Life, Intelligence, and the Selection of Universes

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> *Many worlds might have been botched and bungled, throughout an eternity, 'ere this system was struck out. Much labour lost: Many fruitless trials made: And a slow, but continued improvement carried out during infinite ages in the art of world-making.*
>
> —David Hume (1779)

The far future of our universe and its beginning raise deep and difficult questions: How will it evolve and perhaps end, and why did the big bang occur in the first place? Furthermore, the possibility of life and intelligence is closely connected to these questions: Their final fate, if unchallenged, appears deadly dark, and their origin and continuation depend on specific boundary conditions as well as the laws and constants of nature, which seem to be special or extremely improbable.

The universe continually evolves and develops as life on Earth and human cultures do. The causes of these self-organized processes are different but depend on each other at least in one direction; and they also have some similarities, for example, the increase of complexity (see Chaisson 2001, 2011). Such an "evo devo" perspective (evolution and development) can offer new insights not only regarding underlying mechanisms of those processes but also in respect of the far future of the universe and intelligent beings – and perhaps even the nature of nature (see, e. g., Smart 2008 and this volume). This might be inevitable if there are giant feedback loops from technological cultures to galactic development at some point. Because if life and intelligence, including postbiological descendants (Dick 2003, 2008, 2009; Smart 2012; Sandberg et al. 2016; Vaas 2017a, b, 2018a), resist to be ultimately doomed on their planetary surfaces, radical new options have to be envisaged. Changing the future of the universe at large scales is an extreme possibility – if it is a possibility at all. But it is also a fascinating topic to speculate about, for it might additionally reveal something about the past and the fundamental properties of the universe as well as the boundary conditions of life.

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1 Is Our Universe Fine-Tuned?

Life as we know it depends crucially on the laws and constants of nature as well as the boundary conditions (e.g., Barrow and Tipler 1986; Leslie 1989; Vaas 2004a; Carr 2007; Barrow et al. 2008; Barnes 2012). Nevertheless, it is difficult to judge how fine-tuned it really is, both because it is unclear how modifications of many values together might compensate each other (see Aguirre 2001; Harnik et al. 2006; Jaffe et al. 2009; Stenger 2011; Fedrowa and Griest 2014 for interesting examples) and whether laws, constants, and initial conditions really could have been otherwise to begin with. It is also unclear how specific and improbable those values need to be for the development of information-processing structures – and, hence, intelligent observers. At least for life on Earth, as we know it, specific values of physical and cosmological parameters are necessary – this is an *empirical fact*, and it is not trivial but surprising in its far-reaching depth (and it was therefore also a matter of scientific discovery). If we accept, for the sake of argument, that at least some values are fine-tuned, we must ask how this can be explained.

Sometimes, fine-tuning is conflated with the anthropic principle (AP). This is confusing and misleading, because there are many AP versions – or, indeed, principles – and some are meant as explanations, some are as implications, some are mere consistency conditions, some are metaphysical postulates, and some are almost independent of fine-tuning issues (Barrow and Tipler 1986; Vaas 2004a). Thus, Nick Bostrom's lamentation (2002, p. 6) is justified: "A total of over thirty anthropic principles have been formulated and many of them have been defined several times over – in nonequivalent ways – by different authors, and sometimes even by the same authors on different occasions. Not surprisingly, the result has been some pretty wild confusion concerning what the whole thing is about."

And it is not just the issue of fine-tuning with its existential aspects, which demands explanation. Other features of physics and cosmology, which appear special or improbable, also enter the equation. One might leave the topic of anthropic reasoning aside altogether and can still ask, why the laws and constants of nature (as well as the boundary conditions) are the way they are. Therefore most of the explanatory possibilities and problems (summarized in Table 1) still apply. These are meaningful questions. Whether they can be partly answered in practice or in principle is an open issue.

It was argued (see, e.g., Callender 2004; Manson 2000; McGrew et al. 2001; Mosterín 2005) that searching for such explanation is either a fruitless waste of cognitive efforts and time or even illegitimate as long as the explanandum is not well-defined or because extravagant proposals belong to metaphysics, not serious science. Furthermore, it seems even inevitably that at some point, issues get too complex and difficult to be answered or understood (even if a supercomputer or an oracle would reveal the truth); perhaps we can never overcome some kinds of cognitive closure, which Colin McGinn (1989, p. 350) defined as follows: "A type of mind M is cognitively closed with respect to a property P (or a theory T), if and only if the concept-forming procedures at M's disposal cannot extend to a

Table 1 Digging deeper: Laws, constants, and boundary conditions are the basic constituents of cosmology and physics from a formal point of view (besides spacetime, energy, matter, fields, and forces or more fundamental entities like strings or spin-networks and their properties with regard to content). An ambitious goal and historically at least a successful heuristic attitude are reduction, derivation, and unification to achieve more fundamental, far-reaching, and simple descriptions and explanations. While uniqueness is much more economical and predictive, multiple realizations – presumably within a multiverse – have recently been proposed as an opposing (but not mutually exclusive) alternative. This table (adapted from Vaas 2015, p. 72) provides a summary of different approaches, possibilities, and problems; it is neither complete nor the only conceivable system

	Fundamental laws (L) of nature	Fundamental constants (C)	Boundary conditions (BC)
Uniqueness? (and just one universe?)	(1) *Irreducible* and disconnected? (2) Or *derived* from or unified within or reducible to one fundamental theory (“Theory of Everything,” TOE)? “Logically isolated”? Or even logically sufficient (self-consistent)? (bootstrap principle) Ultimately (logically?) deducible? (thus without empirical content if analytically true? Natural science as pure mathematics?) (3) Or *nonexistent* because emerging via self-organization from an underlying chaos (“law without law” approach)	(1) *Irreducibly* many? (2) Or *only a few or just one* (e.g., string length)? With a unique value? (just random or determined by L?) With (infinitely?) many possible different values? (according to a probability distribution determined by L?) (3) Or *ultimately none*? Because C is just conversion factors (e.g., in a TOE) And/or better understandable as initial conditions (with many different realizations in a multiverse?)	(1) As *initial conditions*? Irreducible? Not accessible? (due to inflation, mixmaster universe, BKL chaos, “cosmic forgetfulness,” decoherence, etc.) Nonexistent (in eternal universe models)? Explanatorily irrelevant? (because replaced by present BC or convergent due to an attractor?) (2) Or as *present conditions*? Sufficient? Or the only useful ones? (e.g., as loop quantum cosmology constraints or according to the top down approach in Euclidean quantum gravity) Or as (additional?) final conditions? (e.g., constraints in some quantum cosmology models) (3) Or *nonexistent* because determined by or interpreted as L? (e.g., the no-boundary proposal)

(continued)

Table 1 (continued)

	Fundamental laws (L) of nature	Fundamental constants (C)	Boundary conditions (BC)
Multiverse?	(1) *Many realizations* As BC if not reducible Separated in principle or with a common origin (cause)? Restricted by or derived from a TOE, or truly random/irreducible? (2) Or with *every* (logically? metaphysically?) *possible realization*? (mathematical democracy, ultimate principle of plentitude) (3) TOE as a "*multiverse generator*"?	(1) *Many realizations* Truly random Restricted by L or BC? (2) Or *every possible combination* of values? (equally or randomly distributed?) (3) Or with some *absolute frequency* according to a probability distribution (determined by L, e.g., string statistics and/or within a framework like cosmological natural selection?) (4) Or just *observational bias*/selection (weak anthropic principle) from a random set?	(1) *Many realizations* Restricted variance due to an attractor (determined by L)? Or truly random (2) Or *every possible combination*? (equally or randomly distributed?) (3) Or with some *absolute frequency* according to a probability distribution (determined by L and/or within a framework like cosmological natural selection)? (4) Or just *observational bias*/selection (weak anthropic principle) from a random set?
Coevolution?	Cosmic endosymbiosis? Spacetime engineering via closed time-like curves? Participatory anthropic principle?		
Design?	Transcendent realization? (nonphysical causation) Random creation or cosmological artificial selection by cosmic engineers? Universal simulation/emulation? (or just a subjective illusion?)		
Randomness?	*Ultimately existing* (even if there is only one self-consistent TOE) Gödel–Turing–Chaitin theorems	*Not necessarily* (if determined by L or reduced to BC)	*Not necessarily* (if determined by L)

grasp of P (or an understanding of T). Conceiving minds come in different kinds, equipped with varying powers and limitations, biases and blindspots, so that properties (or theories) may be accessible to some minds but not to others."

