Evolutionary principles shape the health of humanity as a planetary-scale organism

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Abstract

A study of human social systems at planetary scale examines whether our technology, economy, culture, and flows of information are component-processes in a unified, living system. Through a biological lens of structure, function, and geographic mapping of social systems, we consider this total human ecosystem from evolutionary and developmental principles. The health of this system depends on its capacity for preservation *and* innovation, that is, beyond mere survival. We focus on how principles of evolvability are utilized by planetary-scale systems for innovation and plasticity. Information and communication technologies irreversibly interconnect humanity: the preservation of this socio-technological niche, and further innovation thereof, could facilitate a major evolutionary transition from ecosystem to organism. Here, we explore how this principle of evolvability underpins the One Health of the total human ecosystem, as a resilient, planetary-scale human organism.

Introduction

Life often shows up where we least expect it. Previously the realm of speculation, investigations of human phenomena at planetary scale have recently yielded novel insights. The controversial concept of an Anthropocene epoch, marks the first attempt to examine how a single species, *Homo sapiens*, has left an indelible impact on the planetary geosphere in such a short amount of time (Crutzen 2010). Part of the impact of humanity on the planet is due to rapid changes in technology, in what has been called the "technosphere:" the interlinked communication, transportation and structural features of the built environment that alter energy flows in ecosystems (Haff 2014). This network is now extended to an "infosphere," (Floridi 2014) with globally circulating information, now largely seen as synonymous with the internet. The functionality and intersection of these human-driven, planetary-scale spheres, raises the possibility of an evolutionary progression that could give rise to a form of planetary intelligence (Frank et al. 2022).

This evolutionary progression raises urgent questions about the biology of human technology at planetary scale; whether these spheres form a complex ecosystem or reflect component processes in a singular organism capable of biological cognition (Shoshitaishvili 2021, Frank et al. 2022, Vidal 2024). What might facilitate a transition from ecosystem to organism? What distinguishes collective or planetary-scale cognition? And, most relevant to this issue: what might it mean for this organism to be healthy and flourishing? When we speak of ecosystem health: we often adopt organismal principles as indicators: "vigor", " functional "organization," and "resilience" (Rapport et al. 1998). These assessments refer to the ecosystem as a whole, a system which is not generally thought to be living as an individual unit. Nonetheless, to invoke "health" is also to evoke the medical model, which necessitates understanding pathology, pathophysiology, and therefore, physiology and anatomy, which must be understood as component-processes in a whole organism. The current instantiation of the One Health concept and its historical precursors has its roots in the medical sciences (Br and Fa 2014). With the possible exception of theorizing around Gaia (Hancock 2022), less work has considered extending a physiology-focused, One Health framework to the planet, or humanity as a whole. Therefore, distinguishing between the ecological and organism-like principles of planetary-scale human phenomena is crucial to evaluate our One Health at planetary-scale.

In our previous work, we hypothesized a generic conceptual framework for biological organisms (Jacob 2023). Here we expand this model to evaluate the health of the total human ecosystem (Naveh 2000) and consider humanity, our technology, culture and economy as a living, developing organism. The concept of health in an individual human is defined as *well-being* (at least according to the WHO) a broader concept that captures resilience and adaptability (Wulff et al. 2015). Health, as commonly articulated, is not merely the absence of disease, but the flourishing of the individual, community, and we will extend this concept to the total human ecosystem as organism. Our model examines two primary organismal modes that enable resilience and health: 1) preservation, and 2) innovation. The balance of these two processes work synergistically to enable the health of the organism- its continuity of identity (preservation)- as well as its capacity for novel technology (innovation) to address unforeseen challenges that undermine health.

Although technology is typically considered in material form and limited to humanity, with respect to biology and organisms, technology can take more generic forms, from tools to communication (Seed and Byrne 2010, Visalberghi et al. 2017, Tomlinson 2023). The human capacity for symbolic communication, and social communication more generally, is a defining attribute of our species and its ongoing evolution (Deacon 1998, Tomlinson 2018). As a result, information and communication technologies (ICTs) have yielded a dramatic technological expansion that has irrevocably altered humanity and the planet. In the sections that follow, we explore the hypothesis that human produced, planetary-wide technology can fulfill multiple functions as part of a major evolutionary transition from ecosystem to organism. First, we articulate an overarching bifocal theme that simultaneously examines our technology through evolutionary and developmental perspectives; a novel formulation of “evo-devo.” Next we examine the recent evolutionary history of technological growth and connectivity, focusing on niche construction, material inheritance, and resulting demographic changes. This technological connectivity establishes a primary mode of preservation, necessary to sustain humanity at planetary scale. The economic and sociocultural mechanisms that enable further cycles of innovation are then discussed through theories of evolvability. Lastly, we consider the emergence of a planetary infosphere as enabling knowledge-based inheritance and the possibility of planetary-scale cognition to support its health and resilience.

The global impact of this human technosphere is unquestioned: its total mass now exceeds the biomass of the planet (Elhacham et al. 2020). Given this and the manner in which the technosphere and infosphere are inextricably entangled with humanity, the health of humanity and countless other species depend on how our technology is metabolized. A One Health framework, as a planetary-scale organism, helps to define the fundamental physiologic parameters that distinguish our well-being as a whole, from a collective ecosystem. The total human ecosystem has no particular impulse to survive, beyond its human individuals. However, our interdependence caused by globally shared technology creates an environment in which the persistence of this interdependence becomes a goal, in and of itself. This creates the possibility of a singular, planetary identity to galvanize long-term planning and the globally scaled cognition necessary to sustain a healthy planet. We argue that this aspect of One Health *is* the health of this planetary-scale organism, enabled not only by the preservation of this interdependence, but innovation to face unforeseen changes and establish resilience for our planetary home.

