



Schrape, N., 2014. "Gaia's Game."
communication +1, vol 3, iss 1,
DOI: 10.7275/R54M92GH



Gaia's Game

Niklas Schrape, Leuphana University, niklas.schrape@inkubator.leuphana.de

James Lovelock's vision of Earth as a living cybernetic system is popular again. The surprising new preacher of Gaia is Bruno Latour. He uses the concept to refer to a holistic understanding of Earth, in which mankind is situated as integral part. Gaia becomes the catalyst and fundament for his philosophical attempt to design a new believe-system in the time of ecological crisis. But the concept of Gaia is characterised by a tension between the idea of a powerful but indifferent nature and a grandiose vision of total control over it. This tension reveals itself to be deeply rooted in cybernetic thought. It is not only apparent in Lovelock's own writing, but also in simulation programs based on the Gaia hypothesis such as the Daisyworld model and the computer game "SimEarth: The Living Planet" (1991). The article will distinguish Lovelock's from Latour's concept of Gaia and relate them to first- and second order cybernetics as well as to two different approaches to computer simulation: system dynamics and cellular automata.

Keywords: Gaia, Latour, Lovelock, SimEarth, Simulation, Climate, Evolution

Introduction

I would try to be a God that surprised himself. (Laughter.)
I think being the all-knowing God would be, you know, hell.
- Will Wright, *creator of SimEarth*¹

The figure of Gaia plays a prominent role in Bruno Latour's recent publications. The Gaia hypothesis, first formulated by James Lovelock and Lynn Margulis in the mid-1960s, can be understood as pinnacle of system thinking.² It describes Earth as one cybernetic system, determined by the interplay of biosphere, atmosphere and geosphere. For Latour, Gaia is a catalyst that forces mankind to attain a novel understanding of the relation between culture and nature. But the Gaia hypothesis contains a peculiar tension between the image of a sublime nature, utterly indifferent to the needs of human beings, and the grandiose vision of total control over the system Earth. This tension is not only apparent in theoretical writing, but also in simulation programs based on the Gaia hypothesis, such as the Daisyworld model and the computer game *SimEarth: The Living Planet* (1991). The following article will carve out how Lovelock's Gaia differs from Latour's and discuss how these perspectives relate to two substantially distinct approaches to cybernetics (first-order and second-order) and computer simulations (system dynamics and cellular automata).

Latour's use of Gaia

In his recent book *An Inquiry into Modes of Existence* (2013), acclaimed French sociologist and philosopher Bruno Latour sketches out a quite spectacular research program: He demands nothing less than to overcome the modern preoccupation with objective scientific truth and to rediscover the plurality of vastly different modes of existence (like religion, morality or law). He does not only want to deconstruct the scientific worldview, he wants to redesign it. Latour repeatedly states one reason, why this is needed at this very moment: "Gaia approaches".³

For Latour, "Gaia" is a concept that holds the potential to redefine the relation between *society* and *nature* in the time of an ecological crisis. Gaia implies a

¹ In: Celia Pearce, "Sims, BattleBots, Cellular Automata God and Go: A Conversation with Will Wright by Celia Pearce," *Game Studies* V2 I2 (2002), accessed July 3, 2014, <http://www.gamestudies.org/0102/pearce/>.

² The first paper, in which the principles of the Gaia hypothesis were formulated has been James E. Lovelock and C. E. Giffin, "Planetary Atmospheres: Compositional and Other Changes" Associated with the Presence of Life," *Advances in Astronautical Sciences* 25 (1969), accessed June 30, 2014, <http://www.jameslovelock.org/page19.html>.

³ Bruno Latour, *An Inquiry into Modes of Existence: An Anthropology of the Moderns* (Cambridge: Harvard University Press, 2013), 13.

holistic understanding, in which humankind and Earth's biosphere are being comprehended as tightly coupled and intertwined. When he evokes its imminent approach, he refers to the necessity to adopt this new way of thinking in order to face the impending crisis of climate change. But in Latour's phrasing, Gaia is more than just a conceptual object, it's the subject of the sentences: Gaia approaches. For him, Gaia is an actor with whom humankind enters into confrontation.⁴ Thus, Gaia is both: a concept and a real power. The factuality of the climate change forces the sciences to rethink their conception of nature. But at the same time, this factuality is fabricated by the sciences themselves via measurements, models and computer simulations. The concept of Gaia, that could guide their rethinking, is not less fabricated.

For Latour, mankind stands before the dilemma between *modernising* and *ecologising*.⁵ Shall we keep on with the technoscientific objectivation of Earth, shall we further aim at the mastering of a lifeless nature? Or shall we redefine ourselves as an integral part of a living global ecology? He advocates the latter but is well aware that a mere deconstruction of modern values is not enough to motivate change. What would be needed, instead, would be a positive assemblage of values, a new way of thinking, a novel ecological belief-system - based on the figure of Gaia:

It is now before Gaia that we are summoned to appear: Gaia, the odd, doubly composite figure made up of science and mythology used by certain specialists to designate the Earth that surrounds us and that we surround, the Möbius strip of which we form both the inside and the outside, the truly global Globe that threatens us even as we threaten it.⁶

For Latour, the concept of Gaia has a scientific as well as a mythological dimension: it derives from measurements, data, and modelling but it also incorporates an abundance of mythological connotations as its name evokes the Greek goddess of Earth. Fittingly, Lovelock's hypothesis received its name by a poet: William Golding, the author of *Lord of the Flies* (1954) and one of Lovelock's neighbours, suggested it. It is therefore not surprising that the name carries a substantial ambiguity that irritated several members of the scientific community, who feared an animistic anthropomorphisation of Earth.⁷ But for Latour, that's exactly the point:

⁴ Ibid., 10.

⁵ Ibid., 8.

⁶ Ibid., 9f.

⁷ See for example: Ford W. Doolittle, "Is Nature Really Motherly?" *The CoEvolution Quarterly* Spring (1981).

the concept of Gaia defies the belief in an objective science that studies nature as a passive and de-animated object.

In Latour's view, the metaphysics of Western modernity, with their assumed divide between nature and society, their focus on reason, the one truth, and expanding technological control over the world, would have led directly into the current ecological crisis. But such metaphysics of technological progress would now become useless - and new ones would be needed:

We have to fight trouble with trouble, counter a metaphysical machine with a bigger metaphysical machine. (...) why not transform this whole business of recalling modernity into a grand question of *design*?⁸

Latour writes about the “*recalling* of modernity, in all senses of the word ‘recall’ (including the meaning it has in the automobile industry)”.⁹ Recalling modernity implies to remember and question its underlying assumptions but also to bring it back to the workbench in order to re-design it. For Latour, modernity's metaphysics are broken and have to be replaced like the defect motor of a car. But such a re-design cannot be simply attempted by a single philosopher. Latour recognises that a diplomatic approach is in place. He therefore envisions a grand negotiation process, in which all possible modes of existence enter with equal rights. Religion, Science, Law etc. should openly discuss their logics, presumptions, and premises. He does not claim to have brand-new and ready-to-work metaphysics at hand but insists on their necessity and the need for a general debate. Thus, his whole inquiry is just the beginning of a process that ideally should have novel metaphysics as its outcome. The enigmatic figure of Gaia is the catalyst of this process.

