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The Conception of Life in Synthetic Biology

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Abstract The phrase ‘synthetic biology’ is used to describe a set of different scientific and technological disciplines, which share the objective to design and produce new life forms. This essay addresses the following questions: What conception of life stands behind this ambitious objective? In what relation does this conception of life stand to that of traditional biology and biotechnology? And, could such a conception of life raise ethical concerns? Three different observations that provide useful indications for the conception of life in synthetic biology will be discussed in detail: 1. Synthetic biologists focus on different features of living organisms in order to design new life forms, 2. Synthetic biologists want to contribute to the understanding of life, and 3. Synthetic biologists want to modify life through a rational design, which implies the notions of utilising, minimising/optimising, varying and overcoming life. These observations indicate a tight connection between science and technology, a focus on selected aspects of life, a production-oriented approach to life, and a design-oriented understanding of life. It will be argued that through this conception of life synthetic biologists present life in a different light. This conception of life will be illustrated by the metaphor of a toolbox. According to the notion of life as a toolbox, the different features of living organisms are perceived as various rationally designed instruments that can be used for the production of the living organism itself or secondary products made by the organism. According to certain ethical positions this conception of life might raise ethical concerns related to the status of the organism, the motives of the scientists and the role of technology in our society.

Keywords Biotechnology · Conception of life · Designing life · Living machine · Synthetic biology

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Introduction

'Life' is a multifarious concept that is defined, described and explained by fields as different as philosophy, biology, religions, and psychology.

In this essay I examine the conception of life in synthetic biology, that is, how synthetic biologists understand and conceive of life. A conception of life in this sense is not necessarily based on an explicit theory or definition of life, but it often rests on a certain mind-set, on associations with life or on attitudes towards life that are not explicitly formulated. I will deduce the conception of life in synthetic biology from how synthetic biologists conceive of new life forms, how they want to contribute to furthering the understanding of life and how they want to modify life through rational design. I will try to show that the characteristic features of living organisms used by biologists to describe life, also play an important role in the conception of life in synthetic biology. However, whereas biologists understand these different features as 'markers for life', in synthetic biology they are understood as a set of human-designed tools for the purpose of production. This conception of life will be called 'life as a toolbox'. The transition from the conception of life in biology to that used in synthetic biology has been initiated by earlier methods—such as breeding or genetic engineering—for the purpose of influencing the appearance and capacities of living organisms. However, I would argue that the notions of 'new life-forms' in synthetic biology, the way that synthetic biologists want to contribute to the understanding of life, and how they want to modify life by a rational design reveal a conception of life that differs from that of traditional biotechnology. As a result, synthetic biology adds a new facet to the multifarious notion of life. For certain ethical positions this production- and design-oriented conception of life may raise concerns.

The Prevalent Conception of Life in Biology Rests on a Set of Characteristic Features of Living Organisms

Before addressing the specific conception of life in synthetic biology, I will briefly introduce the prevalent conception of life in traditional biology. Because 'life' is a difficult concept to grasp it is often described as a property, specifically as a property of living organisms. When biologists make general statements about the nature of life, they mostly refer to a list of hallmarks or 'life criteria', which characterize living organisms (Deamer 2010; Ganti 2003, pp. 76–80; Koshland 2002; Mayr 1997, pp. 20–23). These features are what biologists explore in order to learn more about life and they form a central part of the prevalent conception of life in biology. For biologists, these features serve as 'markers', or indicators for life.[1]

I will present a list of seven characteristic features of living organisms. These features appear in different wordings on several lists found in the literature (Deamer

[1] In biology "markers" indicate certain biological objects or properties. Genetic markers are for instance used to follow chromosomes or traits over generations.

2010; Ganti 2003, pp. 76–80; Koshland 2002; Mayr 1997, pp. 20–23) or are referred to as the fundamental biological features of living organisms.[2] Although individual features are not considered to be sufficient for the identification of life, collectively, they can fulfil this function. I shall also attempt to formulate the characteristic features such that each of them necessarily occurs in any entity that is called ‘alive’.