But without seeking we can also never identify the boundaries of (our) knowledge. Suspension of judgment and explanatory nihilism is therefore a personal and often also a conventional, sociological decision, but not an objective demand or a fixed red line. Not to give up too early, but to try better, to explore even suspicious alternatives or to follow bold speculations in a confusing terrain nevertheless led sometimes to surprising progress, as history teaches. Although ultimately inexplicable contingencies will block our ardent longing for a deeper understanding (Vaas 1993) and final, self-sustaining as well as irrefutable explanations and statements are impossible (Vaas 2006a), we still can walk along the shores of the proverbial oceans of truth and knowledge, not knowing where this leads to and how it ends (Vaas 2014a).

In principle, there are many options for answering these foundational questions regarding physics and cosmology and beyond (Table 1). Fine-tuning might (1) just be an *illusion* if life could adapt to very different conditions or if modifications of many values of the constants would compensate each other; or (2) it might be a result of (incomprehensible, irreducible) *chance*, thus inexplicable; or (3) it might be *nonexistent* because nature could not have been otherwise, and with a *fundamental theory*, we would perhaps be able to prove this; or (4) it might be a product of *selection*: either *observational selection* within a vast multiverse of (infinitely?) many different realizations of those values (*weak anthropic principle*), or a kind of *cosmological natural selection* making the measured values (compared to possible other ones) quite likely within a multiverse of many different values, or even a *teleological or intentional selection*; or (5) it might be a coevolutionary development depending on a more or less goal-directed participatory contribution of life and intelligence. (There are further and even more bizarre options beyond naturalism, such as solipsism, but they will be neglected here.)

Even worse, these alternatives are not mutually exclusive – for example, it is logically possible that there is a multiverse, created according to a fundamental theory by a cosmic designer who is not self-sustaining, but ultimately contingent, i.e., an instance of chance. This might please different proponents at the same time, but it is against rational economy and explanatory parsimony. To quote Nicholas Rescher (2000, p. 8): "Never employ extraordinary means to achieve purposes you can realize by ordinary ones." Each of the proposals is strongest as sufficient and independent solution and was developed as such. However, one should not ignore combinations, especially if they are enforcing each other (such as string theory and cosmic inflation scenarios with a multiverse, cf. Clifton et al. 2007, Linde 2006, 2017).

To summarize, the reasoning goes like this:

Premise (1): There is a world w with some specific properties p.
Premise (2): X explains p or w.
Premise (3): There is X.
Conclusion: p or w is explained by X.

Here X stands for irreducible chance, for a fundamental or at least deeper theory, for a multiverse, for observational selection (weak anthropic principle), for cosmological natural selection, for cosmological artificial selection (cosmic engineers or simulation), for a kind of teleological anthropic principle (i.e., an impersonal teleological force or an intentional transcendent designer, e.g., god), or for a combination of more than one of these (e.g., observational and cosmological natural selection require the multiverse). The task for physics and cosmology is thus to find out whether those three premises are true and what p and X are.

From both a scientific and philosophical perspective, the fundamental theory approach and the multiverse scenario are most plausible and heuristically promising (Vaas 2004a, b, 2014b, 2017c).

2 Theoretical Explanation Instead of Fine-Tuning

It is a very controversial issue whether and how far reductionism works in physics – and beyond. Higher-order levels of descriptions are undoubtedly necessary for practical purposes but might still be (approximately and ontologically) reducible to lower levels (depending on certain constraints, of course, i.e., boundary conditions). Putting such issues and the ambiguous meaning of “reduction” (Vaas 1995a; van Riel and Van Gulick 2018) aside, one might argue roughly like this: The bedrock of reality consists of matter–energy, interactions, and spacetime (or even more fundamental “building blocks” such as loops or strings), the properties, states, and dynamics of which can be described by what it is called *laws and constants of nature* (physical as well as cosmological parameters) and a set of *initial or boundary conditions*. These descriptions, embedded and joined in a theory, should in principle suffice to yield explanations.

Thus, the usual scheme of explanations in physics is roughly like this: Given some boundary conditions and laws (including constants) or a theory (which connects or unifies different laws), i.e., the *explanans*, some facts or events, i.e., the *explanandum*, can be explained (*retrodiction*) or forecasted (*prediction*), and thereby the laws or theory can be tested. Different kinds of scientific explanation (e.g., Hempel 1965; Pitt 1988; Salmon 1998; Woodward 2003/2009; Lipton 2004; Mayes 2005) fall within this scheme, especially the deductive-nomological explanation (covering law model) with deterministic laws, the inductive-statistical explanation with probabilistic laws (but with any probability?), and the causal explanation focusing on cause–effect relations (which might be either deterministic or probabilistic).

This scheme works pretty well. However, one can still ask: Why these laws (or theory, respectively), why those constants, and why some particular boundary conditions? If our universe is not eternal – or at least if its laws and constants are not – these questions are related to another, namely, what is the explanation for the big bang?

But these questions differ from the usual ones concerning physical explanations, because they already presuppose or contain what should be explained. Take the big bang, for instance, i.e., the hot and dense very early universe. It is described by observations (e.g., the expansion of space, the cosmic background radiation and its properties, the ratios of light elements, etc.) and laws or theories (especially general relativity, thermodynamics, high-energy physics). But neither the big bang, nor those laws and theories, are explained (retrodicted) by those observations. The observations are explained by big bang theory, not vice versa. So how to explain the big bang, i.e., how did the hot and dense state of the very early universe come into existence? Here, new theories (or constraints of the current theories) and data are required. Some even argue that a new scheme of explanation is needed – perhaps an anthropic, functional, or even teleological one? This would be one of the largest paradigm changes since the advent of classical physics.

It is therefore wise to push the ordinary explanation scheme of physics to its limits and see how far one might really get. Thus, the explanandum now is the big bang with its (causal) connections to the present/observable universe. And the question is which explanans might suffice: which fundamental laws (e.g., of M-theory, supersymmetric grand unified quantum field theories, general relativity, etc.), fundamental physical constants (e.g., c, ħ, G), and initial conditions (e.g., dimensionality, metric, values of the fundamental fields, fluctuations etc.)?

Furthermore, one can ask whether there is a way to simplify the "triangle" of laws, constants (or parameters), and boundary conditions, i.e., to reduce one of its "corners" – or even two – to another one (Table 1). This would be a huge breakthrough in physics. Different possibilities are under consideration, but as yet, they are more or less pure speculation:

Constants might be reduced to boundary conditions: For instance, a huge "landscape" of solutions in string theory could exist, depending on different compactifications of tiny extra dimensions, etc. (Susskind 2005); if all these mathematical solutions are (or could be) physically realized, e.g., as bubble universes in the exponentially growing false vacuum of eternal inflation, then those boundary conditions, set by the phase transition to a specific "true" vacuum of an originating bubble universe, might determine what appears as constants of nature in such a universe (Linde 2005, 2008; Aguirre 2007; for an estimate of the gigantic number of different universes in the multiverse, see Linde and Vanchurin 2010). Another, not mutually exclusive scenario is cosmological natural selection (see below).