Two Faces of Gaia

The notion of Gaia has been coined by the chemist and inventor James Lovelock¹⁰ in close collaboration with evolutionary biologist Lynn Margulis.¹¹ In its essence it describes the biosphere, atmosphere, hydrosphere, and geosphere of the planet Earth as an interconnected system that attains and creates the conditions for con-

⁸ Latour, *Modes of Existence*, 23.

⁹ Ibid., 16.

¹⁰ Especially in his monographies: James E. Lovelock, *Gaia: A New Look at Life on Earth* (Oxford: Oxford University Press, 2000 [1979]). And: James E. Lovelock, *Ages of Gaia* (Oxford: Oxford University Press, 1995 [1988]).

¹¹ For example in: James E. Lovelock and Lynn Margulis, “Atmospheric Homeostasis by and for the Biosphere. The Gaia Hypothesis,” *Tellus* 26 (1974).

tinuous life via feedback-loops. Thus, the beings of the biosphere themselves secure the requirements for their own survival.¹² The obvious objection to this hypothesis is that such a regulation would demand some voluntary action - and thus a planetary consciousness. Several of the original critics of the Gaia hypothesis stressed the impossibility of such a thing.¹³ But Lovelock disagreed wholeheartedly. For him Gaia is a cybernetic system with the capacity for self-regulation, therefore, no consciousness would be needed. In his view, Gaia shows characteristics similar to biological systems like beehives:

Gaia is best thought as a superorganism. These are bounded systems made up partly from living organisms and partly from nonliving structural material. A bee's nest is a superorganism and like the superorganism, Gaia, it has the capacity to regulate its temperature.¹⁴

The cybernetic vocabulary in Lovelock's prose is immediately evident: Gaia is being described as "active adaptive control system", consisting of feedback-loops that maintain homeostasis. However, Lovelock can only define Gaia as superorganism because organisms themselves had already been described as adaptive systems in cybernetic theory.¹⁵ Lovelock himself is very well aware of Gaia's

¹² Lovelock and Margulis identified several such cycles between life and its environment. The most striking one concerns the atmosphere and the global temperature: the chemical disequilibrium of the atmosphere is adhered because of the constant production of oxygen by the life-forms on the planet. But the composition of the Atmosphere changed since the advent of life. Surprisingly, geological findings indicate a slow descend of the average concentration of CO², thus reducing the greenhouse effect, effectively cooling down the planet. At the very same time the energy provided by the Sun increased about 25%, thus constantly heating up the planet. According to Gaia hypothesis, these two developments not only counterbalance each other but are not accidental either. Instead, the live-forms on Earth themselves would have regulated the amount of CO² in the atmosphere: „(...) the total ensemble of living organisms which constitute the biosphere can act as a single entity to regulate chemical composition, surface pH and possibly also climate. The notion of the biosphere as an active adaptive control system able to maintain the Earth in homeostasis we are calling the 'Gaia' hypothesis.“ (Lovelock and Margulis, "Atmospheric Homeostasis".)

¹³ For example: Doolittle, "Is Nature Really Motherly?". And: Richard Dawkins, *The Extended Phenotype: The Long Reach of the Gene* (Oxford: Oxford University Press, 1982). Here, especially chapter 13.

¹⁴ Lovelock, *Ages of Gaia*, 15.

¹⁵ See: Norbert Wiener, *Cybernetics: Or Control and Communication in the Animal and the Machine* (Cambridge, MA: MIT Press, 1948). And: Ludwig von Bertalanffy, *General System Theory: Foundations, Development, Applications* (New York: George Braziller, 1968).

roots in cybernetics as he explicitly compares it to biological, logistical, and engineered systems alike:

(...) whether we are considering a simple electric oven, a chain of retail shops monitored by a computer, a sleeping cat, an ecosystem, or Gaia herself, so long as we are considering something which is adaptive, capable of harvesting information and of storing experience and knowledge, then its study is a matter of cybernetics and what is studied can be called a 'system'.¹⁶

For Lovelock, Gaia's most powerful memory bank are the genomes of its life-forms: "By transmitting coded messages in the genetic material of living cells, life acts as repeater, which each generation restoring and renewing the message of the specifications of the chemistry of early Earth".¹⁷ In a certain way, Gaia works as a immense computer with exceptionally long processing cycles – but it is clearly not adhering to the von Neumann architecture as it doesn't possess a central processor. Instead, its information processes emerge out of an interplay of connected but independent components.

The relation of Gaia to cybernetics and computer technology becomes even more apparent if one considers that the strongest back-up for Lovelock's hypothesis consists in a computer simulation: the famous *Daisyworld* model, through which Lovelock tried to exemplify the mechanism of planetary self-regulation.¹⁸ To accomplish this, he created a highly abstract model of a planet, on which only daisies exist: black and white ones. During the run of the simulation, the intensity of the sun increases constantly (as it is the case with all suns), heating up the planet. The interplay between black daisies, white daisies, the sun, and the planet is modelled through coupled differential equations from population ecology and physics: At the beginning black daisies have an evolutionary advantage as they absorb more heat. Thus, they will spread, amplifying the heating up of the planet. But with growing intensity of the sun, white daisies prove to be better suited as they reflect more light. Therefore, they spread and supplant their black cousins. Their reflection of the sunlight, the so-called albedo effect, is effectively cooling down the planet. When the sun is heating up even more, even the white daisies will die out. The result of this dynamic is quite surprising: At first, the black daisies amplify the heating-up through positive feedback, but later, the white daisies diminish it via negative feedback. Both feedbacks together establish a surprisingly

¹⁶ Lovelock, *Gaia*, 57.

¹⁷ Lovelock, *Ages of Gaia*, 164.

¹⁸ In: James E. Lovelock, "Biological Homeostasis of the Global Environment: The Parable of Daisyworld," *Tellus* 35 (1983). Compare also: Lovelock, *Ages of Gaia*, 41ff.

long lasting temperature plateau in spite of a constant grow of solar radiation. Thus, the dynamics of Daisyworld result in temperature self-regulation.

