensure secure and safe interim storage before transmission either down to Earth or to genuine data centers in space. The third and final portion discusses how the creation of the selector enables high enough density MRAM solutions, which revolutionize system topologies and enable freestanding space data centers. This facilitates the storing of data for the creation of machine learning/deep learning models.

Evolution of ultimate space data centers:

Today and Near Future: The present evolution of space data centers resembles our terrestrial on-premises data centers, with both specialized processing and storage units living as boxes on the satellite gathering the data. However, satellite data centers are emerging right in front of our eyes in order to use data from the myriad sensors orbiting our globe and collect it in a more cost efficient and targeted manner. This allows existing firms and platforms to stay inside their swim lanes while also allowing other entrepreneurs to contribute to the growth of the rest of the new ecosystem. At this point in the evolution, the memory aspect is more conventional which is confined by the space environment and sized in the tens of Terabytes (TB) for delivering data down to the ground at a predictable rate with a low chance of data loss when seen from ground stations. During this phase, the data center expands by adding modules to the satellite boxes, with MRAM holding high-speed streaming transient data from sensors before it is committed to NAND or always-on DRAM.

These 4TB Medium density MRAM modules are constructed with monolithic MRAM devices that switch the MRAM cell using a transistor. The limiting factor in the device's ability to be shrunk has not been the size of the MRAM pMTJ cell, but the transistor capable of generating a switching current. Avalanche's Space Grade Gen 3 monolithic high reliability 1 Gb devices are at the edge of 22 nm technology. These devices have had performance and reliability tuned.

Further Out Future: The next stage in MRAM evolution (increased density) will not come from moving to the next geometry 14-12 nm or 7-5 nm. Such transitions necessitate a change from ordinary transistors to vertical transistors or FinFets capable of producing the requisite switching currents. The transistor will be replaced by a Selector that operates between "AP" and "P" resistance states in the next development and enhanced density. The "Selector" might be four times smaller than a transistor, and similar circuits can be built to increase density by orders of magnitude, resulting in densities in the hundreds of Terabytes of high reliability storage for Space.

This will enable the storing of sensor data in space to refine AI/ML models and continually evolve autonomous space systems to more correctly and quickly adapt tasking and data creation. This allows data centers to expand into a more Space-IoT evolution, blasting data from sensors to customized ultimate data centers that store and handle the data.

These developments allow Space to become even more autonomous and self-sufficient, removing the necessity for a link to Earth. This is critical if we are to deploy a comparable concept around the Moon, Mars, and beyond. There will be no way to return back to Earth.

Conclusion

Many believe space exploration to be a huge waste of time, money, and resources. This is because people believe that there is no use in studying or exploring outer space since we live and function only here, on planet Earth. However, it is crucial that we understand just how important space exploration is to lead a far more comfortable life on Earth. Not only in terms of basic requirements such as healthcare and prevention of natural disasters, but to also enhance and propel our standard of living to a far greater degree using technology and innovation.

Space exploration has been going on and growing at an increasing rate. Even so, the base technological hardware and software systems that are used in major missions have not been upgraded since the initiation of their mission. To take space exploration to the next level, such base components of existing space missions must be upgraded, and new missions must already include the latest technological advancements.

On the ground level of planet earth, data centers are considered to be some of the most powerful groups of computing systems clustered in a single place. Space missions certainly make use of similar types of workloads that existing data centers are already capable of handling. Plus, data centers are known to be exceptional at completing the task at hand to ensure the best outcomes possible for businesses. This technology (data center technology), implemented into space missions, will transform multiple aspects of space exploration and research. Considering modern technology such as Edge computing, Cloud computing, IoT, and Artificial Intelligence which are most relevant to level-up space missions, it is only a matter of time until these missions are capable of becoming self-reliant in space without any direct links back to earth. The sooner we begin to implement more such data center technologies into space missions, the faster humanity's progress into technological novelty and exploration of the unknown will expand, and at an exponential rate. The time is ideal to create a whole new data center ecosystem in outer space.

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