The Evo-Devo Perspective

We focus on the aspects of the total human ecosystem that not only establish foundational structures and sustain functions across the planet, but perhaps more importantly, permit their ongoing development, evolution and health. Our work extends the trend that blurs the boundaries of ecology, evolution, and development, the so-called evo-devo or eco-evo-devo model (Müller 2007, Gilbert et al. 2015, Watson et al. 2016). A study of the total human ecosystem, as an organism, can be seen as the quintessential "evo-devo" field given the extent to which it blurs the distinction between evolutionary and developmental processes. That is, what is development at the scale of a novel organism, could involve evolutionary processes occurring at smaller scales within it. When the trends of the total human ecosystem are examined longitudinally, over a geologic time scale, seemingly passive processes of succession are instead seen as active processes of increasing connectivity, differentiation, integration and functional specialization. All of this begins to appear like a developmental process. When viewed over shorter timescales, planetary-scale humanity appears to be operating on evolutionary mechanisms relevant to persistence and innovation.

To bridge these evo-devo concepts, we focus on technology and information as forming a central, structural axis through which the structure and function of a human, planetary-scale organism can both persist and be evolvable. Persistence depends on the conservation of identity, core infrastructure and functionality. We extend Doolittle's proposal, to consider persistence as evidence for selection, and that can distinguish a planetary-scale organism from an ecosystem (Doolittle 2017). Selection for persistence depends on underlying systems and patterns that demonstrate continuity of identity. We investigate how continuity of identity has developed out of and through planetary-scale technology, and further, how technological developments have also powered evolvability through innovation. Evolvability is itself an evolving term, but includes genetic definitions that emphasize accelerated variation, and extragenetic processes such as niche construction that shape the effect of variation, or selection to increase the probability of evolutionary innovations for a population (Brown 2014, Riederer et al. 2022). Ultimately, we argue that evolvability is entangled with health (Nunn, 2015), most clearly in the sense that organisms utilize the principles of evolvability - translated here as innovation and plasticity - to dedicate resources for resilience and anticipation of unforeseen stressors (beyond just fitting to the environment).

In order to apply these evolutionary concepts to the health of a planetary organism, we must start by defining its structural body and physiology by examining systems that coordinate information and energetic exchange. Specifically, we propose that human populations and our technology are a part of its structural axis, culture and economy are part of its physiologic axis, and collective information processing coordinates structure and function. It is, of course, artificial to distinguish between structure and function in this manner, since living systems don't have a distinct component-process for structures in the body nor a separate component-process for function. Nonetheless, by emphasizing these two "axes," our model offers a framework to delineate the evolutionary-developmental trajectory of a planetary-scale human organism (Figure 1). In the sections that follow, we consider each of these proposed component processes to examine their developmental trajectory, particularly over the past 100 years of planetary scale phenomena.

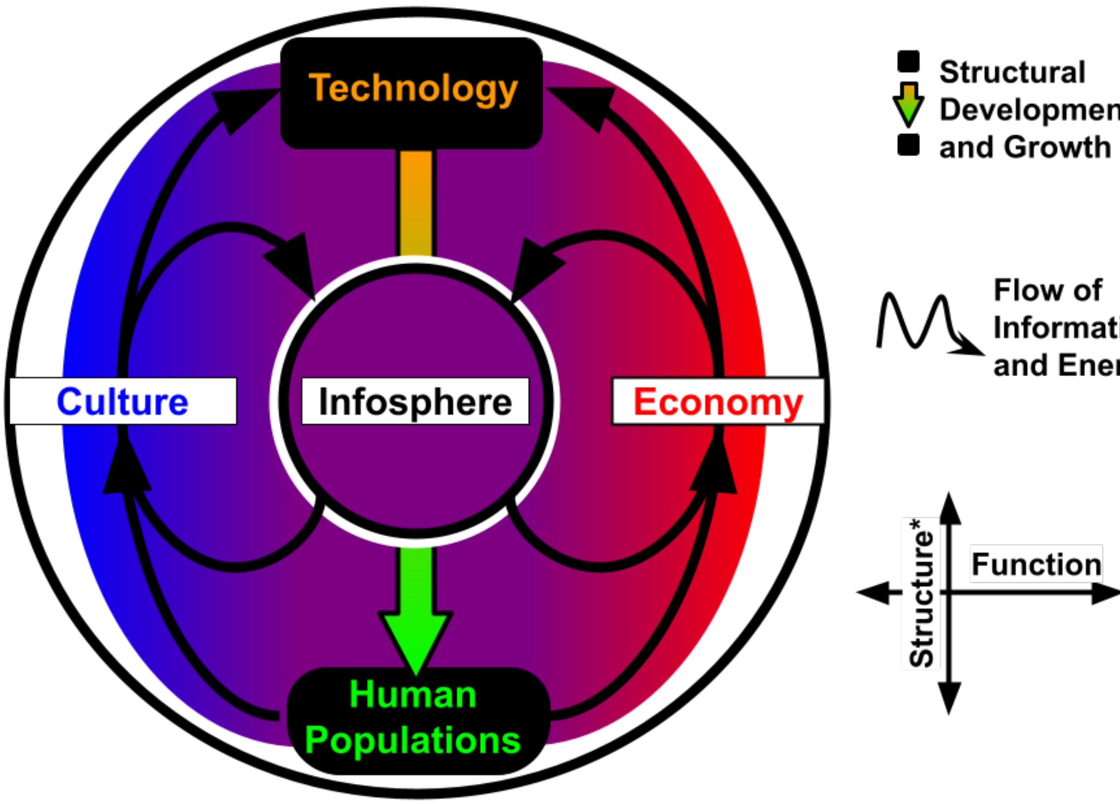

Figure 1. Structure and function of component-processes in a planetary-scale human organism. Structural changes occur over geologic time scales to form the developmental "axis," impacting human populations and the technological infrastructure necessary to support them. The dynamics of economy and culture form the functional "axis," which is necessary to support the year-over-year function of technology, as well as long-term growth and development. Both processes intersect in the infosphere, which guides development supported by persistence and innovation.

Technology as Niche Construction at Planetary Scale

For the first time in the history of the earth, the sheer mass of human derived products exceeds the biomass of the planet (Elhacham et al. 2020). The dramatic communicative and economic activities of humanity are not possible without stably conserved material products; what is known as material inheritance (Ellis 2015). Societies depend on such products, that like the extracellular matrix of a cell, bind us together. Cement, steel, plastic and ammonia (largely fertilizer) are not readily replaceable by other materials and represent 17 percent of the world's primary energy supply. Approximately 4.5 billion tons of cement, 1.8 billion tons of steel, 370 million tons of plastics, and 150 million tons of ammonia; yielding 25 percent of all CO_2 emissions from the combustion of fossil fuels (Smil 2022). Determining how these materials are metabolized into the ecosystem is a critical concern, but forecasts of use are widely varying (Eufrasio Espinosa and Lenny Koh 2024). Development of an organism based model might provide benchmarks for determining which products must remain in production to establish core infrastructure, and how to do so sustainably (Holechek et al. 2022). Thus, we were motivated to consider technology and its development as an organic process that could be viewed through an evolutionary lens. In this section, we focus on material inheritance, niche construction and scaffolding for further innovation, topics that lay the groundwork for the sections that follow.

