
Philosophy of Late-Modern Technology

Towards a Clarification and Classification of Synthetic Biology

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1 Two types of technology?

Synthetic biology is the crystallization point of late-modern technoscientific hopes and hopes. In 2010 the research entrepreneur Craig Venter announced the forthcoming advent of an epochal break and envisioned a fundamental shift in our technical capabilities. Synthetic organisms “are going to potentially create a new industrial revolution if we can really get cells to do the production we want; [...] they could help wean us off of oil, and reverse some of the damage to the environment like capturing back carbon dioxide” (Venter 2010).¹

In order to analyze whether the epochal break claims are justified, I will coin a provisional search term and call the (possible) novel kind of technology “late-modern” (Schmidt 2012a; Schmidt 2012b). Apparently, this new type of technology seems to be inherently linked to the concept of self-organization. If such a self-organization based technology is emerging, we have to clarify what is meant by the catchword ‘self-organization’, and we need to analyze the source or root of self-organization, including the idea(l) of self-productiveness. The thesis is: instabilities — or, in cognate terms, sensitivities — constitute the necessary condition and, hence, the technoscientific core of this type of technology. Based on such analysis, I argue that late-modern technology differs from the classic-modern type of technology in its view and valuation of stability and instability. In fact, this novel kind of technology appears as nature and behaves like nature. In other words, we are experiencing a ‘naturalization of technology’ in a twofold way, as will be shown in this article. My aim here is to disclose a possible new ambivalence and dialectic of this envisioned late-modern turn in technology for our (late-modern) societies.

1 Venter’s visionary claim was evidently induced by the success of his team in the *Creation of a Bacterial Cell Controlled by a Chemically Synthesized Genome*—as his article in Science Magazine was titled (Gibson et al. 2010).

2 Clarifying the umbrella term ‘synthetic biology’

The exact meaning of the umbrella term ‘synthetic biology’ is not clear at all. New labels and trendy watchwords generally play a key role in the construction of new technoscientific waves. ‘Synthetic biology’ is, indeed, an extremely successful buzzword, as was ‘nanotechnology’ more than one decade ago.²

All ethicists and technology assessment scholars are aware of the fact that labels are strongly normative. Labels are not innocent or harmless: they carry content and form the backbones of visions. They are roadmaps towards the future and can quickly turn into reality; they shape the technoscientific field and determine our thinking, perception, and judgment. Labels help to foster hopes and hypes, as well as concerns and fears; their implicit power to create or close new research trajectories and development roadmaps can hardly be overestimated. Labels are part of what could be described as ‘term politics’ that regulate and shape the field with a ‘gate keeper function’ to decide who is *in* and who is *out*, in particular, whose research field can be considered as ‘synthetic biology’ and whose is just part of traditional biotechnology. Labels are relevant with respect to funding, publication opportunities, reputation, and career. Thus, they determine and sway our future, in one way or another. What does the umbrella term ‘synthetic biology’ mean? Is there a unifying arc and common denominator? What visions do synthetic biologists have, and how likely will their visions be achieved? Three popular definitions of ‘synthetic biology’, and of what it should be, stand out.

First – goals: The *engineering definition* frames synthetic biology as being radically new since it is said to bring an engineering approach to the scientific discipline of biology. Such an understanding is advocated by a High Level Expert Group of the European Commission: “Synthetic biology is the engineering of biology: the synthesis of complex, biologically based (or inspired) systems [...]. This engineering perspective may be applied at all levels of the hierarchy of biological structures [...]. In essence, synthetic biology will enable the design of ‘biological systems’ in a rational and systematic way” (European Commission 2005, p.5). This comes close to the definition given by Pühler et al. who define synthetic biology as “the birth of a new engineering science” (Pühler et al. 2011). Similarly, others view synthetic

2 On the one hand, ‘synthetic biology’ seems to be a fairly young term. It was (re-)introduced and presented by Eric Kool in 2000 at the annual meeting of the American Chemical Society. Since then, the term has gone on to enjoy a remarkable career and general circulation in the scientific communities as well as in science, technology, and innovation politics. On the other hand, the notion of ‘synthetic biology’ emerged about 100 years ago—although it was rarely mentioned until 2000. It seems more appropriate to consider the more recent understandings of ‘synthetic biology’.

biology as “an assembly of different approaches unified by a similar goal, namely the construction of new forms of life” (Deplazes and Huppenbauer 2009, p.58). The engineering definition is generally based on the strong assumption that, before synthetic biology arose, a clear line existed between biology as an academic discipline, on the one hand, and engineering/technical sciences, on the other.³ The proponents of the engineering definition believe that the well-established divide between the two disciplines is becoming blurred. Today, engineering is transferring its goals to the new subdiscipline of biology. According to the advocates of this definition, these goals have never been characteristics of other subdisciplines of biology. The essential claim is that we are experiencing an epochal break or a qualitative shift within biology: the aim is not theory, but technology.

