

Anmerkung zur Co-Autorschaft des Textes

Neubert, Christoph und Wiemer, Serjoscha (2014) "Rewriting the Matrix of Life. Biomedica Between Ecological Crisis and Playful Actions," communication +1: Vol. 3, Article 6.

Der Artikel enthält an vielen Stellen gemeinsame Überlegungen von Christoph Neubert und mir. Dies gilt besonders für die allgemeine Fragerichtung nach dem Komplex von Öko-Bio-Medialität, die den Text insgesamt motiviert.

Einzelne Abschnitte lassen sich im Schwerpunkt dennoch zuzuordnen, wenn dies gefordert sein sollte. Die Darstellung der Geschichte der Ökologie (bis S.12) ist maßgeblich von C. Neubert, die Reflexion zum Spiel und zu algorithmischen Medien (S. 12 bis Ende) im Schwerpunkt von mir zu verantworten.

2014

Rewriting the Matrix of Life. Biomedica Between Ecological Crisis and Playful Actions


Christoph Neubert

University of Paderborn, Germany, christoph.neubert@uni-paderborn.de

Serjoscha Wiemer

University of Paderborn, Germany, swiemer@campus.uni-paderborn.de

Follow this and additional works at: <http://scholarworks.umass.edu/cpo>

 Part of the [Cultural History Commons](#), [Epistemology Commons](#), [Esthetics Commons](#), [Film and Media Studies Commons](#), [History of Science, Technology, and Medicine Commons](#), and the [Intellectual History Commons](#)

Recommended Citation

Neubert, Christoph and Wiemer, Serjoscha (2014) "Rewriting the Matrix of Life. Biomedica Between Ecological Crisis and Playful Actions," *communication +1*: Vol. 3, Article 6.

Available at: <http://scholarworks.umass.edu/cpo/vol3/iss1/6>

This Article is brought to you for free and open access by ScholarWorks@UMass Amherst. It has been accepted for inclusion in communication +1 by an authorized administrator of ScholarWorks@UMass Amherst. For more information, please contact scholarworks@library.umass.edu.

Abstract

The paper discusses concepts of 'nature' and 'life' as subjected to historical changes. The 21st century seems to be obsessed with 'life' and 'nature', which are reconfigured as objects of simulation practices and of a multitude of technoscientific enterprises as well as of political struggle. The historical influences and epistemological shifts of systems thinking are significant within two distinctive and interwoven fields: On the one hand the discourse of environmentalism with the paradigm of ecological crises, centered around ideas of resource management, sustainability, the general idea of an 'endangered nature' and the interconnectedness of global politics and individual actions. On the other hand the optimistic promises of artificial life, with synthetic biology and digital cyborg technologies as its avantgarde, which are very much driven by the idea of technoscientific mastery to surpass natures 'weakness' and by desires to improve 'life' and to even refashion 'life itself'.

On the field of historical ecology, concepts of systems thinking are traced back to the middle of the 19th century, where ecological thought emerged at the intersections of biology and geography. Meandering between vitalistic, holistic, and mechanistic concepts, between living and non-living elements, systems ecology finally substitutes 'nature', which in turn is re-established in its new 'gestalt' as computer simulated world model since the early 1970s. Resurrected as an interrelation of system variables at the level of global simulations 'nature' strikes as a zombie.

As a second turning point of the rewriting of the matrix, of life we will discuss the advance of 'games' since the early 1970ies, with the example of 'Game of life' ('Life') as a significant landmark. When 'life' becomes 'Life', it is by computerized modeling in terms of dynamic processes. Computer games can be thought of as instances of the popularization of cybernetic system thinking, functioning as interdiscursive fragments between the specialized discourse of system theories and the sphere of 'common sense' (Nohr 2008), where the specific "gaming situation" (Eskelinen 2001) foregrounds playful individual action and manipulation of system objects within a set of given rules or the manipulation of system rules itself on the level of the 'code'.

We will argue that both, the ecological discourse and the algorithmic model of self-reproduction of 'Life', are historically and systematically related manifestations and mediations of system theory. While they can be regarded as referring to different scales of application (macro-economic reasoning in the case of global eco-systems, modeling of bottom-up-complexity on a micro-level in the case of 'Life') and belonging to distinctive disciplines (economic and ecological research vs. mathematical theory of automata and artificial life studies), they share some common ground in being "algorithmic media" (Marks 2014) that are functional as "rhetorical software" (Doyle 1997) and as "algorithms" (Galloway 2006) of the new compositions of the techno-biological and techno-ecological situation of the 21st century.

Keywords

ecology, media studies, biomedica, historical epistemology, system theory, cybernetics, games, computer games, algorithm, algorithmic media, life, game of life, simulation, artificial life, knowledge, discourse analysis, interdiscourse, environment, ecosystem, anthropocene

Creative Commons License



This work is licensed under a [Creative Commons Attribution-Share Alike 3.0 License](https://creativecommons.org/licenses/by-sa/3.0/).

Introduction

One of the characteristic features of systems thinking can be seen in its unifying approach, where organisms and technological artifacts, ecological relations and man-made infrastructures shall all be described with a common set of concepts. As a consequence, systems thinking can destabilize traditional western ontologies, even those that seemed to have essential value for ethical and political orientation: The very concepts of 'Nature' and 'Life' itself are rewritten by the historical influences and epistemological shifts of systems theory.

This becomes especially significant within two distinctive yet interwoven fields of knowledge: environmentalism and artificial life. As the discourse of 'global warming' illustrates, the impact of systems thinking is not limited to scientific research but on the contrary popularized on a global scale. To understand the historical interconnection of systems thinking with the rise of the ecological paradigm, it is important to see how central elements of systems thinking can be traced back to the emerging ideas of ecological thought in the latter half of the 19th century, and how this thought assumes its current shape under the influence of the media technology of the computer in 20th century.

The concepts of 'Nature' and 'Life' are thus fundamentally irritated by the inclusion of the artificial. In particular, the understanding of natural processes and qualities as well as the concept of 'life itself' become dislocated under the influence of systems thinking combined with computer technologies of modelling, simulation, and manipulation. Furthermore, as we will discuss later with the prominent example of 'Game of Life', it can be argued that the rise of 'games' as part of computer culture since the early 1970s is a significant landmark for the popularization of systems thinking as well as for the transformation of concepts of 'life itself'.

Risk and Closure

Starting with 'Nature', the globalized geopolitical, economic, and ecological crises of the 20th century make evident that space as well as time for humankind as a biological species might be limited. Within geology, the ecological effects of this historical development have led to the assumption of an epochal shift from the holocene to the "anthropocene".¹ The holocene, which had provided the climatic conditions for the development of stable cultures and civilizations, is assumed to be superseded by the anthropocene, as indicated by a significant

¹ Cf. Paul J. Crutzen, "Geology of Mankind," *Nature*, 415 (3. Jan. 2002): 23; Jan Zalasiewicz et al., "Are We Now Living in the Anthropocene?" *GSA Today*, 18.2 (2008): 4–8.

increase of CO₂ found in air entrapments of the arctic ice since the end of the 18th century. Since then, population growth and industrialization with increasing consumption of fossil energies and other natural resources lead to the situation that human behavior engenders significant changes within the biosphere. For the first time, man made history and natural history converge in a paradox way, only to confirm the long standing tradition of theories that assume a circular causality between anthropological and geophysical processes, ranging from ancient cosmogonies over the romantic concept of 'Weltseele' and Hegel's 'Weltgeist' to Vernadsky's 'noosphere' or Teilhard de Chardin's 'omega point', also including versions of Gaia theory that have become influential for ecologic thinking. It is thus not by coincidence that ecology is close to spiritual affairs.

The anthropocentric perspective seems the more inevitable as in the context of globalization, ecological damages amount to a self-impairment of world society. At present, ecological hazards tend to become universal and irreversible, and are moreover supposed to yield boomerang effects, sooner or later turning back on their originators on a global scale. In this context, Ulrich Beck has developed the concept of "world risk society," where global conflicts get more and more centred on the distribution of risks rather than the distribution of resources.² According to the German sociologist Niklas Luhmann, the concept of risk has to be distinguished not from the notion of safety, but from the concept of endangerment: External dangers are not caused by the affected person or institution but are attributed to an intransparent environment; the notion of risk, on the other hand, links an undesirable situation to some previous decision, which could have been made otherwise.³ Contingencies are thus transformed into potential consequences of conscious behavior, so that occurrences such as hurricanes or floods might become symptoms of anthropogenic climate change. Mediated by the concept of global risk, the most influential Aristotelian distinction between *physis* (following internal goals) on the one hand and *téchne* (following human purposes) on the other – which lay at the heart of the distinction between nature and culture – in effect collapses. In the anthropocene driven by a world risk society, human decision making and control gain vital importance on a global scale, while nature as an independent causal force and element in its own right paradoxically disappears. Essentially the same diagnosis is attained with respect to technoscientific endeavours such as genetic engineering and synthetic biology, where the distinction between natural and artificial objects is also increasingly blurred. Thus on the macro level of ecological risk as well as on the micro level of bio-technological mastery, "life itself" becomes a technological

² Cf. Ulrich Beck, *Weltrisikogesellschaft. Auf der Suche nach der verlorenen Sicherheit* (Frankfurt/M.: Suhrkamp, 2008).

³ Cf. Niklas Luhmann, *Soziologie des Risikos* (Berlin/New York: de Gruyter, 2003), 30f.

enterprise. Media theorist Marshall McLuhan links this modern condition of ecology to the historical moment of space exploration:

Perhaps the largest conceivable revolution in information occurred on October 17, 1957, when Sputnik created a new environment for the planet. For the first time the natural world was completely enclosed in a man-made container. At the moment that the earth went inside this new artifact, Nature ended and Ecology was born. 'Ecological' thinking became inevitable as soon as the planet moved up into the status of a work of art.⁴

In this passage, McLuhan draws on a topological inversion: man is no longer surrounded by nature, which is instead encircled by human technology. The exclusion of nature from society turns into its complete technical inclusion or enclosure, as it were, in an artificial container that is represented both by the Sputnik's shape and by its orbit. In terms of this picture, the era of ecology ends that of nature, and ecology is a matter of technology and art. Alluding to Shakespeare as well as military terminology, the globe becomes a theatre which allows no external perspective. That there are no spectators but only actors, as the title of McLuhan's text suggests, again points to the central notion of closure: There is no outside of society resp. technology.

