The New Space Age requires more than just rockets

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I. EXECUTIVE SUMMARY

Space is entering a new era. Rockets have made access affordable, but computing remains a critical bottleneck. Today's electronics are built for Earth, not for radiation, latency, power scarcity, and the vast scale of space. To enable the next wave of exploration and unlocking the next trillion dollar industry, we need a dedicated foundation for compute beyond Earth.

We are embarking on this quest through a stepwise plan to build a universal compute platform for space. It begins with the Mimir Compute Library (MCL), a collection of radiation-tolerant, power-aware algorithms for developers. On top of this, the Mimir Compute Framework (MCF) simplifies application building and optimization. The next step is heterogeneous compute hardware, the Mimir Compute Module (MCM), which integrates off-the-shelf components into space-ready systems. With experience gained, we will design the Interlinked Processing Unit (IPU), a custom system-on-chip for mission-critical compute. Finally, these elements will combine into a distributed satellite compute platform, forming the backbone of a space-based cloud.

The path is difficult but critical. The commercialization of launch has reduced access costs and opened a new era of opportunity. A scalable compute foundation is the next step in enabling the New Space Age. Our mission is to build the systems that power and sustain humanity, beyond earth.

II. THE PROBLEM

A. Space is a harsh mistress

On Earth we are protected from cosmic radiation by the magnetosphere and atmosphere. In space, that protection is gone. Just as too much sunlight is harmful to human skin (and DNA), cosmic radiation is damaging to unshielded electronics.

A big problem in space is Single Event Upsets (SEUs). These happen when ionizing radiation strikes a computer's circuitry, flipping a bit from 0 to 1 or vice versa. These flips corrupts data and can cause critical system failures. In Low Earth Orbit (LEO), commercial-off-the-shelf electronics typically experience between 0.1 and 1000 bit-flips per day per megabit of memory.

Another problem is the vacuum of space. On Earth, we can cool devices using air (convection) or contact with colder materials (conduction). In space, heat can ONLY escape as radiation, which is much less efficient. This makes thermal management a critical constraint.

Finally, consider the scale of space. Low Earth Orbit is 800 km up, already 80x higher than a passenger plane flies. Geostationary satellites hover 36,000 km out.

If you drove there at 120 km/h without stopping, you would arrive in nearly two weeks. And the Moon? A body that is still relatively close to us. At 385,000km away that is a 4.5-month drive.

B. Fighting Physics

Leading from the last section, because space is such an extreme environment, you are up against the limits of Physics itself.

One limit is the speed of light. Communication latency is introduced as a consequence of the distances in space. The round-trip latency to the moon is approximately 2.5s. Which, for human communication is annoying, but not prohibitive. However, for real-time critical operations such as navigation, it is. For Mars, this issue is even worse. The round-trip latency is 8 minutes in the best case, and 45 minutes in the worst case. Latency means time-critical decisions cannot be offloaded to Earth for processing for missions beyond immediate earth orbit.

Another factor is bandwidth. Bandwidth is simply the amount of data a signal can carry. To put information into a signal, we change three things: how fast it vibrates (frequency), how strong it is (amplitude), and where it is in its cycle (phase). Each unique combination of these changes gets a code of 1s and 0s. Higher frequencies can carry more of these codes, allowing them to hold more data; however, this also makes them more sensitive to obstacles and noise. That's why, for example, 5G is faster than 4G, but requires a line-of-sight to work.

In space, every bit needs to be sent wirelessly. Bandwidth is limited and, therefore, a precious resource. With an exponential growth in the number of satellites, we are depleting this resource, resulting in congestion. This phenomenon is called spectrum congestion, and is predicted to cost the U.S $300 billion a year by 2035 [1].

Another limited resource is power. There are currently two primary power sources in space. Solar and thermoelectric. Solar is most popular because it is cheap and scalable, but the drawback is that it requires direct sunlight and a large surface area. Thermoelectric is far more reliable (converting heat from nuclear decay into electricity), but also very expensive. The Mars rovers, Curiosity and Perseverance, utilise Radioisotope Thermoelectric Generators (RTGs) that consistently generate approx. ~100W. Both have their strengths and weaknesses, but both generate a limited amount of power.

Another problem is signal loss. Signals weaken in three main ways:

1) **Distance (Inverse Square Law):** As a signal spreads out in three dimensions, its strength drops quickly the farther it travels. This relation is called the inverse square law. In short, double the distance and you quarter the signal strength.

2) **Obstruction:** Anything in the way when downlinking (walls, trees, rain, buildings, and even clouds) can absorb or scatter the signal, making it weaker and more unreliable.
3) **Interference:** Signals can overlap with other signals and become mixed up or distorted.

You can mitigate signal loss by increasing the transmission power. But because power is a limited resource, space communication sometimes sacrifices speed for reliability. Using lower-frequency bands can carry less data but travel further without degrading the signal, meaning less power is needed. There is a constant trade-off between bandwidth vs. power, and speed vs. reliability.