Second – objects: The *artificiality definition* of synthetic biology is more concerned with objects and material entities than with goals. According to the EU project TESSY, ‘synthetic biology’ deals with “bio-systems [...] that do not exist as such in nature” (TESSY 2008). In an equivalent sense it is stated that synthetic biology encompasses the synthesis and construction of “systems, which display functions that do not exist in nature” (European Commission 2005, p.5). The German Science Foundation similarly identifies the emergence of “new properties that have never been observed in natural organisms before” (DFG et al. 2009, p.7). “Synthetic biology” is here defined by the non-naturalness, or unnaturalness, and artificiality of the constructed and created bio-objects. *Divergence from nature* appears to be the *differentia specifica* of ‘synthetic biology’, with ‘nature’ being seen as the central anchor and negative foil for this definition. Whereas bio-systems were formerly natural, i.e., they occurred exclusively *in*, and were created *by* nature alone, the claim here is that, from now on, they can also be artificial, i.e., constructed by humans.⁴

Third – methods: The *extreme biotechnology definition* leads either to synthetic biology being seen in a more relaxed light or, on the contrary, to it being condemned

3 From this angle, biology is regarded as a pure science aiming at fundamental descriptions and explanations. In contrast, engineering sciences appear to be primarily interested in intervention, construction, and creation. Viewed from this angle, biology and engineering sciences have always been—in terms of their goals—like fire and ice.

4 That is certainly a strong presupposition, and it is also linked to the Aristotelian idea of a dichotomy between nature and technical objects. This dichotomy traces back to the Greek philosopher Aristotle who drew a demarcation line between *physis* (nature) and *techné* (arts, technical systems). In spite of Francis Bacon’s endeavors at the very beginning of the modern epoch to eliminate the dichotomy and naturalize technology, the nature-technology divide broadly persists in the above definition. In a certain sense, the artificiality definition of synthetic biology presupposes the ongoing plausibility of the Aristotelian concept of nature, neglects the Baconian one, and argues for an epochal break in understanding bio-objects and bio-nature: these are not given, they are made.

as a continuation of further trends already perceived as terrible and dangerous. According to the proponents of this definition, we are experiencing a slight shift and mainly a continuation, not an epochal break; nothing is really new under the sun. Synthetic biology merely extends and complements biotechnology. Drew Endy, a key advocate of synthetic biology, perceives only an “expansion of biotechnology” (Endy 2005, p.449). Similarly, but from a more critical angle, the Action Group on Erosion, Technology and Concentration (ETC) defines “synthetic biology” as an “extreme gene technology”, mainly because synthetic biology is based on gene synthesis and cell techniques such as nucleotide synthesis, polymerase chain reaction (PCR), or recombined cloning (ETC 2007). The underlying methods, techniques, and procedures have been well established since the late 1970s. Although there have been tremendous advances from a quantitative standpoint, it is hard to discern any qualitative progress in the core methods.⁵ Briefly, this position perceives a continuation in methods—in contrast to a divergence from biology or nature according to the above mentioned two definitions of synthetic biology.

3 Deficits of the three definitions

The three definitions — the engineering, the artificiality, and the extreme biotechnology definition — tell three different stories. Each one exhibits some degree of plausibility and conclusiveness. In spite of their apparent differences, all are concerned (*first*) with disciplinary biology or biological nature and (*second*) with a rational design ideal in conjunction with a specific understanding of technology, technical systems, and engineering action. However, this is not the whole story.

First, the focus on biology as a discipline alone, including a discipline-oriented framing, prevents an exhaustive characterization of the new technoscientific wave. Synthetic biology is much more *interdisciplinary* than disciplinary at its nucleus. This needs to be taken into account when looking for an adequate definition: biologists, computer scientists, physicists, chemists, physicians, material scientists, and people from different engineering sciences are engaged in synthetic biology. Since various disciplinary approaches, methods, and concepts coexist in synthetic biology, the term seems to be a label for a new and specific type of interdisciplinarity (cf. Schmidt

5 This definition rarely deals with goals or objects, but with methods and techniques. Its proponents claim (1) that methods constitute the core of synthetic biology, (2) that there has been no breakthrough in the synthetic/biotechnological methods, and, moreover, (3) that a quantitative advancement cannot induce a qualitative one.