Not by coincidence, the Sputnik also is a symbol of cold war; the notorious 'shock' that supposedly accompanied its appearance for the Western World in the context of technology and arms race is associated with a historical situation characterized by strict external boundaries (Iron Curtain) and internal paranoia (Manchurian Candidate) of political blocks, a climate which was surely inspiring for cybernetic systems thinking with its fascination by operational closure and autopoiesis.

Ecology: Life in space and time

While McLuhan surely provides a clear sighted definition of modern systems thinking, the latter's historical roots can be traced back to ecological ideas emerging within geography and biology in the second half of the 19th century. In the following sections, we shall highlight some important concepts and developments in this complex discursive field which are related to our argument – without claiming to provide a thorough or complete history of ecology, of course. Central for ecological thought is the assumption that organisms enter into

⁴ Marshall McLuhan, "At the moment of Sputnik the planet became a global theater in which there are no spectators but only actors," *Journal of Communication*, 24.1 (1974): 48–58, 49. Actually, Sputnik I was launched on October 4, 1957.

functional relations to their surroundings und thus cannot be studied in isolation, an idea which is constitutive for the first definition of ecology given by the German biologist Ernst Haeckel (1834-1919) in 1866.⁵ Inspired by Darwin's theories of descent and natural selection, Haeckel develops a strictly mechanist theory, according to which the morphology of organisms and the development of species are completely determined by environmental factors he calls conditions of existence ("Existenz-Bedingungen"), encompassing inorganic factors such as soil and climate as well as organic factors which are mainly given by the surrounding organisms.

Ecological considerations like these allow a fundamental shift of focus from the evolutionary relation between individual organisms and species under the determining influence of their milieus towards collective forms of life in a given spatial environment. In the context on his work on Frisian oyster banks, the German zoologist Karl August Möbius (1825-1908) introduces the concept of biocoenosis ("Lebensgemeinde"), which foregrounds the complex interactions and interdependencies of co-existing individuals and species.⁶ In his seminal paper "The Lake as a Microcosm" Stephen A. Forbes uses the notion of 'community of interest' as a central point of ecological reference.⁷ Corresponding assumptions are found in the context of botany and plant geography. The first and most influencing text book on ecology published by the Danish botanist Eugen Warming (1841-1924) draws on the notion of 'plant community'. Warming's "Plantensamfund. Grundtræk af den økologiske Plantegeografi" (1895) is translated to German in 1896 and to English in 1909 ("Ecology of Plants. An Introduction to the Study of Plant-Communities"). The German limnologist August Thienemann postulates an organic unity between biocoenosis and biotope ("Lebensraum, Milieu") in 1916.⁸

⁵ Ernst Haeckel, *Generelle Morphologie der Organismen. Allgemeine Grundzüge der organischen Formen-Wissenschaft, mechanisch begründet durch die von Charles Darwin reformirte Descendenz-Theorie*, Bd. 2: *Allgemeine Entwicklungsgeschichte der Organismen. Kritische Grundzüge der mechanischen Wissenschaft von den entstehenden Formen der Organismen, begründet durch die Descendenz-Theorie* (Berlin: Reimer, 1866), 286ff.

⁶ Karl August Möbius, *Die Auster und die Austernwirthschaft* (Berlin: Wiegandt, Hempel & Parey, 1877).

⁷ Stephen A. Forbes, "The Lake as a Microcosm," *Bull. of the Scientific Association (Peoria, IL)*, (1887): 77–87.

⁸ Cf. Kurt Jax, "Holocoen and Ecosystem – On the Origin and Historical Consequences of Two Concepts," *Journal of the History of Biology*, 31 (1998): 113–142.

At the beginning of the 20th century, the shift from classical autecological to synecological approaches⁹ combines with philosophical ideas of holism and organicism, which is reflected by such concepts as the “holocoen” developed by the entomologist Karl Friederichs (1878-1969), or the ecological gestalt-systems (“ökologische Gestalt-Systeme”) of Richard Woltereck (1877-1944).¹⁰ Drawing on Frederic E. Clements’ (1874-1945) work on the evolutionary succession of plant communities,¹¹ the South African ecologist John Phillips promotes the concepts of “complex organisms” resp. super-organisms,¹² combining views of Clements with the theory of holism popularized by the South African statesman, general and philosopher Jan Christian Smuts (1870-1950).¹³

The central holistic assumption of the priority of some (physical, biological, or social) ‘whole’ over its ‘parts’ is reflected not only in ecological theories of super-organisms from animal and plant collectives to some versions of the Gaia theory developed by James Lovelock and Lynn Margulis in the 1960s and 1970s.¹⁴ Holistic and vitalist thought also prepare the ground for what might be called proto-constructivist theories of the relation between organisms and their environments. In particular, the determining influence of the milieu originally suggested by Haeckel is called into question. In Haeckel’s mechanistic framework, the morphology and dynamics of life are supposed to be completely reducible to *causas efficientes* of the physical world imposed on some organism. Contrary to this claim, the Scottish physiologist John S. Haldane (1860-1936) in

⁹ The terms “Autökologie“ and “Synökologie“ were introduced around 1900 by Carl Schröter, see Carl Schröter and Oskar von Kirchner, *Die Vegetation des Bodensees*, Vol. 2, (Lindau: Verein für Geschichte des Bodensees und seiner Umgebung, 1902).

¹⁰ Cf. Jax, “Holocoen and Ecosystem.”

¹¹ Frederic E. Clements, *Plant Succession. An Analysis of the Development of Vegetation* (Washington 1916); Frederic E. Clements, “Nature and Structure of the Climax,” *Journal of Ecology*, 24 (1936): 252–284.

¹² John Phillips, “Succession, Development, the Climax, and the Complex Organism: An Analysis of Concepts. Parts I-III,” *Journal of Ecology*, 22.2 (1934): 554–571; 23.1 (1935): 210–246; 23.2 (1935): 488–508.

¹³ On the historical relations of ecological thought to imperialism and colonialism, see Peder Anker, *Imperial Ecology. Environmental Order in the British Empire, 1895-1945* (Cambridge, Mass./London: Harvard University Press, 2001). On the affinities of the German holistic tradition around Thienemann and Friederichs to geopolitics and even fascistic ideologies of blood and soil, see Benjamin Bühler, “Zukunftsbezug und soziale Ordnung im Diskurs der politischen Ökologie,” *Zeitschrift für Kulturwissenschaften*, 2009/2: 35–44, 38f.

¹⁴ Cf. Bruce Clarke, “Neocybernetics of Gaia: The Emergence of Second-Order Gaia Theory,” In *Gaia in Turmoil: Climate Change, Biodepletion, and Earth Ethics in an Age of Crisis*, edited by Eileen Crist and H. Bruce Rinker (Cambridge: MIT Press, 2009), 293–314.

an early paper from 1884 points to the purpose driven and goal oriented behavior of living beings and argues that the causal link between the organism and its environment has to be thought of in terms of a reciprocal instead of a one way relation.¹⁵ Similar considerations lead the Baltic zoologist Jakob Johann von Uexküll to the assumption that the environment is not simply given as an objective milieu at all, but rather construed by each organism in accordance with its perceptive and motor faculties. Thus the worlds of a cow, a tick, and a black bird differ substantially, although these animals might be found in spatial vicinity. In order to account for these differences, Uexküll draws a systematic distinction between the terms “Umwelt” (environmental world), which is a essentially the projection of an organism’s construction plan (“Bauplan”), and “Außenwelt” (external world), which can only be construed by a detached observer.¹⁶ The systemic relation between a living being and its “Umwelt” is analyzed by Uexküll as a feedback loop between perceptive and motor activities and their respective environmental correlates. The concept of linear causality following the model of the unconditioned reflex is thus replaced by the cybernetic idea of circular causality – Uexküll uses the term “Funktionskreis” (functional circle) – as general explanatory principle for the relation between life and its milieu.¹⁷

Ecosystems

Thus at the beginning of the 20th century, basic elements of a proto-cybernetic view of ecology as systems theory are already widely established, when the term “ecosystem” is introduced by Arthur George Tansley (1871-1955) in 1935.¹⁸ Tansley develops the concept in a critical discussion of the holistic approaches of Clements and Phillips.¹⁹ For Tansley, an ecosystem consists of both biotic and non-biotic elements such as soil or water, atmosphere and climate; he therefore rejects the notions of complex or super-organisms with their vitalist implications, proposing the term “quasi-organism” instead. With respect to the ontological and epistemological status of ecosystems, Tansley furthermore argues that they are

¹⁵ Cf. John Scott Haldane, “Life and Mechanism,” *Mind*, 9.33 (1884): 27–47.

¹⁶ Johann Jakob von Uexküll, *Umwelt und Innenwelt der Tiere* (Berlin: Julius Springer, 1909), 1–10, 191–196, 248–253 et. pass.

¹⁷ Cf. Johann Jakob von Uexküll, *Theoretische Biologie* (Berlin: Julius Springer, 1928), ch. 5.

¹⁸ The term “ecosystem” was actually suggested to Tansley in the early 1930ies by Arthur Roy Clapham, then a young colleague of Tansley’s at Oxford; cf. A. J. Willis, “The Ecosystem. An Evolving Concept Viewed Historically,” *Functional Ecology*, 11.2 (1997): 268–271, 268.