Daisyworld is structurally very similar to the system dynamics models by Jay Forrester.¹⁹ Such models also consist out of coupled differential equations that form complex feedback-loops. The modelling technique emerged directly out of the cybernetic discourse in the 1950s. A famous example is the *World 3* model, based on Forrester's *World Dynamics* (1971), that was used by the Club of Rome to study the diminishing natural resources, leading up to the much discussed book *The Limits to Growth* (1972).²⁰

As it becomes obvious, Gaia is not only rooted in cybernetic theory, its main evidence consists in an engineered prototype of its cybernetic mechanism. From this perspective, Gaia seems to be the epitome of cybernetic thought. But surprisingly, Latour understands the concept in quite a different way:

The term proposed by James Lovelock to define a composite being corresponding to the character Earth (the Ge of mythology). Feedback loops highlighted by Lovelock evoke the possibility of a living Earth not in the sense of an organism or even an organization but in the sense of a simple assemblage of loops that achieve equilibrium by chance, according to the Darwinian model proposed in the name "Daisyworld". This character's particular interest derives from the precise fact that she is not unified (...) ²¹

The feedback-loops of Latour's Gaia hint at an origin in cybernetics, but he consciously decides not to call it a system. Instead, he defines Gaia as a "composite corresponding to the character Earth", thereby personifying Earth as agent – however, not as a unified whole, but a composition of parts. To make this seeming contradiction even more explicit, Latour clarifies that he envisions Gaia as "a simple assemblage of loops that achieve equilibrium by chance". In this reading, moments of equilibrium or homeostasis are the consequence of an ongoing emergent and unpredictable process – small islands of stability in a constant dynamic flow.

¹⁹ Jay Forrester, *Urban Dynamics* (Waltham, MA: Pegasus Communications, 1969).

Jay Forrester, *World Dynamics* (Cambridge, MA: Wright-Allen Press, 1971).

²⁰ Donella H. Meadows et al., *The Limits to Growth* (New York: Universe Books, 1972).

²¹ Definition of "Gaia" in the vocabulary section of www.modesofexistence.org, accessed June 6, 2014,

<http://www.modesofexistence.org/inquiry/index.php#a=SEARCH&s=0&q=Gaia>

This understanding of Gaia builds the foundation for a “Political Theology of Nature”²², thus the subtitle of Latour’s 2013 Gifford lectures “Facing Gaia” that in many ways forms the counterpart to *An Inquiry into Modes of Existence* (2013). Here, Latour glorifies James Lovelock as the new Galileo and Pasteur²³, and explains why he deems the Gaia hypothesis to be so revolutionary: Traditionally, nature would be characterised as being *outside* (independent from the subject), *unified* (one whole), *de-animated* (while it might shelter living beings, nature itself is not alive), and *undisputable* (the touchstone of truth). Quite similar, god would be characterised as being *exterior*, *unified*, and *undisputable*. The only difference to nature being that god wouldn’t be de-animated, but *over-animated* – he is not only alive, he is the essence of life.²⁴ Consequently, Latour claims that in modernity the idea of one undisputable Nature substituted the believe in one undisputable god.

In stark contrast to both, God and Nature, Latour’s Gaia is an ever-evolving composite of living agents (e.g. bacteria) and non-living agents (e.g. rocks) as well as disputed hypotheses, locally situated measurements and technical instruments alike. Gaia would be immanent in everything: an assemblage of entities that is fully animated deeply intertwined with society – and highly contested as a hypothesis. Gaia, therefore, becomes the great alternative to god and nature alike (see: table 1).

But what irritates is that Latour describes Gaia as essentially anti-cybernetic. For him, Gaia’s cybernetic roots are problematic as he considers cybernetics to be deeply bound to the traditional ideals of science that he wants to contest: objectivity, universality, and the strive for the control of nature.²⁵ And indeed, there’s no denial that the original cybernetics as envisioned by Norbert Wiener²⁶ is a theory of control, and that system theory as written by Ludwig von Bertalanffy²⁷ has the unification of the sciences as its explicit goal.

²² The subtitle refers to *Politische Theologie. Vier Kapitel zur Lehre von der Souveränität* by Carl Schmitt (1922). However, it could also be understood as an ironic inversion of *Natural Theology or Evidences of the Existence and Attributes of the Deity* by the British theologian William Paley (1802) who made an argument for the intelligent design of the living beings on Earth – refuted by the evolutionary biologist Richard Dawkins (1986) in *The Blind Watchmaker* nearly two centuries later.

²³ Bruno Latour, “Facing Gaia: Six Lectures on the Political Theology of Nature. Being the Gifford Lectures on Natural Religion (Presented at Edinburgh, February 18-28, 2013), 53ff.

²⁴ Ibid., 24ff.

²⁵ Ibid., 65ff.

²⁶ Wiener, *Cybernetics*.

²⁷ Bertalanffy, *General System Theory*.

Ideal Nature (according to Latour)	Ideal God (according to Latour)	Latour's Gaia (own interpretation)
Outside (transcendent)	Exterior (transcendent)	Inside (immanent)
Unified	Unified	Multiple
De-animated	Over-animated	Animated
Undisputable	Undisputable	Disputable

Table 1 – Nature, God, and Gaia

There exists a curious tension between Latour's reading of the Gaia hypothesis and Lovelock's own wording that makes one wonder if they are actually writing about the same thing. This disparity might be explained by the development of cybernetic thought itself: Lovelock developed his original hypothesis under the influence of what has been called *first-order cybernetics*. He doesn't refer to the concept of *recursion* by von Foerster²⁸ or the one of *autopoiesis* by Maturana & Varela²⁹ – and neither does Latour. But as Bruce Clark points out, the Gaia hypothesis does indeed incorporate concepts of *second-order cybernetics*:

Simply put, first-order cybernetics is about control; second-order cybernetics is about autonomy. (...) Unlike a thermostat, Gaia - the biosphere or system of all ecosystems - sets its *own* temperature *by* controlling it. (...) In second-order parlance, Gaia has the operational autonomy of a self-referential system. Second-order cybernetics is aimed in particular, at this characteristic of natural systems where circular recursion *constitutes the system* in the first place. (...) natural systems - both biotic (living) and metabolic (super organic, psychic, or social) - are now described as at once *environmentally* open (in the non equilibrium thermodynamic sense) and *operationally* (or organisationally) closed, in that their

²⁸ See for example: Heinz von Foerster, "On Constructing a Reality," in *Understanding Understanding: Essays on Cybernetics and Cognition* (New York: Springer, 2002 [1973]). The notion of *recursion* undermines the idea of causality. It postulates a mutual and iterative effect of the interplay of systems components: organisational structures emerge out of recursion not simple causes.

²⁹ See for example: Humberto R. Maturana and Francisco J. Varela, *Autopoiesis and Cognition: The Realization of the Living* (Dordrecht, Boston, London: Reidel Publishing, 1980 [1972]). The concept of *autopoiesis* describes the self-organisational capacity of living systems: the autopoietic entity creates and maintains itself in a recursive loop.

dynamics are autonomous, that is, self-maintained and self-controlled.³⁰

According to Clark, Margulis, influenced by Varela, overcame the metaphor of the thermostat in her latter works and focussed on the autopoietic qualities of Gaia.³¹ From this perspective, Gaia is not primarily a system of feedback-loops that can be described, analysed, controlled, and maybe even build; it is an ever evolving and becoming entity that emerges out of a co-evolutionary interplay between life and non-living matter. This autopoietic concept of Gaia is quite similar to Latour's understanding of an animated, evolving assemblage.

