Technosphere

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Abstract The technosphere, the interlinked network of the world's humans and technological artefacts, is the defining structure of the Anthropocene. The technosphere is undesigned, autonomous and possesses agency. Where influenced by human knowledge, its future behaviour is unpredictable, although constrained by generic principles of organization. Humans face a fundamental dilemma in the conflict between (i) the technosphere's increasing rate of energy consumption, required to support discovery and application of the new knowledge essential for improvement and maintenance of human well-being, and (ii) the fact that no system can sustain an accelerating regime of energy use indefinitely.

The technosphere concept arose from an attempt to describe in physical terms the nature of a new geological Epoch, the Anthropocene (Haff, 2014a). Massive, energetic, and globally ubiquitous, the technosphere is a product of the continuing process of planetary evolution. It is an emerging Earth sphere, taking its place alongside the classical spheres of air (atmosphere), water (hydrosphere), rock (lithosphere) and living matter (biosphere).

Like the other spheres, the technosphere is a physical system. Here 'system' means 'dynamical system', an energy-consuming collection of entities (parts) identified and recognized on the basis of their mutually organized motion (behaviour).

Examples of the contents of the technosphere include most of the world's humans, domestic animals and plants, agricultural soils, transistors, cell phones, computers, computer networks, legal treatises, artwork, medical offices, buildings, schools, corporations, political parties, government bureaucracies, armies, and infrastructure, as well as the world's communication, transportation, educational, health and financial systems, and its nation states.

The emergence of the technosphere represents a major transition in the development of Earth through time. Its imprints and waste products mark the beginning of

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the Anthropocene Epoch and constitute the Anthropocene's most distinctive stratigraphy (Zalasiewicz et al., 2014).

Among the most important questions for humans regarding the technosphere is not simply "what is it?" but rather "what does it mean for humans that they themselves are among its components?" The answer is counterintuitive, calling into question the view that civilization and technology are human constructs.

This physical view of the technosphere has been criticized as incompatible with sustainable development discourse founded on humanitarian principles (e.g., Donges et al., 2017). However, it is the detached perspective afforded by paying attention to physical necessity that defines the possible scope of those principles and identifies limits on achievability of desired goals.

Because patterns of civilized life across the globe are enabled by the actions of the technosphere, the future of the new sphere will determine the prospects for human well-being in the Anthropocene.

The path to understanding this novel phenomenon is obscured by the fact that humans do not stand outside the system but are integral parts of it. The individual human's perspective on the technosphere tends to be restricted in scope, magnifying the importance of that which is "up close" and affects the individual directly. One consequence of this condition is a failure to credit the power and reach of larger-scale forces that are out of sight but mould human experience and behaviour.

Because the technosphere has grown up around them, and because their ideas, skills and intentions were clearly essential to its emergence, humans tend to view the technosphere as a human construct.

However, the technosphere was created not by human actions alone, but by positive feedback processes whose scale, complexity and even existence, like Adam Smith's Invisible Hand, lay beyond the knowledge or comprehension of most humans.

The technosphere grew organically as opportunity permitted, with only piecemeal planning, into a globe-spanning, interlinked composite of billions of humans and trillions of technological artefacts.

Given its complexity, emergent (undesigned) origin and its ad hoc growth pattern, the technosphere's ability to maintain metabolic activity over years and at global scale in the absence of human understanding of the underlying dynamics, suggests that the system has at its command more modes of behaviour than putative human controllers are aware of or have the means to regulate.

In this picture (Ashby, 1957), the technosphere, like the four classical Earth spheres, is effectively autonomous, i.e., largely beyond human control (Haff, 2014b). The emergence of technospheric autonomy marked a technological tipping point in Earth history, the effects of which cannot now be undone.

Although control is lacking, the technosphere is responsive to and in turn affects the actions of its human components. These action-reaction loops are the sinews of technospheric dynamics (Haff, 2014b). The participation of knowledge-producing humans in positive feedback processes is a principal source of innovation in the Anthropocene and so of improvements in human well-being.

Equation-of-motion approaches like those used to predict some aspects of climate change are not sufficient to anticipate the evolution of the technosphere, a

system which lacks such governing equations. A new framework is necessary to help prepare humans for dealing with the future of this recently emerged sphere. A similar situation prevailed in the nineteenth century where in order for humans to understand the behaviour of the biosphere (which is also devoid of an equation of motion) a novel reconception of the nature of change through time was required—the principles of Darwinian evolution.