Laws might also be reduced to boundary conditions: Cosmological natural selection is an example here again, at least for some laws. And if no law and constant describing our universe is fundamental, but all are ultimately random, they can also be seen as boundary conditions in a wider sense. Thus, a specific set of laws might just be a set of boundary conditions with respect to a specific (kind of) universe within a multiverse. However, this does not necessarily imply a "law without law" approach (Wheeler 1980, 1983) in the strict sense – i.e., that the only law is that there are no (fundamental) laws, but pure randomness – because there might be a fundamental (although contingent) law nevertheless, which rules the multiverse-generating processes.

On the other hand, *boundary conditions might be reduced to laws:* A famous example is the no-boundary proposal in quantum cosmology as the quantum state of the universe (Hartle and Hawking 1983; Vaas 2018b).

Up to now, this discussion was quite abstract, surveying a range of possibilities. But there is something more to say which might add some flesh (albeit not yet very nutritious) to the backbone of particle physics and cosmology. Their standard models contain at least 31 free parameters which have to be measured and cannot be explained yet (Tegmark et al. 2006). Perhaps more advanced models or theories will reduce the number of these parameters significantly. But there is no guarantee for this. More fundamental approaches like supersymmetry might even increase the number, and perhaps further theories are needed with their own constants. However, string theory deigns to provide only very few, perhaps only two (Duff et al. 2002): the string length and the speed of light (*pacem* critics who claim that string theory rather dangles on a string). It was also argued that the number of dimensional constants like the gravitational constant G, the speed of light c, or the reduced Planck constant $\hbar = h/2\pi$ (with units $m^3\ kg^{-1}\ s^{-2}$, $m\ s^{-1}$, and $m^2\ kg\ s^{-1}$, respectively) could be dropped altogether (normalized to 1). They depend on conventions, i.e., our unit system, and are dimensional again in other unit systems – and such dimensions are necessary for making measurements. Dimensionless constants, however, are pure numbers and independent of any unit system. They are ratios between physical quantities (e.g., the electron–proton mass ratio $m_e/m_{pr} \approx 1/1836.15$) and cannot be skipped.

Often in calculations, the values of fundamental constants are normalized to 1 (e.g., $G = c = \hbar = 1$). But this is only a simplification. To make measurements, the units are still relevant. However, one can go a step further and define “natural” units independent of human standards, i.e., as dimensionless constants. Indeed, h, c, and G can be seen as mere conversion factors. c transforms energy into mass ($E = mc^2$), h energy into frequency ($E = h\nu$), and G mass into length, namely into the Schwarzschild radius R_s, the radius of a black hole ($R_s = 2GM/c^2$). Taking another important quantum property into account, the Compton wavelength ($\lambda_c = h/mc$), the following is possible: a mini black hole with the Compton wavelength as its Schwarzschild radius can act as a natural measuring rod and thermometer as well as clock and weighing machine (Duff et al. 2002). Any extraterrestrial civilization could understand it. But doing without any arbitrary human scales and definitions, “true” constants must be expressed with pure numbers, i.e., independent of dimensional quantities like velocity, mass, and length or reference systems like black holes. This is not possible with Planck units alone. To get pure numbers, one has to multiply them with another dimensional constant, e.g., the proton mass m_{pr}. For example, one gets $m_{pr}{}^2G/\hbar c = 10^{-38}$. Every physicist in our universe could understand, measure, and use such a value, independent of their yard stick, and discuss it with any other habitant in any other galaxy. But of course the question remains why this value is 10^{-38} and not something else.

Future theories of physics might reveal the relations between fundamental constants in a similar way as James Clerk Maxwell did by unifying electric and magnetic forces: he showed that three until then independent constants –

the velocity of light c, the electric constant ε_o (vacuum permittivity), and the magnetic constant μ_o (vacuum permeability) – are connected with each other: $c = (\mu_o \times \varepsilon_o)^{-0.5}$. Indeed some candidates for a grand unified theory of the strong, weak, and electromagnetic interaction suggest that most of the parameters in the standard model of particle physics are mathematically fixed, except for three: a coupling constant (the electromagnetic fine-structure constant) and two particle masses (namely that of down and up quarks) (Hogan 2000). A promise of string theory is even to get rid of any free parameter – if so, all constants could be calculated from first principles (Kane et al. 2002). However, this is still mainly wishful thinking at the moment. But it is a direction very worth following and, from a theoretical and historical point of view, perhaps the most promising and powerful.

So even without an ultimate explanation, *fine-tuning might be explained away within a (more) fundamental theory*. Most of the values of the physical constants should be derived from it, for example. This would turn the amazement about the anthropic coincidences into insight – like the surprise of a student about the relationship $e^{i\pi} = -1$ between the numbers e, i, and π in mathematics is replaced by understanding once he comprehends the proof. Perhaps the fact that the mass of the proton is 1836 times the mass of the electron could be similarly explained. If so, this number would be part of the rigid formal structure of a physical law which cannot be modified without destroying the theory behind it. An example for such a number is the ratio of any circle's circumference to its diameter. It is the same for all circles in Euclidean space: the circular constant π.

But even if all dimensionless constants of nature could be reduced to only one, a pure number in a Theory of Everything, its value would still be arbitrary, i.e., unexplained. No doubt, such a universal reduction would be an enormous success. However, the basic questions would remain: Why this constant, why this value? If infinitely many values were possible, then even the multitude of possibilities would stay unrestricted. So, again, why should such a universal constant have the value of, say, 42 and not any other?

If there were just one constant (or even many of them) whose value can be *derived* from first principles, i.e., from the ultimate theory or a law within this theory, then it would be completely explained or reduced at last. Then there would be no mystery of fine-tuning anymore, because there never was a fine-tuning of the constants in the first place. And then an appreciable amount of contingency would be expelled.

But what would such a spectacular success really mean? First, it could simply shift the problem, i.e., transfer the unexplained contingency either to the laws themselves or to the boundary conditions or to both. This would not be a Pyrrhic victory, but not a big deal either. Second, one might interpret it as an analytic solution. Then the values of the constants would represent no empirical information; they would not be a property of the physical world, but simply a mathematical result, a property of the structure of the theory. This, however, still could and should have empirical content, although not encoded in the constants. Otherwise fundamental physics as an empirical science would come to an end. But an exclusively mathematical universe, or at least an entirely complete formal description of everything there is, derivable from and contained within an all-embracing logical system without any free parameter or contingent part, might seem either incredible (and runs into severe logical problems due to Kurt Gödel's incompleteness theorems, see Chaitin 1987, 1992, 2001 in reference to irreducible randomness and algorithmic information theory) or as the ultimate promise of the widest and deepest conceivable explanation. Empirical research, then, would only be a temporary expedient like Ludwig Wittgenstein's (1922, 6.54) famous ladder: The physicist, after he has used empirical data as elucidatory steps, would proceed beyond them. "He must so to speak throw away the ladder, after he has climbed up on it."