Moreover, in this view of Gaia, the structure and components of the earth system are not given, they emerge out of geohistorical events and contingent trajectories. Latour emphasises this point when he interprets Lovelock's reasoning about the influence of early bacteria on the composition of the atmosphere:

If we now live in an oxygen-dominated atmosphere, it is not because there is a preordained feedback loop. It is because organisms that have turned this deadly poison into a formidable accelerator of their metabolisms have spread. Oxygen is not there simply as part of the environment but as the extended consequence of an event continued to this day by the proliferation of organisms.³²

Latour's reading of the role of oxygen in evolution makes it apparent how insufficient Lovelock's Daisyworld model is in regard to *his* understanding of Gaia: The feedback-loops of Daisyworld are products of an engineer, they exemplify a mechanism, they do not emerge out of contingent and changing conditions. Therefore, Daisyworld cannot surprise: only a few possible pathways can be realised during repeated runs of the simulation. To take up a notion from computer game theory: the *possibility space* of Daisyworld is very limited.³³

But Daisyworld fits to Lovelock's view on cybernetics. After all, he is an inventor, who always liked to engineer his own research instruments. He describes feedback-loops and mechanisms – and who does so might fantasise about controlling them. And indeed, Lovelock does write about the possibilities for

³⁰ Bruce Clark, "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*, ed. Eileen Crist and Bruce H. Rinker (Cambridge: MIT Press, 2009), 296.

³¹ See for example: Lynn Margulis and Dorion Sagan, *What is life?* (Oakland, CA: University of California Press, 2000).

³² Latour, "Facing Gaia", 71.

³³ See: Katie Salen and Eric Zimmerman, Eric, *Rules of Play: Game Design Fundamentals* (Cambridge, MA: MIT Press, 2004), 67.

geoengineering³⁴, and even co-authored a book about the terraforming of Mars.³⁵ Thus, Lovelock's original first-order Gaia hypothesis must be differentiated from a second-order Gaia hypothesis, developed in the latter works of authors like Margulis. While first-order Gaia can be observed from the outside to some degree (Lovelock repeatedly refers to the view from space)³⁶, is a unified system, and might partially allow controlling its feedback-loops, second-order Gaia is a emergent property (see: table 2).

First-order Gaia	Second-order Gaia
Exterior	Inside
Unified	Multiple
Animated	Animated
Disputable	Disputable

Table 2 – First- and second-order Gaia

If first-order Gaia is the product of a cybernetic engineer and found its incarnation in the computer-model of Daisyworld, the question arises how second-order Gaia might manifest *in silico*. This question is not just pure speculation as the concept of Gaia revealed itself to be bound to specific technological conditions: If the cybernetic thermostat is the original model for Gaia, and if the Daisyworld model follows the system dynamics approach, what would be a second-order equivalent?

This question entails a reversal of perspective as system dynamics can be characterised as a top-down approach that does not completely fit to second-order cybernetics. Such simulation models might produce contra-intuitive outcomes but their structures and feedback-loops have necessarily to be pre-defined – like the circuits of a thermostat. There are, however, other modelling techniques, e.g. on the basis of cellular automata, that allow for emergent structures: Only a small set of rules for very simple components are being defined, but when they interact with each other in the run of a simulation, complex and unpredictable patterns and dynamics emerge. Surprisingly, there exists an implementation of Gaia theory in a

³⁴ James E. Lovelock, *The Vanishing Face of Gaia* (New York: Basic Books, 2009), 139ff.

³⁵ James E. Lovelock and Michael Allaby, *The Greening of Mars* (New York: Warner Books, 1985).

³⁶ For example: James E. Lovelock, preface to *Gaia: A New Look at Life on Earth* (Oxford: Oxford University Press, 2000 [1979]), XII.

program that makes use of cellular automata. Even more surprisingly it is not a scientific simulation but a commercial computer game: Will Wright's *SimEarth – The Living Planet* (1991).

SimEarth and the Player-God

In *SimEarth*, the player takes over the control of Earth – from the Pre-Archean to the Anthropocene (if the notion had been coined in 1991). She controls the atmosphere, the geosphere, and the biosphere, forms continents, lets meteors rain, and observes how humanoid and non-humanoid civilisations rise and fall. She can choose to play specific scenarios on Earth, to terraform Mars and Venus or to explore Lovelock's Daisyworld model. In all cases, the planet is presented as a map with several layers. In a menu on the left, tools can be chosen to change the surface, unleash catastrophes or plant animals and biota at specific places.

Every of such actions costs energy (called "Omega"), from which only a limited budget exists. Life-forms do generate more energy that can be invested in turn. And the more intelligent these life-forms are, the more energy they deliver. Thus, an evolutionary economy is implemented in the game, in which the player aims to optimise the return of investment.

SimEarth also allows it to manipulate some of its models that define the principles according to which the planet reacts. The player can e.g. choose to switch off the mutation rate for life-forms in the *biological model*, to enforce the cloud production in the *atmosphere model*, and to speed up the continental drift in the *geosphere model*. In the *civilisation model*, she can define how an intelligent species shall invest its allocated resources: whether in science, medicine, philosophy, agriculture or art. All domains have to be carefully balanced: while investments in science e.g. lead to technological advancement, it will also cause devastating wars and plagues if not counterbalanced with investments in philosophy (preventing wars) and medicine. Thus, *SimEarth* effectively implements two tightly interconnected economic models: one for *nature* and one for *culture*.

The development of every planet is structured into succeeding ages or levels. To progress in the ages, the player has to achieve defined victory conditions. The game starts in the *geological age*, enters the *evolutionary age* after the appearance of life-forms, continuous to the *civilisation age* when intelligent life arises, and progresses to the *technological age* with the beginning of the industrial revolution. The highest level is the *nano-tech age* that allows the civilisation to leave the planet. In this case it falls back to the evolutionary age, opening up the possibility for a new cycle of evolution with a different outcome. This emigration from Earth is what comes closest to a goal in *SimEarth*.

Biological and cultural evolution takes on various forms in *SimEarth*, but is always directed towards growing intelligence and complexity. Starting out with Prokaryotes (single celled life-forms without a nucleus), 15 classes of life-forms can evolve, which each differentiate in up to 16 possible species. The evolvement of species with certain intelligence is often the precondition for the emergence of a new class: Avians (birds) e.g. evolve out of dinosaurs, which evolve out of reptiles. The interrelated classes and species form a multi-linear phylogenetic tree.³⁷ Civilisations do not need to be human, they can evolve out of amphibians, reptiles, dinosaurs, insects, carniferns, avians, cetaceans (whales), and trichordates. Regardless of the species, the atmosphere and biosphere are heavily effected by the civilisation from the technological age on.