1. Living organisms are subject to *constant transformation* by exchange of material and energy with the environment, this feature allows for development and growth. 2. Living organisms are confined entities delineated by a defined border. They are capable of self-production and self-maintenance; these features are captured by the term ‘*autopoiesis*’ (Luisi 2003; Maturana and Varela 1980). 3. Transformation, as well as autopoiesis, depend on the next property, namely the *metabolism*, by which living organisms take up energy and other sources from the environment and convert them by biochemical reactions. 4. The constant exchange of energy and material allows the living organism to maintain a stable inner milieu, which is different from the outer milieu. This maintenance of a dynamic equilibrium between the inner and outer milieu is called *homeostasis* in an open system. 5. Living organisms are controlled by a *genetic programme*. This is an encoded version of the blueprint of the organism, which carries and propagates information, for instance about the basic processes that take place in the organism and about its general appearance. 6. The existing diversity of life and the ongoing diversification depend on another characteristic of living organisms, namely that they contribute to *evolution*. This means, certain organisms reproduce and form lineages, which can adapt to their surroundings over generations by the mechanisms of evolution. 7. Finally, living organisms are in constant interaction and communication with the environment, to which they respond and adapt.

This description suggests that the different features are in fact, closely related. For this reason, in some lists, certain of these features are combined into one, others are divided into two. The listed features allow living organisms to form, develop and persist without external control. To date, all organisms had shared an additional feature, namely that they were essentially based on a natural layout, which did not depend on any human assistance. Even when certain features had been altered by breeding and genetic engineering, the resulting organism could still be considered a new version of its natural precursor.

[2] Some comments on features 2 and 7 on my list: Feature 2: The term “autopoiesis” has been introduced by the Chilean Biologists H. Maturana and F. Varela as the only necessary and sufficient feature to describe and explain life (Maturana and Varela 1980). I apply the term here not to refer to the complete theory of autopoiesis but to summarize the features of self-maintenance, self-production and an external boundary, which in different wordings occur on most of the quoted lists.

Feature 7: Of the four lists quoted here, “active response to the environment” only appears on E. Mayr’s list as “capacity for response to stimuli from the environment”. However, this feature is also extensively discussed by biologists for instance in context of biosemiotics (Kull et al. 2009) or modern interpretations of the autopoiesis theory (Bitbol and Luisi 2004).

In Synthetic Biology, Scientists Follow Different Methodological Approaches

In contrast to the focus in traditional biotechnology, which has generally been set on singular genes and traits, synthetic biologists apply a more integral perspective and a more systematic approach on organisms. However, it would be wrong to think of synthetic biology as one uniform technology with one specific method. The different types of synthetic biology have emerged from different disciplines such as engineering, chemistry, molecular biology and computer science. Although the borderlines between the disciplines are blurring there are still clear biases towards a specific field, depending on the type of synthetic biology. The different branches of synthetic biology differ in their methods, strategies and their immediate goals (O'Malley et al. 2008). Elsewhere, I have divided synthetic biology into five different approaches, which I also apply in this article (Deplazes 2009). They can be introduced briefly as follows:

1. In *Bioengineering* researchers aim at introducing novel, human-designed metabolic pathways into living cells using traditional biotechnological tools. They want to turn biotechnology into a real engineering discipline by introducing a more systematic organisation and procedure. This systematic procedure would allow for more extensive and deeper genetic alterations than previously known by traditional genetic engineering.
2. *In silico synthetic biology* is carried out by computer scientists, who establish simulations and sophisticated models of potential synthetic organisms on a computer. Researchers in bioengineering and in silico synthetic biology aim at designing organisms with novel metabolic pathways and regulatory mechanisms. However, their strategies differ in some respects. A. Moya et al. (2009) assert for instance, that at least in certain cases, in silico synthetic biology implies a stronger focus on the overall models than on the singular parts, and thus leads to a more 'systemic' perspective to living organisms. These authors speak of a systems-biology approach to synthetic biology. Nevertheless, the main difference between the two approaches is that scientists in the first case work in the wet lab whereas in the second case they focus their work exclusively on the computer.
3. In *synthetic genomics* scientists aim at synthesising genomes and introducing them into host organisms. One aim of researchers in this field is that eventually the synthetic genomes may be reduced to the minimal number of genes and may thereby serve as a chassis genome for the introduction of useful transgenes.
4. *Protocell synthetic biology* is the discipline in which scientists produce lipid vesicles containing the molecular components for biochemical reactions, these vesicles are called protocells. At the current state of research, protocells are not alive yet. However, in the future, this method may allow for the production of fully synthetic cells that fulfil the requirements to be called alive.
5. Scientists in *unnatural molecular biology* develop novel types of genomes or coding systems, for instance with new kinds of nucleic acids or with quadruplet instead of triplet codons. Novel codons could encode for a large set of

additional amino acids, which do not occur in natural proteins, but which could be integrated into proteins of synthetic organisms.

