Exploring the Long Future and Survival of Human Civilization

by Arpi Derm, Astronomical and Planetary Sciences (BS), arpiderm@gmail.com.

Abstract

This paper presents a proposal for Proxima—a conceptual and practical framework aimed at understanding and enhancing the long-term survival of human civilization. Rather than focusing solely on modeling and simulation, Proxima provides a holistic foundation for reflecting on the deep interconnections between society, environment, technology, information, and economics. It combines insights from systems thinking, planetary ethics, and future studies to offer a structured way of imagining, testing, and shaping the trajectory of civilizations. By integrating historical context, philosophical reflection, and real-world challenges, Proxima aspires to foster a global conversation around resilience, sustainability, and cooperative long-term thinking. The proposal lays the groundwork for a shared intellectual space where interdisciplinary collaboration can help navigate uncertainty and support transformative societal decisions.

I. Introduction

A. Learning from the Past: Rise and Fall of Civilizations

The fabled city of Ubar, a once-thriving center of the frankincense trade, was renowned for its prosperity and formidable status as a fortified city [1]. Buried beneath the sands, it remained hidden from the world for centuries. The space shuttle Challenger and remote sensing played a crucial role in rediscovering this ancient city, in the southern region of Oman, in the Middle East.

Contrary to its current arid location, Ubar was not always situated in such a dry environment. Previously, the area was considerably more humid, with abundant underground water reserves. Scientists believe that Ubar's demise was precipitated by a dramatic decrease in water levels, leading to the formation of a sinkhole that ultimately consumed the city [2].

Despite disagreements regarding the existence and fate of Ubar, the point stands that historical patterns of environmental change have played a role in the rise and fall of civilizations.

In recent times, NASA's satellite imagery has aided archaeologists like Jason Ur in pinpointing thousands of potential sites for ancient Mesopotamian cities. These findings suggest that climate change may have played a significant role in the rise and fall of various civilizations, including the Maya and other lost cities in Central and South America [2].

Climate change, however, does not always contribute to the downfall of civilizations. A close examination reveals instances where civilizations have demonstrated resilience and adaptable responses to environmental changes.

Through careful studies, it becomes evident that certain populations adapted to climate disruptions by creating new commodity circulation networks. Another way of adapting and coping involved mobility, specifically through migration. One illustrative example of this phenomenon is seen in the Jurchen armies in China and the establishment of the Qing dynasty [3].

As we delve into the intricacies of complex civilization dynamics, climate change emerges as just one of numerous interconnected factors that collectively shape the course of civilization development. Climate change intersects with a range of anthropogenic stressors, including, but not limited to, alterations in land use, biodiversity loss, pollution, and the excessive exploitation of available resources. These interplays, in turn, give rise to further indirect stressors, encompassing economic repercussions, food insecurity, shifts in regional dynamics, political instability, and financial risks [5].

Technological development is another key factor in spatiotemporal variations of civilization dynamics. This development hasn't progressed uniformly throughout history.

Significant advancements in technology bring about economic transformations, increased labor or land productivity, which in turn lead to population growth. This population growth, in effect, influences social structures, inevitably triggering changes in political aspects and consumption patterns. Simultaneously, the economic activities resulting from technological leaps impact the external environment, potentially affecting nature and climate [7].

Furthermore, some of these technological shifts are prompted by crises and disruptions in human history. During such crises, the demand for change and innovation within society rises sharply as a means to survive these disruptions. Consequently, this heightened demand leads to technological advancements [7].

B. Interconnected Systems: Civilization and Biosphere

To begin, it's crucial to clarify key terms frequently used in this discussion, particularly 'civilization.' According to the Cambridge Dictionary, civilization refers to a society's advanced culture, including its social frameworks, governance, legal systems, and arts, or the dominant cultural features of a community or nation at a given time.

Another important definition throughout this paper is biosphere. According to Britannica, it is characterized as a vital yet relatively thin layer enveloping Earth's surface. It stretches from a few kilometers into the atmosphere down to the depths of the ocean's deep-sea vents. This layer is integral to our planet, functioning as the global ecosystem where living organisms, known as biota, coexist and interact with nonliving elements. These interactions are crucial for the exchange of energy and nutrients. In essence, as Meurer et al. (2023) succinctly put it, 'The biosphere is Earth’s entire ecosystem.'"

Jay Forrester's seminal work ‘World Dynamics,’ conceptualizes ‘world system’ as “man, his social systems, his technology, and the natural environment.” By these definitions, we can view a world system as a holistic unit that merges the biosphere with human civilization.

In discussing the 'world system,' it is crucial to recognize that the terms 'biosphere' and 'civilization' are not static. While they commonly refer to Earth's biosphere and our contemporary human civilization, these terms can extend beyond. The concept of a biosphere is applicable to habitable planets beyond Earth, and 'civilization' might evolve to include future forms of human society, like the 'cybernetic W-society' envisioned by V. Sadovichy et al.

C. Innovation and its Ripple Effects

The invention of celluloid and other early plastics in the late 19th and early 20th centuries offered alternatives to natural materials like ivory, which were becoming scarce due to over exploitation, such as the hunting of elephants. (Freinkel, 2011) By providing a synthetic substitute for ivory, celluloid helped mitigate the demand for natural ivory, contributing to the conservation of elephants by reducing the incentive for ivory poaching. This shift to using plastics for products previously made from natural materials represents an early example of how synthetic materials can offer environmental conservation benefits.

While early plastics like celluloid provided alternatives to natural materials such as ivory, significantly contributing to the conservation of species like elephants, the subsequent widespread use of plastics has led to severe environmental challenges to both living and non-living systems. However, there are challenges to plastic pollution mitigation efforts. Some of which are economic and political influences, a lack of governmental commitment, varying scientific opinions, and underreported polluters. (Iroegbu et al., 2021)

The example of celluloid and the subsequent proliferation of plastics embodies a classic case of unintended consequences, revealing how a solution to one problem can inadvertently spawn new challenges. Had the long-term environmental repercussions of plastics been anticipated, this foresight might have enabled a more measured approach to their use, potentially steering innovation towards sustainable alternatives or more effective waste management strategies from the outset.