2008b). Accordingly, a strong biology bias would surely be overly simplistic and entirely inadequate; to frame synthetic biology merely as a new subdiscipline of biology would represent a far too narrow approach. Thus, we need to ask whether we are faced with a much more fundamental technoscientific wave than simply a change in one particular discipline or academic branch alone.

Second, in line with what has become known as bionano or nanobio research, the three definitions look at synthetic biology from the angle of technology and engineering. This manner of approach appears viable in some respects: synthetic biology extends and complements advancements in nanotechnology and hence spurs a position that can be called “technological reductionism” (Schmidt 2004, pp.35f.; cf. Grunwald 2008, pp.41f./190f.). Technological reductionists aim at eliminating the patchwork of engineering sciences by developing a fundamental technology, or a “root, core, or enabling technology” (Schmidt 2004, p.42). The slogan promoted by technological reductionism is: Shaping, constructing, and creating the world ‘atom-by-atom’. Eric Drexler is a prominent advocate of technological reductionism. He argues that there are “two styles of technology. The ancient style of technology that led from flint chips to silicon chips handles atoms and molecules in bulk; call it bulk technology. The new technology will handle individual atoms and molecules with control and precision; call it molecular technology” (Drexler 1990, p.4). Now, it has been argued that the three definitions of synthetic biology given above concur strongly with technological reductionism. It certainly seems plausible to put synthetic biology in the context of this new type of technology oriented reductionism. But whether that is all that can, or should, be said to characterize synthetic biology still needs to be clarified. Most clearly, synthetic biology differs from nanotechnology, which can be regarded as a paradigm of a technological reductionist approach. Synthetic biology claims to pursue an approach that is complementary to nanotechnology and has been called ‘systems approach’ or, in a more visionary sense, ‘holistic’. Given the widespread reference to ‘system’, including the claim of successful application of ‘systems thinking’, synthetic biology seems to involve a convergence, or dialectical relationship, of seemingly contradictory concepts: (systems’) holism and (technological) reductionism (with its strong control ambitions and emphasis on rational engineering). This inherent dialectic is obviously central to an adequate and appropriate understanding of synthetic biology. The three definitions presented so far do not consider this point.

4 Towards a new technoscientific paradigm?

For a better and more comprehensive characterization of synthetic biology we should not restrict ourselves to goals (as in definition 1), objects ('ontology', as in definition 2), or methods ('methodology', as in definition 3), but also consider the underlying principles, concepts and theories within the technoscientific field. A further definition is prevalent in synthetic biology's R&D programs: *the self-organization* (or systems) *definition*. Synthetic biology harnesses, or at least aims to harness, self-organization power (of nature) for technological purposes.

The paradigm of self-organization is present in many papers on synthetic biology: "Harnessing nature's toolbox" in order to "design biological systems", as David A. Drubin, Jeffrey Way, and Pamela Silver (2007) state. As early as in 2002, before synthetic biology had been coined as a term (although its main ideas were already present), Mihail Roco and William Bainbridge anticipated new frontiers in research and development by "learning from nature". They perceived the possibility of advancing technology by "exploiting the principles of automatic self-organization that are seen in nature" (Roco and Bainbridge 2002, p.258). According to Alain Pottage and Brad Sherman, the basic idea of synthetic biology is to "turn organisms into manufactures" and to make them "self-productive" (Pottage and Sherman 2007, p.545). "We think that in order to design products 'of biological complexity' that could make use of the fantastic fabrication abilities [...], we must first liberate design by discovering and exploiting the principles of automatic self-organization that are seen in nature" (Pollack 2002, p.161). In a similar vein, the 2009 report "Making Perfect Life" of the European TA Group refers to advancements in synthetic biology: "Synthetic biology [...] present[s] visions of the future [...]. Technologies are becoming more 'biological' in the sense that they are acquiring properties we used to associate with living organisms. Sophisticated 'smart' technological systems in the future are expected to have characteristics such as being self-organizing, self-optimizing, self-assembling, self-healing, and cognitive" (ETAG 2009, p.4).⁶ Obviously, "[t]he paradigm of complex, self-organizing systems is stepping ahead at an accelerated pace, both in science and in technology" (Dupuy 2004, pp.12f.; cf. Luisi and Stano 2011).