The core aspect of the technosphere forms something that might appear as an “exoskeleton” for humanity. Some of this infrastructure is in active use, while other historical components may be like a molting remnant or “exuviae;” fossils of the developmental anatomy of a planetary scale living system. As noted, this infrastructure establishes material inheritance (Ellis 2015), a nongenetic form of inheritance that increases our chances of survival (Bonduriansky and Day 2009). Material inheritance, most notably the industrial products such as buildings, roads and networks for energy supply and communication, provide the next generation with a conserved system that supports societal persistence. However, this technology accumulates from generation-to-generation and could be built with an emphasis on repair and maintenance, rather than disposal (Graham and Thrift 2007). Implementing more sustainable approaches may depend on how we conceptualize our relationship to each other, the environment, and particularly at planetary-scale. While planetary-scale models, such Gaia theory have had an outsized media impact on public perception of sustainability (Litfin 2013), emerging work suggests that human social connection and shared identity are critical drivers of sustainability in daily life (Mackay et al. 2021; which we will explore in more detail in the section on "Planetary Identity.")

The ongoing development of technology and infrastructure can be seen as a means for scaffolding new functions (Meulman et al. 2012, Mann and Patterson 2013, Visalberghi et al. 2017, Jacob 2023), such as global telecommunication networks that have replaced roads for trade. When human produced technology is stable and materially persistent, other core functions for humanity (such as trade and communication) can become offloaded onto newer technology (from roads to communication cables etc.). As a result, technological innovation is enhanced through the release from previously required functions, similarly to Kauffman's adjacent possible (Kauffman 2000, 2014) and Deacon's formulation of relaxed selection (Deacon 2022). This process whereby traits that originally evolved for one function became co-opted for new functions is also known as exaptation - an evolutionary biology concept described by Gould and Vrba (1982). On a planetary scale, an example would be how early trade routes - initially utilized for trade - were exapted for digital communication. Similarly, the development of the planetary infosphere, in the form of the internet, was first preceded by a massively global infrastructure via the physical connectivity of roads and communications cables co-occurring with a stabilization of populations and economies. This innovating pattern of evolutionary development will be discussed in detail, in our section on "Planetary Metabolism."

Archaeological theories of human cultural evolution emphasize our heightened capacity for niche construction, which is the shaping of the cultural and technological environment, that in turn supports our evolution (O'Brien and Lala 2023). But as distinct from traditional niche construction, these sociocultural and technological environments could become "internalized" as the milieu intérieur for a planetary-scale organism, and as a heritable feature (Laubichler and Renn 2015). A similar scaffolding via social niche construction has been proposed in the emergence of multicellularity (Ryan et al. 2016). Thus, human technology appears unique in that it serves as a stable material inheritance *and* a mechanism for scaffolding further innovation, which itself may be a heritable feature. In the sections that follow, we will examine how technological innovation mirrors critical developmental processes and the cultural, economic and evolutionary mechanisms underlying its development toward a planetary scale organism

Critical Periods of Growth and Connectivity

The emergence of this materially core infrastructure and the novel technologies it affords, appears to have yielded a critical period in development. This impact is evidenced by urbanization and humanity's dramatic population growth over the 20th century, a growth that is well captured by a sigmoidal curve (and the phrase "great acceleration," (Shoshitaishvili 2021)). Such growth rates are foundational in population ecology, but also during periods of development (Zonneveld and Kooijman 1993, Ricklefs 2010). Historical Malthusian descriptions of a population "bomb" have given way to a more complex planetary transition period, characterized by high degrees of divergence between developed and developing countries (Bongaarts 2009). This divergence has led to new sociocultural models in order to make sense of fertility changes, particularly arising as a result of urbanization (Gries and Grundmann 2018). Human population dynamics are coupled to technological development in a manner that distinguishes our growth from other species as distinct sociocultural transitions (Kendal et al. 2011), appearing like a developmental critical period.

During critical developmental periods, the rate of cell genesis, differentiation, and connectivity vary dramatically to support growth and emerging functions in the organism (Estrin and Bhavnani 2020). Specific environmental factors during developmental critical periods must be present to determine the long-term health and resilience of a developing organism (Cameron and Demerath 2002). Across the planet, dramatic periods of growth have preceded technological innovation and connectivity, with younger generations driving cultural creativity and adoption of new technology (Jones 2020). As connectivity is concretized through urbanization, population growth and fertility rates reflect complex interactions between resource availability and socio-cultural phenomena (Chabé-Ferret 2019). Deceleration of population growth may beneficially offset climate change (Dodson et al. 2020), while a severe reduction in fertility may undermine societal stability (Bricker and Ibbitson 2019) and with likely interactions between these phenomena. Therefore, demographic changes have unanticipated and reverberating effects from nested feedback cycles with technological changes. These effects must be examined at planetary scale because of the manner in which core technology and structural connectivity has stabilized globally, and since innovation never remains local for long. And further, as this dynamic is suggestive of a developmental critical period, then humanity may be in a "critical window" with which to impact the health and trajectory of a planetary-scale organism.

The structural development of collective humanity is displayed in Figure 2. These maps examine the growth in human populations and technological connectivity over the past 100 years. We focus on technologies that depend on core materials and that have dramatically expanded our structural connectivity, including physical (roads) and virtual connectivity (communication cables). This analysis reveals that once humanity maximized its population, further growth occurred through increased connectivity and via technology. As both an "evo" and "devo" progression, this process mirrors the development of the nervous system, where accelerating connectivity follows neurogenesis in the first years of mammalian life. It also mirrors the evolution of the nervous system, in that the communicative capacity of electrically conductive cells have been enhanced by "technological developments" of myelin, synapses, and dendritic architecture. This process of complexification has been described as "systematizing;" a hallmark of human technological and cultural development (Gabora 2008, Tomlinson 2018, 2023). Therefore, an expansion in structural connectivity in the technosphere likely reflects an interaction between culture, economy and technology as part of a reciprocal amplifying process of innovation. Next, we evaluate this dynamic in greater detail.