II. CONCEPT DEFINITION

A. The Promise of Proxima

The question then arises: with the benefit of hindsight, would humanity opt for immediate solutions, knowing their eventual drawbacks, or would a longer-term perspective prevail, guiding us towards choices that balance short-term benefits with long-term sustainability?

Looking ahead, whether future generations would act more prudently when faced with similar dilemmas hinges on our capacity to learn from past experiences and integrate this wisdom into our decision-making processes. It prompts reflection on whether, given clear foreknowledge of the consequences, societies would persist in favoring short-term conveniences or shift towards decisions that safeguard the long-term health of any environment humans live in.

Exploring these profound questions is vital, yet our ability to do so through experimentation remains elusive. Imagine if we could dismantle the barriers that obscure our view of humanity's long-term consequences. Beyond the hurdles of technology, we venture into the territory of moral and philosophical debate.

The unpredictability of human behavior stands as our most formidable obstacle. Still, we are compelled to ask: how might we glimpse into the future, exploring the outcomes of human decisions and actions with some degree of certainty? How can we use this glimpse into the future to devise concrete and realizable actions to address some of humanity's biggest challenges? Some of these actions might not be straightforward or conform to societal norms. Given the state of the world, what we might need is out-of-the-box thinking that transcends conventional societal rules and constraints. These rules and constraints are intended to provide order and guide humanity, but they should not prevent us from moving forward.

For example, consider the impact of oil companies on climate change. Instead of trying to ban them or force them to change, we could explore solutions that reward them for taking an alternate path. If greed is a factor, why not help them make a profit by providing incentives for switching to cleaner energy forms? By creating win-win situations, we can address the problem more effectively. These are the types of scenarios that could be explored by having a glimpse into the future.

This challenge is further compounded by what Haff describes as technological lock-in—where existing investments in fossil fuel infrastructure create strong resistance to change. As Haff notes, societies rely on technological and institutional structures that both enhance stability and constrain transformation [16]. The energy sector exemplifies this phenomenon: massive investments in fossil fuel technologies represent costs that both companies and societies seek to recover, making rapid shifts toward renewables economically and politically difficult. Rather than attempting to dismantle these entrenched systems outright, a more effective approach would be to leverage incentives and transition mechanisms that align economic interests with sustainability, gradually unlocking dependencies while minimizing economic disruptions. By acknowledging these systemic constraints, we can develop policies that facilitate adaptive transitions rather than abrupt, impractical shifts.

To this end, we propose the creation of an exploratory World System Model (X) that integrates the established world system spheres with human psychological, cultural, and natural patterns, surpassing current limitations. In addition to the traditional world system spheres, Model X will introduce an Information Sphere, emphasizing the critical importance of information persistence and its role in shaping and sustaining the system.

Imagine a transformative mechanism, mirroring the complexity of a neural network, where the world's intricate systems are interlinked, reacting selectively to various events. This mechanism would deconstruct world system's elements into smaller, manageable units, harmonizing them collectively, powered by a comprehensive repository of world history and human behavioral patterns. By granting this system the ability to evolve, with a steadfast objective of enriching humanity's future, it would autonomously adjust to our decisions, policies, and actions. This presents a compelling prospect: a glimpse into what lies ahead. More specifically, the ability to explore human civilization's survival odds over long future timescales.

It is crucial to make abundantly clear that this model of the world system is not intended to replace human agency or take control over life as we know it. No machine, model, or neural network currently possesses consciousness, and nothing can replace human intentions. The goal is not to relinquish control, but to understand the long-term implications and pattern-changing outcomes of our actions and decisions. This understanding aims to help us make better judgment calls before embarking on irreversible paths, as per the law of entropy, we can only move forward.

The dependability of such foresight, coupled with humanity's reaction to it, prompts significant inquiry. Are we better off with this capability, or without it? It's conceivable that our fate is to continue on our current trajectory, accepting the consequences. Conversely, it might be our responsibility to take the reins of the future. Without subjecting this conceptual system to practical tests, these questions remain speculative. Regardless of the outcome, this venture could enhance our grasp of the universe's complex operations and the essence of human nature. At the very least, Proxima holds the promise of steering us toward potential course corrections, uncovering previously obscured facets of our existence. Our efforts may not match the relentlessness of evolution, but as humans, from a biological perspective, our reach is bounded only by our imagination. Granted that from a social, psychological and philosophical perspective, there are certainly other limitations such as greed and lust for power and perhaps the most limiting factor of them all, ego. Nevertheless, perhaps, it is time for a shift in paradigm, a time to adapt.

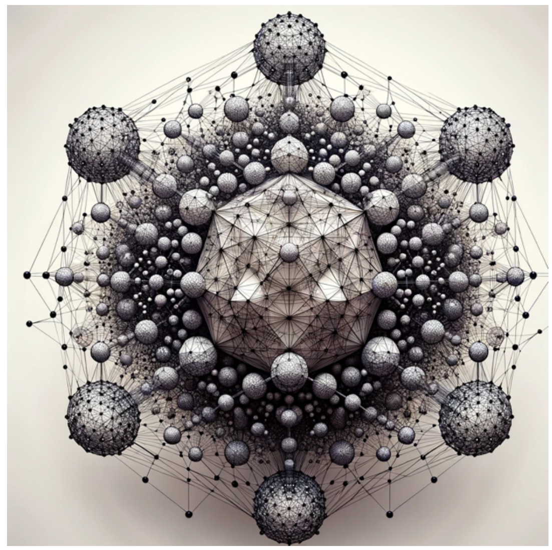
The impetus behind this endeavor is clear: to extend the lifespan of human civilization as much as possible, thereby equipping future generations with the best possible chance to unravel the mysteries of life and the cosmos.

In this idealized scenario, the operation and utility of Proxima pose intriguing questions. How will Proxima function, and more importantly, how will it prove beneficial? The system's potential to inform policy, guide societal shifts, and even inspire individual choices with a forward-looking perspective could redefine our approach to global challenges and personal endeavors alike, marking a significant leap toward a future where humanity is better prepared, more resilient, and profoundly informed.