In spite of the differences in methods, strategies and immediate goals of the five approaches, they share the common aim of synthesising novel life forms. Moreover, researchers from the bioengineering and in silico branches for instance, collaborate closely. The synthetic genomics branch too, is likely to be combined with bioengineering in the future, and maybe this could eventually also be true for the unnatural molecular biology approach. For these reasons, it makes sense to combine the different approaches under the umbrella term 'synthetic biology'. This common vision is also why the conception of life in synthetic biology as a whole is being discussed here.

Synthetic Biologists Focus on Different Features of Living Organisms in Order to Design New Life Forms

What is a new life form for synthetic biologists? This question brings us back to the characteristic features of living organisms that contribute to the conception of life in traditional biology, introduced above. Interestingly, in the various branches of synthetic biology outlined above, different features of living organisms are addressed in order to design and produce new life forms.

1. According to bioengineers new life forms will contain new metabolic and regulatory pathways, resulting for instance in a new type of behaviour or the production of new substances (Martin et al. 2009). The novelty in these new life forms mainly addresses the *metabolism* and regulatory mechanisms in living organisms. 2. In silico synthetic biologists simulate new life forms on the computer. In this case too, the emphasis lies on the *metabolism* and regulatory mechanisms.[3] 3. Scientists in synthetic genomics focus on the *genetic programme* of living organisms. They endeavour to produce new life forms that contain synthetic, and eventually minimised genomes (Holt 2008; Wimmer et al. 2009). 4. In protocell synthetic biology, researchers aim at producing artificial cells that display the seven features of living organisms. Protocell synthetic biologists working with Pier Luigi Luisi set a particular focus on the capacities of living cells to be *autopoietic,* to be under *constant transformation* and thereby to *respond to the environment* (Bitbol and Luisi 2004; Stano and Luisi 2010). A new life form in this case would display similar features to a natural organism but would have been produced from scratch. 5. Finally, scientists in unnatural molecular biology, like those in synthetic genomics, focus on the *genetic programme* of organisms. However, in case of unnatural molecular biology, new types of organisms would eventually have an alternative type of genome or genetic code (Benner and Sismour 2005; Bergstrom 2009; Wang et al. 2006).

[3] In contrast to the discipline ALife (artificial life), which develops computer programs that reproduce and evolve themselves, the idea with the computer simulations in in silico synthetic biology is that they represent processes, which could be integrated into material living organisms.

Table 1 Overview of how synthetic biologists want to design new life forms, starting from the characteristic features of living organisms

	"Addressed" feature of living organisms	Novelty in 'new life forms'	Modifications by a rational design
Bioengineering	Metabolism	Signalling pathways, regulatory mechanisms	Optimising life
			Overcoming life
		Substances produced by the organism	Utilising life
		Behaviour of the organism	
		Controllability	
Synthetic genomics	Genetic programme	Synthetically produce genome	Minimising life
		Size and composition of the genome,	Utilising life
		Chassis genome	
Protocell synthetic biology	Autopoiesis	Synthetically produced cell	Minimising life
	Interaction with the environment	Simplified version of a cell	
	Constant transformation		
Unnatural molecular biology	Genetic programme	Types of nucleotides or genetic code	Varying life
		Orthogonal life	Utilising life
In silico synthetic biology	Metabolism	Models, simulations	Optimising life
		Regulatory mechanisms	

This list, summarised in Table 1, shows that in the different synthetic biology approaches we come across different understandings of 'new life forms'. The reason for this is, on the one hand, that the different synthetic biology approaches focus on different features amongst the seven characteristics discussed earlier. On the other hand, there can be different notions on how a certain feature could be altered in order to yield new life forms. This is illustrated by the cases of synthetic genomics and unnatural molecular biology, both of which focus on the genetic programme. However, whereas the new life forms of synthetic genomics would carry a streamlined, synthetically produced genome based on natural codes and nucleic acids, future products of unnatural molecular biology would rest on human-designed codes or nucleic acids.