¹⁹ George Arthur Tansley, “The Use and Abuse of Vegetational Concepts and Terms,” *Ecology*, 16.3 (1935): 284–307.

not given or objective entities, but ‘mental isolates’.²⁰ The identification of ecosystems relies on heuristic boundaries that are introduced by an observer rather than representing real physical closures. The first consequent application of the ecosystem concept is ascribed to Raymond Laurel Lindeman (1915-1942), who in a seminal study scrutinizes the trophic dynamics of a small lake in Minnesota, taking the lake as an energy system made up of living and non-living elements.²¹ Lindeman’s use of quantitative and statistical methods is inspired by his teacher, the noted limnologist George Evelyn Hutchinson (1903-1991). Hutchinson later takes part in the Macy Conferences and publishes a paper on “Circular Causal Systems in Ecology”.²²

Historically, the notion of ecosystem thus reflects an important shift in ecological thinking. The ecosystem concept made possible a reconfiguration of central assumptions developed in the frameworks of holism and vitalism, seemingly avoiding teleological and metaphysical implications while at the same time allowing to maintain basic explanatory principles such as the irreducibility of the whole to its parts or the existence of emergent properties. In terms of ecosystems, nature becomes an object of mathematical, technical and economic analysis, and ecology turns into a knowledge which is essentially concerned with resource management. In this form, ecosystem thinking became institutionalized as the most influencing branch of ecology. One of its renowned proponents is Eugene P. Odum, who advocates and further develops the ecosystem concept in his textbook *Fundamentals of Ecology*. First published in 1953, this book remained the standard work of academic teaching until the 1970s.²³ The book was co-authored by Eugene’s brother Howard T. Odum, who also was a pioneer of ecosystem ecology and, like Lindeman, a disciple of Hutchinson. Mainly under the influence of Howard T., the *Fundamentals*, especially in their third edition of 1971, make extensive use of cybernetic concepts and vocabulary such as input

²⁰ Ibid. 299f.

²¹ Raymond L. Lindeman, “The Trophic-Dynamic Aspect of Ecology,” *Ecology*, 23.4 (1942): 399–417; on the background of this paper and Lindeman’s work, see Robert E. Cook, “Raymond Lindeman and the Trophic Dynamic Concept in Ecology”, *Science*, New Series 198.4312 (1977): 22–26.

²² Cf. Peter J. Taylor, “Technocratic Optimism, H. T. Odum, and the Partial Transformation of Ecological Metaphor after World War II,” *Journal of the History of Biology*, 21.2 (1988): 213–244, 215ff.

²³ Eugene P. Odum and Howard T. Odum, *Fundamentals of Ecology* (Philadelphia: W.B. Saunders, 1953; 2nd ed., 1959; 3rd ed., 1971; 4th ed., 1983, 5th ed., 2005) The book was translated in more than thirty languages. On the reception of the *Fundamentals*, see Joel B. Hagen, “Teaching Ecology during the Environmental Age, 1965-1980,” *Environmental History*, 13.4 (2008): 704–723.

and output relations, control and feedback, organization and complexity to describe the flows of energy and material in natural systems.²⁴

Eugene P. Odum did not share his brother's addiction to energetic reductionism, but he surely also was a technocratic optimist. Influenced by his father Howard D. Odum, a noted sociologist, and by the political visions of the New Deal, Eugene P. Odum understood ecology as a theory with broad implications, bridging between natural and social systems, and believed in the possibility of sustainable resource management. Accordingly, he favored such biological concepts as mutualism and co-operation over competition.²⁵

In the 1950s and 1960s, ecosystem ecology, which had so far been a rather technical academic subdiscipline of biology, enters into complex relations with environmentalism as a new form of popular and political concerns about the conditions of existence under global industrialization and capitalism. Ecological hazards caused by smog, the use of pesticides, radioactive fallout, and ecocidal warfare, combined with global shortages of grain and oil reserves, led to a growing public awareness of environmental problems.²⁶ One of the most suggestive settings for the popularization of ecological consciousness was the planetary perspective offered by space exploration, which is reflected by McLuhan's recourse to the Sputnik. In 1965, the economist Kenneth E. Boulding coined the metaphor of "spaceship earth" and contrasted the model of a wasteful "cowboy economy" with that of a sustainable "spaceman economy" aware of strictly limited resources and the potential finiteness of existential conditions.²⁷ The metaphor of spaceship earth, which replaced that of the lifeboat,²⁸ soon gained popularity and was developed further by Buckminster Fuller and others. Photographs of the earth taken from satellites, later by Apollo astronauts, provided icons for environmental consciousness. The blue marble figured on the cover of Stewart Brand's "Whole Earth Catalog" in 1968. Consequently, Eugene P. Odum's book "Ecology and Our Endangered Life-Support Systems", published

²⁴ Cf. Taylor, "Technocratic Optimism," 224. On the Odum brothers and the historical relations between cybernetics and ecosystems thinking, see Claus Pias, "Paradiesische Zustände. Tümpel – Erde – Raumstation," in *Stehende Gewässer. Medien der Stagnation*, ed. by Butis Butis (Zürich, Berlin: Diaphanes, 2007), 47–66.

²⁵ On Eugene Odum's intellectual background, see Hagen, "Teaching Ecology", 704–709.

²⁶ Cf. Mauricio Schoijet, "Limits to Growth and the Rise of Catastrophism," *Environmental History*, 4.4 (1999): 515–530, 517f.

²⁷ Cf. W. Patrick McCray, *The Visioneers. How a Group of Elite Scientists Pursued Space Colonies, Nanotechnologies, and a Limitless Future* (Princeton and Oxford: Princeton University Press, 2013), 23.

²⁸ Cf. Hagen, "Teaching Ecology", 709–713.

in 1989, begins with a prologue on the Apollo 13 disaster as a general allegory of ecology.

Probing the Limits

By these discursive transformations, ecological questions in general and the dominant ecosystems approach in particular become increasingly concerned with the problem of finiteness. When the Club of Rome set out to model the future dynamics of economic growth in the 1970s, the term ecology advanced to a universal synonym for the limitations of nature itself, abandoning the historical ideas of perfectibility and infinite progress as constitutive for human nature. In 1970, the Club issued a paper entitled “The Predicament of Mankind. Quest for Structured Responses to Growing World-wide Complexities and Uncertainties,”²⁹ which aims at developing tools for analyzing the existential conditions of humankind on a global scale. The leading assumption is that particular problems such as population growth, scarcity of resources, pollution, food shortage, and educational deficits can no longer be treated in isolation and locally, but rather represent a complex setting of interacting hazards that requires a systemic analysis and treatment. The future of humankind is embedded into a horizon which the Club of Rome dubs “world problematique”. This “problematique” is defined by its global scale, dynamic and complex character, and especially by its temporal urgency.

The paper on the ‘predicament of mankind’ laid the foundations for the famous report *The Limits to Growth*, published in 1972, which was prepared for the Club of Rome by a team of researchers of the Systems Dynamics Group of the Sloan School of Management at the MIT under the direction of Jay W. Forrester.³⁰ Technically, the study is based on a model (dubbed “World3”) that covers important global scale anthropogenic effects in mathematical terms and allows to experiment with the temporal interaction of these effects by means of computer simulation.³¹ Central to this approach are cybernetic considerations

²⁹ The Club of Rome. *The Predicament of Mankind. Quest for Structured Responses to Growing World-wide Complexities and Uncertainties. A Proposal* (Genf, 1970).

³⁰ Donella H. Meadows, Dennis L. Meadows, Jørgen Randers and William W. Behrens III, *The Limits to Growth. A Report for The Club of Rome’s Project on the Predicament of Mankind* (New York: Universe Books, 1972).

³¹ During the years, two updates of the *Limits* have been published, providing some revisions and changes of the simulation methods and prognoses, cf. Donella H. Meadows et al., *Beyond the Limits* (Post Mills: Chelsea Green, 1992) and Donella H. Meadows et al., *Limits to Growth. The 30-Year Update* (White River Junction: Chelsea Green, 2004).

concerning the role of positive and negative feedback on progressive growth rates. Assuming that the carrying capacity of the earth is limited, exponential growth of parameters such as world population, fertilizer consumption, industrial capital savings, or pollution lead to a global “overshoot” that is predicted to cause more or less catastrophic changes until the world system settles to a new state of equilibrium.³² The report to the Club of Rome thus transports the Malthusian scenario of natural limits imposed on exponential population increase to the digital age.³³ The idea of limitations to growth provides a stable frame of reference which remains valid for ecological thought up to the present. Recent approaches to the concept of global sustainability and resilience, e.g., draw on the concept of “planetary boundaries”, trying to define threshold values for parameters such as species diversity, pollution, and population, with the goal of “estimating a safe operating space for humanity with respect to the functioning of the Earth System.”³⁴

As a central innovation, the world model used in the *Limits to Growth* follows a logic of simulation to the effect that ecology is no longer descriptive, but rather construed as an operational setting that demands experimental interaction. Tuning parameters such as population growth or industrial capital rate, and observing the non-predictable outputs, is open to assume qualities of playful action, which explains the affinities of scientific ecological modelling to computer games of world simulation such as the “Daisy World” of Andrew Watson and James Lovelock, or “SimEarth”.³⁵

³² For critical discussion of the background and the reception of the *Limits*, cf. Schoijet, “Limits to Growth”; Francis Sandbach, “The Rise and Fall of the Limits to Growth Debate,” *Social Studies of Science*, 8.4 (1978): 495–520; Vaclav Smil, “Limits to Growth Revisited: A Review Essay”, *Population and Development Review*, 31.1 (2005): 157–164.

³³ In his book *An Essay on the Principles of Population* (London: J. Johnson, 1798), the English cleric and political economist Thomas Robert Malthus (1766-1834) developed an influencing though controversial theory of the relation between population growth and limiting factors such as famine and disease. According to Malthus, population multiplies geometrically, while food supply increases only arithmetically, leading to catastrophic future scenarios. Present Neo-Malthusian approaches extend the argument from population growth and food shortage to other critical resources and environmental factors. On historical discussion and recent debates in the context of the “Limits to Growth”-reception, see Schoijet, “Limits to Growth”.

³⁴ Cf. Johan Rockström et al., “Planetary Boundaries: Exploring the Safe Operating Space for Humanity,” *Ecology and Society*, 14.2 (2009): 32, <http://www.ecologyandsociety.org/vol14/iss2/art32/>

³⁵ One of the earliest and prototypical large-scale ecological simulation environments is Buckminster Fuller’s ‘World Game’ of the 1960s, cf. Christina Vagt, “Fiktion und

While the *Limits to Growth* of 1972 are commonly supposed to have substantially contributed to the rise of ecological consciousness,³⁶ they did so mainly by popularizing a specific scientific approach to ecological modelling, and by drawing on a specific technical medium, the computer. The normative impact of the “Limits” does not aim at a cautious treatment of nature, but rather serves to promote the ideas of technical and social engineering.³⁷ Which leads to the master mind of the project. Jay Wright Forrester, electrical engineer and systems researcher, started his career at MIT during World War II with the development of servomechanisms for radar antennas and gun mounts. At the end of the war, Forrester directed the development of an aircraft flight simulator. The work on this project stimulated the design of the first digital computer, the Whirlwind system, which laid ground for experimental research on military combat information systems that resulted in the renowned SAGE (Semi-Automatic Ground Environment) air defence system for North America.³⁸

In the 1950s, Forrester turned from military environments to economic management and in this context developed his theory of Dynamic Systems, which is concerned with modelling and simulating complex systems that exhibit a non-linear behavior. In the following years, Forrester applied his theory on different scales, publishing books on “Industrial Dynamics” (1961), followed by the broader socio-political context of “Urban Dynamics” (1969), and finally by the global context of “World Dynamics” (1971). In the latter book, Forrester outlines the computer model that underlies the World3 simulation of the “Limits to Growth”, which was published nine months later. Supported by the seeming authority of the most advanced and promising technology, computer modelling here gains the status of a universal tool of scientific explanation as well as practical management, irrespective of the domain or scale of application.