SimEarth is obviously not a conventional game. Johnny L. Wilson, the author of the official strategy guide *The SimEarth Bible*, calls it “a laboratory on a disk”.³⁸ James Lovelock describes it in a similar way in his preface to the same book:

SimEarth itself is neither a game nor a science based model. (...) it represents an original form; a convenient dynamic map (...) of a planet, displayed in time as well as space – something on which speculative games or models can be played, a test bed for all those „what-ifs“. It is a wonderful and timely integration of our newly developed capacity to make personal computer models with our need to use them to understand the earth and ourselves. (...) SimEarth gives you the chance to enter the Gaia argument as a player.³⁹

³⁷ The existence of such a prescriptive evolutionary tree indicates that *SimEarth* does not really simulate evolutionary processes but just mimics them. The tree defines trajectories through a limited possibility space of evolutionary development. Every trajectory is contingent but nevertheless predefined. In contrast, there are no pre-existing pathways in real evolution. *SimEarth* simply cannot simulate the processes of evolution properly because this would require simulating heredity on the level of individuals and their genomes. The simulation model of *SimEarth* is too macroscopic to allow for such detail. Nevertheless, it is possible: The next game in the Sim-series *SimLife: The Genetic Playground* (1992) did simulate ecological systems on a much smaller scale and included a genetic model of heredity. In a perfect simulation of Gaia the microscopic and the macroscopic simulation of ecology would have to be merged into one – but this was technically impossible in the early 1990s and probably still is.

³⁸ Johnny L. Wilson, preface to *The SimEarth Bible*, by Johnny L. Wilson (New York: Osborn McGraw-Hill, 1991), XIII.

³⁹ Ibid., XI.

But *SimEarth* is not only a laboratory on a disk, it also is a playground for scientifically tamed would-be gods. The phantasms of omnipotent control is shining through the sales arguments on the backside of the game's packaging:

Take the charge of an entire planet from its birth until its death – 10 billion years later. Guide life from its inception as single-celled microbes to a civilization that can reach for the stars.

Rule an infinite number of worlds.

Control your planet's Geosphere, Atmosphere, Biosphere and Civilizations.

Place life-forms on the land and in the seas. Put various levels of civilization where you want them. Use special Terraforming Tools to change an inhospitable world into a paradise.

Unleash volcanoes, earthquakes, meteors, tidal waves, and other natural (and unnatural) powers to reshape your planet

Promote life. Move mountains. Create and destroy continents. Terraform hostile worlds. Influence evolution. Cultivate intelligent life-forms. Create civilized dinosaurs, mollusks, mammals, and more. Guide your intelligent species through the trials of war, pollution, famine, disease, global warming, and the greenhouse effect.

Such claims obviously allure the potential player with promises of almighty power. *SimEarth* seems to put her in the place of God. This impression is supported by *The SimEarth Bible*: Its deeply religious author struggles to reconcile his creationists viewpoints with the evolutionary model inscribed in the game but finds obvious fun in using pseudo-quotes from the bible as headlines for chapters, e.g. "And God Called the Dry Land Earth: The Geosphere Model"⁴⁰ or "Behold, I Create New Heavens: The Biome Factory".⁴¹ In headlines like this, religion is coupled with science in the most obvious way imaginable.

In fact, all games of the Sim-series were on the one hand simulations, based on specific scientific theories and models,⁴² but established at the same time a

⁴⁰ Ibid., 66.

⁴¹ Ibid., 138.

⁴² *SimCity* (1989) is based on Forrester's *Urban Dynamics* (1969). *SimLife: The Genetic Playground* (1992) incorporates many elements from the Artificial Life discourse (cp.: Christopher Langton, "SimLife from Maxis: Playing with Virtual Nature," in *The Bulletin of the Santa Fe Institute* Vol 7 (1992).) as well as the evolutionary thinking that Richard Dawkins presented in *The Blind Watchmaker* (1986). *SimAnt: The Electronic*

whole genre of video games, commonly known as “god games”.⁴³ Such games are characterised by the indirect control of semi-autonomous agents and a panoptic view on a virtual world, which can be interacted with without spatial restrictions.⁴⁴ The label “god game” should, of course, not be taken literally. The concept of God by Christian theologians implies omnipotence, which is simply impossible within the constraints of any given computer program. Even if the player would transcend her role to become a programmer, the programming language and the hardware would limit her capabilities. But *SimEarth* offers far more options to change the workings of its rules and processes than most other so-called god games. *Populous* (1989), for example, puts the player in the role of an actual god or goddess that has to take care of worshipers in order to gain karma (the resource for godly-acts and wonders). But in contrast to this narrative, the player’s potency is strictly restricted to a very limited numbers of actions that have to be performed to overcome adversary gods. *Populous* is agonistic with little room for experimentation. The game’s rules are strict and cannot be changed. In contrast, *SimEarth* sets no predefined goals and allows the player to substantially alter the underlying models of the simulation.

From this perspective, *SimEarth* appears as the epitome of the grandeur of the technosciences that Latour sets out to critique: The simulation elevates the experimenter to a position close to a god. The world is simulated in order to gain control over it. It therefore is not surprising that Donna Haraway views the Sim-Games quite critically:

The popular Maxis Corporation games SimAnt, SimEarth, SimCity, SimCity 2000, and SimLife are all map-making games based on computer simulation software. In these games, as in life itself, map-making is world-making. Inside the still persistent Cartesian grid convention of cyber-spatialization, the games encourage their users to see themselves as scientists within narratives of exploration, creation, discovery, imagination and intervention. Learning data-recording practices, experimental protocols, and world design

Ant Collony (1991) is influenced by Bert Hölldobler and E. O. Wilson, *The Ants* (New York: Springer, 1990).

⁴³ The notion of “god game” is defined in: Mark Hayse, “God Games,” in *Encyclopedia of Video Games: The Culture, Technology, and Art of Gaming. Volume One A-L*, ed. by Mark J. P. Wolf (Santa Barbara, Denver, Oxford: Greenwood, 2012), 264.

⁴⁴ Compare: Britta Neitzel, “Point of View und Point of Action: Eine Perspektive auf die Perspektive in Computerspielen,” in *Computer/Spiel/Räume: Materialien zur Einführung in die Computer Game Studies*. Hamburger Hefte zur Medienkultur, published by Institut für Medien und Kommunikation des Departments Sprache, Literatur, Medien SLM I der Universität Hamburg, ed. by Klaus Bartels and Jan-Noel Thon (2007).

is seamlessly part of becoming a normal subject in this region of technoscience.⁴⁵

It is a curious contradiction: *SimEarth* is possibly the closest manifestation of the Gaia hypothesis that one could imagine. It was created, after all, under the watchful eyes of James Lovelock himself. But how can this be the same hypothesis from which Latour claims that it would hail a new type of science that would finally overcome the technoscientific phantasm of control? How can it be that one and the same hypothesis can on the one hand be interpreted as epitome of scientific megalomania and on the other as pioneer of a humble worldview?