Synthetic Biologists Want to Contribute to the Understanding of Life

Synthetic biologists like to quote Richard Feynman's saying: "*What I cannot create I do not understand*" (Carr and Church 2009; Drubin et al. 2007; Simpson 2006). A similar thought has been phrased by Michel Morange: "*The best way to demonstrate that the 'mystery' has been definitively banished from the realm of organisms would be to synthesize a living organism 'from scratch' [...]*" (Morange 2009). According to these words, we can only understand life once we are able to produce living organisms. Synthetic biology would thus provide a fundamental contribution to the understanding of life and it would remove the remaining 'mystical' associations attached to this concept. Craig Venter sees his synthetic genomics approach as a mission to prove a reductionist explanation of life (Cho et al. 1999). In contrast to this explanation by reducing the complexity of life to its fragments, researchers from in silico synthetic biology point out that they start from an integral perspective on the living organism and thereby study life by its complexity. They want to provide knowledge about life in biological systems with emergent properties (Moya et al. 2009). For many scientists in the protocell approach the main aim is to contribute to the understanding of life, particularly of its origin. In his book, "The emergence of Life: From Chemical Origins to Synthetic Biology", Pier Luigi Luisi emphasises that his model of a minimal cell might help us to understand the origin of life. The minimal cell may give an account of how life started by the concentration of chemical molecules in lipid vesicles (Luisi 2002, 2006, pp. 3–4). Even the experiments on alternative genomes may provide insights into why living organisms are the way they are, by revealing the advantages of the existing genetic system over certain artificial alternatives (Benner 2004; Szathmary 2003).

Researchers from all different branches of synthetic biology thus consider their work to be a contribution to our basic understanding of life.

The aims associated with a technology normally concern specific applications or procedures. The aim to contribute to the general understanding of the world is normally assigned to basic research. If synthetic biology is understood as a new form of biotechnology, the relation between biological knowledge and biotechnological applications has thus shifted. In traditional forms of biotechnology biological applications were understood as the result of biological knowledge, not the source of it. Of course, basic research in biology has also previously profited from biotechnology because of the development of useful tools that could be applied in basic research. However, this indirect contribution of biotechnology to basic research is not the same as the claim of synthetic biologists, that biotechnological products will directly provide scientific insight. Also, the name 'synthetic *biology*' given to this application and production-oriented field illustrates that here, biology and biotechnology are not clearly separable anymore.

Synthetic Biologists Want to Modify Life through a Rational Design

Synthetic biologists not only want to produce new life forms, they also want to design them. This notion of life as a property based on a rational design is characteristic of the conception of life in synthetic biology. By a rational design I mean a design, which is based on rational deliberations of human designers, in contrast to, for instance, an evolutionary development based on random variations. In the different branches of synthetic biology the rational design is applied to different structures of the organism, depending on which characteristic features of living organisms are addressed by the specific synthetic biology approach (see above). In bioengineering it is applied to the metabolic pathways and regulatory mechanisms. In synthetic genomics the structure of the genome, meaning that the arrangement of genetic and intergenic sequences are designed rationally. Scientists of the protocell approach design the configuration and composition of the minimal cell. Finally, practitioners of the unnatural molecular biology approach design the respective nucleotides or genetic codes.[4]

The notion of designing living organisms emphasises the analogy between organisms and machines. The idea that living organisms function similarly to machines is not new. In 1637 René Descartes suggested that animals are comparable to machines (Descartes 1985-8) and in 1747 Julien Offray de La Mettrie proposed that even human beings are nothing other than machines (La Mettrie 1996). However, the understanding of organisms as machines in synthetic biology, particularly in bioengineering, adds a new element to the analogy between living organisms and 'other' machines as understood by Descartes and La Mettrie. The latter meant that animals (La Mettrie included humans) are based entirely on material substance, without any immaterial soul, exactly as we know it in machines. In other words, there is no difference between biological and mechanical processes, all of them are based on physical laws. Bioengineers on the other hand want to turn biology into an engineering discipline, they want to introduce engineering and a rational design into biotechnology (Andrianantoandro et al. 2006; Heinemann and Panke 2006). Of course they agree with Descartes and La Mettrie in that the processes in living organisms are based on physical laws. However, this seems not to be what they refer to when they use terms such as 'genetically engineered machines' or when they compare the products of synthetic biology with computers. They are referring to the rational design that is common to their products and traditional machines.[5]

Not only philosophers, but also, engineers, of the 18th century were fascinated by the similarities between organisms and machines. The construction of automata such as the 'defecating' duck in 1739 by the automate-maker Jacques Vaucanson illustrates an early interest of 'engineers' in life processes. This mechanical duck could pick grains and seemed to digest and excrete them. Although the apparent digestion process in the duck was feigned, the idea of such a machine already suggests that people thought that biological processes could be simulated by a rational design (Riskin 2003). However, in synthetic biology, researchers go beyond the mere simulation of the features of living organisms, they want to copy, develop and improve them. The blurring between organisms and machines is thus substantiated by the idea of producing artificial organisms as living machines made from organic substances. What makes these organisms artificial and similar to machines, is the idea of a rational design and layout, not their material.