3 Cosmic Coevolution as Fine-Tuning

A process with two manifestations within a special domain of space, time, and energy or, alternatively, correlated processes involving strong and repeated interaction can led to the coevolutionary emergence of complex features and entities. A classic example is the endosymbiotic theory of the origin of eukaryotic cells in evolutionary biology (Sagan 1967; Zimorski et al. 2014). Putting this to an extreme one can ask whether nature and its properties, especially the fine-tunings, are the result of a *coevolution of the universe and observers* (Ćirković and Dimitrijević 2018). This is speculative metaphysics, going back to ancient stoicism. Modern examples are Pierre Teilhard de Chardin's (1955) Omega Point theory with its claimed co-presence of the Omega Point in all previous moments of the history of the universe and Frank Tipler's (1994) refurbished version of it. Another example is John Wheeler's (1975, 1977) participatory anthropic principle; it postulates a feedback loop which links physical reality and observers, relying on a subjectivist interpretation of quantum mechanics, where the collapse of the wave function occurs only through interaction with an observer. Such ideas have huge problems (for criticism see Vaas 2001a, 2004a) and go beyond naturalism, but other approaches might be more promising, for instance, top-down causation (e.g., Okasha 2012; Ellis 2015).

Coevolution sounds like putting the cart before the horse – and this is arguably the case indeed (but such a proverbial action was actually tried in the late nineteenth and early twentieth centuries, especially in France, see Windsor 1907 for this historical point of view). However, coevolution as such is an important process – and cosmological natural or artificial selection can be interpreted as specific instantiations of it (see below). Therefore it is worth exploring such a framework to see whether and how it could be possible for life to fine-tune or adapt its own preconditions via an interaction with its cosmic environment (Ćirković and Dimitrijević 2018).

4 Natural Selection Instead of Fine-Tuning

What appears fine-tuned might not be – either because it is a unique, derivable consequence of an underlying lawful structure, and hence determined, or because it is the probable outcome of a stochastic process. An especially attractive possibility, also from an explanatory perspective, is a kind of Darwinian evolution of the values of fundamental constants (and perhaps even laws and boundary conditions). As in biology, i.e., evolutionary theory, ostensible features of design would be revealed as results of a nonintentional, self-organized process based on mutation, selection, and differential reproduction. Darwinian evolution is a well-established, indeed paradigmatic case of such a "blind" self-organization leading to astonishingly complex structures (Dennett 1995; Kanitscheider 2009; Vaas 2009a; Vollmer 2016). It is therefore a reasonable, although bold speculation to blow up a Darwinian kind of explanation to a cosmological scale within a multiverse framework.

In contrast to observational selection or bias according to the weak anthropic principle, which works in any multiverse scenario, but is not predictive, an observer-independent selection mechanism must generate unequal reproduction rates of universes, a peaked probability distribution, or another kind of differential frequency. For example, as Andrei Linde (1987) first pointed out, the constants of nature might vary from one inflationary domain to another, generating different rates of exponential expansion and bubble universe formation.

Up to now the best elaborated model of *cosmological natural selection* (CNS) is Lee Smolin's scenario (1992, 1997, 2006). Actually he started the whole approach and coined the term CNS. In contrast to observational selection, Smolin's CNS scenario is predictive and, thus, directly testable and falsifiable – at least under certain assumptions. (Note that CNS implies observational selection, but not vice versa.)

The hypothesis of CNS assumes, like anthropic observational selection, the existence of a multiverse or of a landscape of possible low-energy parameters. Furthermore, CNS assumes that black hole interiors bounce and evolve into new universes; that the values of the fundamental parameters can change thereby in small and random ways; that, therefore, different universes have different reproduction rates – universes with more black holes create more offspring universes; and, hence, that it is very probable after sufficient time that a universe chosen at random from a given collection of physically possible universes has parameters that are near a maximum of black hole production. If our universe is a typical member of that collection, then its fundamental parameters must be close to one of the maxima of the black hole production rates. Hence, our universe is selected for maximizing its number of black holes, and it is a descendant of universes which were already selected for this. Therefore, the fundamental parameters have the values we observe because this set of parameters leads to a (local) maximum of descendant universes, making the production of black holes much more likely than most alternatives. Thus, there is no need to invoke the weak (or even strong) anthropic principle – the existence of life is not used as part of the explanation of the parameter values. Just the reverse: Life's preconditions can be explained by CNS because the existence of stars and, as an offshoot, carbon chemistry, comes along with a high black hole formation rate. Therefore it is possible to continue physical research within a multiverse scenario without invoking the anthropic principle. In particular, this is true whether or not the ensemble of universes generated by bouncing black holes is a subensemble of a larger ensemble that might be generated by a random process such as eternal inflation. And CNS leads to a testable prediction: Most changes in the fundamental parameters would decrease the rate at which black holes are produced in our universe or leave it unchanged, but would not increase it. This prediction still holds.

So CNS is quite successful from a theoretical point of view. But there are also some crucial open issues and problems. They shall be analyzed more closely now (see Vaas 1998, 2003). If alternative explanatory frameworks could do better here, this would be a huge achievement.

First, there are *open questions regarding new universes emerging out of black holes*. Even if black holes are places of birth for universes, CNS still lacks a hereditary mechanism (Harrison 1995; Gardner 2003, p. 85). Why should descendant universes resemble their producers? It is also not clear whether the values of the physical parameters vary at all (if not, no multiverse evolution would occur in this framework), whether they really vary by *small* amounts and *randomly* as it is presumed, whether parameter sensitivity leads to (an increasing) fine-tuning instead of rendering universes sterile or at least hostile against life (cf. Stenger 2011), what happens to the universes already born if their mother black holes merge together or evaporate, whether there are further universes created if black holes merge together (and how many: one or two?), why there is only *one* offspring from a black hole and not (infinitely) many, and, if the latter is true, whether the numbers of new universes which are born from each black hole may differ according to the mass of the black hole. It was suggested that a large number of universes might be created inside each black hole and that the number of universes produced that way may grow as the mass of the black hole increases (Barrabès and Frolov 1996). If so, universes should be "selected" for *supermassive* black holes, not for sheer numbers of black holes. It is also not clear whether the different universes interact which each other. There is even the threat of a reciprocal destruction. Another restriction of Smolin's approach is that his cosmic reprocessing mechanism only leads to different values of parameters, but not to different *laws*. His hypothesis still requires the same basic structure of the laws in all the universes. But an even more radical proposal – a variation not only of constants but also of laws – is beyond the possibility of scientific investigation (at least for now). We simply do not know whether a distinction is useful between universes which are physically possible, as opposed to those that can only be imagined (which are only metaphysically or logically possible).

Second, *black hole production could be much more efficient without necessarily improving or suppressing parameter fine-tuning for life* (Rothman and Ellis 1993; Silk 1997). Because there are other mechanisms apart from core-collapse of old massive stars, there is no necessary correlation between black hole numbers and life-friendly parameter values for star numbers. For example, an enormous amount of primordial black holes, and not only microscopic ones, could have been produced within the first second of our early universe – and they might still be around as dark matter as well as gravitational-wave sources when colliding (see Carr et al. 2010; Calmet et al. 2014; García-Bellido 2017 for recent reviews). Also a larger cosmological constant (Λ) correlates with a higher black hole production rate, as Alexander Vilenkin (2006a) emphasized in the framework of CNS: In a vacuum energy dominated (de Sitter) universe, driven by Λ, which is related to the vacuum energy density ($\Lambda \sim 8\pi\rho_V$), quantum fluctuations of geometry lead occasionally to black hole formation via quantum tunneling. (In fact, our own universe will be completely vacuum dominated in a few dozen billion years.) Their semiclassical nucleation rate can be estimated and, although being extremely small, produces an infinite number of black holes, because de Sitter space is eternal to the future. Since quantum fluctuations increase with higher values of Λ, the black hole productions rate grows faster too. This is in tension with Smolin's conjecture that the values of all constants of nature are selected for maximizing black hole formation. Either Λ is an exception from that or the astronomically inferred dark energy of our universe (if real and not something else, e.g., an effect of a modification of general relativity on large scales) is not based on a true cosmological constant (but, e.g., on a scalar field which possibly decreases with time and might even get negative), such that accelerated de Sitter expansion stops before black holes can nucleate. Even then, however, other mechanisms (such as variations of the Higgs potential parameters) could also lead to a vacuum dominated expansion stage and produce infinitely many black holes, as Vilenkin (2006a) pointed out.