In retrospect, ecological systems thinking presents itself as a field where the technical figuration of life and of nature becomes inseparable from the naturalization and animation of technology. This reversibility, which is characteristic already for the parallel conception of machines and human

Simulation. Buckminster Fullers *World Game*,” *Archiv für Mediengeschichte*, 13 (2013): 117–145.

³⁶ In fact, the appearance of the report was well planned and announced in ways which would trigger public interest in advance, cf. Sandbach, “The Rise and Fall of the Limits to Growth Debate.”

³⁷ This also applies to earlier cybernetically inspired systems ecology, cf. Taylor, “Technocratic Optimism”.

³⁸ Cf. Forrester’s autobiographical description, Jay W. Forrester, *The Beginning of System Dynamics. Banquet Talk at the International Meeting of the System Dynamics Society Stuttgart, Germany July 13, 1989.*

(working) bodies in the industrial age, is even more characteristic for the information age, where computer programming, modelling, and simulation become dominant techniques of knowledge as well as biopolitic practice, both on the macroscopic level of ecology ('world dynamics') and on the microscopic level of organisms, finally on the molecular basis of 'life itself'.

From Ecological Systems to the Transformation of 'Life'

One of the most prominent examples for the modelling and simulation of features of 'life' on a micro-level is the algorithmic artefact 'Game of Life'. The media history of 'Game of Life' (in the following abbreviated 'Life') also brings forward how the rise of 'games' as part of computer culture since the early 1970s is interconnected with the popularization of systems thinking.

'Life' is commonly understood as a game that provides an example of emergence and self-organization, therefore supporting concepts like 'autopoiesis' and 'emergence' that were brought into debate from thinkers of the second wave of cybernetics.³⁹ It is also known to be the most popular version of a cellular automaton. It was first presented in Martin Gardner's popular column in *Scientific American* in October 1970. The basic algorithm was developed by British mathematician John Horton Conway between 1968 and 1970. The original game is played on a 2-dimensional grid, similar to a checkerboard that is populated with so called 'cells'. The development of any 'Life' pattern is determined by Conway's "genetic laws" for births, deaths, and survivals of the cell population. The rules of the game are quite simple, and its very simplicity is part of its success. Gardner listed the complete rules in his article from 1970:

1. Survivals. Every counter with two or three neighboring counters survives for the next generation.
2. Deaths. Each counter with four or more neighbors dies (is removed) from overpopulation. Every counter with one neighbor or none dies from isolation.
3. Births. Each empty cell adjacent to exactly three neighbors--no more, no fewer--is a birth cell. A counter is placed on it at the next move.⁴⁰

³⁹ Cf. B. Clarke and M. B. N. Hansen, "Neocybernetic Emergence: Retuning the Posthuman," *Cybernetics and Human Knowing*, no. 16 (2009): 83–99.

⁴⁰ M. Gardner, "Mathematical Games – The Fantastic Combinations of John Conway's New Solitaire Game 'Life,'" *Scientific American*, no. 223 (October 1970): 120–23, 120.

By repeated application of the rules to the subsequent generations of cells, different patterns occur on the checkerboard. Because of the way patterns seem to evolve to ‘life-like’ behavior the game was often described as ‘fascinating’ and ‘surprising’.

While it could be argued that computer games in general are an offspring of cybernetics and therefore means of the proliferation of cybernetic systems thinking, this certainly fits as a description of ‘Game of Life’.⁴¹ When ‘Life’ became more and more popular during the 1970s, it attracted significant interest in different scientific disciplines, like computer science, economics, mathematics, philosophy, physics and biology. Since ‘Life’ started just in time with the growing distribution of a new generation of minicomputers it also became a part of the hobbyist computer culture. The influential American microcomputer magazine BYTE discussed ‘Life’ prominently already in its first issue in 1975, and editor Carl Helmer dedicated an ongoing column called LIFE-line to the game. A later issue (1978/3/12) gave detailed instructions for “Life with your computer” and encouraged its readers to develop their own version of ‘Life’.

Until today, the *computer* is the essential medium of ‘Life’ and the game is used to teach programming skills as well as to study pattern generating algorithms and ‘emergent behavior’. It remarkably crosses and interconnects scientific research with hobbyist computer culture, computer science with biology, cybernetic ideas with simulation techniques. Within various scientific disciplines it supports the transformation of epistemic practices that combine aspects of ‘playful experimentation’, simulation techniques and computer programming. A contemporary example for this function of the game can be found in the prize awarded scholarly book “Self-Organization in Biological Systems“, published in 2003 in the series Princeton Studies in Complexity and edited by Scott Camazine. In this book, ‘Life’ is used as an example for complexity and self-organization and at the same time as a software-tool to teach simulation techniques. Interestingly, the authors feel obliged to clarify that ‘Game

⁴¹ While games were already present in early cybernetic theory, with prominent examples like von Neumann’s interest in the mathematical theory of games as a possible application to economic theory, Turing’s references to chess as a testing ground for advances in artificial intelligence or Shannon’s obsession with all kinds of playful machines, it is not until the 1970s that computer-based games found their way to popular culture. For a more detailed discussion of the relevance of games in early computer discourse cf. Serjoscha Wiemer, “Strategiespiele und das Medium-Werden des Computers. Computerschach als Faktor der Rekonzeptionalisierung des Computers als programmierbare Maschine zwischen 1945 und 1960“, in *Diskurse des strategischen Spiels. Medialität, Gouvernementalität, Topografie*, ed. by Rolf F. Nohr, Serjoscha Wiemer, and Stefan Böhme (Münster: LIT, 2014), 83–112.

of Life' "is merely a stylized model of the dynamic evolution of a population of organisms and without real biological relevance". Nevertheless it is repeatedly used as a point of reference, because "its simplicity makes it a good didactic example."⁴² 'Life' can be found in a list of programs for the simulation software StarLogo, together with simulations of pattern formation in slime molds, synchronized flashing among fireflies or colony thermoregulation in honey bees.

Within the broader field of digital culture, 'Life' is part of the distribution of programming skills in conjunction with ideas of self-organization and emergence as well as with 'entertainment' in the sense of fun and playful practice. It is a striking example of a decentered distribution of knowledge and its (re)production by algorithmic media.⁴³ Algorithmic media like 'Life' can be seen as elements of today's 'nature-database', re-codifying concepts of nature and information.⁴⁴

Ludic Function as Interdiscourse and Naturalization

The broad application of 'Life' from scientific research to entertainment can be understood with regard to its specific features as a *game*. To further explore this

⁴² See Scott Camazine, *Self-Organization in Biological Systems* (Princeton, New Jersey: Princeton University Press, 2003), 81.

⁴³ Within the field of cultural and media studies scholars like Laura Marks, Alexander Galloway, and Jussi Parikka among others have contributed to a theoretical understanding of "algorithmic media", but the concepts are still in a flux. One common aspect could be seen in the drive towards a neo-materialistic understanding of algorithmic media that tries to overcome a traditionally staged "opposition between mechanistic and vitalist understandings of (dead versus lively) matter". Cf. Diana H. Coole and Samantha Frost, eds., *New Materialisms: Ontology, Agency, and Politics* (Durham [NC]; London: Duke University Press, 2010), 11. For the approaches of Marks and Galloway cf. Laura U. Marks, "Thinking like a carpet: embodied perception and individuation in algorithmic media", in *Ent-Automatisierung*, ed. by Annette Brauerhoch and Anke Zechner (Paderborn: Fink, 2014); Alexander R. Galloway, *Gaming: Essays on Algorithmic Culture* (Minneapolis: Univ. of Minnesota Press, 2006).

⁴⁴ Referring to concepts of new materialism, German Duarte proposed the term 'nature-database' to describe the new relation between materiality and information that evolves from the intensified interrelation of 'nature' and 'technology'. As Duarte states "nature-database can be understood as a new codification of 'reality' from which non-fix meaning derives and in which biological (material) and non-biological (technology and information) coexist and are in constant transformation." German Duarte, "New-Materialism and Reification in the Infoproduction Era," *Communication +1*, no. 2 (September 8, 2013), <http://scholarworks.umass.edu/cpo/vol2/iss1/4>.

idea we will draw on Rolf F. Nohr's concept of the "naturalization" of knowledge and Gerald Voorhees' concept of computer games as "game of truth".⁴⁵ German media scholar Rolf Nohr discusses the function of games within a general framework of the discursive circulation of knowledge.⁴⁶ According to Nohr, a characteristic discursive function of computer games is that of "naturalization" which is realized by "translating" elements of special discursive knowledge to the level of the common sense.⁴⁷ A key attribute of this theory is the importance of the *ludic function* of games as a performative process and how a general idea is transferred to the level of individual perception and belief. By playing a game one activates its aesthetic dimension not as an abstract, but as an *individual, temporal* experience, where a game unfolds as something that is more or less defined in relation to one's active involvement and *configurative actions*.⁴⁸ In other words: to play a game is the *subjective* instantiation of an abstract form as a sensual experience and therefore coupled with the temporality of perception and subjectivity. According to Nohr, this "sensualization" should be interpreted as an element of "naturalization", which leads to the translation of special discourse knowledge to common sense. Therefore computer games realize a "procedure of integration" which is part of their function as "interdiscourses".⁴⁹ While Nohr points to the function of games for the *transfer* of knowledge, this idea can be complemented by Gerald Voorhees' concept of the epistemological function of games.⁵⁰ Adopting the term 'game of truth' from Foucauldian discourse analysis and applying it to the study of computer games, Voorhees points to the epistemological relevance of games: "digital games model the discursive formations that give shape to what is reasonable, what is possible and what is

⁴⁵ Gerald Voorhees, "Discursive Games and Gamic Discourses," *Communication +1*, no. 1, <http://scholarworks.umass.edu/cpo/vol1/iss1/3>.