The notion of living organisms as rationally designed entities, and thus of their property 'life' based on a rational design, implicates certain notions about how life would be modified. Each of these notions reflects an attitude towards life that

[4] Rational design in the unnatural molecular biology approach could for instance be applied for the development of alternative genetic codes, to design HNA or GNA nucleotides (Schmidt 2010) or alternative nucleobases (Benner and Sismour 2005).

[5] Some synthetic biologists increasingly apply directed evolution as a non-rational designing aid (Dougherty and Arnold 2009). This constitutes an interesting withdrawal from the machine-analogy. One could argue that the application of directed evolution that might indicate that in the end, the rational design of a living organism might be beyond human capacities.

reveals something about the conception of life in synthetic biology. In the following, four different notions of how life would be modified by synthetic biology will be described: utilising, minimising/optimising, varying and overcoming life.

Utilising Life

The idea that other living organisms can be utilised for human purposes is probably as old as human civilisation. Humans have always taken advantage of the fact that their domesticated animals and crops reproduce and evolve over generations. These capacities made breeding possible. In biotechnology too, the fact that living organisms reproduce, and thereby propagate their genetic information have been utilised. Moreover, the ability of organisms to produce certain substances through metabolism has been utilised, for instance in the production of recombinant proteins by genetically engineered bacteria.

Synthetic biologists too, want to take advantage of the useful features of living organisms such as *metabolism*, *autopoiesis*, *homeostasis*, reproduction and growth.[6] But instead of adapting them by the directed selection of existent properties or by the transfer of singular genes from one species to another, synthetic biologists want to introduce a new dimension of creativity into biotechnology. On the one hand, DNA synthesis technologies and the introduction of alternative genetic codes or nucleic acids is expected to allow departing from certain limitations encountered in traditional biotechnology. On the other hand, the strategies and procedures of bioengineering and in silico synthetic biology could enable humans to develop novel applications much more removed from the original functions of living organisms.

Minimising and Optimising Life

In the case of protocell synthetic biology, the rational design of living organisms is only conceivable for minimal versions of life. The only way, that creating a living cell from scratch ever appears to be feasible is by starting from an extremely simplified version of a cell. The synthesis of such a cell could in turn provide insight into the minimal set of components required for a living system. In other cases, designing living organisms might allow to get from complex to simpler life forms. An example would be the search for minimal genomes consisting of the necessary and sufficient genes for a living system. An organism carrying a minimal genome might provide information about the minimal requirements for life. Moreover, it would be useful for bioengineers, who could then add the genes for their novel pathways into the almost empty genome. In a cell with a minimal genome and thus a minimal metabolism, they would expect less background reactions interfering with the designed reactions. Scientists in synthetic genomics have developed a strategy to determine a minimal genome. They started from organisms built on very few genes,

[6] As described above, "growth" is a direct consequence of feature 1. *constant transformation*. "Reproduction" has been mentioned as part of feature 6. *evolution* related to the capacity of living organisms to form lineages that can evolve.

such as Mycoplasma bacteria. In such organisms they expected very few, if any, redundancies regarding protein functions. Therefore, the genes without which the organism could not survive were expected to be "*a close approximation to the minimal set of genes needed to sustain bacterial life*" (Glass et al. 2006). In contrast, more complex organisms often contain several genes encoding for proteins with overlapping functions. In these cases, essential functions would be more difficult to detect, because redundant proteins can take over the function of proteins that might be missing due to gene deletions.

Organisms with minimal genomes could already be called 'optimised' when assessing their usefulness as carriers of chassis genomes. However, particularly for bioengineers, the notion of 'designing life' allows for optimisation that goes beyond minimisation. Drew Endy has been quoted as saying, "*No intelligent designer would have put the genomes of living organisms together in the way that evolution has […]there is no sense of organisation or hierarchy. That is because, unlike an engineer, evolution cannot go back to the drawing board, it can merely play with what already exists*" (Anonymous 2006). Natural life forms are thus not as efficient and effective as they could be. Endy and others therefore aim at optimising life by introducing hierarchy and standardisation into the organisation of organisms (Purnick and Weiss 2009).

Varying Life

The human-designed life forms of all synthetic biology approaches are in some sense new variants of life. However, in unnatural molecular biology the rational design affects a more basic structure of biological life, and thus leads to deeper changes. It is the vey molecular and chemical foundation that is varied in this type of synthetic biology. The organisms that may eventually be produced in unnatural molecular biology could be considered to form a second type of living organism altogether. The synthetic biology specialist Markus Schmidt speaks of a 'Second Nature' in this context (Schmidt 2010). As mentioned above, researchers following this approach work on new genomes based on artificial nucleotides, as well as alternative genetic codes. Such variations in the genetic system could lead to genetic variants of life, which biologically cannot interact with natural[7] life forms. Interbreeding or recombination would not be possible between organisms with alternative nucleic acids and those carrying DNA and RNA (Schmidt 2010).[8] The vision of a fundamentally different life form besides life based on DNA, RNA and the 20 canonical amino acids is already familiar in astrobiology (Schulze-Makuch

[7] "Natural" is understood here as "not intended by a human design".