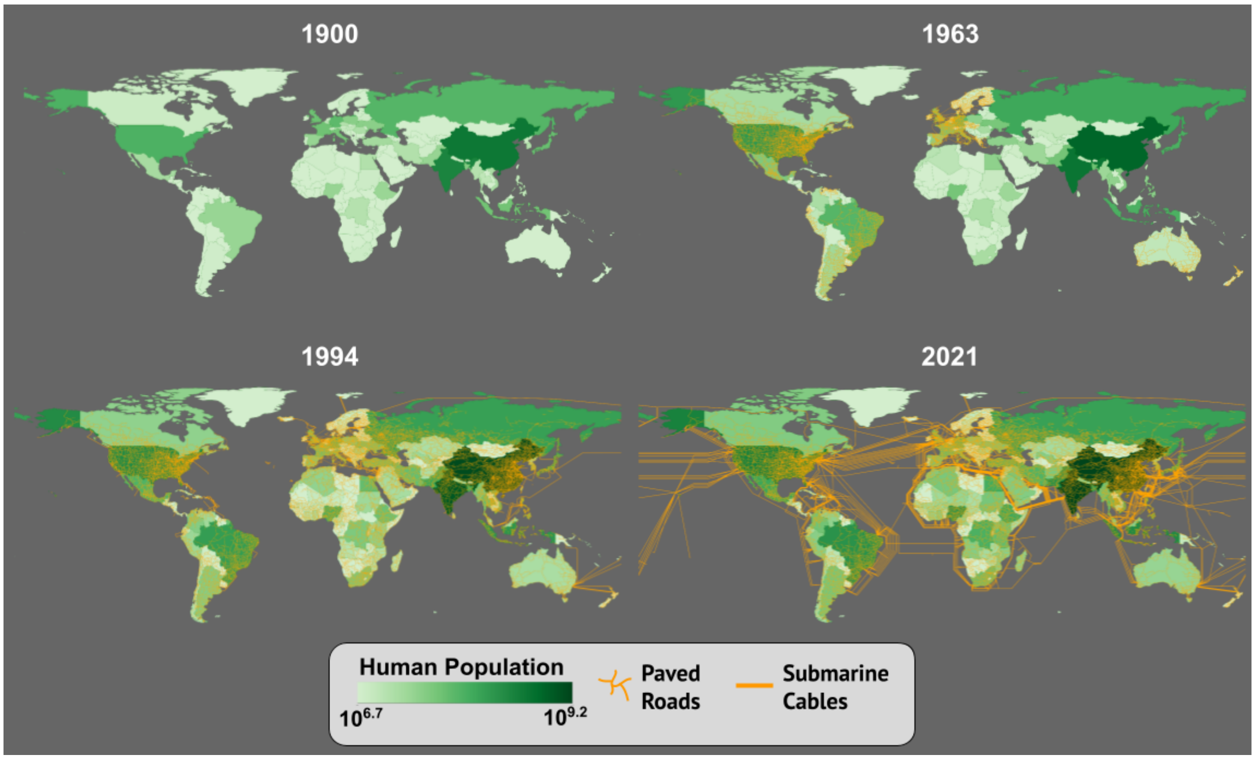

Figure 2. Development of the structural body of collective humanity. Total population estimate (green, by order of magnitude) for each country regardless of legal or citizenship status (source: https://data.worldbank.org/indicator/SP.POP.TOTL). The location of the global network of submarine cables (thick orange; source: https://www.submarinecablemap.com/) and paved roads (thin orange, curved; source: (Meijer et al. 2018)**).**

Planetary Metabolism for Preservation and Innovation

At planetary scale, the development of conserved, material technology has coincided with a plateau in human population growth and an acceleration in technological connectivity. Not only is this technological infrastructure actively maintained, but it serves as a scaffold for further innovation, fueled by cultural and economic developments. How does this happen? We propose that technological maintenance and innovation reflects similar modes of evolutionary persistence and evolvability. This is seen in the evolution of genetic networks that identify a necessary balance between phenotypic conservation and innovation through mutation (Torres-Sosa et al. 2012). These modes may also distinguish a stable, merely “surviving” ecosystem (or self-maintaining, self-organizing system; (Maturana and Varela 1991, Razeto-Barry 2012)) from a healthy organism in which there’s a balance between persistence and innovation. Traditional mechanisms of natural selection and multilevel selection can stabilize novel innovations, especially at higher levels of scale (Wilson 1997). However, increased variation itself, necessary for innovation and major evolutionary transitions may rely on different mechanisms, most notably relaxed selection, which we discuss in detail below (Hui and Deacon 2010, Deacon 2022). Here, we extend this theory to humanity as a whole, in that innovative technology yields novel social functions and specialization, that in turn yields energetic abundance to fuel further innovation.

Szathmary and colleagues have previously identified how energy and metabolism are the drivers for prior major evolutionary transitions. With each increase in spatial scale in biology, the storage, utilization and release of energy proceeds through more complex biological forms, systems and networks. For example, intermediary metabolism (e.g. glycolysis, citric acid cycle, etc.) makes use of complex macromolecules to store, release and utilize energy as ATP. Multicellular organ systems, complexify this process further, with dedicated organ systems to distribute and process those macromolecules for energy storage. As a result of these new functions, systemic metabolism in a multicellular organism cannot simply be reduced to the sum-total thermodynamics of cellular metabolism (Pontzer et al. 2021). Multicellular organisms have evolved systems, such as the neuroendocrine system, to regulate metabolism at the whole-body level in order to anticipate stressors. These higher-order hormonal or neural regulatory systems provide mechanisms for organisms to manage their own health, by recruiting metabolic and other resources in anticipation of needs, rather than merely reacting via homeostatic mechanisms. This phenomenon is known as allostasis, which is related to stress induced increased energy requirements (Bobba-Alves et al. 2022), and is also the biological basis for resilience (Kalisch et al. 2024). Extending the work of others (Daly 1968, 2014), we examine how culture and economies reflect a further externalization of metabolic energy at planetary scale. Of course, these systems reflect our collective energetic needs, but they also support persistence, innovation, and resilience.