But where do we begin, and how do we test such an expansive concept? Currently, the global push towards space exploration, the burgeoning space economy, and the utilization of resources from space represent humanity's hope to address some of its most significant challenges. These endeavors, aimed at either offloading our terrestrial problems into the cosmos or harnessing technologies developed during these initiatives, and of course space resources for use on Earth, signal a new era of exploration and innovation. This renewed vigor towards space exploration offers an ideal testing ground for Proxima. After all, these ventures are the culmination of decisions and policies that are redirecting the course of humanity. But is this redirection the right one? How can we ensure that it won't trigger a domino effect with unforeseen negative consequences? These are the questions we hope to answer.

Can we truly answer these questions using predictive models? Perhaps not entirely, as unforeseen technologies cannot be fully integrated and there are many unknown unknowns. However, by continuously updating with information and data on new technologies and actions taken, and by leveraging methods such as data-driven methods similar to those used for complex dynamical systems, or Decision Making under Deep Uncertainty (DMDU) methods, we might have a chance. This will remain uncertain until experiments are conducted, and the concept is tested and validated.

B. Idealistic Mechanism for Proxima



In an ideal state, devoid of constraints, the Proxima system can be envisioned as a multifaceted polygon, with each edge symbolizing an aspect of the system. Within this polygon, spheres representing the world system are intricately interconnected, each sphere comprising smaller, segmented spheres.

While all these spheres and sub spheres maintain connections, the strength and impact of these connections vary, illustrating the complex interdependencies within the global system.

This polygon intentionally incorporates a degree of uncertainty, reflecting the inherent unpredictability and complexity of the world systems it seeks to model. It is designed with an adaptive ability to reshape itself in response to new information or changing conditions. This flexibility ensures that the structure remains dynamic and can evolve over time, avoiding rigidity. By embracing complexity and uncertainty as fundamental attributes, the Proxima system can more accurately simulate and explore the ever-changing realities of the world.

At the heart of the Proxima system's polygonal structure resides a central sphere, dynamic in its dimensions, embodying the survival prospects of human civilization over extended future timescales. This sphere serves as a barometer for the health and viability of our global society, expanding or contracting in response to the flux of world systems and the decisions we make.

As the conditions of the world system improve, reflecting decisions that bolster sustainability, equity, and resilience, the sphere's size increases, symbolizing enhanced odds for the long-term survival of human civilization.

Conversely, when the world system faces challenges—be it through environmental degradation, socio-economic disparities, or geopolitical tensions—the sphere diminishes in size. This contraction is a stark visual cue of declining survival odds, a signal that the trajectory we're on is diminishing our collective future prospects.

Naturally, this approach will be challenging, particularly if high-fidelity models are required. Some of the foundational work for this concept is discussed in "Reconsidering the Limits to Growth" by Sadovnichy et al. Additionally, we are exploring data-driven dynamical systems to aid in the study of complex systems involved in the concept.

The fundamental spheres of the world system are outlined below. Each sphere will be detailed in Section V, including the specific world system components they represent.

- **Sociosphere:** The structure of societies and their cultural, political, and social dynamics, including human behavior, values, and governance.
- **Econosphere:** Economic exchanges, wealth generation, resource allocation, and the interaction between economic systems and other spheres.
- **Technosphere:** The role of human-made systems and technological advancements, and their influence on economic and social development as well as environmental impact.
- **Biosphere:** Interactions within ecosystems, environmental resources, and the impact of human activity on natural processes.
- **Infosphere:** Information networks, media, data systems, and knowledge dissemination and information persistence in general.

C. Mission Principles and Goals

The World System Model is conceived as a living, evolving construct, born on a local supercomputer and designed for continuous growth. From its inception, the model expands in both scope and capability, integrating new phases of Proxima as they are developed.

Unlike conventional simulations, the model never resets to zero. Its history, accumulated state, and knowledge remain intact across updates. When improvements or additions are introduced, execution simply pauses; the system is updated; and upon restart, it resumes from the last known good state. This preserves continuity and ensures that every change can be studied in context, revealing long-term impacts as if they were unfolding in the real world.

The World System can be replicated—but never restarted from nothing—creating a persistent, cumulative record of its evolution. A publicly accessible online interface will allow anyone, anywhere, to observe its progress. This transparency provides a unique window into how the World System adapts, reforms, and matures over time.

To ensure successful implementation, each world system sphere will be developed by collaborative groups distributed across the globe. These groups must embody the following principles to align with Proxima's overarching mission:

- Multi-disciplinary expertise to ensure comprehensive approaches.
- Representation from diverse cultural and demographic backgrounds to capture a wide range of perspectives.
- Inclusion of varied worldviews to foster innovative and adaptive solutions.
- Commitment to Proxima's long-term goals, ensuring every contribution advances resilience, sustainability, and survival.

D. Mission Charter

Building upon the mission principles and goals, the Proxima Mission Charter provides a structured framework to ensure alignment, continuity, and actionable progress.

Principles: Proxima is grounded in persistence, adaptability, transparency, interdisciplinarity, and equity. The system must evolve without resets, reform in response to new information, remain publicly observable, integrate insights from multiple disciplines, and represent diverse cultures and perspectives.

Core Functions: At its heart, Proxima connects the major spheres of civilization—the Sociosphere, Econosphere, Technosphere, Biosphere, and Infosphere—into a single adaptive model. It tests alternative scenarios, evolves policies through reinforcement learning, measures long-term survival odds, and extracts actionable guidance from its outcomes. Beyond research, Proxima functions as a bridge to the real world, translating results into concrete strategies. These strategies will be advanced in collaboration with both nonprofit organizations, who ensure equity and ethical grounding, and for-profit entities, who can scale innovations and deliver practical impact.

Implementation Roadmap: Proxima begins with *World System Beta*, a controlled lunar testbed. Insights from Beta inform the expansion to *World System Alpha*, a global-scale model of Earth. From there, the model incorporates cross-system interactions between multiple world systems, ultimately converging toward a fully integrated framework capable of continuous adaptation and global application.