Third, and related to the former point, *there is no necessary connection between black holes and life*. In principle, life and CNS could be independent of each other. There are two reasons for this: On the one hand, there may be universes full of black holes where life as we know it couldn't evolve. For instance, it might be possible that there are only short-lived giant stars which collapse quickly into black holes or that there are universes dominated either by helium or by neutrons (corresponding to the neutron/proton mass difference being either zero or negative) or that there are universes without stars at all but many primordial black holes. Such universes might be very reproductive because of their giant stars or primordial black holes but are not able to produce earth-like life. On the other hand, we can conceive of a universe without black holes at all (if supernovae lead to neutron stars only) but which could be rich in earth-like life nevertheless. Thus, there is not a (logically) necessary connection between black holes and life (Rothman and Ellis 1993; Ellis 1997). Smolin's CNS hypothesis, therefore cannot necessarily explain the presumed fine-tuning of the universe for life. By the way, Smolin (1997, p. 393) also stressed that these two properties of our universe – containing life and producing a maximum number of black holes – must be taken as independent for the purpose of testing the theory. Nevertheless, there may be a contingent connection between black holes and life – via the role of carbon as the "molecule of life," because its ability to make complex molecules (to a much larger extent than any other element), and as an element accelerating star formation, because of the role that carbon monoxide plays in shielding and cooling the giant molecular clouds of gas and dust where stars are born (Smolin 1997). Thus, there may be at least a coincidental connection between the conditions for maximizing black hole formation and being hospitable for life. But we must still wonder why the laws of nature are such that this linkage occurs. (And it is not clear whether carbon monoxide really does increase the number of black holes, because hydrogen cools efficiently, too, and all the stars in the early universe were carbon-free.)

Fourth, in CNS, *life and intelligence are a kind of epiphenomenon*. If they do not contribute to black hole formation, life and intelligence are a mere by-product in Smolin's scenario, i.e., they are causally inert (regarding the evolution of the universes). Thus, in CNS our universe was not positively selected for life, even if the conditions of life would be exactly the same as the conditions for maximizing black holes. Therefore, CNS does not imply (or entail) a "meaning," function or advantage of life.

Fifth, there are *problems with predictability and testability*. According to Smolin, there are eight known variations in the values of fundamental parameters that lead to worlds with fewer black holes than our own, but there is no variation known with has clearly the opposite effect. This is already an interesting observation. Furthermore, Smolin's hypothesis has some predictive power, because there are physical effects and properties influencing black hole formation rates which are still not known (at least not precisely enough). Here, Smolin's hypothesis provides some constraints for these effects if the number of black holes is almost maximized. These predictions can in principle be tested, some even in the near future. They are related to the masses of K^- mesons (and hence the mass of the strange quark), electrons and neutron stars, the strength of the weak interaction, the density of protons and neutrons, the duration of the presumed inflationary epoch of the early universe, temperature patterns of the cosmic microwave background, the black hole formation rate dependence on the gravitational constant, etc. These predictions are testable in principle, and they are at home in the realm of current cosmology and particle physics. However, Smolin's central claim cannot be falsified. Falsifiability of a hypothesis depends on holding fixed the auxiliary assumptions needed to produce the targeted conclusion. In practice, one tries to show that the auxiliaries are themselves well confirmed or otherwise scientifically entrenched. What should be falsifiable according to Smolin is his claim that *our* universe is nearly optimal for black hole formation. However, this is not a necessary consequence of his premises. A consequence is only that *most* universes are nearly optimal. To move from this statistical conclusion to the targeted conclusion about our universe, Smolin (1997, p. 127) simply assumes that our universe is typical. This is an additional hypothesis as he admits. But this auxiliary assumption is neither confirmed nor otherwise scientifically entrenched. Thus, if changes in the values of our parameters did not lead to a lower rate of black hole formation – contrary to Smolin's prediction – we could always "save" CNS by supposing that our universe is not typical. Hence, there is (at least at the moment) no possibility to falsify Smolin's central claim that our universe is nearly optimal for black hole formation (Weinstein and Fine 1998). One could introduce other ad hoc hypotheses as well in order to keep the central idea of CNS. But this might undermine its falsifiability. For example, if there are parameters whose variation from their actual value leads to an increase of black hole formation, one could still claim that these parameters cannot be varied without also changing other parameters, leading, e.g., to large side-effects in star formation; hence, the originally varied parameters are no *independent* parameters contrary to the assumption. But note: if there is a Theory of Everything someday, which uniquely determines the values of the physical parameters, the CNS hypothesis would be falsified after all.

Sixth, Smolin's *Darwinian analogy of CNS is in some respect misleading*. Natural selection as described in biology depends on the assumption that the spread of populations (or genes) is mainly constrained by *external* factors (shortage of food, living space, mating opportunities, etc.). In comparison with that, the fitness of Smolin's universes is constrained by only one factor – the numbers of black holes – and this is an *internal* limitation. Furthermore, although Smolin's universes have different reproduction rates, they are not competing against each other (Maynard Smith and Szathmáry 1996; Vaas 1998). Although there are "successful" (productive, fecund) and "less successful" universes, there is no "overpopulation" and no selective pressure or "struggle for life," hence no natural selection in a strict biological (Darwinian) sense. Smolin's universes are isolated from each other (except maybe for their umbilical cords). Therefore, there couldn't be a quasi-biological evolution of universes. Thus, a central feature of Smolin's CNS scenario is that the values of the constants were not selected due to competition but only due to differential reproduction: Some universes have more offspring than others, but there is no rivalry about resources, space, etc. as in life's evolution according to Darwinian natural selection.

However, according to Andy Gardner and Joseph P. Conlon (2013, p. 3), "CNS acts as if according to a design objective of black-hole maximization, such that successive generations of universes will be increasingly contrived – that is, appearing designed – as if for the purpose of forming black holes"; to describe this with the Price equation of evolutionary genetics "neither mortality nor resource competition are fundamental aspects of selection." Whether this is accepted or not, Smolin's biological analogy or concept transfer of *fitness* in his cosmological context is in any case appropriate and independent of resource competition according to the usual definition in biology: "In evolutionary theory, fitness is a technical term, meaning the average number of offspring left by an individual relative to the number of offspring left by an average member of the population. This condition therefore means that individuals in the population with some characters must be more likely to reproduce (i.e., have higher fitness) than others" (Ridley 2004, p. 74).

Furthermore, one could envisage other scenarios of cosmic evolution where not only mutations of natural constants occur, leading to differential reproduction, but also competition between the universes or their origins and, hence, a Darwinian selection process. (Such descriptions are analogous to those of biological evolution, but of course do not refer to that in the strict sense; for the heuristic value and advantages of analogies, see Vidal 2010.) In biological settings, there is always a cost trade-off between seed production and something else, such as somatic complexity or environmental resources; so Smolin's seed production model is not very evo devo biology compliant and terms like "fecundity" versus "optimization" could be a more fruitful claim, with some bio-inspired models for fecundity (thanks to John Smart for pointing this out).

For instance, universes might nucleate out of accidental fluctuations within a string vacuum (Gasperini and Veneziano 2003) or within the vast landscape of string theory (Susskind 2005), inheriting certain properties. There could be a natural selection of such universes depending, for example, on their energy and matter densities (cf. Mersini-Houghton 2008): If the matter density is above a certain limit (or the cosmological constant is negative), the emerging universe would rapidly collapse and vanish; other universes would expand too fast, if their vacuum energy (cosmological constant) is too large – matter or structures like stars and, thus, life could not form in it. If the emergence of such universes would affect (suppress? increase?) the formation probabilities of others, for example, by influencing their "surrounding" parts of the string vacuum or landscape, a kind of competition could be the result.