[8] In this context, synthetic biologists use the term "orthogonality": orthogonal systems are characterised by their ability to process information independently from natural systems, without crosstalk between the natural and the synthetic systems. At the moment, such orthogonal systems are introduced into organisms that still rely on the natural coding system (Neumann et al. 2010). However, one could imagine that eventually living organisms may be produced, which are based exclusively on the alternative information system.

and Irwin 2006). But the notion that fundamentally different variants of organic life could be designed and produced by humans has only emerged with the unnatural molecular biology approach.

Overcoming Life[9]

The bioengineering branch is driven by the aim of adapting the products of biotechnology to the layout of computers, especially in their organisation in a hierarchical structure made from standardised elements (Andrianantoandro et al. 2006). It is therefore not surprising that the international synthetic biology competition, which largely follows the engineering approach, is called iGEM, with GEM standing for 'genetically engineered machines'. The end product is perceived as a living machine (Boldt et al. 2009; iGEM 2007).

Although, since the 18th century living organisms have been described as 'machines', it has always been clear that living organisms were different from 'other' machines.[10] One of the main differences is that machines are produced and designed to fulfil human purposes. In contrast, the major part of living organisms has not been designed according to human purposes. This is true even in case of cultured animals and crops or genetically modified organisms. With synthetic biology it seems possible to abolish this difference between living organisms and machines. When synthetic biologists speak of their products as machines they imply that these entities have lost their independence and are thus controllable (Deplazes and Huppenbauer 2009). However, at least one of the characteristic features of living organisms is not compatible with this understanding of a machine, namely the ability of living organisms to adapt and evolve. This is normally not desirable for machines because they should remain stable and controllable. With regard to this feature, the goal of bioengineers is to 'overcome' life by an elaborated design. The goal of turning biotechnology into a real engineering discipline implies preventing independent and unpredictable changes and adaptation by evolution in the bioengineering products (Endy 2005; Hold and Panke 2009).

In this section I have endeavoured to illustrate that in synthetic biology, life is perceived as something that can be utilised, minimised/optimised, varied and overcome by a rational design. I have also indicated how this perception of life differs from other notions of utilising life, of organisms as machines or of variants of life in astrobiology. The described notions how life could be modified by synthetic biology reveal an underlying attitude towards life. Life is not considered to be a *given* property anymore but rather a property of the product that can be systematically adjusted to human interests and needs.

[9] "Overcoming" is understood here in the sense of overcoming obstacles, problems or limits.

[10] According to certain definitions of machines living organisms would not be part of this group at all, see for instance Oxford English Dictionary Definition II, Machine: "A material structure designed for a specific purpose, and related uses.".

The Conception of Life in Synthetic Biology

What the Previously Discussed Observations Tell Us about the Conception of Life in Synthetic Biology

I have discussed three different observations on synthetic biology in order to infer the underlying conception of life in this discipline: First, that different synthetic biologists focus on different features of living organisms when aiming at producing new life forms; second, that they want to contribute to our understanding of life and third, that they have specific notions on how to modify life.

The first observation indicates that the seven characteristic features of living organisms, which set the foundation of the conception of life in traditional biology, also play an important role in synthetic biology. However, in contrast to traditional biology they are not conceived as a *given* set of features that characterize life, but rather as individual starting points towards the design of new life forms.

The second observation was that synthetic biologists aim at contributing to our understanding of life. It indicates a common aim between synthetic biology and basic research in biology. However, in contrast to biologists who try to unveil the secret of life by investigating the characteristic features of living organisms, synthetic biologists want to learn about life by producing new life forms. This relation between science and technology, which is tighter than in traditional biotechnology, indicates that synthetic biologists want to make general claims about life and thus deduce what life is from their productions and applications. In other words, 'life' is not understood as a property that is automatically associated with nature anymore but primarily as the property of technological products.