C. The struggles of Terrestrial Tech

There are many constraints put on systems in space; however, terrestrial commercial-off-the-shelf (COTS) systems are not designed with these constraints in mind. COTS do not worry about SEUs (except airlines and mission-critical systems) because they are protected from radiation by buildings and the atmosphere. Putting these systems in space would be the equivalent to not using sunscreen while staying in the most intense sunlight 24/7/365.

To protect electronics from SEUs, you can use Radiation Hardening (RadHard) methods. The most effective methods involve adding physical protection during chip manufacturing but they are expensive due to their high complexity and low market demand. Therefore, RadHard manufacturing often relies on older chip designs, which are larger and less complex, making them easier and cheaper to adapt for space. For example, NASA's Perseverance rover from 2020 uses a hardened version of the 1998 PowerPC 750, running at just 200 MHz, and it still cost $200,000 to manufacture.

Another method used for commercial mission in LEO is Triple Modular Redundancy (TMR), where three identical systems run in parallel and vote on the results. This works great, but it triples everything (size, power, and memory).

Our problem is clear when we recall the constraints on size, power, and robustness. Terrestrial technology is not fit for the next era of space computing. Space requires dedicated software and hardware, engineered for the harshness beyond Earth. This is what we are going to build. John von Neumann and IBM coined and pioneered the John von Neumann architecture, also known as the Sequential Compute paradigm. NVIDIA: The Parallel Compute paradigm. And we, the Interlinked Compute paradigm.

III. SOLUTION

A. Overview

Pioneering a new paradigm is difficult and requires a bold plan. The reason NVIDIA won the Parallel Compute era is the software. While AMD's hardware is better on paper, NVIDIA's CUDA and supporting libraries make it easy for engineers to get real-world performance in HPC and AI. When AMD had improved its software, it was too late. Great hardware needs great software to succeed.

We will build a universal platform for computing in space. We achieve this step by step: first software, then custom compute hardware, and finally a full-stack satellite platform. Starting with software reduces business risk, lets us leverage existing talent, and avoids diving into aerospace engineering on day one. This stepwise plan enables us to build the world's best compute stack for space and mission-critical systems.

B. Mimir Compute Library (MCL)

Our first step is to design a library of functions, algorithms, and objects for space. This library is our equivalence to cuBLAS, FFTW, cuFFT, RocBLAS, CUDA Thrust, etc. It provides developers with the tools to build custom space applications in standard low-level programming languages such as C/C++/Rust/Zig/etc.

MCL offers multiple versions of each algorithm, enabling developers to choose based on mission needs. The key trade-offs are: 1) Radiation Tolerance, 2) Memory Usage, 3) Power Usage, and 4) Performance.

The library will continually evolve and serve as the foundation of our plan. It can also be adapted for terrestrial fields, such as robotics, edge computing, and on-device AI. MCL is to the Interlinked Compute Paradigm what CUDA is to the parallel compute paradigm.

C. Mimir Compute Framework (MCF)

A library of algorithms is a good start, but working with them still requires dealing with low-level code, which is something most end-user companies are not equipped to handle. This is where the Mimir Compute Framework (MCF) comes in to play. The MCF is a set of tools used to easily build and run programs using MCL algorithms. It automates the selection of optimal algorithms, letting the developer focus on creating value for their customers instead of complex performance details. This framework also has the potential to be applied to terrestrial High Performance Compute and AI.

D. Mimir Compute Module (MCM)

While software can significantly improve radiation tolerance, efficiency, and adaptability, well-designed hardware is essential. The real value lies in the tight synergy between software and hardware. However, custom hardware is expensive and takes time to design. To move quickly, we will first build heterogeneous compute systems using commercial off-the-shelf components, combining CPUs, GPUs, FPGAs, DSPs, and other ASICs. Our first version will likely use the Nvidia Jetson Orin, extended with additional capabilities and a minimal runtime. This approach enables us to optimize MCL and MCF for a specific hardware target, resulting in better out-of-the-box performance than other space compute companies. It also helps us learn which features are most valuable for a future custom space SoC. Again, this can also be used for optimizing terrestrial applications.

E. Interlinked Processing Unit (IPU)

When ready, we will proceed to design our own custom silicon for space computing, called the Interlinked Processing Unit (IPU). With the knowledge gathered from previous steps, we will combine different types of accelerators into a single, flexible system, optimized for mission-critical use in extreme environments. This hardware may also serve industries on Earth with similar demands.

F. Satellite Compute Platform

Ultimately, we will produce, launch, and deliver a full-stack satellite computing platform for our customers to build upon. We will create a network of these interlinked compute nodes all over the solar system. This enables builders to run applications anywhere in the solar-system, without having to send a satellite there themselves. Essentially forming a distributed cloud system in space.

IV. THE HISTORY & IMPORTANCE OF SPACE

A. Overview

The path we have chosen is difficult, filled with risk and uncertainty. Why embark on such an extreme endeavor? With the commercialization of the space industry, we are at an inflection point that could kickstart a new golden era of technological advancement. The following section describes the history of human spaceflight, and why commercialization is a must.