Another example of cosmic Darwinism was recognized in the stochastic approach to quantum cosmology (García-Bellido 1995): In Brans–Dicke chaotic inflation, the quantum fluctuations of Planck mass M_P behave as mutations, such that new inflationary domains may contain values of M_P that differ slightly from their parent's. The selection mechanism establishes that the value of M_P should be such as to increase the proper volume of the inflationary domain, which will then generate more offspring. (Of course this selection mechanism only works if the values of the fundamental constants are compatible with inflation.) It is assumed here that the low-energy effective theory of string theory has the form of a scalar-tensor theory, with nontrivial couplings of the dilaton ϕ to matter. It is therefore expected that the description of stochastic inflation close to Planck scale should also include this extra scalar field. Brans–Dicke theory of gravity is the simplest scalar-tensor theory, containing a coupling constant ω. The string dilaton plays the role of the Brans–Dicke scalar field, which acts like a dynamical gravitational coupling: ${M_P}^2(\phi) = 2\pi\phi^2/\omega$. This scenario is in principle testable, by the way, because it predicts that the larger M_P is in a given inflationary domain, the smaller the amplitude of density perturbations should be. The universe evolves toward largest M_P and smallest amplitude of density perturbations compatible with inflation, which agrees well with observations. Thus our universe, with its set of values for the fundamental constants, would be the offspring of one such inflationary domain that started close to Planck scale and later evolved toward the radiation and matter dominated eras.

Besides the question whether one of the sketched scenarios turns out to be true, an important point is their common general idea, which shows already that cosmological natural selection provides a quite simple physical explanation of what seems to be mysterious fine-tuning – an explanation without any reference to intentionality or design. Analogous to Darwinian evolutionary theory in biology, the apparently sophisticated structure of the foundations of our universe might simply be the result of a *multiversal self-organization*. This is a straightforward explanation.

Whether it is true is not a philosophical question, however, but depends on empirical and theoretical data. The same holds for the other main approach discussed above: the hypothesis that the fine-tuning can be derived from a fundamental law.

Nevertheless, there are severe limits and problems, so other approaches should be welcomed. Critical competition is always good for science and heuristic developments of conceptual issues. This is also a philosophical advantage which should not be neglected. So why not work out other scenarios – can they do even better or, at least, as well?

5 Artificial Selection as Fine-Tuning

That intelligent life could play an essential role in a universal or multiversal reproduction cycle sounds outlandish and seems to be science fiction or speculative philosophy, not serious science. In fact it was firstly discussed in science fiction (such as Olaf Stapledon's *Star Maker*, 1937, David Brin's *What Continues*… *And What Fails*…, 1991, see also Gregory Benford's *Cosm* 1998); and Quentin Smith (1990) envisaged it from a concise philosophy of science perspective. One of the strongest proponents, Clément Vidal (2014, p. 194), also understands it as "a philosophical theory and not a scientific one." But the borders between science fiction, philosophy, and speculative science are somewhat fuzzy, and in the 1990s, scientists started to discuss those ideas too.

Louis Crane (1994/2010) speculated about the artificial making of universes and a "meduso-anthropic principle." Edward Harrison (1995, 1998) wrote about a "natural creation theory" and John Barrow (1998, p. 175) about "forced breeding" as well as "artificial selection." Steven Dick (2000, p. 204) envisaged a "natural God" as an "advanced intelligence," which "could have fine-tuned the physical constants." James N. Gardner (2000, 2003, 2007) argued that the universe is a product of intelligent architects acting for the "selfish biocosm" to run its own replication (and even proposed a few falsifiable predictions, cf. 2003, p. 135). Béla A. Baláz (2005) mused about a "cosmological replication cycle." John Smart (2000, 2008, 2012) discussed related issues with his "developmental singularity hypothesis" and his "transcension hypothesis"; in reference to CNS, he speaks about "cosmological natural selection with intelligence" (CSNI), whereupon artificial cosmogenesis is not necessarily implied (Smart 2008; for an up-to-date introduction, see http://evodevouniverse.com/wiki/Cosmological_natural_selection_(fecund_universes)#CNS_with_Intelligence_.28CNS-I.29). Clément Vidal (2008, 2010), also with reference to CNS, coined the term *cosmological artificial selection* (CAS) and provided a detailed review and discussion (2014, ch. 8.3). This term shall be used as an umbrella term in what follows.

Vidal (2010, 2014) also scrutinized the issues of the beginning and far future of our universe as well as their connections with life and intelligence and related them in an ambitious and speculative way. According to his proposal, the presumably fine-tuned laws and constants of nature can be interpreted as a result of CAS – as if they were chosen either physically or within an advanced computer simulation. So according to Vidal, the CAS hypothesis provides (1) an understanding of our apparently fine-tuned universe by explaining or reconstructing it with advanced simulations and as a possible result of cosmic design; (2) a fundamental role of life and intelligence in our universe and beyond, perhaps even refuting the impression that it is epiphenomenal, incidental, futile, or absurd; and (3) a scenario allowing for the really long-term or even eternal existence of life, by offering a way out of our universe if it is ultimately doomed. Put differently, the strength of CAS could be claimed to consist in a better understanding of (1) the origin, (2) the meaning, and (3) the potential far future of life. These three issues are connected, but nevertheless logically and physically independent of one another – thus, if one is wrong or inadequate, the other ones might still stand.

From an explanatory perspective, CAS is a new and very speculative hypothesis to understand the beginning and foundations of the universe. This might seem far-fetched and superfluous in comparison to other explanatory accounts such as a fundamental theory and/or the multiverse hypothesis. But CAS is neither meaningless nor a waste of time if one takes the problems of the other accounts seriously; at least CAS is worth a try from a philosophical standpoint. And it is not per se unscientific. It is important to note that a CAS scenario is fully reconcilable with physicalism or *ontological naturalism*. Cosmic engineers are not envisaged to be something "above" or "beyond" nature – either our universe or the multiverse – but they are a part and, indeed, a product of it. CAS does not require new or transcendent metaphysical entities or forces. (For introductions, definitions, discussions, and criticism of naturalism and physicalism, see, e.g., Mahner 2018; Papineau 2016; Poland 1994; Stoljar 2017; Vollmer 2017).

A potential – but of course very controversial – strength of CAS is that such models aim to explain the presumed fine-tuning of our universe easily: as the result of a goal-oriented, intentional action. This might or might not lead directly to our universe, and it might entail a certain amount of randomness. But artificial cosmogenesis seems to be at least a possibility to enhance or alter the natural selection of real universes (like a blind cosmic watchmaker intervening from outside – for even stronger claims see below). This might be done via studying and selecting simulated universes first, investigating the range of physical possibilities, or it might be done directly via making or starting new universes. Note that artificial selection in biology, on animals or plants or microorganisms, does not replace natural selection, and it does not "design" new organisms or create them from scratch; it tries only to foster some traits over others. So CAS might "just" extend this manipulation to cosmological scales. Thus an important part of CAS might consist in carefully selecting the right conditions, perhaps via extensive computer simulations prior to the replication events, and therefore the successor universes would really be the result of an intentional fine-tuning.