As indicated above, the third observation—concerning the specific notions on how to modify life by designing new life forms—reveals an application-oriented attitude towards life. It is understood as a property that can be utilised, minimised/optimised, varied and overcome, and that therefore can be modified according to our wishes, needs and creativity. The idea is that life in this sense is based on the rational design of the synthetic biology product. As a result, life turns into a property of the product that is evaluated according to its efficiency, usefulness and suitability, with the possibility to be improved if necessary. It is not really the *given* property of living organisms anymore. This type of evaluation is not only applied to life as a whole but also to the individual features of living organisms.

Taken together, these observations indicate that the conception of life in synthetic biology still rests on the characteristic features of living organisms known from traditional biology. However, for synthetic biologists, these features are starting points to designing new life forms, which could in turn provide us with more insight about life itself. Life is thus interesting as a property of living organisms and the source of potential useful applications. It is also something that can be designed by humans and thus minimised, optimised varied or overcome. These aspects of life are more relevant than the fact that original forms of life occurred naturally or that evolution is acting on al living organisms.[11]

The Conception of Life as a Toolbox

The characteristic features described above fulfil a different role in this conception of life than in the conception found in traditional biology. They are not perceived as a *given* set of features of living organisms but rather the different features of living organisms are assessed and modified separately. Rather, the rational design described in the third observation is being applied to one or the other feature, depending on the approach. This understanding of life means that humans can vary, minimise optimise, evaluate and improve one or the other of the seven characteristic features of living organisms. In order to illustrate the function of the characteristic features of living organisms in synthetic biology I compare them to tools in a toolbox. On the one hand, tools are designed according to the wishes of their human designers; on the other hand tools serve specific purposes. Analogously, synthetic biologists design the features of living organisms according to human requirements while these features also serve production. The primary product, the organism itself, is formed and produced by these tools. As secondary products, the respective organism can for instance produce useful substances. I add a few examples to illustrate how the characteristic features of living organisms can serve as tools: Reproduction and growth,[12] are valuable instruments for multiplication. *Autopoiesis* enables the organism to make and maintain itself. Through their *metabolism* organisms can produce useful substances. *Homeostasis* stabilizes the producing organism. The *genetic programme* is the tool that encodes and controls the system and even *evolution*, if desirable, can serve as a designing-aid.[13] The interaction with and *responsiveness to the environment* is a tool for external control and regulation of the organism. These different tools are connected by their common appearance in living organisms. I thus call the conception of life in synthetic biology 'life as a toolbox'. This metaphor can also serve to illustrate the difference between the conception of life in synthetic biology and in traditional biotechnology. If for synthetic biologists the characteristic features of living organisms are comparable to tools in a toolbox, in traditional biotechnology they would be comparable to the tools used by apes or prehistoric humans, namely sticks or stones that have been rudimentarily modified for useful purposes. In a similar way, humans have been taking advantage of the features of living organisms and have adapted them rudimentarily by breeding or genetic engineering. This is in contrast to the idea of rationally designed features of living organisms as designed tools in synthetic biology.

[11] Except of those bioegineers who explicitly want to overcome evolution and those who apply directed evolution as a designing aid, most synthetic biologists just accept evolution as an aspect of their products, which seems not to be of too much interest.

[12] See foonote 6.

[13] See footnote 5 .

Potential Ethical Implications

In the ethical discourse on synthetic biology some authors have pointed to the possibility that an altered conception of life propagated by synthetic biology may raise ethical concerns (Boldt and Muller 2008; de Vriend 2006, p. 60). In the following, three ethical positions are briefly introduced, based on which it might be argued that the conception of life as a toolbox raises ethical concerns.

Biocentrism

Biocentrists hold that all living organisms have intrinsic value and hence are morally considerable. Because of this moral 'considerability' living organisms are significantly different from machines. Following this view, the conception of life in synthetic biology neglects a relevant aspect of life. According to biocentrists, living organisms have a good of their own or they can flourish. The production of synthetic organisms would thus imply a moral responsibility towards the produced organism not to cause unnecessary harm to it (Attfield 1998; Taylor 1986 p. 57) .

Virtue Ethics

Virtue ethicists state that it is the character of the acting person that is morally decisive, not the consequences of the action, or the extent to which the action complies with rules. A moral person acts from certain character dispositions such as helpfulness or generosity, which are called 'virtues' (Hursthouse 2007). The emphasis on virtues directs the attention towards the attitudes and conceptions of an agent. Therefore, a particular conception of life such as that of 'life as a toolbox' might be a target for a virtue ethics enquiry. Synthetic biologists have indeed been accused of hubris or of missing respect for life. Some of the quotations cited in this essay may support such an impression. If it can be shown that the conception of life as a toolbox necessarily leads to such objectionable attitudes one could argue on virtue ethical grounds that this conception of life is morally objectionable.