The seemingly obvious explanation would be that *SimEarth* is an incarnation of first-order Gaia hypothesis. The immediate assumption being that if incarnated *in silico*, Gaia must manifest in a form that dramatically emphasises its first-order cybernetics origins and its focus on controllability. After all it has been modelled on a computer that is cybernetic by definition and has to conform to the conventions of games, which are all about control. But at a closer look, *SimEarth* reveals itself to be more complex.

From God to Gardener

A close reading of the aforementioned sales arguments helps to gain a new perspective (see: table 3): While some of the words used promise total control over an powerless object, others seem to circumscribe a very different regulation of a partly independent agent. On the one side, Earth is presented as an object to be controlled (by the player-god). On the other side, Earth is presented as a living agent with its own will that has to be carefully guided and regulated.

Control	Regulation
Create, Destroy, Take Charge, Control, Rule, Terraform, Unleash	Guide, Cultivate, Promote, Influence
World as object	World as assemblage of semi-independent agents

Table 3 – Control and Regulation in *SimEarth*’s Sales Arguments

⁴⁵ Donna Haraway, “Gene. Maps and Portraits of Life Itself,” in *Modest_Witness@Second_Millennium. FemaleMan_Meets_OncoMouse. Feminism and Technoscience*, ed. by Donna Haraway (New York, London: Routledge, 1997), 132f.

The player is promised the role of God but also the one of someone close to a gardener. The metaphor of gardening has been used by Will Wright himself to describe the experience of playing *SimCity* - a city building simulation that shares a lot of structural similarities to *SimEarth*:

(...) *SimCity*, most people see it as kind of a train set. (...) when you start playing the game, and the dynamics become more apparent to you, a lot of time there's an underlying metaphor that's not so apparent. Like in *SimCity*, if you really think about playing the game, it's more like gardening. So you're kind of tilling the soil, and fertilizing it, and then things pop up and they surprise you, and occasionally you have to go in and weed the garden, and then you maybe think about expanding it, and so on. So the actual process of playing *SimCity* is really closer to gardening.⁴⁶

The metaphor is striking: A garden is all but a de-animated passive object, it is an assemblage of living and non-living agents that interact in complex ways that have to be anticipated by the gardener. But nevertheless, the gardener is in a position of tremendous power towards herbs and vegetables. Unlike a god, he cannot do to the garden whatever pleases him. He has to gain a deep understanding about the interrelatedness of all its agents and to anticipate their possible reactions. A garden cannot be fully controlled but it can be carefully regulated. And if it would be possible to speed-up the feedback that a garden offers to its gardener in such a way that a continuous rhythm between planting, growing, and weeding could be realised – then a garden could indeed be played.

Quite similarly, in playing *SimEarth*, the world is being experienced as anything but as passive object. Frequently, the player's actions have curious and at first glance counter-intuitive results that only close inspection of the various graphs can clarify. Moreover, the consequences of the actions are repeatedly being rendered insignificant by the dynamics of the program – similar to weed that just reoccurs. The player might plant dozens of volcanoes on her Earth to push CO₂ into the atmosphere to heat it up. But it might very well be that this effect is quickly counterbalanced: The raising temperature lets the ice melt, creating new landmasses in which boreal forests can spread that in turn bind CO₂, counterbalancing the greenhouse effect.

Such counter-intuitive outcomes are one of the cornerstones of system dynamic models, as e.g. Jay Forrester claims.⁴⁷ But *Daisyworld*, being such a model,

⁴⁶ Will Wright in an interview with Celia Pearce in: Pearce, "Sims, BattleBots, Cellular Automata God and Go".

⁴⁷ Jay Forrester, "The Beginning of System Dynamics," Banquet Talk at the international meeting of the System Dynamics Society Stuttgart, Germany (July 13, 1989), transcript

offers these insights only for a fleeting moment. Soon, the user has tried out all existing variables and understands the mechanism. *SimEarth*, however, constantly surprises the player by showing unpredictable behaviour. The reason being that *SimEarth* combines system dynamics with *cellular automata*.

As mentioned above, cellular automata can be considered as the bottom-up counterpart to system dynamics: where in the latter the structure of the system is predefined, in the former, it emerges in unpredictable ways out of just a few rule sets. A cellular automata program consists of a grid of cells, where each cell is programmed to use the input of its neighbouring cells and to process it according to rules. The interplay of a huge number of such cells can produce unpredictable patterns.⁴⁸

Like most of Maxis' Sim-games, *SimEarth* has a cellular automata module built into its core. It is coupled with five system dynamics models, that represent the Lithosphere, Aquasphere, Atmosphere, Biosphere, and the Civilisation on the planet.⁴⁹ Some of them can be tweaked and twisted by the player as explained. All of these models, however, are affecting one huge cellular automata module with 128 horizontal and 64 vertical tiles. The map, the player is interacting with, is the visual representation of its several layers. The description by Fred Haslam, the co-designed of *SimEarth*, gives a good impression of its complexity:

The basic model in this game is a state-based cellular automata. Cells maintain information on all five systems mentioned above. Our cells are organized into a number of two-dimensional arrays collectively called "the map." Generally speaking, cells are only affected by themselves and the eight adjacent cells—although there are exceptions. There are also a number of global values.

accessed July 28, 2014, <http://clexchange.org/ftp/documents/system-dynamics/SD1989-07BeginningofSD.pdf>.

⁴⁸ The best known example of cellular automata is Conway's "Game of Life" that abstractly exemplifies how complexity can emerge out of a few evolutionary principles (cp. Martin Gardner, „Mathematical Games: The fantastic combinations of John Conway's new solitaire game 'life'," in *Scientific American* 223 (1970)). The early Artificial Life experiments by Christopher Langton (cp. Langton, „Studying Artificial Life") were also built on the basis of cellular automata. From the 1980s on, the mathematician and physicist Stephen Wolfram explored the epistemological potential of cellular automata – a research that culminated in his controversial book *A New Kind of Science* (2002), where he suggested a paradigm shift in science via experimentation with cellular automata.

⁴⁹ Explained in: Fred Haslam, "SimEarth: A Great Toy," in *Integrated Global Models of Sustainable Development, Volume 3: Encyclopedia of Life Support Systems*, ed. by Akira Onishi (Oxford: EOLSS Publishers, UNESCO, 2009).