Collaboration: Implementation depends on distributed research hubs around the world, each focused on refining specific spheres. A shared parameterized database ensures common standards. Beyond academia, Proxima will establish action networks with civil society groups, governments, nonprofits, and corporations, linking simulation-derived guidance to decision-making and innovation pipelines.

Ethics and Responsibility: The Charter reaffirms that human agency remains primary. Proxima does not seek control but rather to inform judgment and foresight. It is designed to encourage planetary citizenship and interplanetary responsibility—acknowledging that survival depends on cooperation, foresight, and stewardship of shared systems.

III. Research and Development Approach

In this section we layout the overall approach for our research and development for the realization of Proxima. Given the large scale of the goal at hand and challenges involved in the realization of Proxima, the approach has been broken down into five major phases where each has its own sub-phases.

A. Starting Point

Starting from a contained and small world system where plans and specifications exist is crucial for developing a proof of concept. Currently, major countries around the globe have renewed their goals and efforts to achieve Lunar Permanence. The realization of this goal is underscored by the establishment of Artemis missions, structured in distinct phases.

The Artemis missions are designed not only to provide the transportation infrastructure required for easier and more reliable access to the Moon but also to lay the groundwork for long-term lunar habitation. These missions aim to establish habitats that will allow humanity to learn how to live and work in another world. Furthermore, Artemis facilitates scientific discovery by providing unprecedented opportunities to study the Moon's surface and resources.

A significant focus of the Artemis program is the development of technologies for In Situ Resource Utilization (ISRU), enabling the extraction and use of lunar materials to support sustained human and robotic presence. ISRU advancements are critical for reducing dependency on Earth's resources and ensuring the viability of long-term missions [13].

In addition to scientific and technological advancements, the Artemis missions aim to foster the establishment of a lunar economy. By enabling a collaborative framework between governments, private industries, and international partners, Artemis envisions a sustainable ecosystem that supports exploration, innovation, and commercial activity on the Moon [13].

To advance this vision, we select lunar base development and lunar permanence as the test ground for Proxima's proof of concept and our starting point. By beginning with existing lunar base specifications, we can create a small-scale model of a world system on the Moon. This phased approach will allow us to progressively incorporate and refine each world system sphere, establishing their interactions in a controlled environment. This model, referred to as World System Beta.

World System Beta represents the first controlled iteration of a cybernetic world system, where real-time adaptation, predictive foresight, and emergent societal dynamics can be observed, tested, and refined. Through continuous interaction with Proxima's world system model, it will provide actionable insights into the viability of interplanetary governance, decentralized resource management, and self-sustaining civilizations.

By leveraging complex system dynamics, agent-based modeling, and cybernetic governance, World System Beta lays the groundwork for multiplanetary civilization survival and explorative long-term decision-making platform. This isolated testbed ensures that humanity's transition beyond Earth is not just a reaction to crises but a deliberate and scientifically guided evolution.

B. Implementation of World System Alpha

Based on developments from World System Beta, each sphere will be studied in depth and adapted for integration into World System Alpha. Given the larger scale and maturity of Alpha, this effort will pose significant challenges and demand considerable time and resources.

Each sphere's development will adhere to a platform that remains independent of any specific target world system. The following aspects of each sphere will be defined and considered:

- Subtypes of the sphere
- Components
- Policies
- Desired attributes and characteristics
- Target outcomes to measure sphere performance against.
- Interactions with other spheres
- Inputs
- Outputs
- Internal dynamics
- Emergent properties

Additionally, the current state of each sphere within our existing world system will be analyzed, focusing on:

- Challenges
- Positive and negative impacts
- The initial state at which development begins
- Advancements achieved thus far

This structured approach ensures that the lessons learned from World System Beta are effectively scaled and adapted to the complexities of World System Alpha, paving the way for a comprehensive and resilient model of global system development.

Another challenge to overcome is the integration of all spheres to compose our World System Alpha. This will require significant computing power. However, with the current advancements in distributed computing, we have the advantage of leveraging various computing modules across the globe while maintaining seamless communication.

We will have a central computing system that will act as the core of Proxima, representing our civilization's odds of survival as World System Alpha evolves. Each world system sphere than will reside on different computing modules.

C. Interactions of World Systems

All the current conversations around humans becoming multiplanetary species requires overcoming of significant challenges. These concerns are not only technological but also ethical and social ones.

Examining perspectives from philosophers like Edgar Morin reveals the notion that humanity remains in a "Planetary Iron Age." Despite advancements in technology that enhance communication and relationships, our mindset continues to be fragmented by national boundaries, beliefs, and ideologies. Although we share the same planet, our actions and way of life do not reflect this shared reality. Globalization, Morin argues, does not equate to recognizing ourselves as "planetary citizens" (Chon-Torres & Murga-Moreno, 2021).

Another consideration is that for humanity to occupy another celestial body, we must rely on resources from our current World System Alpha and undertake intensive processes, including defining new policies. This will continue until the second world system becomes fully occupiable and self-sufficient. Consequently, any initial development of a new world system will heavily depend on World System Alpha. This raises an important question: how will World System Alpha be impacted by this reliance, and will it diminish or enhance humanity's odds of survival in the interim?

It is clear, therefore, that world systems must interact within our models. Intra-world system dynamics need to be accurately captured and represented within a feedback loop to ensure a comprehensive understanding of their interdependence and mutual influence.

D. Full Scale Integration of World Systems with Live Adaptation/Reformation

In this phase of development, after establishing world system spheres, their interactions, and intra-world system dynamics, the world system models can run continuously, adapting to introduced policies, decisions, and anthropogenic or natural events. The adaptation includes constant reformation of policies as needed to ensure world system operates within desirable outcomes.

This is the phase where we can observe the full growth and interaction of the world systems as they adapt and reform. To do so, a series of carefully defined experiments will have to be defined to allow us to study the dynamics of the model and its outputs.

E. Generalization and Real-World Applications

In this final phase, the Proxima model can be generalized and refined based on experiments and observations from previous phases, enabling its application to real-world scenarios to its full extent. However, this phase still contains many unknowns and uncertainties. As progress is made in earlier phases, the specifics of this phase can be refined and adjusted, with course corrections applied if necessary.