Energetic reserves and the ability to distribute them, reflect the anticipatory capacities of allostasis as well as innovation through mutation. Stressors play a role in each; variation itself can be amplified in times of stress as a mechanism for evolvability (Chuang and Li 2004, King and Kashi 2007). Under stress, communities of bacteria form coordinated layers called microfilms in order to share resources and stabilize collective persistence (Martinez-Corral et al. 2019). Notably, this stress response is coordinated by electrical communication, perhaps a precursor to the evolution of the autonomic nervous system that regulates allostatic responses (Shimizu and Okabe 2007). Cellular interdependence also creates risks, that is, communities must deal with “cheaters” who do not “contribute to the public goods” (Smith and Schuster 2019). Perhaps counterintuitively, in some experimental conditions of bacteria, cheaters are supported by an intensification of cooperative behaviors that enhance phenotypic variability and evolvability (Foster and Kokko 2006, Martin et al. 2020). In global economic terms, interdependence yields similar exposure to risks and rewards, which mirror each other, allowing greater access to abundance and opportunities in good economic times, but exposure to coercion during downturns. By incorporating resilience into economic policy frameworks, mechanisms such as stockpiling, diversification, and the emphasis of regional opportunities have been developed to offset risk (Roberts 2023). Resiliency oriented frameworks have the added benefit of potential synergy with ecological sustainability that is supported by regionally emphasized supply chains (Gruner and Power 2017). Therefore, while some planetary scale economic models consider the organism-oriented lens of allostasis to buffer stressors, the role of technological innovation in economic health is less frequently considered, and we suggest benefits from the the lens of relaxed selection.

Energetic surplus has been a key driver of economic development, beginning in early agricultural societies (Graeber 2012). Abundant resources and functional interdependence are linked through an evolutionary process that has been referred to as relaxed selection (Deacon 2010, 2022). According to this theory, abundance relaxes traditional selection pressures, supports variation and redundancy, and particularly in extragenetic information and functions. In this environment, genetic information can degrade, leading to dependence on extragenetic mechanisms. As Deacon outlines, this process can be applied to any lower order (internal, genetic) or higher-order (external, extragenetic) hierarchy. Take human trade, for example. New technology such as roads, phone cables and the internet, have dramatically changed the medium in which trade occurs. These are redundant functions for many (although not all) aspects of human communication and exchange. New, higher-order redundancies relax selection on the prior skills/functions for the old medium. In the 20th century, a salesperson typically relied on a car to make trade possible, today the internet is required, which relaxes the energy and time required to maintain the prior function. Deacon, Smith Szathmary and others refer to this as a ratchet effect, or “contingent irreversibility” (Szathmáry and Smith 1995, Szathmáry 2015, Deacon 2022), and provides a fertile ground further technological innovation (Zhang and Xu 2023).

Technological innovation and the ratchet effect are further amplified by the transition from an economy of matter and energy to an economy of information and knowledge: “one that organises and structures those resources into configurations of value” (Potts and Dopfer 2024).

As a result, sociocultural factors that are the source for our knowledge and value systems must be included alongside traditional assessments of economies for technological innovation. Culture has been described as a socially transmitted, extension of technology (Gabora 2008, Tomlinson 2018, 2023), and that accelerates innovation (Urban 2001, Gabora 2019). Throughout most of the course of human history, cultural spread and economics were interwoven through the dynamics of trade (Campbell 2010). From a planetary organism perspective, this weave begins to look like "neurovascular bundles:" conduits for energy exchange (analogous to vascular blood flow) and cultural communication (analogous to neuronal fibers). These processes operating in concert contribute to positive feedback dynamic between the cultural exchange of ideas and new technologies that support the exchange of those very ideas. As noted, with the emergence of the internet, cultural exchange is no longer bound to economic trade in the same manner as prior centuries (Dueñas and Mandel 2023). Traders need not necessarily have in-depth knowledge of the cultures with which they are engaged. Instead, cultural exchange is now offloaded into the digital space of the infosphere. The infosphere establishes virtual networks for communicative exchange, analogous to how brain processing is in some sense "virtual," that is, not always based on the material present but engaged with remembered pasts and imagined futures. This raises the novel possibility of planetary scale identity for the coordination of function, cognition and resilience.

Infosphere, Knowledge and Planetary Persistence

Through our application of evolutionary and development lenses to planetary scale humanity, we've observed that the technosphere supports a novel form of niche construction, systematizing global metabolism and catalyzing further innovation thereof. However, for innovations to be actively incorporated, developed and "remembered," an inheritance system, beyond mere material, is necessary. It is at this stage of development that a system for planetary regulation, and therefore regulation of planetary-scale health and resilience, starts to become a possibility. In a sense, we see knowledge and cognition as fundamental biological properties that make health possible. For example, the immune system maintains memory and constantly innovates upon those memories in order to anticipate novel stressors; it performs a process that is analogous to cognition (Koseska and Bastiaens 2017). We agree with Frank et al. who see our earth system as "immature" and lacking full-scale, planetary intelligence, which they define as: "the acquisition and application of collective knowledge, operating at a planetary scale, which is integrated into the function of coupled planetary systems." Their proposal conceptualizes the application of knowledge as an emergent property, but how this might emerge to support planetary intelligence remains unknown. Here we distinguish between generally intelligent systems and cognition. It is our contention, extending the work of others, that cognition emphasizes not only knowledge, but the context-dependent nature of knowledge with respect to the organism's identity or self (Deacon et al. 2011, Sherman 2017, Levin 2019, Jaeger et al. 2024). A planetary "self" and perhaps even "sense of self" is necessary to develop, evolve and anticipate the future, and not merely function as a complex, adaptive ecosystem. Here we examine whether a planetary infosphere may ultimately serve cognitive functions: coordinating collective knowledge to support economic production, cultural exchange and ultimately, and evolvability in the service of planetary health.