6 Black Holes, Life, and the Multiverse

It was argued that not black holes but intelligent beings are what universes might be selected for. If so, (1) either universes with life must have a higher reproduction rate – but why? (2) Or life must somehow be much more probable to occur than black holes – for which there is no indication yet (no single example of extraterrestrial life, let alone intelligent life is known, but the evidence for numerous stellar and supermassive black holes is overwhelming). (3) Or life-friendly universes must be preferred by a design process from an earlier universe.

Michael E. Price (2017), for example, argued that "intelligent life (as the least-entropic known entity) is more likely than black holes or anything else to be an adaptation designed by cosmological natural selection" and that "life appears more likely than black holes to be a mechanism of universe replication." He speculated that "intelligence functions ultimately (after evolving to a sufficiently sophisticated state) to create new universes that replicate the physical laws and parameters of its home universe." And: "As the most improbable known thing in the universe, designed by the strongest known antientropic process, life seems more likely than black holes – or any other known entity – to be a CNS-designed adaptation." This is not meant as an ultimate explanation of the universe – "unless we assume an infinite regression of biofriendly universes being produced by intelligent life, then we must assume that biofriendliness was at some point generated by a nonintelligent process," Price emphasized, but some properties of our universe might be indeed a product of cosmic artificial selection by intelligent inhabitants of our progenitor universe.

So black holes are essential for the current CAS models too, but in contrast to CNS, life and intelligence are not mere by-products in the cosmic reproduction cycle. On the contrary, there might be a hidden connection between the hospitality of universes for life on the one hand and black hole formation on the other. Perhaps black holes are advantageous for life, or life is advantageous for black hole formation. Therefore a CAS proponent can argue that cosmic engineers might create universes by means of black holes. There would be no self-organized evolution in this case but rather a preplanned development. Nevertheless, life could still be seen as a "tool" of the multiverse to produce more universes. But it would be no epiphenomena in this case.

Black holes might indeed be attractors for intelligence because of technological reasons: waste sinks, energy production, communication, computing, gravitational lens telescopes as cosmic learning devices, space travel, perhaps even time travel, etc. (see, e.g., Crane 1994/2010; Lloyd 2000; Inoue and Yokoo 2011; Smart 2012; Vaas 2018a, c; Vidal 2011; 2014). John Smart (2000, 2008, 2012, and this volume) extrapolated the trend toward increasingly computationally effective, dense, and energy-intensive technologies; he concluded that the ultimate technology might reach black hole density.

As with CNS, CAS also postulates that there is an evolution of the multiverse. This must be the case if not all universes are identical in respect of their physical laws and constants, and if the laws or constants of the descendants depend on those of their progenitors and also change at least partly from the former to the latter. Furthermore, if this evolution is analogous to biological development or evolution in the strict sense, explanatory transfers from biology might be useful and promising. Therefore these cosmological speculations could be inspired from and improved by evo devo universe approaches (see Smart 2008).

CAS might be realized both without a fundamental theory and by means of it. If there is a unique set of laws and constants with no alternatives, it might nevertheless allow the creation of new universes and, possibly, some variations of initial conditions. However, is CAS more convincing than multiverse scenarios that do without intentional causation? Or, to put it differently, why should a multiverse scenario not suffice?

Neglecting the possible meaning and far future of life, CAS has to be defended against two much simpler kinds of multiverse scenarios: (1) those with a random distribution of laws, boundary conditions, and values of constants and (2) those with a probability distribution of some kind.

Within the first scenario, the fine-tunings can be understood by anthropic bias or observational selection, i.e., the weak anthropic principle: We are able to live only in a specific universe whose physical properties are consistent with our existence – a prerequisite for it – and therefore we should not be surprised that we observe them. Thus according to the weak anthropic principle, the world consists of an ensemble of universes, a multiverse, with different laws and parameters of nature, and we can detect only those which are compatible with our existence or even among its necessary conditions. But this is, strictly speaking, not a physical explanation (Vaas 2004a) and might not even be testable, i.e., predictive (Smolin 2006).

Within the second scenario, the fine-tunings can be understood either via a case of cosmological natural selection or as the result of an underlying law, determining a probability distribution with a (local or global?) maximum, and the physical properties of our universe are in the vicinity of this maximum, i.e., quite probable. At the moment, we do not know of such law. We might just assume there is one. A stronger position is to adopt the principle of mediocrity (Vilenkin 1995), saying that we are typical observers in a certain sense. However, this principle might not be applicable here; or our universe is special, i.e., not at or near the maximum of the probability distribution. Then we have to find a different explanation, or we must come back to anthropic observational selection.

Another option – compatible with more fundamental laws, perhaps even depending on them – is cosmological natural selection. It could be seen as both the nearest relative of and strongest alternative to CAS. It seems to be testable, but CAS proponents might still argue that it does not explain enough and has many problems. This is true at least for Lee Smolin’s version, because the bounce within black holes and the physical “mutations” are completely mysterious, and a “selection” mechanism is also missing.

In principle, CAS could work without the assumption and existence of a physical multiverse and the making of new universes via black holes. Some (restricted) kind of artificial cosmogenesis is also on stage if it is possible to use our universe endlessly (especially if it is infinite in space and the future), or to recycle it, or to start it all again, or to travel within it not only through space but also through time. This could even provide the chance for endless life. Regarding the far future, postbiological existence within a computer simulation might be very advantageous, but the problem of needing a capable hardware remains – and with it cosmological boundary conditions necessary for running it: especially enough available energy and the possibility of getting rid of entropy (waste heat). However, it is doubtful to achieve this infinitely long in a single universe. But perhaps it could be done with closed time-like loops (see Hoyle 1983, pp. 211 ff; Gardner 2005; Yurov et al. 2006; Vaas 2018c).

7 Creation Out of Something: Deism in the Lab?

As with the notions of the multiverse, the anthropic principle and selection, there are varieties of CAS (and CNS-I), that is different meanings and models. Vidal (2014, p. 181) distinguished and reviewed six levels of universe making and took all but (1) as instantiations of CAS (in the following summarized with a few minor modifications): (1) *blind*, without a role for intelligence, e.g., CNS; (2) *accidental*, e.g., as a by-product of black hole making for other goals such as energy production (Crane 1994/2010); (3) *intentional*, i.e., artificial universe making via black holes; (4) *cosmic breeder* with the ability to nudge the properties of the descendant universes in certain directions (*artificial selection* in a stronger sense, John Smart, personal communication, spoke about "intelligence-guided gardening"); (5) *cosmic engineer* with the ability to set precisely the physical laws and parameters, i.e., to create designer universes; and (6) *God player* with the ability to control every parameter and to create any nomological possible universe. All these levels of universe making are compatible with naturalism or physicalism! (Conceptually speaking, qualitatively different levels would be settled within other ontological frameworks such as mentalism/idealism/spiritism/solipsism, mind-matter dualism, or theism.)

Related is the question of motivation: Why would intelligent beings want to make offspring universes? This is very hard to imagine, but at least some possibilities can be envisaged from our primitive perspectives (reflecting probably just our own wishes and fears). Perhaps cosmic engineers simply want to test their physical theories and technological abilities (Harrison 1995, p. 200). Perhaps God players use other universes for entertainment against boredom (cosmic soap operas) or as cosmic competition games or for a sadistic satisfaction. Perhaps advanced civilizations would produce new universes out of altruistic motives (Gardner 2003, p. 224), perhaps to make them even more hospitable than their own universe (Harrison 1995, p. 200). Perhaps the creators want to fight their ultimate mortality, trying to send at least some of their heritage and knowledge into new universes to persist and develop (Ćirković and Bostrom 2000; Garriga et al. 2000) – or they even want to inhabit a new universe when their own one is dying

(Tough 1986, p. 497; Harrison 1995, p. 200; Lifton and Olson 2004; Vidal 2008, 2014; Vaas 2009b). In the end, CAS might be the only self-defense against cosmic doom.