IV. Initial system definition

To realize the vision of a dynamically adaptive and future-oriented Integrated World System within the Proxima framework, a modular and systemic simulation architecture is essential. This simulation design brings together the technosphere, biosphere, econosphere, sociosphere, and infosphere into a co-evolving system of systems. It emphasizes interoperability, modularity, feedback-driven adaptation, and the capacity for continuous experimentation with policies, events, and emergent behaviors.

A. Dynamics

The world system dynamics are broken down into functional categories of agent evolution (world system component and sub-component), world system evolution, world system performance, human survival rate, and impacts on external environment, in this case cislunar environment.

Agent Evolution:

Each agent's state X_t evolves based on its previous state, policies, and external events. And ideal mathematical representation of agent's evolution in linear state-space form can be written as.

$$X_t = AX_{t-1} + BP_t + CE_t$$

Where:
- $\mathrm{X_t}$ agent state at time
- A agent transition matrix
- B policy influence matrix
- C external event influence matrix
- $\mathrm{E_t}$ externally, injected events at time t
- $\mathrm{P_t}$ agent policies at time t

Agents can adapt their policies based on injected policies, current polices, agent state, and world system goals.

$$P_t = P_{t-1} + K(X_t - X_{t-1}) + G + P_t^*$$

Where:

- K policy adaptation matrix
- $\mathrm{P_t^*}$ externally injected policies
- G world system goals

Agents can be initialized with world system goals, and initial set of default policies before world system starts evolving. Initialization function is represented as $\mathrm{f(.)}$.

$$X_0 = f\,(G_0, P_0)$$

Evolution of each agent can be then represented in an integrated form of:

$$X_t = (I - BK)^{-1}\,((A - BK)X_{t-1} + BP_{t-1} + BP_t^* + BG + CE_t$$

World System Evolution:

The world system is essentially aggregation of its components and sub-components. Combination of components for virtual world system spheres where one component may be in one or more world system spheres. (i) is the component index (e.g., economy, technology, governance, etc.).

$$X_{i,t} = A_i X_{i,t-1} + B_i P_{i,t} + C_i E_{i,t}$$
$$P_{i,t} = P_{i,t-1} + K_i\left(X_{i,t} - X_{i,t-1}\right) + G + P^*_{i,t}$$

Given the aggregates then the overall world system state can be shown as:

$$X_t^{WS} = \sum_{i=1}^{N} \omega_i \, X_{i,t}$$

Where:

- ω_i is a weighting factor representing the importance or contribution of each component.
- N is the total number of components.

$$X_t^{WS} = \sum_{i=1}^{N} \omega_i \, A_i X_{i,t-1} + \sum_{i=1}^{N} \omega_i B_i P_{i,t} + \sum_{i=1}^{N} \omega_i C_i E_{i,t}$$

World System Performance:

The performance of the world system is a function of system state deviations from world system goals and policy effectiveness.

$$P_t^{WS} = \sum_{i=1}^{N} \omega_i \, P_{i,t}$$

$$W_t = \alpha_1 \|X_t^{WS} - X_G\| + \alpha_2 \left\|P_t^{WS} - P_{optimal}\right\|$$

Where:

- X_G desired world system goals, state
- $P_{optimal}$ optimal policy set
- α_1, α_2 scaling parameters
- $\|.\|$ Euclidean norm (measures of deviation)

Human Society’s survival rate on long term timescales:

The survival odds of the society in long future timescales Is essentially based on world system performance, policy effectiveness, and world system stability. There are many ways to incorporate the survival rate probabilities. In a simplified form, the survival rate can be shown as the following.

$$S_t = S_{max} \exp\left(-\beta_1 \|X_t^{WS} - X_G\| - \beta_2 W_t\right)$$

Where:

- S_{max} maximum survival probability
- β_1, β_2 decay parameters, controlling how deviations affect survival

Impact of world system state on external environment:

In case of world system beta, the external environment is considered as cislunar environment. If new world systems are built, impact on external environment is a key factor to consider, as the external environments link world system together, in a way that world system states might be impacted through indirect connections.

This impact on Cislunar environment can be represented as the following.

$$E_t^{CIS} = \gamma_1 E_{t-1}^{CIS} + \gamma_2 X_t^{WS} + \gamma_3 N_t - \gamma_4 P_t^{MIT}$$

Where:

- N_t are the external natural processes of cislunar environment
- P_t^{MIT} are the policy-driven mitigation efforts
- γ_1 controls how much the previous environmental state persists
- γ_2 represents impact from the world system (pollution, resource extraction, etc.)
- γ_3 represents natural cislunar processes affecting the system.
- γ_4 represents mitigations actions, which reduce chaos and environmental degradation

With the environmental impact in mind, the system performance, and human civilization's survival rate presentations can be modified as following.

$$W_t = \alpha_1 \|X_t^{WS} - X_G\| + \alpha_2 \|P_t^{WS} - P_{optimal}\| + \alpha_3 \|E_t^{CIS} - E_{goal}^{CIS}\|$$

$$S_t = S_{max} \exp\left(-\beta_1 \|X_t^{WS} - X_G\| - \beta_2 W_t - \beta_3 \|E_t^{CIS} - E_{goal}^{CIS}\|\right)$$

B. Architecture Overview

As illustrated in the High-Level Integrated Flow Diagram, the overall structure is hierarchical and modular:

- The Integrated World System Model (IWSM) acts as the central container, maintaining synchronization and coherence across all spheres.
- Each World System (WS) Component corresponds to one of the key spheres—technosphere, biosphere, econosphere, sociosphere, or infosphere—and is subdivided into specialized Subcomponents.
- These subcomponents represent functional domains (e.g., transportation networks, climate feedbacks, financial systems, social norms, or media ecosystems) and are governed by tailored simulation methods and internal logic.

To enable global collaboration, all specifications, parameters, and configurations for these components are stored in a centralized parameterized database. This database infrastructure allows multiple contributors, institutions, and simulation hubs around the world to co-develop and co-validate parts of the model in a standardized format.