⁴⁶ Rolf F. Nohr, "The Naturalization of Knowledge. Games Between Common Sense and Specialized Knowledge," in *Logic and Structure of the Computer Game*, ed. Michael Liebe, Dieter Mersch, and Stephan Günzel, vol. 4, DIGAREC Series (Potsdam: University Press, 2010), 130–43.

⁴⁷ With reference to Jürgen Link's theory of 'critical discourse analysis', Nohr distinguishes between 'special discourses' of highly specialized knowledge, for example in scientific discourses of economics, biology, mathematics etc., and a level of 'shared' or 'common' knowledge being part of the everyday of a given society (for Link's theory cf. Siegfried Jäger, *Kritische Diskursanalyse: Eine Einführung*, 6th ed., Edition DISS 3 (Münster: Unrast, 2004)).

⁴⁸ Markku Eskelinen, "The Gaming Situation," *Game Studies. The International Journal of Computer Game Research*. 1, no. 1 (July 2001), <http://www.gamestudies.org/0101/eskelinen>.

⁴⁹ Nohr, "The Naturalization", 137.

⁵⁰ Gerald Voorhees, "Discursive Games".

foreclosed in a given historical moment, enabling critical scholars of communication to better conceptualize the operation of power.”⁵¹

Game of Truth: Cybernetic’s Concept of Self-Reproduction and the Invention of Cellular Automata

Following Voorhees’ suggestion to ask about the “given historical moment” when ‘Game of Life’ came into existence, it is not sufficient just to name the publication of the rules and descriptions in Martin Gardner’s column on recreational mathematics in *Scientific American* in October 1970. Understood as an expression of a certain “epistemological force”⁵², one has to take the conceptual foundation of ‘Life’ as an example of cellular automata more serious.⁵³ This leads to the epistemological presuppositions of ‘Life’ and to the question how Conway’s rules of the game refer to the historical epistemology of cybernetics. Media scholar Jussi Parikka identified Conway’s work as part of an epistemological idea “to see nature as a computational process” and, in particular, “as part of the history of mathematical organisms and simulations”.⁵⁴ When Parikka discussed ‘Game of Life’ in “Digital Contagions”, his seminal study of computer viruses, he pointed to the “key role” of self-reproduction and to the fact that with cellular automata, the concept of self-reproduction was combined with “principles of universal computation”.⁵⁵ The crucial point is that ‘Life’ is a leading example of the idea of the *computability of nature* by the means of systems theory.

⁵¹ Ibid., 16.

⁵² Voorhees, “Discursive Games”, 13.

⁵³ Since ‘Game of Life’ itself refers to the notion of ‘life’, it is of great importance to reconstruct the concept of life that leads to the possibility of ‘Game of Life’ and to be sensitive to the historical movement that ‘Life’ is involved in, how it is enmeshed in the struggle of the reconceptualization of life as ‘information’. To look at ‘Game of Life’ as a ‘game of truth’ in this sense might imply to try to reconstruct the ‘discursive formation’ that gave shape to the game. Including questions like “What are the necessary conditions to make the formation of this specific game possible?”, “What are the epistemological articulations and the power relations, that are specific to the game in a given historical moment?”, “What were the epistemological concepts that could lead to the formulation of cellular automata?”, “What was their theoretical function within the ‘game of truth’ that cybernetics played in the 1940s and 1950s?”, “What was their ‘strategic’ value?”, “What were the questions and theoretical problems that lead to the concept of cellular automata?”.

⁵⁴ Jussi Parikka, *Digital Contagions: A Media Archaeology of Computer Worms and Viruses* (New York [u.a.]: Peter Lang, 2007), 232f.

⁵⁵ Ibid.

The basic idea of cellular automata was formulated by John von Neumann in the 1940s.⁵⁶ Von Neumann's first approach to a theory of self-reproducing automata was about an automaton that could *materially* reproduce itself.⁵⁷ In addition to this concept of a "Universal Constructing Machine" (also called "kinematic model") he later developed a second model of self-reproducing automata, which does not pose the mechanical and material problems of the first and which became known as the theory of *cellular automata*: In this approach, the automata are based on a two-dimensional array of elementary "cells."⁵⁸ This concept finally led to the invention of 'Game of Life' by Conway.

It is remarkable that von Neumann developed his initial idea of automata as self-reproducing structures when he tried to find a mathematical description of *complexity*. Self-reproduction and the theory of biological evolution served as a key to von Neumann's understanding of the meaning of 'complexity'. He argued that while natural organisms would show the ability for increasing complexity, which would be the case with "long periods of evolution", the artificial automata would suffer from a "degenerating tendency" and a "decrease of complexity".⁵⁹

⁵⁶ Claude Shannon summoned von Neumann's ideas in 1953. The following paragraphs are based on his subsumption of von Neumann's approach. Cf. Claude E. Shannon, "Computers and Automata," *Proceedings of the IRE* 41, no. 10 (1953): 1234–41, 1240.

⁵⁷ Von Neumann thought that, analogous to Turing's universal computing machine, it could be possible to "design a kind of universal construction machine [...] The universal constructing machine can be fed a sequence of instructions, similar to the program of a digital computer, which describe in a suitable code how to construct any other machine that can be built with the elementary components. The universal constructing machine will then proceed to hunt for the needed components in its environment and build the machine described on its tape." *Ibid.*, 1240.

⁵⁸ Claude Shannon gave a short and very precise description of the general mechanism of von Neumann's initial conception of cellular automata: "Each cell is of relatively simple internal structure, having, in fact, something like thirty possible internal states, and each cell communicates directly only with its four neighbors. The state of a cell at the next (quantized) step in time depends only on the current state of the cell and the states of its four neighbors. By a suitable choice of these state transitions it is possible to set up a system yielding a kind of self-reproducing structure." *Ibid.*

⁵⁹ "Organisms are indirectly derived from others which had lower complexity", but "a certain degenerating tendency must be expected, some decrease in complexity as one automaton makes another automaton." See John von Neumann, "The General and Logical Theory of Automata," in *Collected works*, ed. Abraham Haskel Taub, vol. V (Oxford; New York [etc.]: Pergamon, 1976), 288–326, 312. This statement is logical, if one assumes that in order for an automaton A to produce another automaton B it must have contained a complete description of B together with some instructions how to build it and therefore A must have a higher degree of "complication" than B. (*ibid.*, 312). After von Neumann sketched the logical and mathematical description of an

Looking at how von Neumann presents his argument in “The General and Logical Theory of Automata”, one recognizes that at the beginning he is very strict and careful to develop his theoretical comparison of ‘natural organism’ and artificial automata only as means of *interpretation* for certain problems regarding the understanding of complexity. But later that relation is reversed when he takes the self-reproduction of automata as a model for the explanation of the self-reproduction of genes and the production of enzymes.⁶⁰ It is precisely at this point that an *epistemological operation* becomes functional, which Lily E. Kay analyzed as “cyborg dialectic”. Cyborg dialectic points to a procedure where machines and organisms are taken as a model to mutual explain the other and at the same time narrowing both concepts, so that their distinction becomes more and more blurred. According to Kay this specific cross-identity-conceptualization of machines and biological systems is one of the characteristics of the first wave of cybernetics.⁶¹ As Kay has shown in her writings about the history of science, this *cyborg dialectic* can be found explicitly in the formation of the concepts of the ‘genetic code’ and the reconceptualization of ‘life’ in modern molecular biology. Within the ontological framework of cybernetics, ‘life’ was not only regulated by cybernetic mechanisms of feedback and homeostasis, but it finally became thinkable to understand ‘life itself’ as pure ‘information’.

Thus, at the time when British mathematician John Horton Conway started his work on ‘Game of Life’ around 1968, he entered an already established array of mutual conceptualizations of ‘living organisms’ and ‘artificial automata’. At the end of the 1960s the idea of taking self-reproducing automata as a model for the understanding and ‘calculation’ of biological processes of cellular

automaton with the ability of self-reproduction that could possibly be a solution to the degenerating tendency, he proposed a direct comparison of the process of self-reproducing automata and living organisms, declaring “the copying mechanism B performs the fundamental act of reproduction, the duplication of the genetic material, which is clearly the fundamental operation in the multiplication of living cells.” (ibid., 317).

⁶⁰ Ibid., 318.

⁶¹ The concept of cyborg dialectic is developed as part of Kay’s analysis of the epistemological shift of neuroscience in the theoretical works of Warren S. McCulloch and Walter Pitts that played a crucial role in the ‘cognitive turn’ of the 1950s: “McCulloch-Pitts neural nets and Turing’s machine became the twin pillars of early automata studies and computer design [...]. And just as with Wiener’s cybernetics, in which the nervous system became a model for negative feedback machines and, in turn, the machine a model for biological systems, this cyborg dialectic obtained also in logical automata.” Lily E. Kay, “From Logical Neurons to Poetic Embodiments of Mind: Warren S. McCulloch’s Project in Neuroscience,” *Science in Context* 14, no. 04 (2001): 591–614, 602.

reproduction on a molecular level was already in circulation.⁶² Some of these conceptions privileged the phenomenon of ‘self-reproduction’ as paradigmatic feature of ‘life’, while others were more structured by concepts of information, program, feedback or complexity.