B. The Space Race

The space race is a marvel of human history to unpack in hindsight. In just 12 years, humanity went from the first object in orbit to first humans on the moon, powered by Cold War tensions between USA and the USSR. To show technological and ideological superiority, and to project global power.

In 1957, the USSR launched the first satellite, Sputnik, into orbit. In 1961, Yuri Gagarin became the first human in space. A month later, Alan Shepard became the first American in space. The first spacewalk occurred in 1965, by Alexei Leonov. Apollo 8 was the first crewed mission to another celestial body in 1968. One year later Neil Armstrong and Buzz Aldrin became the first humans to walk on the moon in 1969. An impossible timeline from our modern perspective.

Those 12 years inspired an entire generation to believe the impossible was possible, and the technological fallout is still impacting us today. Without the Space Race, society would be very different. Yet, it only happened because of the political and societal will to push humanity to new frontiers.

C. The Post-Race Plateau & Decline

The Cold War came to an end, and so did the Space Race. Pushing the technological boundary was no longer a compelling interest. The momentum from the space age was still felt for decades, but the ambitions were not as grand, nor the timelines as urgent. Interest in space had waned as we entered the 21st century. Eugene Cernan (1972) was the last person to walk on the moon, and since then, we have almost lost the know-how to land even uncrewed vehicles on the moon[1]. With the retirement of the Space Shuttle Program in 2011, USA even lost its independent capability to send astronauts to space.

Despite the decline, many technologies found groundbreaking use cases on Earth. GPS became available for civilian use in 1983. Satellite television emerged as a massive commercial industry in the 70s and 80s. The first weather satellites were launched in the 70s, improving forecasting capabilities. Even many of the technologies used to scale the internet can be traced back to the space race. ARPANET (the precursor to the World Wide Web) was a response to the launch of Sputnik, aimed at establishing fast and secure terrestrial communication.

Fast-forward to the 21st century and every single human with access to a smartphone or the internet are either directly using SpaceTech (Navigation-, weather-, Broadcasting-satellites, etc), or indirectly using technology tracing back from

[1] While there have been some successful landings since the Apollo era, in modern times there have been far more failures than successes. China's Chang'e rovers being the major exception to that grim statistic.

the space age (Memory foam, Scratch resistant glass, Water filters, solar panels, baby formula, and much much more). Now imagine what a new commercial era of space exploration could do for human technological progress.

D. The Rise of Commercial Launch

Elon Musk founded SpaceX in 2002 with the mission of making humanity multi-planetary. Elon bet the money he made from PayPal to create reusable rockets. A bet that kickstarted the NewSpace movement. NewSpace is a private-public procurement process based on fixed-price contracts for services or products produced and owned by private companies. This leads to an incentive to efficiently develop the product or service, delivering it with a profit. In the United States NewSpace has replaced the old way of using cost-plus contracts, where the the government cover all costs (incl. delays and fixed profit margins) for bespoke solutions, de-incentivizing reusability and efficiency. Instead the companies got paid more by introducing complexity. Europe, however, is severely behind and still clinging to the old ways. NewSpace is slowly getting picked up by ESA, but some individual states (ex. Sweden) are yet to follow suit.

In 2008, SpaceX had a final all-or-nothing launch of Falcon 1. Luckily they succeeded and reached milestones that unlocked significant funding which saved the company from bankruptcy. Since then, SpaceX successfully launched Falcon 9 in 2010. Falcon 9 was the first reusable system and an essential milestone in pushing the cost-to-orbit down. Launching with the Falcon 9 costs approximately $2,600/kg to Low Earth Orbit, and the Falcon 9 Heavy is priced as low as $1,500/kg. Compare that to the Space Shuttle price tag of $65,500/kg [2] and it is easy to understand that we are in the midst of a paradigm shift. Space is no longer prohibitively expensive, opening the door to a new era of humankind, and with it, multi-trillion dollar [3] opportunities for those bold enough to seize them.

E. The New Space Age

The New Space Age needs more than just rockets. Reaching space is only the first step in capitalizing on this huge opportunity. The New Space Age is a race to build the next batch of generational companies. That requires scalable infrastructure to support.

Space is filled to the brim with treasure. The bold ones are already on a mission to make their claim. From commercial satellites to asteroid mining and everything in between. But, space is harsh, and Earth technology is not designed for it.

V. CONCLUSION

What we are building is the boldest venture to emerge from Europe in decades. We will break rules, challenge the status quo, and execute with ruthless efficiency. Anything less will fail. When we succeed, we will not just push boundaries. We will change the course of humanity and lay the foundations for a thriving multi-planetary civilization.

Sixty years ago, the Space Race proved what is possible when ambition meets resolve. Back then, it was a matter of political will that made us reach for the stars. Today, a multi-trillion-dollar industry is emerging, not driven by nations but by daring entrepreneurs. SpaceX has reignited the world's appetite for the vast unknown. But a New Space Age requires more than just rockets; it necessitates a technological foundation upon which ambitious individuals and companies can build the future. A platform designed for the reality of space.

This is what we are building. Not just to explore the universe, but to make it our home.

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