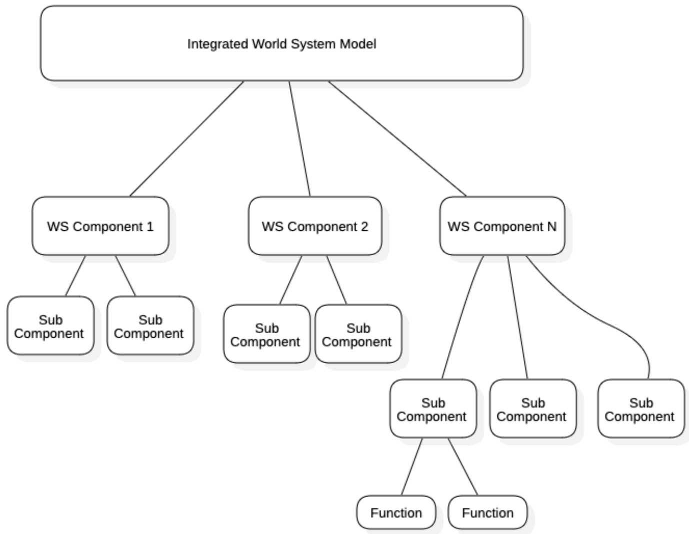


Figure 1 World System Model Breakdown

C. Simulation Control Logic

The Simulation Flow Diagram presents the step-by-step execution process for the system:

World System Configuration: Load all WS components, structures, parameters, and their interconnections from the database.

Setup WS Components: Initialize individual sphere models and their internal subcomponents.

Load Initial Policies: Introduce predefined governance structures, legal systems, economic rules, and social settings.

Load World System Goals: Define long-term global objectives, such as planetary health, social resilience, economic equality, or technological sustainability.

Run World System: Enter iterative time-stepped simulation, updating the state of each component based on interactions and feedbacks.

Inject Events and Policies: Allow for dynamic injection of unexpected events (e.g., pandemics, AI breakthroughs, ecological collapse) and new policy interventions during simulation.

Update World System State: Recalculate all component states, metrics, and cross-sphere effects in response to internal dynamics and external interventions.

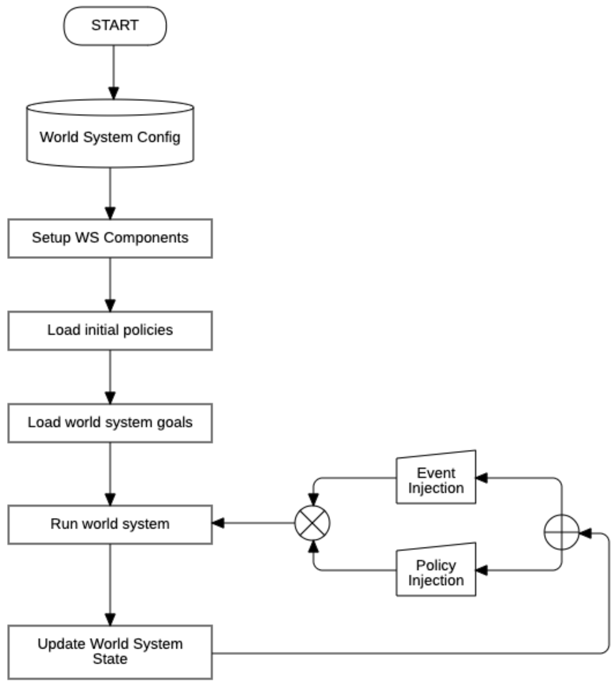


Figure 2 Simulation Flow Diagram - High Level Concept

Proxima adopts a goal-first, policy-from-data loop rather than traditional hand-crafted policy design. We declare high-level goals, run the world system, and let reinforcement learning search the control space to discover policies that meet those goals under constraints. From the resulting trajectories, we perform system identification and policy distillation to extract compact, human-readable policy equations (e.g., parametric rules or MPC-compatible forms), then re-insert and test those policies in simulation for stability, safety, and performance. This approach leverages RL's ability to find non-obvious strategies in complex, coupled environments, while ending with interpretable, auditable policies suitable for governance and deployment.

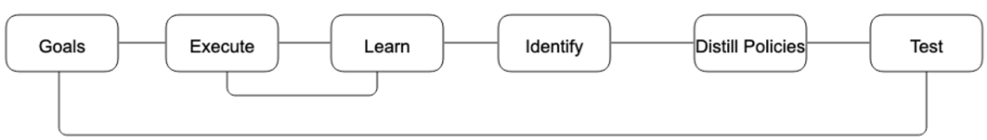


Figure 3 Reverse Policy Identification

D. Sphere Specific Modeling Techniques

Some of the techniques under consideration for modeling each sphere are listed in this section. This list by no means is a comprehensive list and might very well change. However, it helps paint a picture of type of modeling considered for each sphere.

- **Technosphere**: Infrastructure network analysis, technology diffusion models, mixed-integer optimization, Petri nets for manufacturing systems.
- **Biosphere:** Earth system and climate models, ecological network simulation, population dynamics (e.g., Lotka-Volterra), stochastic feedback models.
- **Econosphere:** Agent-based economic simulations, input-output analysis, computable general equilibrium (CGE) models, system dynamics models.
- **Sociosphere:** Social network modeling, opinion dynamics algorithms, institutional rule systems, and cultural evolution models.
- **Infosphere:** Information diffusion algorithms, cybernetic feedback models, semantic knowledge graphs, and entropy-based complexity measures.

Each sphere interacts with others through defined interfaces, shared variables, and feedback mechanisms—allowing, for example, economic activity to impact environmental health or social cohesion to influence technological adoption.

E. Multi-Scale and Multi-Method Integration

To capture the interdependent nature of the world system, Proxima will employ hybrid modeling approaches:

- Agent-based models (ABM) to represent individual actors and adaptive behavior.
- System dynamics (SD) for modeling aggregated flows, feedbacks, and thresholds.
- Differential equations for modeling physical and ecological processes.
- Game theory and optimization algorithms to simulate strategic decision-making.
- Machine learning techniques to uncover patterns, forecast trends, and optimize complex interactions.

These methods are integrated through shared ontologies, synchronized update cycles, and event-driven cross-component messaging, ensuring that each model remains context-aware and interconnected.