Artificial Life

While ‘Game of Life’, until today, is used for modeling ‘natural’ and ‘lifelike’ processes and as algorithmic medium for theoretical research across a broad range of disciplines,⁶³ a very distinct and specific role of ‘Life’ can be found within *artificial life research*. Christopher Langton, one of the founding figures of artificial life (also abbreviated A-Life) as an academic field of study, proposed to acknowledge non-organic entities as ‘alive’ and proclaimed cellular automata as preferred research tool.⁶⁴ The ‘lifelike’ behavior of Conway’s ‘Life’ is a much used ‘visual’ argument for this approach.⁶⁵ It seems plausible that much of the game’s continuous attraction is related to its *visual attributes*, how it “offers direct

⁶² As Evelyn Fox Keller has shown, ‘program’ and ‘computer’ became influential as metaphors for the understanding of biological development during the 1960s, namely with regard to genetic research and molecular biology. Cf. Evelyn Fox Keller, “Beyond the Gene but beneath the Skin,” in *Arguing about Science*, ed. Alexander Bird and James Ladyman (New York: Routledge, 2012), 125–39, 129f. Stahl is one of the early researchers who also referred directly to the idea of self-replicating machines as theorized by von Neumann; Apter (1966) emphasized the importance of logical or computer models of genetic control and differentiation mechanisms, after François Jacob and Jacques Monod, who had applied cybernetic concepts of ‘regulation’ and ‘control’ successfully to the description of biochemical mechanisms of enzyme synthesis, were awarded with the Nobel Prize in Medicine in 1965 (together with André Lwoff). Cf. Walter R. Stahl, “A Computer Model of Cellular Self-Reproduction,” *Journal of Theoretical Biology* 14, no. 2 (1967): 187–205; Michael John Apter, *Cybernetics and Development*, International Series of Monographs in Pure and Applied Biology. Div.: Zoology; 29 (Oxford: Pergamon Press, 1966).

⁶³ An ongoing interest in ‘Game of Life’ can be observed in mathematics, physics, biology, chemistry, music theory, simulation theory, and other disciplines. A collection of different approaches, with a certain emphasis on mathematics, can be found in Andrew Adamatzky, ed., *Game of Life Cellular Automata* (London; New York: Springer, 2010).

⁶⁴ Christopher G. Langton, “Studying Artificial Life with Cellular Automata,” *Physica D: Nonlinear Phenomena*, Proceedings of the Fifth Annual International Conference, 22, no. 1–3 (October 1986): 120–49.

⁶⁵ The reference of A-Life to ‘Life’ has been discussed in more detail in Sherry Turkle, *Life on the Screen* (New York: Simon & Schuster, 1995).

visual evidence of how simple rules can generate complex patterns”.⁶⁶ In this regard, it is possible to identify at least two different aspects of the visual qualities of ‘Life’: a) the aesthetic experience of movement or animation and b) the pleasing unpredictability of pattern development with a rich diversity of reoccurring ‘organisms’ (specimens) and designs in constant flux.

While the geometrical and topological features of ‘Life’ may be regarded as a direct outcome of its specific mathematical foundation, this does not hold true for its visual aspects, since the visibility and its perceivability as well as perceptibility in general is not only an outcome of its mathematical structure but also very much of its materialized processing by *computer media* and the related graphical displays. This is an important aspect that exemplifies how algorithmic media are relying on *material processes*, where ‘matter’ and ‘information’ are not opposed but entangled. If ‘Life’ can be regarded a significant historical landmark concerning the rewriting of the matrix of life, it is because its main feature is not on the level of the ‘symbolic’ or in the register of ‘representation’, but how it brings together concepts, code, algorithm, material calculation, and perception in a dense process of mediation. At least from the perspective of new materialisms or materialist media theory⁶⁷ it would be wrong to treat ‘Life’ as an example of the ‘immaterial’ essence of ‘life itself’ – since the very mechanism of computer technology is the specific arrangement of ‘matter’ for the purpose of calculation. Computers are essentially material devices, as media scholars have often emphasized.⁶⁸ One of their material features is the ability to *display* structures of information and rule based processes.

To See It is to Know It - Aesthetic-Epistemological Power

Regarding the importance of computers as *visual media*, Sherry Turkle’s description of her first encounter with ‘Life’ is an instructive example of how the

⁶⁶ John Johnston, *The Allure of Machinic Life: Cybernetics, Artificial Life, and the New AI* (Cambridge, Mass.: MIT Press, 2008), 10.

⁶⁷ According to Milla Tiainen and Jussi Parikka, the new materialist approach can be characterized by a “commitment to developing models of immanent and continuously emergent relationality” as well as by a certain *materialist* understanding of media as a “network of concrete, material, physical and physiological apparatuses and their interconnections”. See Jussi Parikka and Milla Tiainen, “What Is New Materialism-Opening Words from the Event,” accessed April 1, 2014, <http://machinology.blogspot.de/2010/06/what-is-new-materialism-opening-words.html>.

⁶⁸ For example Frank Hartmann, *Mediologie: Ansätze einer Medientheorie der Kulturwissenschaften* (Wien: Facultas Universitätsverlag, 2003), 11. Hartmann points to the fact that „digital“ in the realm of the computer means that binary arithmetic is switched electronically, which implies electronic engineering and material processes.

aesthetic function of computer mediated mathematical processes structures and rules the perception of a game's 'epistemological' message. In *Life on the screen* Turkle recalls how 'Life' began to challenge the way she thought about 'life itself':

When I first came upon it, the Game of Life was running on a small, unattended screen. Things came together and flew apart, shapes emerged, receded, and reemerged. I remember thinking about fire and water. The French philosopher Gaston Bachelard had written about the universal fascination of watching fire, which, like watching moving water, is something that people seem drawn to across all times and cultures. There is repetition and sameness, surprise and pattern. Fire and water evoke eternal patterns of life, and now, so could a computer screen. In 1977, I stood alone at the screen, watched the Game of Life, and felt like a little girl at the oceans' edge. At the same time I assumed that all life had to be carbon based. [...] But as I came to understand how the Game of Life could be reset to generate complexity from initial randomness, it took on another level of fascination. I saw how this evolving, unfolding visual display might challenge my simple preconceptions. Perhaps something about life could be understood in terms of these evolving forms. I was intrigued by the idea but resisted it.⁶⁹

From a perspective of media theory, Turkle's fascination with the visual movements, reminding her of "eternal patterns of life" by resembling the experience of watching *fire and water*, should not be understood as the analogue to a "universal fascination" that is essentially the same "across all times and cultures". Rather it should be understood as an effect of 'animation' specifically related to the medium of the computer. It is precisely the visual display that is in the center of Turkle being "intrigued by the idea" of life as formations of evolving patterns and informational description of complexity. However, Turkle's dense rhetorical scene is not only instructive regarding the rhetorical potential of the game to translate visual qualities into intriguing ideas, but also regarding the reference to eternity, fire and water. As physical phenomena fire and water do not fall into the realm of common ontologies of 'life' or 'living organisms'. And more so, "life" is commonly understood as limited, since mortality is one of the essential properties of "life", which is very much in contrast to Turkle's awestruck invocation of "eternal patterns".

⁶⁹ Turkle, *Life on the Screen*, 155.

In fact, Turkle's description seems to be closer to a familiar cultural concept of 'nature' than of 'life'. This might become even more obvious regarding the overlap between Turkle's affirmation of '(L)life' and Hans-Georg Gadamer's description of "play" which he developed in his theory about the artwork: Gadamer's ideas about 'play' are directed against any individual or 'subjective' aspects of games, trying to reflect on 'play as such', apart from personal experience or idealistic tradition. "Play" is described in direct correspondence to "the mobile form of nature".⁷⁰ For Gadamer, nature itself is understood as a play – without the necessity of human subjects involved:

If we examine how the word 'play' is used and concentrate on its so-called metaphorical senses, we find talk of the play of light, the play of the waves, the play of gears or parts of machinery, the interplay of limbs, the play of forces, the play of gnats, even a play on words. In each case what is intended is to-and-fro movement that is not tied to any goal that would bring it to an end. Correlatively, the word 'Spiel' originally meant 'dance', and is still found in many word forms (e.g., in Spielmann, jongleur).⁷¹

In a manner that could be evocative of aspects of 'Life', Gadamer further explains his idea about "play as such":

The movement of playing has no goal that brings it to an end; rather, it renews itself in constant repetition. The movement backward and forward is obviously so central to the definition of play that it makes no difference who or what performs this movement. The movement of play as such has, as it were, no substrate. It is the game that is played—it is irrelevant whether or not there is a subject who plays it. The play is the occurrence of the movement as such.⁷²

Gadamer's philosophy of play can help to explain how Turkle's fascination with 'Life' transcended into a fascination of 'nature'. The similarities between Gadamer's approach to play and Turkle's narration of her impressions of 'Life' seem to culminate in the affirmation of certain aesthetic qualities of movement. The patterns of 'Game of Life' can be attributed the quality of 'dancing' light, visible on a computer screen. In Turkle's description, 'Life' resembles "the mobile form of nature" that Gadamer calls 'play'.

⁷⁰ Hans-Georg Gadamer, *Truth and Method*, 2nd ed., Continuum Impacts (London: Continuum, 2006), 105.

⁷¹ Ibid.

⁷² Ibid., 104.

However, Turkle's contribution to the discourse of 'Life' is more or less a byproduct of her interest in the scientific project of artificial life (A-Life). Christopher Langton, one of the prominent advocates of A-Life, follows the credo that "the 'molecular logic' of life can be embedded within cellular automata".⁷³ As Langton states, the principle assumption made in A-Life-research is that "the 'logical form' of an organism can be separated from its material basis of construction, and that 'aliveness' will be found to be a property of the former, not of the latter".⁷⁴ For Langton, of course, this logical form is equivalent to an algorithm, and therefore the "ideal tool" for the study of life is exactly the computer.⁷⁵ Following the ideas of a bottom-up approach, where "emergent behavior" is thought of as an outcome of the dynamic interaction of rather simple "low-level primitives",⁷⁶ A-Life discourse takes 'Life' as an essential reference. Because it is not just a metaphor, but an 'algorithmic machine', it implies the promise to bridge the gap between biological studies on complexity and self-organization in natural organisms or "biological systems"⁷⁷ and the computer based understanding of life as complex systems of information processing.

As the example of 'Life' shows, there is an ongoing translation between epistemological and aesthetic reasoning, where the rhetorical function depends very much on the specific mediality of games. While on the one hand, 'Life' may be used as an example for the conceptual shift from a notion of 'life' as carbon based to the idea that "'information' can be 'life'"⁷⁸, on the other hand it can point to the importance of aesthetic qualities as fundamental aspects of the notion of 'life' or 'nature'. From a perspective of media theory, it is important to notice the fact that the game's 'meaning' is not only determined by its context and its rhetorical instrumentalization for different strategic goals within the 'game of

⁷³ Christopher Langton, "Studying Artificial Life with Cellular Automata," *Physica D: Nonlinear Phenomena*, Proceedings of the Fifth Annual International Conference, 22, no. 1-3 (October 1986): 120-49, 120.