In addition to energetic abundance, novel information and inheritance mechanisms are critical to major evolutionary transitions (Szathmáry 2015). Two canonical examples of self-knowledge systems include genetic and neural processes that each work on vastly different timescales, and where both support the moment-by-moment adaptation of behavior (at the level of a cell or whole organism), and the stabilization of those adaptations in an evolution-like manner (such as memory/habit formation in neural systems, also known as microevolutionary processes). "Self-knowledge" systems emphasize the active process knowledge plays in sustaining the "self" as an individual organism, its continuity of identity, and the role of optimizing this knowledge through directed evolution (evolvability). Information by itself, including recording and transmission thereof, does not fulfill this functionality. As the infosphere has evolved processing capabilities, this has accelerated dependence, innovation (Floridi 2014), and the possibility of something more abstract, such as identity itself.

The capacity for abstract processing of information captures a "virtual" or "simulative" aspect of knowledge processing which is necessary for anticipating the future, like a brain (Bastos et al. 2012). Through this "virtuality" of the infosphere, humans are no longer dependent on the slower timescale of macroevolution through genetic change, and for many, they are also freed from the many of the most immediate material and energetic constraints. Nonetheless, this virtual system for knowledge, is also emergent from and dependent upon the material energetic substrate that enabled it in the first place. Like any other biological system for knowledge, information processing must be understood in the context of the whole organism. Although we often conceive of the infosphere as atmospheric, "in the cloud," it is accomplished via dramatic material, economic and energetic cost (Qureshi et al. 2009). Moreover, that such a large fraction of the human population has access to this infosphere, is largely because of advances in cellular telecommunication, a dramatic example of our technological niche construction. Geographic mapping of this infosphere demonstrates how growth in cellular telecommunication access enabled planetary-scale information connectivity (Figure 3). This mirrors how the central nervous system differentiates from ectodermal tissue (known as neurulation), yielding epidermal tissues that will form the skin and connective tissues (analogous to our infrastructure) and a neural tube that will form the brain and spinal cord (analogous to our telecommunications technology). Thus, the infosphere is dependent upon and maintains the reach of the underlying structure of the technosphere while enabling massively new functions for information processing.

Extending the evolutionary ratcheting mechanisms described above, the infosphere can support both preservation and innovation. This is already occurring via the coordination of planetary scale political and economic processes. Many societal functions that typically relied on physical processing have been offloaded to the internet. For example, economic transactions depend on a stable, reliable infrastructure within the internet. This basic, functional maintenance is analogous to an autonomic nervous system, which regulates core-physiologic functions (Koban et al. 2021). By extension, the infosphere and its supporting infrastructure becomes a part of a digital commons, where certain basic processes must be protected and conserved (De Rosnay and Stalder 2020). It may be that global stressors (such as COVID-19) might push humanity to establish a digital commons in the infosphere where content relevant to survival and health can be reliably shared and propagated.

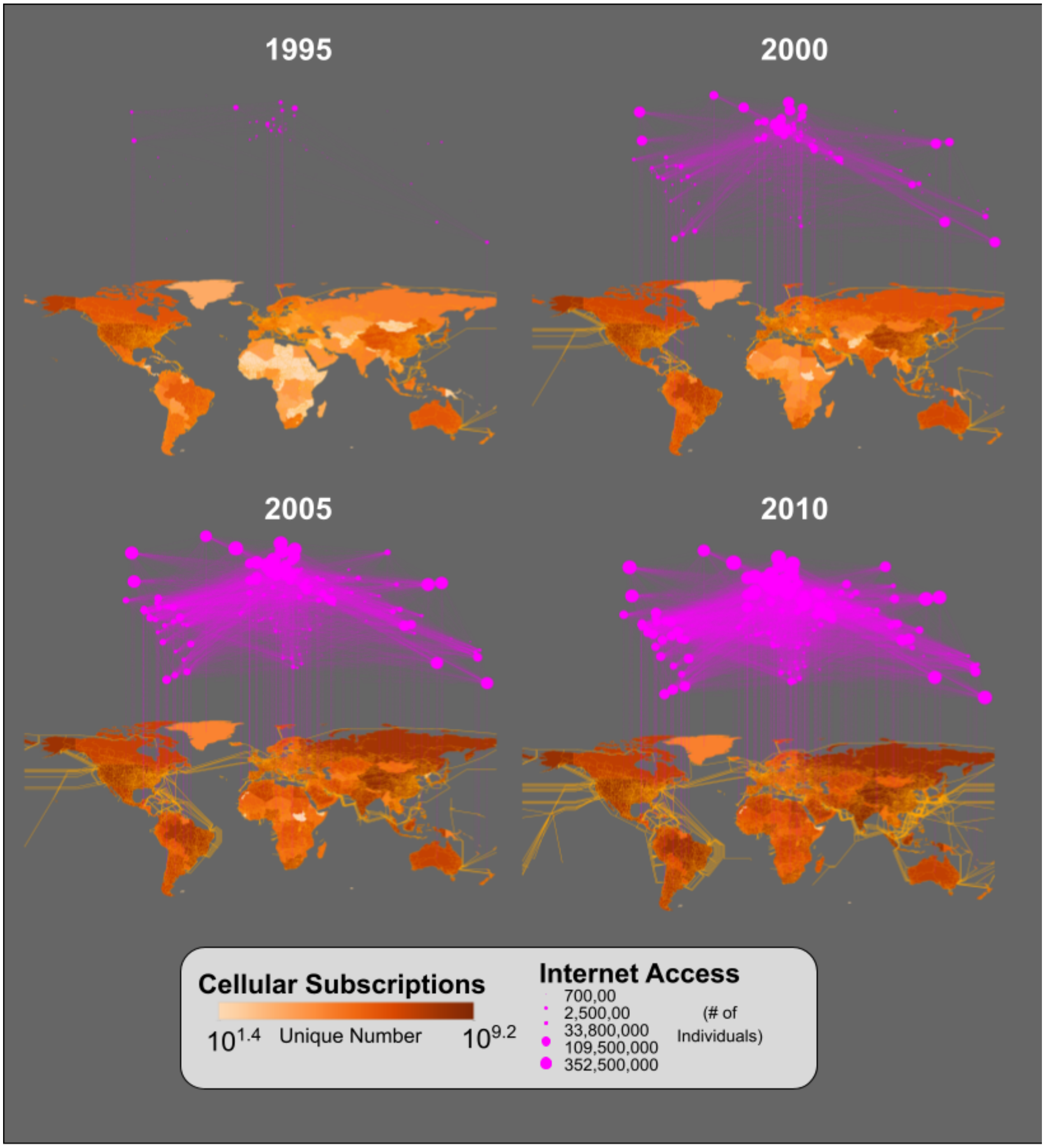

Figure 3. Emergence of the Planetary Infosphere. Number of unique cellular mobile subscriptions for each country (orange; source: https://data.worldbank.org/indicator/IT.CEL.SETS.P2). Number of individuals with internet access is given by the size of the magenta circles https://data.worldbank.org/indicator/IT.NET.USER.ZS). Countries with less than 700,000 are excluded from the network.