F. Experimentation and Post-Processing

The Proxima platform will be designed to support deep experimentation and exploration of alternative futures. Key capabilities include:

- Injection of historical, hypothetical, or extreme scenarios to stress-test the system.
- Real-time testing of adaptive policies and governance innovations.
- Monitoring of cross-sphere health indicators and survival odds.
- Generation of alternative future pathways through scenario branching and policy permutations.

All simulation runs will be logged and available for analysis, enabling post-simulation evaluation through statistical tools, network metrics, or AI-based diagnostics to identify leverage points, emergent threats, and possible attractor states.

V. A SURVEY OF WORLD SYSTEM SPHERES

A. Biosphere

The biosphere is the sum of all ecosystems on Earth, forming a dynamic and self-regulating system where life interacts with the atmosphere, lithosphere, and hydrosphere. It encompasses all environments where life exists, from the deepest ocean trenches to the highest mountains, spanning approximately 20 kilometers in thickness. The concept of the biosphere was first introduced by Austrian geologist Eduard Suess in 1875 and later expanded by Vladimir Vernadsky, who emphasized its role in shaping Earth's environment over billions of years. Vernadsky's work highlighted that the biosphere is not just a passive layer but an active geological force, influencing planetary processes through biological and ecological interactions. Today, human activities, technological advancements, and climate change have significantly altered the biosphere, leading to discussions on the Anthropocene—the current era where human influence dominates natural processes [17].

B. Technosphere

The technosphere is a planetary-scale system encompassing all human-made technological and infrastructural components that sustain and shape modern civilization. It is an emergent sphere of the Earth system, deeply intertwined with the biosphere, but distinct in its composition, dynamics, and impacts. According to Galbraith et a. (2024), technosphere can be defined as, all non-food matter extracted from other spheres of the Earth system and transformed to novel states that achieve end-uses intended by humans [15].

The technosphere is a highly dynamic component of the Earth system, undergoing constant internal transformations while driving large-scale environmental changes, such as climate shifts and habitat destruction. Its origins can be traced back to early human tool-making, with stone and wooden tools emerging around 3 million years ago (Otter, 2022). [15]

It is worth noting that Haff (2014) presents the technosphere as a quasi-autonomous geological phenomenon governed by systemic physical laws, such as the principle of maximum entropy production. From Haff's perspective, while human agency played a crucial role in its initial development, technological systems have since evolved beyond direct human control. This challenges conventional perspectives by framing human progress as just one aspect of the broader dynamics of the technosphere, rather than its guiding force.

With respect to Proxima and its goals however, no assumptions are being made with this regard, weather humans are in control of the technosphere or not. The goal of Proxima is to explore these scenarios on long future timescales.

The concept of the technosphere has been categorized in various ways by different institutions and academic papers. However, across all classification schemes, certain foundational components—such as transportation, energy infrastructure, and communication—remain consistent.

For Proxima, we adopt the categorization framework proposed by Galbraith et al. (2024), with a few distinct modifications. Notably, under the "information" category, we include only infrastructure as part of the technosphere, as we find it necessary to designate a separate sphere solely for information, given the prominence of big data in the modern era. Another key distinction is the establishment of a dedicated major category for energy infrastructure. Additionally, we incorporate technology transfer and diffusion, research and development (R&D) institutions, and universities under the category of technosphere creation and maintenance, acknowledging their critical role in sustaining and advancing technological systems.