⁷⁴ Christopher Langton, "Artificial Life. Introduction," in *Artificial Life: Proceedings of an Interdisciplinary Workshop on the Synthesis and Simulation of Living Systems*, ed. Christopher Langton (Reading, Mass.: Addison-Wesley, 1988), 1-47, 11.

⁷⁵ *Ibid.*, 2.

⁷⁶ *Ibid.*, 2-3.

⁷⁷ See Camazine, *Self-Organization in Biological Systems*. Due to its simplicity with only a few rules to calculate the status of a single cell, determined by the status of its neighbors, 'Life' is suited to the propagation of a hands-on approach to simulation techniques, as it is common practice not only to experiment with the initial state of the system, that is the specific distribution of cells on the two-dimensional grid, but to *alter* the rules themselves.

⁷⁸ Richard Doyle, *On Beyond Living: Rhetorical Transformations of the Life Sciences* (Stanford University Press, 1997), 110.

truth', but that the meaning-making properties have slid to the process of translation or mediation between 'information' and perception.

Final Prospect

Ongoing debates about biomedicine show the traces of systems thinking on several levels. Remarkably, it is not only the historic relevance of systems theory's epistemological project that irradiates contemporary ontologies, but also a strong drive to use simulations and games as means of popularization. The world models of system ecology and the games of 'lifelike' patterns both underline the relevance of algorithmic media as part of the production and interpretation of (our shared) reality. While the genealogy of systems thinking can be traced back to the emerging ecological thought of the late 19th century, it is the technoscientific approach of simulation that re-folds biology, ecology and systems thinking onto another. Finally, the afterlife of systems thinking becomes more or less undistinguishable from the afterlife of 'nature'. Does this mean that world modelling should be identified as the historical vanishing point of 'nature', since system-ecological thinking is incapable of rendering anything outside as relevant counterpart? Or how might one think any 'outside' of the ecological paradigm? The debates between poststructuralism, systems theory and actor-network-theory are haunted by the ghost of nature. A zombielike afterlife: It seems likely that system-ecology aka "undead nature" keeps revisiting contemporary theory.

Following an argument of gender-and-media scholar Marie-Luise Angerer, algorithmic media might circumscribe a new kind of mediatechnological state, where the 'interval of perception' is 'played' in a way that technology and life become "soldered" („verlötet") in accordance to the conditions of electronic affective temporality. This could lead, as Angerer argues, to a point where technology and life, the social and the somatic, lose their mutual differentiation.⁷⁹

⁷⁹ Cf. Marie-Luise Angerer, "Die 'Biomediale Schwelle'. Medientechnologien und Affekt," in *Situiertes Wissen und Regionale Epistemologie: Zur Aktualität Georges Canguilhem's und Donna J. Haraway's*, ed. Astrid Deuber-Mankowsky and Christoph F. E. Holzhey, *Cultural Inquiry* 7 (Wien: Verlag Turia + Kant, 2013), 203–22, 210. This idea of a biomedical threshold („biomedialer Schwelle") is based on Angerer's reading of George Canguilhem's philosophy of technology. Canguilhem developed his philosophy of technology in distancing himself from the cybernetic "pursue of hegemony" (ibid., 209). Angerer follows Canguilhem's proposal to understand technology as "universal biological phenomenon" (ibid., 208), as Canguilhem argued in his essay *Machine and Organism*. Unlike in cybernetics, for Canguilhem technology is not identical with rationality and teleological thinking. The assumed rationality of

Referring to Foucault's concept of the productivity of power, Richard Doyle describes algorithmic media as elements of the "practice and tactics (what Foucault has dubbed a 'technological ensemble')" that are involved in the game of truth where "life gets networked, located, and articulated through a computer screen".⁸⁰ In addition to the onto-aesthetical, epistemological, and rhetorical functionality of algorithmic media, Alexander Galloway theorized their allegoric power. He states that "to interpret a game means to interpret its algorithm (to discover its parallel 'algorithim')"⁸¹, but the playful actions that are necessary to discover a game's possible worldings are not acts of hermeneutic exegesis and interpretation, but can be called 'playacts'. Within algorithmic media, the allegorical dimensions of a game are less on the level of representations but communicate as playful actions: playacts refer to this situation of algorithmic media, where we "do" allegory, rather than comment and reflect on it.

As part of the new compositions of the techno-biological and the techno-ecological situation of the 21st century, the example of 'Life' can help to avoid some of the epistemological pitfalls and misconceptions that arise with the ideology of simulation and the afterlife of systems theory in ecological modeling of 'Gaia' and synthetic biology. 'Life' should remind us of the allegorical qualities of algorithmic media, where the game of truth has not been played through, but still requires ongoing playacts.

technology that is brought in opposition to life and is used as a model to gain control and power over the living would then be an anthropocentric illusion. For Canguilhem's critique of anthropocentric concepts of technology cf. Astrid Deuber-Mankowsky, "Kritik des Anthropozentrismus und die Politik des Lebens bei Canguilhem und Haraway," in *Situiertes Wissen und Regionale Epistemologie: Zur Aktualität Georges Canguilhems und Donna J. Haraways*, ed. Astrid Deuber-Mankowsky and Christoph F. E. Holzhey, *Cultural Inquiry* 7 (Wien: Verlag Turia + Kant, 2013), 105–20.

⁸⁰ Doyle, *On Beyond Living*, 110.

⁸¹ Galloway, *Gaming: Essays*, 91.

Bibliography

- Adamatzky, Andrew, ed. *Game of Life Cellular Automata*. London; New York: Springer, 2010.
- Angerer, Marie-Luise. "Die 'Biomediale Schwelle'. Medientechnologien und Affekt." In *Situiertes Wissen und Regionale Epistemologie: Zur Aktualität Georges Canguilhems und Donna J. Haraways*, edited by Astrid Deuber-Mankowsky and Christoph F. E. Holzhey, 203–22. *Cultural Inquiry* 7. Wien: Verlag Turia + Kant, 2013.
- Anker, Peder. *Imperial Ecology: Environmental Order in the British Empire, 1895-1945*. Cambridge, Mass./London: Harvard University Press, 2001.
- Apter, Michael John. *Cybernetics and Development*. International Series of Monographs in Pure and Applied Biology. Div.: Zoology; 29. Oxford: Pergamon Press, 1966.
- Beck, Ulrich. *Weltrisikogesellschaft: Auf der Suche nach der verlorenen Sicherheit*. Frankfurt/M.: Suhrkamp, 2008.
- Bühler, Benjamin. "Zukunftsbezug und soziale Ordnung im Diskurs der politischen Ökologie." *Zeitschrift für Kulturwissenschaften* 2009/2: 35–44.
- Camazine, Scott. *Self-Organization in Biological Systems*. Princeton, New Jersey: Princeton University Press, 2003.
- Clarke, Bruce. "Neocybernetics of Gaia: The Emergence of Second-Order Gaia Theory." In *Gaia in Turmoil: Climate Change, Biodepletion, and Earth Ethics in an Age of Crisis*, edited by Eileen Crist and H. Bruce Rinker, 293–314. Cambridge: MIT Press, 2009.
- Clarke, Bruce, and Mark B. N. Hansen. "Neocybernetic Emergence: Retuning the Posthuman." *Cybernetics and Human Knowing* 1–2, no. 16 (2009): 83–99.
- Clements, Frederic E. *Plant Succession: An Analysis of the Development of Vegetation*. Washington, 1916.
- . "Nature and Structure of the Climax." *Journal of Ecology* 24 (1936): 252–284.
- Cook, Robert E. "Raymond Lindeman and the Trophic Dynamic Concept in Ecology." *Science, New Series* 198 (1977): 22–26.
- Coole, Diana H., and Samantha Frost, eds. *New Materialisms: Ontology, Agency, and Politics*. Durham [NC]; London: Duke University Press, 2010.
- Crutzen, Paul J. "Geology of Mankind." *Nature* 415 (3. Jan. 2002): 23.

- Deuber-Mankowsky, Astrid, and Christoph F. E. Holzhey, eds. *Situiertes Wissen und Regionale Epistemologie: Zur Aktualität Georges Canguilhems und Donna J. Haraways*. Cultural Inquiry 7. Wien: Verlag Turia + Kant, 2013.
- Deuber-Mankowsky, Astrid. "Kritik des Anthropozentrismus und die Politik des Lebens bei Canguilhem und Haraway." In *Situiertes Wissen und Regionale Epistemologie: Zur Aktualität Georges Canguilhems und Donna J. Haraways*, edited by Astrid Deuber-Mankowsky and Christoph F. E. Holzhey, 105-20. Cultural Inquiry 7. Wien: Verlag Turia + Kant, 2013.
- Doyle, Richard. *On Beyond Living: Rhetorical Transformations of the Life Sciences*. Stanford University Press, 1997.
- Duarte, German. "New-Materialism and Reification in the Infoproduction Era." *Communication +1*, no. 2 (September 8, 2013). <http://scholarworks.umass.edu/cpo/vol2/iss1/4>.
- Eskelinen, Markku. "The Gaming Situation." *Game Studies. The International Journal of Computer Game Research*. 1, no. 1 (July 2001). <http://www.gamestudies.org/0101/eskelinen>.
- Forbes, Stephen A. "The Lake as a Microcosm." *Bull. of the Scientific Association (Peoria, IL)* (1887): 77-87.
- Forrester, Jay W. *The Beginning of System Dynamics: Banquet Talk at the International Meeting of the System Dynamics Society Stuttgart, Germany July 13, 1989*.
- Frasca, Gonzalo. "Simulation Versus Narrative: Introduction to Ludology." In *The Video Game Theory Reader*, edited by Mark J. P. Wolf and Bernard Perron, 221-36. New York u.a.: Routledge, 2003.
- Gadamer, Hans-Georg. *Truth and Method*. 2nd ed. Continuum Impacts. London: Continuum, 2006.
- Galloway, Alexander R. *Gaming: Essays on Algorithmic Culture*. Minneapolis: Univ. of Minnesota Press, 2006.
- Gardner, Martin "Mathematical Games – The Fantastic Combinations of John Conway's New Solitaire Game 'Life.'" *Scientific American*, no. 223 (October 1970): 120-23.
- Haeckel, Ernst. *Generelle Morphologie der Organismen: Allgemeine Grundzüge der organischen Formen-Wissenschaft, mechanisch begründet durch die von Charles Darwin reformirte Descendenz-Theorie, Bd. 2: Allgemeine Entwicklungsgeschichte der Organismen. Kritische Grundzüge der*