Planetary Identity and Innovation

In the sections above, we have stressed preservation and innovation as relevant to the health of humanity at planetary scale. To support these processes, a self-knowledge system, in the form of an infosphere may be necessary to provide informational inheritance for persistence and innovation. We liken this informational inheritance to a rudimentary form of identity, that is knowledge of self, *itself*. This proposal for the infosphere parallels the function of the mammalian brain that supports core autonomic function for preservation (of self) and for the generation of creative behavior via cortical structures (also typically self-relevant). At planetary scale, information is amplified by culture and higher order symbolic capacity of human language (Deacon 1998); spreading "virally" (Welker 2002, Wang and Wood 2011), and catalyzing innovation (Literat and Glăveanu 2016, Gabora 2019). Thus, our connectivity in the infosphere has the potential to accelerate this process of cultural creativity (Literat and Glăveanu 2016). Through a virtualized space for cultural exchange, the generation of new ideas and planetary scale dialogue, there is also potential for the infosphere to be uniquely situated to address planetary scale problem solving (Breyer et al. 2017) and the evolution of novel technology (Brian Arthur 2009). How these endeavors are linked back to humanity's sense of self, or identity, remains unclear, but is nonetheless central for distinguishing between planetary-scale health and physiologic imbalance.

Much of the focus on social media has instead raised concerns about its ability to foment planetary problems rather than solve them. If our model is accurate, it would suggest that this is in part related to the fact that the infosphere maintains no "sense of self" at planetary scale, but instead, amplifies individual or specific groups (McFarland et al. 2012, Tuen et al. 2022). There are notable exceptions, such as during the COVID-19 pandemic, when a significant mass of humanity was in fact circulating information through social media channels that was directly relevant to both our survival and our shared humanity, as a species. This could be commensurate with multilevel selection theory, with an emphasis on higher-order, collective identity and purpose that could serve as the foundations for supporting pro-social principles, such as equity, fair decision-making, conflict resolution and governance (Wilson and Snower 2024). With increasing access to the infosphere, each person has the potential to access and contribute to the entire knowledge bank of humanity. Individuals also need to read-out and make use of this knowledge in an efficient manner. Here we speculatively suggest a novel "catalytic readout" role for the infosphere, that like DNA and a brain, depends on the contextual circumstances in which information is expressed. If realized, such a system might in fact behave intelligently as a cognitive system; demonstrating a capacity for contextual regulation, not merely amplifying patterns of information.

A formal, technical outline of how this might occur is speculative, and outside the scope of this manuscript. Here we present a general outline, starting from the recognition that the infosphere flattens and condenses space and place. This is analogous to how DNA compresses information about protein structure, or the cerebral cortex compresses both sensory information and action plans as fundamental to intelligent behavior (Ganguli and Sompolinsky 2012, Maguire et al. 2016, Wolff 2016). For self-knowledge systems such as DNA and the cerebral cortex, ancillary systems are needed to organize and catalyze the retrieval of information for the appropriate context. For DNA, this is accomplished by histones, ribosomes, and the "machinery" of transcription and translation. In the brain, non-cortical structures such as the basal ganglia, cerebellum and subcortical structures coordinate cerebral activity, to modulate behavior and plasticity (Graybiel 1998, Huang 2008). In the space of human society, individual humans decompress this information through their own creativity and the distinct aspects of local culture. Biological and human information is not valueless nor context free: it matters where it came from, from whose voice, in what community, and for what purpose. Perhaps new technologies such as artificial intelligence can be seen in this light, critical processes to help retrieve, catalyze and organize the information of the infosphere; to make it "function" as an internalized biological component.

Thus, our proposal for planetary information processing extends self-organizing / self-maintaining proposals that examine the global brain as an integrated system (Heylighen and Lenartowicz 2017). The functions of this system must be delineated with respect to autonomic (in order to be grounded to its underlying physiology) and innovative functions (in order to remain evolvable) in order to understand its role in keeping the system healthy and in balance. As in the brain, information compression could be accomplished via recurrent, reverberating and sustained activity that is necessary for adaptive and anticipatory behavior (Pezzulo et al. 2021). This mirrors proposals for cognition that emphasize the need for a core of ongoing neural activity to create an embodied sense of self, some semblance of basic "identity" for an otherwise multicellular being (Koban et al. 2021). At planetary scale, we all participate in this infosphere, even if the individual content at any given moment is not tuned to our collective identity as humans. Perhaps, over time, this ongoing and circulating activity could form the basis of a planetary identification with all humanity (McFarland et al. 2012), even as local decompression of this information helps apply it to specific needs. In the most simple terms, we suggest that the infosphere could actualize a longstanding rallying cry for global environmental causes: "think globally, act locally." Through the emergence of a planetary-scale identity, technological innovation and preservation might arise in reference to the "self" of the planet, and thus provide an organizing drive toward One Health, even as the local expression of this "self" allows emphasis of regional needs.

Limitations and Future Directions for Planetary Health Ethics

We have proposed that examining humanity as a planetary-scale organism can provide novel insight into the functional mechanisms, as physiologic processes, that underlie our One Health, as a species. To understand the physiology of this system, and therefore improve our capacity to understand pathophysiologic mechanisms, we have mapped an evo-devo perspective onto the concept of the total human ecosystem to explore whether such a system could facilitate a major evolutionary transition from ecosystem to organism. This modeling effort finds that technology forms the core of this planetary organism that scaffolds ever more complex technology as material inheritance and a niche for innovation. Economic and material flows maintain this technology; supportive conditions for relaxed selection and ratcheting effects for further innovation. Ultimately, this innovation has extended to informational inheritance mechanisms that could help coordinate essential planetary scale functions and our shared identity. As such, this system appears capable of both preservation as a singular organism and evolvability, with respect to humanity that comprises it. To understand One Health, as more than mere survival, we have proposed that evolvability through innovation is necessary to sustain developmental critical periods, anticipate stressors through the coordination of resources, and support a shared identity necessary to tackle collective challenges.