These values record systemic state changes (such as the current era), summarized values (such as biomass or zoomass), and cumulative values (such as fossil fuels or nitrogen levels). (...) Each cell has 10 bytes of information. Here is a list of the values each tile contains: terrain altitude, magma drift direction, magma drift speed, ocean existence bit, ocean temperature, ocean motion direction, ocean motion speed, air temperature, air motion direction, air motion speed, air cloud density, random events, biomes, creatures, sapient objects, and a city preclusion bit.⁵⁰

The outcome of the complex coupling of two very different approaches to simulation is striking: compared to the simple Daisyworld model, *SimEarth* holds much more potential for surprising outcomes that puzzle the player. Its possibility space is huge. In every run, it shows divergent emergent behaviours. The player doesn't always have the impression of being in control of the planet. Quite often, it feels, like Gaia is taking charge. The Earth can be played only to a certain degree, because at the same time it is playing with the player. As Haslam writes, this brings *SimEarth* actually in conflict with being a game in the traditional sense:

Another limitation on the simulation was our desire to make the resulting application into a game. We had to consider what would be interesting for the player, and we had to give him the power to change the environment. Ironically, we sort of failed in our initial attempt to make *SimEarth* into a game. Players could frequently win without touching a key.⁵¹

A simulation might run on its own (after receiving input values) but surely not a game. *SimEarth* therefore dwells precisely at the threshold between being a game and a quasi-scientific simulation. One could maybe call it a popular simulation - like one speaks of popular science books.

Even if not qualifying as a proper game, *SimEarth* surely allows to play with Gaia. McKenzie Wark describes a peculiar but fitting playing style.⁵² He started the program every day before work with differing configurations, let it run, and returned in the evening to observe what happened to his planet: sometimes the world stayed barren, sometimes civilisation rose and fell, sometimes a nuclear winter froze the world, sometimes the greenhouse effect cooked it to death.

SimEarth gamers tell amazing stories: About the time the lid blew off the biosphere, but up rose a strain of intelligent robots. Or the

⁵⁰ Ibid., 48f.

⁵¹ Ibid., 47f.

⁵² McKenzie Wark, *Gamer Theory* (Cambridge: Harvard University Press, 2007), §201ff.

time it ticked over for months, populated with a million sentient cetaceans, all using nanotechnology to run their watery utopia.⁵³

In its capacity to surprise with unpredictable outcomes, emergent evolutionary paths, and geohistorical trajectories, *SimEarth* comes surprisingly close to Latour's autopoietic understanding of Gaia. It is not perfect in this regard: evolution occurs on multilinear but predefined ways, and the structures of its models (governing atmosphere, geosphere etc.) are fixed. The player might change the weight of specific factors, but she cannot change their coupling. Thus, the importance of e.g. oxygen for the prospering of higher life-forms is not contingent in this game. *SimEarth* remains a hybrid between a pure bottom-up and a top-down simulation. But this is exactly what opens up the possibility to play.

Can Gaia be Played?

Lovelock's hypothesis was always heavily contested and often criticised for being too vague or not falsifiable.⁵⁴ But it became at least partly respectable because he made Gaia's principles explicit by translating his reasoning into equations that produced a seemingly objective and visual outcome, when processed. The recursion into mathematical notation and the implementation into a computer model proved that Gaia could actually work – it could be build and therefore exist. The incarnation of Gaia *in silico* was much more than an illustration; it was a proof of concept.⁵⁵

But the modelling approach of system dynamics used to build Daisyworld is not fit to exemplify Latour's Gaia. The reason being that the structure of such simulation models have to be predefined, what contradicts the emergent character of an autopoietic Gaia. A simulation built out of cellular automata, however, could very well create the unpredictable and contingent patterns, cycles and feedback-loops that Latour describes.

Such a simulation, where all forms of life as well as their environment and the feedback-cycles between them emerge out of the interplay of digital equiva-

⁵³ Ibid., §213.

⁵⁴ For an overview of the common points of critique see: James W. Kirchner, "The Gaia Theory: Fact, Theory, and Wishful Thinking," in: *Climatic Change* 52 (2002), accessed June 30, 2014,

http://seismo.berkeley.edu/~kirchner/reprints/2002_55_Kirchner_gaia.pdf.

⁵⁵ Moreover, the mathematical model allowed for a much more substantial critique of its premises – Gaia could become an object of critical discussion within the sciences. See, e.g., Kirchner's discussion of the premises of the Daisyworld model in the aforementioned article.

lences to (bio)-chemical molecules, is, of course, utterly impossible at the present state. And even if it would be created, its emergent complexity would be so huge that it could hardly be analysed. It would therefore be nearly impossible to verify its validity. The perfect simulation of Gaia would be as bottom-up, as complex, and as opaque as the real world.

But if, nevertheless, someone would try to model this kind of Gaia, it could be quite similar to *SimEarth*. While the inclusion of civilisations out of robots or dinosaurs in this game surely springs out of joy of pulp literature, its playful approach might be adequate to Gaia. The enormous variance in possible world histories that emerge out of the interactions with the game shows what Gaia is about: The fact that this or that specific cycle of nitrogen or CO² can be modelled in neat cybernetic feedback-loops is maybe not so relevant after all. The provocative power of the Gaia hypothesis lies in the description of a constantly emerging and contingent entity. Gaia cannot be built, it has to emerge. Such a view of Earth is not well suited for the fabrication of hard knowledge that can be put in explicit and non-ambiguous equations. The Gaia hypothesis (at least in Latour's reading) might not be fit to become a proper theory for the natural sciences. But it could deliver a good foundation for the exploration of various possible historical trajectories. The facticity of our world would thus become contingent. In such an understanding it is impossible to control Gaia - but maybe it can be played with.

BIBLIOGRAPHY

- Bertalanffy, Ludwig von. *General System theory: Foundations, Development, Applications*. New York: George Braziller, 1968.
- Clark, 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*, ed. by Eileen Crist and Bruce H. Rinker, 293-314. Cambridge: MIT Press, 2009.
- Dawkins, Richard. *The Extended Phenotype: The Long Reach of the Gene*. Oxford: Oxford University Press, 1982.
- Dawkins, Richard. *The Blind Watchmaker*. New York: Norton & Company, 1986.
- Doolittle, W. Ford. "Is Nature Really Motherly?" in *The CoEvolution Quarterly*, Spring (1981): 58-63.
- Foerster, Heinz von. "On Constructing a Realty," in *Understanding Understanding: Essays on Cybernetics and Cognition*. 221-227. New York: Springer, 2002 [1973].
- Forrester, Jay. *Urban Dynamics*. Waltham, MA: Pegasus Communications, 1969.
- Forrester, Jay. *World Dynamics*. Cambridge, MA: Wright-Allen Press, 1971.
- Forrester, Jay. "The Beginning of System Dynamics" (Banquet talk at the international meeting of the System Dynamics Society Stuttgart, Germany, July 13, 1989). Transcript Accessed July 28, 2014.
<http://clexchange.org/ftp/documents/system-dynamics/SD1989-07BeginningofSD.pdf>.
- Gardner, Martin. "Mathematical Games: The fantastic combinations of John Conway's new solitaire game 'life'," in *Scientific American* 223 (1970): 120-123.
- Golding, William. *The Lord of the Flies*. London: Faber and Faber, 1954.
- Haraway, Donna. "Gene. Maps and Portraits of Life Itself," in *Modest_Witness@Second_Millennium. FemaleMan_Meets_OncoMouse. Feminism and Technoscience*, ed. by Donna Haraway, 131-172. New York, London: Routledge, 1997.
- Haslam, Fred. "SimEarth. A Great Toy," in *Integrated Global Models of Sustainable Development, Volume 3: Encyclopedia of Life Support Systems*, ed. by Akira Onishi, 47-67. Oxford: EOLSS Publishers, UNESCO, 2009.
- Hayse, Mark. "God Games," in *Encyclopedia of Video Games: The Culture, Technology, and Art of Gaming. Volume One A-L*, ed. by Mark J. P. Wolf, 264-266. Santa Barbara, Denver, Oxford: Greenwood, 2012.