- mechanischen Wissenschaft von den entstehenden Formen der Organismen, begründet durch die Descendenz-Theorie.* Berlin: Reimer, 1866.
- Hagen, Joel B. "Teaching Ecology during the Environmental Age, 1965-1980." *Environmental History* 13.4 (2008): 704–723.
- Haldane, John Scott. "Life and Mechanism." *Mind* 9.33 (1884): 27–47.
- Hartmann, Frank. *Mediologie: Ansätze einer Medientheorie der Kulturwissenschaften.* Wien: Facultas Universitätsverlag, 2003.
- Jäger, Siegfried. *Kritische Diskursanalyse: Eine Einführung.* Münster: Unrast, 2004.
- Jax, Kurt. "Holocoen and Ecosystem – On the Origin and Historical Consequences of Two Concepts." *Journal of the History of Biology* 31 (1998): 113–142.
- Johnston, John. *The Allure of Machinic Life: Cybernetics, Artificial Life, and the New AI.* Cambridge, Mass.: MIT Press, 2008.
- Kay, Lily E. "From Logical Neurons to Poetic Embodiments of Mind: Warren S. McCulloch's Project in Neuroscience." *Science in Context* 14, no. 04 (2001): 591–614.
- Keller, Evelyn Fox. "Beyond the Gene but beneath the Skin." In *Arguing about Science*, edited by Alexander Bird and James Ladyman, 125–39. New York: Routledge, 2012.
- Langton, Christopher. "Artificial Life. Introduction." In *Artificial Life: Proceedings of an Interdisciplinary Workshop on the Synthesis and Simulation of Living Systems*, edited by Christopher Langton, 1–47. Reading, Mass.: Addison-Wesley, 1988.
- Langton, Christopher G. "Studying Artificial Life with Cellular Automata." *Physica D: Nonlinear Phenomena*, Proceedings of the Fifth Annual International Conference, 22, no. 1–3 (October 1986): 120–49.
- Lindeman, Raymond L. "The Trophic-Dynamic Aspect of Ecology." *Ecology* 23.4 (1942): 399–417.
- Luhmann, Niklas. *Soziologie des Risikos.* Berlin/New York: de Gruyter, 2003.
- Marks, Laura U. *Enfoldment and Infinity: An Islamic Genealogy of New Media Art.* Cambridge, Mass.: MIT Press, 2010.
- . "Thinking like a Carpet: Embodied Perception and Individuation in Algorithmic Media." In *Ent-Automatisierung*, edited by Annette Brauerhoch and Anke Zechner. Paderborn: Fink, 2014 (projected).

- Maturana, Humberto R., and Francisco J. Varela. *Autopoiesis and Cognition: The Realization of the Living*. Vol. 42. Boston Studies in the Philosophy of Science. Dordrecht [u.a.]: Reidel, 1980.
- McCray, W. Patrick. *The Visioneers: How a Group of Elite Scientists Pursued Space Colonies, Nanotechnologies, and a Limitless Future*. Princeton and Oxford: Princeton University Press, 2013.
- McLuhan, Marshall. "At the moment of Sputnik the planet became a global theater in which there are no spectators but only actors." *Journal of Communication* 24.1 (1974): 48–58.
- Meadows, Donella H., Dennis L. Meadows, Jørgen Randers, and William W. Behrens III. *The Limits to Growth: A Report for The Club of Rome's Project on the Predicament of Mankind*. New York: Universe Books, 1972.
- Meadows, Donella H. et al. *Beyond the Limits*. Post Mills: Chelsea Green, 1992.
- Meadows, Donella H. et al. *Limits to Growth: The 30-Year Update*. White River Junction: Chelsea Green, 2004.
- Möbius, Karl August. *Die Auster und die Austernwirthschaft*. Berlin: Wiegandt, Hempel & Parey, 1877.
- Neumann, John Von, Oskar Morgenstern, Ariel Rubinstein, and Harold W. Kuhn. *Theory of Games and Economic Behavior*. Princeton, New Jersey: Princeton University Press, 2007.
- Nohr, Rolf F. *Die Natürlichkeit des Spielens: Vom Verschwinden des Gemachten im Computerspiel*. Münster: LIT, 2008.
- . "The Naturalization of Knowledge. Games Between Common Sense and Specialized Knowledge." In *Logic and Structure of the Computer Game*, edited by Michael Liebe, Dieter Mersch, and Stephan Günzel, 4:130–43. DIGAREC Series. Potsdam: University Press, 2010.
- Odum, Eugene P., and Howard T. Odum. *Fundamentals of Ecology*. Philadelphia: W.B. Saunders, 1953; 2nd ed., 1959; 3rd ed., 1971; 4th ed., 1983, 5th ed., 2005.
- Parikka, Jussi. *Digital Contagions: A Media Archaeology of Computer Worms and Viruses*. New York [u.a.]: Peter Lang, 2007.
- Parikka, Jussi, and Milla Tiainen. "What Is New Materialism-Opening Words from the Event." Accessed April 1, 2014. <http://machinology.blogspot.de/2010/06/what-is-new-materialism-opening-words.html>.

- Phillips, John. "Succession, Development, the Climax, and the Complex Organism: An Analysis of Concepts. Parts I-III." *Journal of Ecology* 22.2 (1934): 554–571; 23.1 (1935): 210–246; 23.2 (1935): 488–508.
- Pias, Claus. "Paradiesische Zustände. Tümpel – Erde – Raumstation." In *Stehende Gewässer. Medien der Stagnation*, edited by Butis Butis, 47–66. Zürich, Berlin: Diaphanes, 2007.
- , ed. *Cybernetics - Kybernetik: The Macy-Conferences 1946 - 1953. Bd. 2: Essays and Dokumente*. Zürich; Berlin: diaphanes, 2004.
- Pickering, Andrew. "Cyborg History and the World War II Regime." *Perspectives on Science* 3 (1995): 1-48.
- Rockström, Johan et al. "Planetary Boundaries: Exploring the Safe Operating Space for Humanity." *Ecology and Society* 14.2 (2009): 32, <http://www.ecologyandsociety.org/vol14/iss2/art32/>
- Sandbach, Francis. "The Rise and Fall of the Limits to Growth Debate." *Social Studies of Science* 8.4 (1978): 495–520.
- Schoijet, Mauricio. "Limits to Growth and the Rise of Catastrophism." *Environmental History* 4.4 (1999): 515–530.
- Schröter, Carl and Oskar von Kirchner. *Die Vegetation des Bodensees, Vol. 2*. Lindau: Verein für Geschichte des Bodensees und seiner Umgebung, 1902.
- Shannon, Claude E. "Computers and Automata." *Proceedings of the IRE* 41, no. 10 (1953): 1234–41.
- . "Von Neumann's Contributions to Automata Theory." *Bull. Amer. Math. Soc* 64, no. 3 (1958): 123–29.
- Siegert, Bernhard. *Relais. Geschieke der Literatur als Epoche der Post 1751-1913*. Berlin: Brinkmann & Bose, 1993.
- Smil, Vaclav. "Limits to Growth Revisited: A Review Essay." *Population and Development Review* 31.1 (2005): 157–164.
- Stahl, Walter R. "A Computer Model of Cellular Self-Reproduction." *Journal of Theoretical Biology* 14, no. 2 (1967): 187–205.
- Tansley, George Arthur. "The Use and Abuse of Vegetational Concepts and Terms." *Ecology* 16.3 (1935): 284–307.
- Taylor, Peter J. "Technocratic Optimism, H. T. Odum, and the Partial Transformation of Ecological Metaphor after World War II." *Journal of the History of Biology* 21.2 (1988): 213–244.

- Thacker, Eugene. "Biomedica." In *Critical Terms for Media Studies*, edited by W. J. T. Mitchell and Mark B. N. Hansen, 117–30. Chicago; London: The University of Chicago Press, 2010.
- The Club of Rome. *The Predicament of Mankind: Quest for Structured Responses to Growing World-wide Complexities and Uncertainties. A Proposal*. Genf, 1970.
- Turkle, Sherry. *Life on the Screen*. New York: Simon & Schuster, 1995.
- Uexküll, Jakob Johann von. *Umwelt und Innenwelt der Tiere*. Berlin: Julius Springer, 1909.
- . *Theoretische Biologie*. Berlin: Julius Springer, 1928.
- Vagt, Christina. "Fiktion und Simulation. Buckminster Fullers *World Game*," *Archiv für Mediengeschichte* 13 (2013): 117–145.
- Von Neumann, John. "The General and Logical Theory of Automata." In *Collected works*, edited by Abraham Haskel Taub, V: 288–326. Oxford; New York [etc.]: Pergamon, 1976.
- . *Theory of Self-Reproducing Automata*. Edited by Arthur W. Burks. University of Illinois Press, 1966.
- Voorhees, Gerald. "Discursive Games and Gamic Discourses." *Communication +1*, no. 1 (August 29, 2012). <http://scholarworks.umass.edu/cpo/vol1/iss1/3>.
- Wiemer, Serjoscha. „Strategiespiele und das Medium-Werden des Computers. Computerschach als Faktor der Rekonzeptionalisierung des Computers als programmierbare Maschine zwischen 1945 und 1960“. In *Diskurse des strategischen Spiels. Medialität, Gouvernamentalität, Topografie*, edited by Rolf F. Nohr, Serjoscha Wiemer, and Stefan Böhme, 83–112. Münster: LIT, 2014.
- Wiener, Norbert. *Cybernetics Or Control and Communication in the Animal and the Machine*. 12th ed. New York: Wiley, 1948.
- Willis, A. J. "The Ecosystem: An Evolving Concept Viewed Historically." *Functional Ecology* 11.2 (1997): 268–271.
- Zalasiewicz, Jan et al. "Are We Now Living in the Anthropocene?" *GSA Today* 18.2 (2008): 4–8.