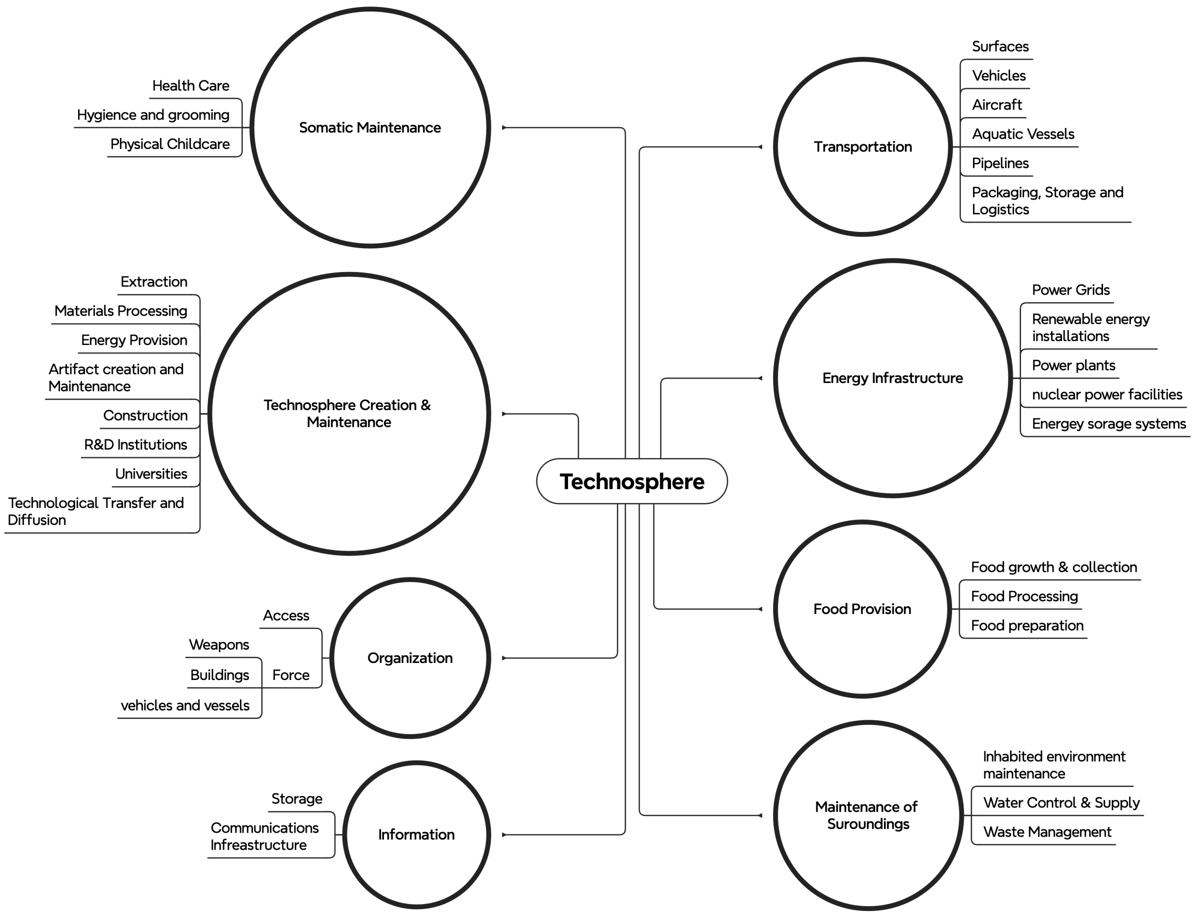


Figure 4 Technosphere Component Categorization

C. Econosphere

In the context of the Proxima world system architecture, the Econosphere represents a dedicated sphere encompassing all economic dimensions of civilization. It is conceptualized not merely as a subset of societal functions, but as a complex, dynamic, and interdependent component of the world system—deserving focused analysis in its own right.

At its core, the Econosphere includes systems and structures such as markets, trade, financial institutions, employment mechanisms, and consumption patterns. These are not viewed in isolation but rather as interwoven elements that collectively shape economic exchanges, drive wealth generation, and mediate the allocation and circulation of resources. The dynamics within this sphere influence and are influenced by other spheres.

What distinguishes the Econosphere in the Proxima model is its treatment as a natural and emergent sphere, much like the biosphere or technosphere. This framing allows us to analyze economic behavior as a product of systemic interactions—not only between human actors, but also across ecological, technological, and informational domains. The dedicated focus on the Econosphere enables a more rigorous understanding of how economies adapt, transform, or collapse in the face of internal inefficiencies or external shocks.

According to Craig Thomas “the Econosphere is our social environment, where we work, live, raise our families, and govern ourselves. We need to start thinking about the economy as a holistic, natural system.” [19]

Aligning with Thomas’s view, Proxima treats the Econosphere not merely as a functional domain of economic exchange, but as a quasi-organic subsystem with emergent properties. It is shaped by human behavior, intention, and institutions, yet also subject to systemic constraints comparable to those found in natural systems—such as energy input limitations, feedback dynamics, and inter-sphere dependencies.

The inclusion of the Econosphere as a standalone sphere within Proxima reflects a commitment to systems thinking. It invites us to develop policies and simulations that can trace not only the direct economic outcomes of decisions but also their second- and third-order effects across biospheric resilience, technological innovation, social cohesion, and long-term survival odds.

D. Sociosphere

The sociosphere, as described by Tolba (1980), refers to the sphere encompassing human needs, values, and aspirations. It represents the human-constructed system of intangible structures—such as institutions, norms, and social constructs—that govern both internal societal relations and interactions between society and other spheres of the world system. This includes the full range of socio-political, socio-economic, and socio-cultural institutions and capacities that shape human civilization. The sociosphere has evolved over centuries, incorporating both enduring elements from the past—like religious traditions, legal systems, and cultural legacies—and continuously emerging ones, such as new laws, political reforms, and contemporary social movements [20].

In weaving the social sphere and human behavior into the fabric of the Proxima system, several key methodologies stand at the forefront, each offering a unique lens through which to explore survival rates and enhance the system's capabilities for self-regulation and adaptability. The integration of these methodologies underscores Proxima's comprehensive approach to understanding the complex interplay between human societies and their environments. Here's how these considerations could be articulated and utilized within Proxima:

1. Macrohistorical patterns
2. Past climate states
3. Archeological data
4. Rise and fall of civilizations
5. Established psychological patterns: Feedback loops from human psychology
6. Cultural and ideological mapping

E. Infosphere

The concept of the infosphere has been discussed across multiple disciplines, each offering unique perspectives on its scope and significance. While traditionally, information infrastructure has been considered a subset of the technosphere, the exponential growth of data generation, processing, and dissemination in the information age necessitates the recognition of a distinct and autonomous sphere dedicated entirely to information.

In the context of Proxima, the infosphere is envisioned as an invisible yet omnipresent layer that permeates all other spheres within a world system. It is composed not of physical matter, but of information itself—structured, unstructured, dynamic, and persistent. Like the biosphere governs life and the technosphere governs tools and machines, the infosphere governs informational dynamics: flows, storage, entropy, and feedback.

Despite our increasing reliance on data, humanity struggles with information persistence—the ability to retain, contextualize, and act upon accumulated knowledge over time. This systemic shortcoming is evident in the repetitive nature of our collective failures across political, social, and technological domains. We often reinvent the wheel, repeat past mistakes, and lose hard-won insights due to fractured or ephemeral information ecosystems.

In Proxima's world-system design, the infosphere is not merely a passive repository; it is a critical active agent for systemic memory, adaptation, and foresight. Its integration aims to ensure that civilizations—whether human or post-human—can overcome limitations of cognition, memory, and coordination. The goal is to build infrastructures and protocols that allow knowledge to persist across generations and transformations, enabling true globalization of intelligence and culture.

By embedding the infosphere as a foundational layer in all Proxima systems—whether on Earth, the Moon, or beyond—we move closer to designing self-reflective, self-improving, and genuinely adaptive world systems. This is essential not only for survival but for the evolution of civilization itself.

VI. Conclusion

Proxima is more than a theoretical exercise—it is a call to action. It invites scientists, technologists, philosophers, policymakers, artists, and citizens from all walks of life to participate in a bold and necessary endeavor: building a framework for understanding and improving the conditions of long-term human survival.

By embracing the complexity of our global civilization and acknowledging the fragile interdependence between ecological, technological, economic, and social systems, Proxima lays the foundation for a new kind of collaboration—one rooted in foresight, systems thinking, and a shared commitment to future generations.

This proposal is not the end, but the beginning of an open, global, and ongoing conversation. The tools to explore our collective future already exist; what’s needed now is the will to use them. Let this be an invitation to join in constructing, refining, and expanding Proxima. The future remains unwritten—together, we can help shape it with wisdom, creativity, and courage.

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