- Hölldobler, Bert; Wilson, E. O. *The Ants*. New York: Springer, 1990.
- Kirchner, James W. "The Gaia Theory: Fact, Theory, and Wishful Thinking," in *Climatic Change* 52 (2002): 391-408. Accessed June 30, 2014. doi: 10.1023/A:1014237331082
- Langton, Christopher. "Studying Artificial Life with Cellular Automata," in *Physica D: Nonlinear Phenomena* 22 (1986): 120-149. Accessed June 30, 2014. doi: 10.1016/0167-2789(86)90237-X
- Langton, Christopher. "SimLife from Maxis: Playing with Virtual Nature." In: *The Bulletin of the Santa Fe Institute* 7 (1992): 4-6.
- Latour, Bruno. *An Inquiry into Modes of Existence: An Anthropology of the Moderns*. Cambridge: Harvard University Press, 2013.
- Latour, Bruno. "Facing Gaia: Six Lectures on the Political Theology of Nature. Being the Gifford Lectures on Natural Religion (Presented at Edinburgh, February 18-28, 2013). Pre-released manuscript accessed July 2, 2014. http://www.bruno-latour.fr/sites/default/files/downloads/GIFFORD-SIX-LECTURES_1.pdf.
- Lovelock, James E., and Giffin, C. E. "Planetary Atmospheres: Compositional and Other Changes Associated with the Presence of Live," in *Advances in Astronautical Sciences* 25 (1969), 179-193. Accessed June 30, 2014. <http://www.jameslovelock.org/page19.html>.
- Lovelock, James E., and Margulis, Lynn. "Atmospheric Homeostasis by and for the Biosphere: The Gaia Hypothesis," in *Tellus* 26 (1974): 2-10. Accessed July 30, 2014. doi: 10.1111/j.2153-3490.1974.tb01946.x.
- Lovelock, James E. *Gaia: A New Look at Life on Earth*. Oxford: Oxford University Press, 2000 [1979].
- Lovelock, James E. "Biological Homeostasis of the Global Environment: The Parable of Daisyworld," in *Tellus* 35 (1983): 284-289. Accessed July 30, 2014. doi: 10.1111/j.1600-0889.1983.tb00031.x.
- Lovelock, James E., and Allaby, Michael. *The Greening of Mars*. New York: Warner Books, 1985.
- Lovelock, James E. *Ages of Gaia*. Oxford: Oxford University Press, 1995 [1988].
- Lovelock, James E. *The Vanishing Face of Gaia*. New York: Basic Books, 2009.
- Margulis, Lynn, and Sagan Dorion. *What is Life?* Oakland, CA: University of California Press, 2000.

- Maturana, Humberto R., and Varela, Francisco J. *Autopoiesis and Cognition: The Realization of the Living*. Dordrecht, Boston, London: Reidel Publishing, 1980 [1972].
- Meadows, Donella H., and Meadows, Dennis L., and Randers, Jorgen, and Behrens III, William W. *The Limits to Growth*. New York: Universe Books, 1972.
- Neitzel, Britta. "Point of View und Point of Action: Eine Perspektive auf die Perspektive in Computerspielen," in *Computer/Spiel/Räume: Materialien zur Einführung in die Computer Game Studies. Hamburger Hefte zur Medienkultur 5*, published by Institut für Medien und Kommunikation, University Hamburg, ed. by Klaus Bartels and Jan-Noel Thon (2007): 8-28.
- Paley, William. *Natural Theology or Evidences of the Existence and Attributes of the Deity*. London: R. Faulder, 1802.
- Pearce, Celia. "Sims, BattleBots, Cellular Automata God and Go: A Conversation with Will Wright by Celia Pearce," in *Game Studies 2* (2002). Accessed July 3, 2014. <http://www.gamestudies.org/0102/pearce/>
- Salen, Katie, and Zimmerman, Eric. *Rules of Play: Game Design Fundamentals*. Cambridge, MA: MIT Press, 2004.
- Schmitt, Carl. *Politische Theologie: Vier Kapitel zu der Lehre von der Souveränität*. München: Duncker und Humblot, 1922.
- Wark, McKenzie. *Gamer Theory*. Cambridge: Harvard University Press, 2007.
- Wiener, Norbert. *Cybernetics: Or Control and Communication in the Animal and the Machine*. Mass.: MIT Press, 1948.
- Wilson, Johnny L. *The SimEarth Bible*. New York: Osborn McGraw-Hill, 1991.
- Wolfram, Stephen. *A New Kind of Science*. Champaign, Ill: Wolfram Media, 2002.

LUDOGRAPHY

- Populous (1989): Bullfrog. Electronic Arts. Acorn 32-bit, Amiga, Atari ST, DOS, Genesis, Macintosh, PC-98, SEGA Master System, Sharp X68000, SNES, TurboGrafx-16, Windows 3.x.
- SimAnt: The Electronic Ant Colony (1991): The Electronic Ant Colony. Maxis Software. Ocean Software. Amiga, DOS, FM Towns, Macintosh, PC-98, Sharp X68000, SNES, Windows 3.x.
- SimCity (1989): Maxis. Various Publishers. Acorn 32-bit, Amiga, Amstrad CPC, Atari ST, BBC Micro, CDTV, Commodore 64, DOS, Electron, FM Towns, Mac-

intosh, OS/2, Palm OS, PC-98, Sharp X68000, SNES, Wii, Windows, Windows 3.x, ZX Spectrum.

SimCity 2000 (1993): Maxis. Acorn 32-bit, Amiga, DOS, FM Towns, Game Boy Advance, Macintosh, Nintendo 64, OS/2, PC-98, PlayStation, PlayStation 3, PSP, SEGA Saturn, SNES, Windows, Windows 3.x, Windows Mobile.

SimEarth: The Living Planet (1991): Maxis Software. Ocean Software. Amiga, DOS, FM Towns, Macintosh, PC-98, SEGA CD, Sharp X68000, SNES, TurboGrafx CD, Wii, Windows 3.x.

SimLife: The Genetic Playground (1992): Maxis Software. Maxis Software. Amiga, DOS, Macintosh, Windows 3.x.