In the twenty-first century, progress has been made in understanding technospheric dynamics thermodynamically (e.g., Garrett, 2011, 2014), and, alternatively, through elucidation of generic, or regulative, rules of behaviour that apply to all dynamical systems (Haff, 2014b). These rules include:

The Rule of Agency
That every system, including the technosphere, has an intrinsic purpose, namely, to ensure its own survival (Haff, 2016). The presence of intrinsic purpose, an emergent physical property, does not imply consciousness or intentionality.

System survival requires energy consumption, a task implemented according to two additional regulative rules:

The Rule of Performance
That the parts of a system act to support the intrinsic purpose of that system. As parts of the technosphere, humans and other components are obligate participants in the process of securing and using the energy and material resources that underpin survival of the system.

The Rule of Provision
That a system acts to ensure that its parts follow the Rule of Performance. As the host system for humans and technological artefacts, the technosphere enables, and also compels, constrains, or incentivizes humans and other components to help secure and process the resources essential to its survival.

Compulsion and incentivization are specific mechanisms supporting a positive feedback process that acts to increase technospheric energy consumption. However, metabolic speedup in emergent systems like the technosphere is more an expectation than an exception. In the presence of abundant energy reserves, there are more ways for the system to increase energy use than there are to maintain it at a fixed level.

The state of chronically increasing energy consumption by the technosphere presents humans with an ironic and difficult-to-resolve conflict, one which might be called the Fundamental Dilemma of the Anthropocene, namely:

(i) An increasing rate of global energy consumption is essential to human well-being: Improvement in the human condition (e.g., creation of a global health network) and preparing for and responding to potential and recent disasters that can threaten civilizational stability (e.g., effects of climate change, pandemics, Carrington-type Event, asteroid impact) require continuing increases in energy use beyond the base metabolic rate of the technosphere.

(ii) However, a state of chronically increasing global energy consumption is unsustainable: Increasing energy consumption, even when used to improve human well-being, opens the door to increasing frequency of unwanted side-effects. These can spread and intensify at rates that threaten to outpace the speed of effective human response. Recent examples include spread of fake news and techniques of mass surveillance, dispersal of novel pathogens and cyber weapons, and the destructive effects of climate change. If the rate of occurrence and intensity of such phenomena continue to increase, eventually biologically-limited humans will be unable to adjust to changing conditions fast enough to follow the Rule of Performance. At this point the technosphere would lose its internal coherence and, in consequence, the ability to improve and sustain human well-being.

This dilemma might be addressed (Haff, 2019) in the short run by making use of the fact that both humans and the technosphere possess the same intrinsic purpose common to all physical systems—to survive. For example, human support for increases in overall energy consumption might be the anthropic compromise offered in return for technosphere acquiescence in focusing energy flows into sectors such as medicine or atmospheric carbon capture where growth seems compatible with increasing human well-being.

In the long run, avoiding the negative consequences of growth in technospheric energy consumption while retaining acceleration-enabled benefits of resilience and innovation will require a radical reconceptualization of possible technospheric futures. The apparent haven of a steady-state technosphere is not a solution, not because of lack of human commitment, but because the human-technological artifice is a precariously-balanced structure that will require energy-demanding innovation if it is to maintain and increase human well-being in a turbulent, unpredictable world.

Summarizing: The technosphere is the emergent stage on which human desires and actions will play out, and human fate be realized, during the opening years of the Anthropocene. The future of *Homo sapiens* depends on the human ability (i) to discover and use new tools for framing the dynamics of the technosphere, (ii) to acknowledge that the technosphere has agency and is unpredictable where its behaviour depends on future knowledge, (iii) to relinquish the view that humans are the sole architects of the technosphere, (iv) to abandoned the idea of control over an innovating technosphere, (v) to accept the need for increasing technospheric energy consumption, (vi) to compromise with this new world system in a way that both humanity and the technosphere can, at least in the short run, achieve their most

fundamental goal, survival, and finally (vii) to strategize novel reconfigurations of the human-technological enterprise that might be compatible with human prosperity over the long run.

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