In this concluding section we briefly address the implications, limitations and future directions of this model. As a first-pass attempt to explore a novel, planetary evo-devo model, we have left many questions unanswered and even unasked: is this planetary scale organism fixed in place? What about the possibility of other planetary scale organisms? What is the role of the biosphere? In addition, the geographic approach provides only a partial sketch of what this organism might look like, given that it was limited by the availability and use of mean aggregate data (Holt et al. 1996). We have also ignored most of the qualitative dimensions to the social systems discussed (Pearce and Louis 2008, Sharp 2009). Further work will be required to explore this topic and ethical frameworks invoked by our proposal. On the whole, it remains speculative as to whether the model we propose actually constitutes a living entity. We have relied on major evolutionary transitions theory, niche construction and relaxed selection to infer evolvability. Nonetheless, it is unclear how traditional natural selection could operate at planetary scale, particularly with respect to competition. This has been previously discussed by (Doolittle 2017), hence our emphasis on persistence rather than traditional Darwinian selection, per se.

Regarding the ethical implications of our model, we strongly notfe that biological, evolutionary and superorganism analogies have a dangerous political history (Koenigsberg 2007). While some of these concerns have been raised previously (Vidal 2023, 2024), we have attempted to provide evidence for a multiscale framework of analogous functions in developmental and evolutionary processes. This contrasts with singular metaphors such as: the U.N. is an “immune system” for the planet (Okada 2020) that fail to capture the multiscale nature of evo-devo processes. This U.N. metaphor is a bit like proposing that a membrane spanning domain protein in a bacterium is its “immune system” because it fulfills a function of self-other distinction. The self-other distinction is relevant, but the concept of an “immune system” does not apply to a bacteria. In the same manner, it likely doesn’t apply to a planetary scale organism. Applying the wrong model could yield harmful consequences, with respect to One Health, particularly when higher-order interdependencies are not taken into account. Nonetheless, there may be self-other systems at planetary scale, but that doesn’t mean that they function like the immune system of an individual human being. Therefore, the critical challenge is in explicating the *generic* biological function, and underscoring the distinct technology to emerge at each scale.

We favor identifying generic functions from developmental and evolutionary frameworks, rather than inferring them from a descriptive engineering based approach, such as living systems theory (Miller and Miller 1992), that assumes function but not the mechanisms of development, evolvability or self-knowledge. Moreover, there is additional risk in assuming mechanistic, descriptive language that evokes algorithmic solutions for collective humanity. For example, historian Yuval Harari writes that individual humans are like the “chip[s] inside a giant system that nobody really understands.” We feel that this “dataist” philosophy (Harari 2016) could be interpreted as promoting the interchangeability of human “units,” or questioning the value of individuals or species that intersect with our complex ecosystem. This engineering model makes (ever more popular) computational assumptions about society, and that like living systems theory, merely offers a description, but not actual life (see also (Jaeger et al. 2024)) and no potential mechanism for further evolution as we’ve emphasized here. These approaches could be interpreted as emphasizing the persistence mode of One Health, but minimizing the lived experience that is necessary for self-knowledge and evolvability. A planetary organism approach could offer an alternative from which ecological, ethical and moral principles could be explored organically. For example, our multiscale model emphasizes the part-whole dynamics of living systems, and in particular, the self-knowledge systems that guide individual development, expression and evolvability. Aspects of evolvability, including innovation and creativity, are not typically included in ethical frameworks and will be developed in additional work.

The implications of this work pertain to our role as stewards of planetary scale ecosystems within the One Health framework. In this context, the concept of a “noosphere,” complementing the biosphere, has returned to evolutionary conversation. This concept builds from the 20th century perspectives of Teilhard de Chardin and Vladimir Vernadsky, who coined the term “noosphere” to describe the mental or thinking layer that captures the symbolic flow of information at the scale of collective humanity (Vernadsky 1945, de Chardin 2018). As recently described by David Sloan Wilson, Teilhard de Cahrdin recognized the importance of integrating the “hard evolutionary sciences with conscious efforts to manage cultural change” (Wilson

2022). Such a massive interdisciplinary project is of high relevance today, but we cannot make progress without attempts to bridge disparate scientific siloes, languages and microcultures. Our attempt here shows that the science of biology and social studies might interact more explicitly through the models of evo-devo science. In closing, we point to the role of the U.S. national space program, which was initially driven by political agendas, transformed technology, struggled economically and foundationally shaped our culture and ultimately our self-knowledge in unexpected ways. The images of earth from space have been promoted by some to be the most important, unanticipated outcomes of the space program (Nezami et al. 2021). The 'overview effect' is the feeling of awe and connectedness that is experienced when the earth is seen from space. These may be like our first glimpses of our planetary home, like an infant who first recognizes themself in a mirror (Bahrick and Moss 1996). As biological organisms ourselves, a geography of a human planetary organism can help us see our individual role in this potential organism as we are mirrors of it on a microscale. That is, as we see our own biological systems and the vulnerability of those systems mirrored on a planetary scale, we might come to newfound appreciation for our shared One Health amongst our fellow humans.

Data and Code Availability:
The original contributions presented in this study are included in the article itself material, with relevant data citations included in figure legends above. All data wrangling, preprocessing, and visualizations were done in Python programming language and its libraries including: Numpy, Pandas, GeoPandas, Geoplot, Shapely, Cartopy, Matplotlib, and Json. Code is available upon reasonable request, further inquiries can be directed to the corresponding authors.

Author contributions:
Jacob developed the idea of the model contained in the manuscript, performed a literature review, synthesized the material, developed the theory and wrote the initial draft. Pourdavood refined the theory and wrote the computer code to analyze and map the data. Pourdavood and Jacob generated all figures, and edited the manuscript for publication.

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