The systems approach of putting the self-organization power of bioengineered entities at the very center of the new technoscientific wave has enjoyed an impres-

6 And the ETAG goes on to stress: "Central in their ideas is the concept of self-regulation, self-organization and feedback as essential characteristics of cognitive systems since continuous adaption to the environment is the only way for living systems to survive" (ETAG 2009, p. 25).

sive history over the last three decades. It goes back to one of the most popular and highly controversial publications by K. Eric Drexler in the early 1980s. Drexler talks about “self-assembly”, “engines of creation”, and “molecular assemblers” (Drexler 1990; cf. Nolfi and Floreano 2000). “Assemblers will be able to make anything from common materials without labor, replacing smoking factories with systems as clean as forests.” Drexler goes even further and claims that emergent technologies “can help mind emerge in machine.” Richard Jones takes up Drexler’s ideas and perceives a trend towards “self-organizing [...] soft machines” that will change our understanding of both nature and technology (Jones 2004).

Synthetic biology – this is interesting to note – does not stand alone. Self-organization also plays a constitutive role in other kinds of emerging technologies such as

1. Robotics, AI, ubiquitous computing, autonomous software agents, bots;
2. Nano- and nanobio-technologies;
3. Cognitive and neuro-technologies.

In addition, self-organization in technical systems serves as a leitmotif in science policy: “Unifying science and engineering” seems to become possible by “using the concept of self-organized systems” (Roco and Bainbridge 2002). Self-organization appears to be the kernel of the ideal of the *convergence of technologies*, and it also seems central to any kind of *enabling technology* (ibid.; Schmidt 2004). In other words, synthetic biology is not unique; it can be considered as just a prominent example of a very universal trend in technology.

5 Late-modern technology

If we take the visionary promises as serious claims, they announce the emergence of a new type of technology. We do not know whether the promises can be fully kept. However, should this be the case, we would encounter a different kind of technology: a *late-modern technology*.

Late-modern technology does not resemble our established perception and understanding of technical systems. It displays nature-like characteristics; it does not appear as technology; it seems to be “un-technical” or “non-artificial”; the signs and signals, the tracks and traces are no longer visible (Hubig 2006; Karafyllis 2003; Kaminski and Gelhard 2014). Technical connotations have been peeled off; well-established demarcation lines are blurred. Late-modern technology seems to possess an intrinsic momentum of rest and movement within itself — not an extrinsic one.

Such characteristics come close to the Aristotelian and common life-world understanding of nature: technology *is* alive or *appears* to be alive, as nature always has been. The internal dynamics (i.e., acting, growing, and changing) of self-organization technology make it hard to draw a demarcation line between the artifactual and the natural in a phenomenological sense. Traditional technical connotations have been peeled off. Nature and technology seem indistinguishable. Even where it is still possible to differentiate between the artificial and the natural, e.g., in robotics, we are confronted with more and more artifacts displaying certain forms of behavior that traditionally have been associated with living systems. The words used by Schelling and Aristotle to characterize nature also seem to apply to technology. Late-modern technical systems are “not to be regarded as primitive.” Late-modern technology appears to act by itself: (a) it creates/produces; (b) it selects means to ends (means-ends rationality); (c) it takes decisions and acts according to its environmental requirements. Technology evidently presents itself as an actor: “autonomy” — a term that is central to our thought tradition — seems to be ascribable to these systems.

What is the background of this trend towards a *phenomenological convergence* of nature and technology or, in other terms, towards a *phenomenological naturalization of technology* — besides and in addition to “technological reductionism” (Schmidt 2004)? Much more relevant and foundational, it seems, is what could be called *nomological convergence* that gives rise to a fundamental trend towards a *nomological naturalization of technology*. Mathematical structures that describe self-organization in technical systems are said to converge with those in nature. Although the objects might differ, their behavior and dynamics show a similarity. According to M.E. Csete and J.C. Doyle, “advanced technologies and biology are far more alike in systems-level organization than is widely appreciated” (Csete and Doyle 2002, p.1664). The guiding idea of nomological convergence can be traced back to the cyberneticist Norbert Wiener (1968, first published in 1948). He defined structure-based convergence with regard to specific “structures that can be applied to and found in machines and, analogously, living systems.” As the physicist, philosopher and programmatic thinker Carl Friedrich von Weizsäcker pointed out about 50 years ago: “Structural sciences encompass systems analysis, information theory, cybernetics, and game theory. These concepts consider structural properties and features of different objects regardless of their material realm or disciplinary origin. Time-dependent processes form a common umbrella that can be described by an adequate mathematical approach and by using the

powerful tools of computer technology”⁷ (Weizsäcker 1974, pp.22f.; cf. Küppers 2000; Schmidt 2008a).