Technology Critique

The technological development of the past century has triggered ethical concerns about the role of technology in our society. For this position, the rising importance of technology has caused society to see nature increasingly as a mere source for technical manipulation (Heidegger 1977; Jonas 1985). The conception of life as a toolbox could be understood as the culmination of treating nature as a mere source and thus of an objectionable tendency.

This brief outline of ethical arguments that could be brought forward against the conception of life as a toolbox indicates that this conception might trigger at least three types of ethical concerns 1. about the treatment of living organisms resulting from such a conception of life, 2. about the self-image of humans or 3. about the roles of nature and technology and their relation in our society.

Summary and Conclusion

This essay enquires how synthetic biologists understand and conceive of life, what they associate with life and how they deal with the fact that their products are alive. In short, it addressed the conception of life in synthetic biology. The essay starts from a biological understanding of life based on seven characteristic features of living organisms: 1. *constant transformation*, 2. *autopoiesis*, 3. *metabolism*, 4. *homeostasis* 5. *genetic programme* 6. *evolution*, and 7. *responsiveness to the environment*. I have followed three different approaches in order to examine the conception of life in synthetic biology: First, I discussed what synthetic biologists have in mind when they speak of new life forms, then, I showed that synthetic biologists want to contribute to the general understanding of life and third, I addressed different notions about the modifications of life that could be introduced by a rational design. These three observations lead to the conclusions that for synthetic biologists, life is of interest as the feature of living organisms that humans want to understand better. But more importantly, life, based on the different characteristic features is an interesting source for the production of novel life forms or secondary products created by these life forms. Finally, life based on the different characteristic features can be designed and modified towards more efficient and useful life forms. The characteristic features of living organisms are thus understood as instruments as well as products of synthetic biology.[14] I have depicted this dual role of the characteristic features of living organisms by the metaphor of 'life as a tool box'. The tools in a toolbox are on the one hand produced according to a rational design but on the other hand they also serve as instruments of production. The essay closes by indicating that this understanding of life might trigger ethical concerns or conflicts with ethical values.

In what respect is this conception of life in synthetic biology different from that in traditional forms of biology or biotechnology? Biologists further their understanding of life by analysing the natural structures, processes, mechanisms, behaviour etc. of living organisms. Synthetic biologists want to acquire new knowledge about life by design and production rather than by investigation. Moreover, synthetic biologists are driven by application-oriented aims. They want not only to *produce* in order to learn about life but also more importantly because they hope that their products might be useful, for instance for medical applications, bioremediation or biofuel production. The approach to life in synthetic biology thus goes beyond contemplation and exploration into modification, design and application. The comparison with tools indicates that this conception of life focuses on production. In short, whereas for a biologist the different features of living organisms are comparable to markers for life, for the synthetic biologists they are tools for production.

Such an application-oriented understanding of life has already been initiated long time ago by breeding and earlier forms of biotechnology. However, the interdisciplinary character of synthetic biology has introduced new methods and techniques

[14] A related dual role of life as producer and as product has been highlighted by the autopoiesis theory but without reference to human involvement or purposes.

such as DNA synthesis or chemical methods that result in novel and deeper changes in living organisms as well as novel approaches, strategies and procedures. Such strategies include the introduction of standardisation, systematization and hierarchical organisation into biotechnology. Bioengineers such as David Baker et al. claim in a scientific American article with the title "Engineering Life: Building a FAB for Biology" that what has been known as 'genetic engineering' to date, has "*little in common with engineering*". They explain why genetic engineering is not a real engineering discipline: "*One reason is that the tools available for building with biological 'parts' have yet to reach a level of standardization and utility equal to that in other engineering fields. Another has to do with methods and mind-sets in biology […].*" (Baker et al. 2006) Bioengineers expect synthetic biology to turn biotechnology into a real engineering discipline that justifies the utilisation of the term 'engineering'. Thereby, the mind-sets in biology and biotechnology will be replaced by a more engineer-like way of thinking about life. To what extent the aims of synthetic biologists will be implementable is not clear, but in any case the endeavours towards these goals are based on the conception of life as a toolbox. I do not argue that all synthetic biologists consciously propagate this conception of life, but rather that it underlies the notion of synthetic biology and is communicated by its programme. The conception of life in synthetic biology has developed from the conceptions of life in biology and biotechnology and is still related to them. However, by the introduction of new scientific disciplines, methods, strategies and mind-sets and a new connection between biotechnology and biology the conception of life as a toolbox in synthetic biology adds a new facet to the multifarious concept 'life'.

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