Today, we can add self-organization theories which encompass nonlinear dynamics, complexity theory, chaos theory, catastrophe theory, synergetics, fractal geometry, dissipative structures, autopoiesis theory, and others. Following the first wave of structural and systems sciences such as information theory, game theory, and cybernetics (e.g., Bertalanffy, Wiener, Shannon, von Neumann) in the 1930s and 1940s, we are now experiencing a second wave (e.g., Maturana, Varela, Prigogine, Haken, Foerster, Ruelle, Thom) that began in the late 1960s. Self-organization, macroscopic pattern formation, emergent behavior, self-structuring, growth processes, the relevance of boundary conditions, and the Second Law of Thermodynamics (entropy law) with its irreversible arrow of time are regarded as conceptual approaches to disciplinarily different types of objects, based on evolutionary thinking in complex systems. Assisted by the spread of computer technology, concepts of self-organization had a tremendous impact on scientific development in the second half of the 20th century.

6 Self-organization and instability

Since Kant and Schelling, the concept of self-organization has been in flux. However, ‘self-organization’ seems to have retained its central meaning, which is the immanent creation and construction of *novelty*: the emergence of novel systemic properties — new entities, patterns, structures, functionalities, capacities. Beyond the philosophical dispute on the notion and characteristics of novelty, the following criteria to specify ‘self-organization’ are widely accepted (Stephan 2007; Schmidt 2008a):

1. Internal dynamics, inherent processes, and time-dependency;
2. Irreducibility of the description length;
3. Unpredictability of the self-organizing or emergent phenomena.

In consequence, self-organization processes cannot be generally separated from their environment; they are hard to control by an external actor. “The engineers of the future will be the ones who know that they are successful when they are surprised by their own creations” (Dupuy 2004). In brief, the notion of self-organization is,

⁷ My translation from German (J.C.S.).

from an engineering perspective, linked to characteristics such as ‘productivity’, ‘processuality’, and ‘autonomy’.

It has been said that synthetic biology’s core is its claim of harnessing self-organizing power for technological purposes. But what is the core or root of self-organization? The basic answer that I propose is that *instabilities* turn out to be essential for self-organization; they are constitutive to all systems or structural theories (Schmidt 2008a). The physicist J.S. Langer (1980), for instance, underlines the role of “instabilities for any kind of pattern formation.” According to Werner Ebeling and Reiner Feistel (1994, p.46), “self-organization is always induced by instability of the ‘old’ structure through small fluctuations. This is why studying instability is of major importance.” Gregory Nicolis and Ilya Prigogine (1977, pp.3f.) argue that “instabilities [are ...] necessary conditions for self-organization.” Wolfgang Krohn and Günter Küppers (1992, p.3), in the same vein, emphasize that “instabilities are the driving force and the internal momentum for systems evolution and development.”

Instabilities can generally be regarded as situations in which a system is on a razor’s edge: criticalities, flip or turning points, thresholds, watersheds. They generate sensitive dependencies, bifurcations, phase transitions. The classic-modern *strong* type of causation does not govern these processes; rather, it is the *weak* type of causation that enables feedback procedures and amplification processes. Instabilities can induce random-like behavior, deterministic chance, and law-based noise, which are inherently linked to uncertainty. The most prominent example used to illustrate instability is the butterfly effect. The beating of a butterfly’s wings in South America can have tremendous influence on the weather in the U.S. and cause a thunderstorm.⁸

Unstable systems show certain limitations of: predictability, reproducibility, testability, and reductive describability. An isolation or separation from their environment is impossible as they interact with it continuously. In general, instability should not be equated with the collapse of a system. Insofar as engineers today aim at harnessing self-organization power, they have to provoke and stimulate insta-

8 The list of examples is extensive (cf. Schmidt 2011): the emergence and onset of a chemical oscillation, the role dynamics of a fluid in heat transfer, an enzyme kinetic reaction, a gear chattering, or turbulence of a flow. A fluid becomes viscous, ice crystallization emerges, a phase transition from the fluid to a gas phase takes place, a solid state becomes super-fluid, a laser issues forth light, a water tap begins to drip, a bridge crashes down, an earthquake or tsunami arises, a thermal conduction process comes to rest, and a convection sets in, e.g., Bénard instability. New patterns and structures appear. These examples underscore the fact that instabilities are the necessary condition for *novelty*. The various definitions of complexity refer directly or indirectly to instabilities.



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