From a speculative point of view, CAS might be praised for stressing that in principle *design* is – although not mandatory of course – at least possible within a cosmological and naturalistic framework. To emphasize it again: In contrast to theistic postulates of transcendent, nonphysical entities, and causation, a CAS scenario is fully reconcilable with ontological naturalism or physicalism.

But CAS is in its stronger sense – Vidal's (2014) levels (3) to (6) above – also an example of teleological selection. For this, there are other nonnaturalistic alternatives, for instance, some versions of the strong anthropic principle and even deistic or theistic creation. And in fact it was argued that a new scheme of explanation for the fine-tunings is needed – perhaps an anthropic, functional, or even teleological one? This would be one of the largest paradigm changes since the advent of classical physics. Insofar as CAS constitutes, a certain flavor of such a new kind of explanation, neither its challenge nor the reluctance against it, should be underestimated.

Also issues of terminology are delicate. Of course, the term "cosmic engineers" (Harrison 1995) is somewhat metaphorical. It indicates correctly that there must be an advanced technological activity at work. But it remains completely open what kind of supreme technician or civilization this is supposed to be. Perhaps the creators are organic or robotic individuals; perhaps it is a collective intelligence with a single (even nonpersonal?) mind; perhaps it pervades its universe completely or hides within castles made from neutron stars – most probably it radically exceeds our imagination. In some respects, those "cosmic engineers" might be seen as god-like. But nevertheless, they are not supernatural, not independent of spacetime and energy, not beyond the physical realm. They are "transcending" our universe, but not the multiverse.

Thus, CAS is compatible with and part of ontological naturalism and does not contradict the scientific attitude – in fact it pushes it to the extreme. Therefore, in the CAS scenario "creation" does *not* mean theistic creation. CAS can be seen as a kind of creation out of something – in contrast to a divine creation out of nothing, a world-making ex nihilo, a Kabbalahistic tzimtzum, a mystical emanation, or a mythical transformation of chaos into order. And artificial cosmogenesis can, in principle, be understood in physical or naturalistic terms entirely; no religious context is attached here. Vidal (2014, p. 182) prefers not to talk about "creating" but "producing" or "making" universes (following Davies 2006; Gribbin 2009); also he dislikes "design" because of religious "intelligent design" contexts. The ambiguities, on the other hand, point out that there are naturalistic alternatives to much more outlandish transcendent religious claims.

From a theological perspective, CAS might be seen as a technocratic successor of creation myths, a naïve secular belief, an exuberant scientism gone wild. This is not surprising. However, it goes astray. CAS is a (perhaps weak) scientific and philosophical hypothesis or speculation, not a substitute religion. CAS might be bold or beyond belief, depending on personal taste and sincerity, but it does neither attack the nature of science nor the science of nature. (Of course CAS proponents have to carry the burden of proof and should provide theoretical and empirical evidence, not the sceptics.) One could even think about some sort of naturalizing the divine – CAS as *deism in the lab*: If one defines deism simply as belief in a transcendent entity, absent of any doctrinal governance, who created our universe but does not interfere with it anymore via miracles, etc., the cosmic engineer(s) could be identified with such a deity, a "supreme being," "divine watchmaker," "grand architect of the universe," or "nature's god." Of course, this "god" is *not* the theistic one, it "transcends" *not* nature in general but only our universe, and "creation" is *not* a nonphysical causation. However, as classical deism claims, such an engineer god might indeed be determined using reason and observation of the natural world alone, without a need for either faith or organized religion. By the way, even deistic interventions in human affairs (or with respect to our universe as a whole after its fabrication) are not excluded in principle if the grand architect is able to interact with it, for instance, via gravitons from a five-dimensional bulk space, nonlocal quantum entanglements, or wormholes (which simple-minded beings like humans might understandably perceive or interpret as miracle or revelation). And of course a CAS-like deism would be a truncated deism, because the religious versions of deism – and there is plenty of variation here – have a very different background and goal, and they often contain much more, including moral and spiritual aspects (e.g., Waring 1967; Gay 1968; Byrne 1989; Johnson 2009).

Admittedly, all this sounds much more like science fiction or science fantasy than serious science, and it was not put forward by CAS proponents. But if one wants to adopt a theological perspective here at all, from that point of view CAS has indeed something provocative to offer: a radically physical deistic natural theology. Said with a twinkle in the eye, CAS both puts deism in the lab (of physical and philosophical reasoning) and is a result of deism in the lab (as a presumable process somewhere in the multiverse).

Sure enough, such theological contexts or connotations reinforce doubts about CAS and show what delicate issues this proposal raises. Critics might object that CAS is creationism or intelligent design in new clothes (and in certain respects it actually is, but without theological baggage or God and within a naturalistic framework); or that CAS reintroduces the teleological thinking that was painstakingly expelled in the history of physics and biology (and in certain respects it actually does); or that CAS blurs the distinction between science and theology/religion/metaphysics (which might also be the case if supernaturalism is watered down or abandoned – and surely one can always relabel the supernatural as "natural" by claiming an appropriate physical "explanation" exists). Such criticism might be exaggerated, but should be taken seriously. Therefore CAS proponents must emphasize the hypothetical character of their proposal as well as their own scientific (and even naturalistic?) stance; they must search for demarcation criteria between science and theology or metaphysics and accept them; they have to seek rigorous tests, both theoretical and empirical; they should clearly stress the distinction between CAS and ideological creationism; and they should point out that cosmic engineers are not divine beings to worship or to suppliantly submit to.

CAS is far from proven true and poses many crucial questions and problems, but as an inspiring and far-reaching hypothesis, it deserves unprejudiced discussion like any serious effort to improve the understanding of the strange world we live in.

8 Objections and Challenges

Sure enough, CAS has problems on its own (Vaas 2009b, 2012a).

First and foremost, there is the difficulty of realizing CAS: It is completely unclear whether universes can not only be simulated to some extent but also physically instantiated. A few scientific speculations are already on stage (see below), but still in their infancy.

Second, one must distinguish between intentional creation and simulation (even if it were empirically impossible to decide between them from "within"). A simulated universe does not have all the properties of a physically real universe – as a simulated river might obey hydrodynamical equations but doesn't make anything wet. Admittedly, deep epistemological problems are lurking here. And perhaps it will be possible to make the simulation so real that the missing properties are simply irrelevant; or to make it at least so useful that, for instance, conscious life within it is possible and the creators could "upload" their minds, knowledge, and experiences, surviving within their simulation if they can no longer do in their own universe. But the hardware problem remains: How can something simulate something else which is comparably complex? And if the programmer's universe is doomed, their universal computer and, hence, computed simulation sooner or later should be doomed too. So perhaps we live in (and are!) a computer simulation (Bostrom 2003). But this might have implications that could even lead to a reductio ad absurdum. As Paul Davies (2007, p. 496) emphasized, "there is no end to the hierarchy of levels in which worlds and designers can be embedded. If the Church-Turing thesis is accepted, then simulated systems are every bit as good as the original real universe at simulating their own conscious subsystems, sub-subsystems, and so on ad infinitum: gods and worlds and creators and creatures, in an infinite regress, embedded within each other. We confront something more bewildering than an infinite tower of virtual turtles: a turtle fractal of virtual observers, gods, and universes in limitlessly complex interrelationships. If *this* is the ultimate reality, there would seem to be little point in pursuing scientific inquiry at all into such matters. Indeed, to take such a view is as pointless as solipsism." The notion of a rationally ordered real world altogether would be effectively abandoned "in favor of an infinitely complex charade, where the very notion of explanation is meaningless."

Third, artificial selection includes also intended destruction, not only gardening or creation. Therefore, one can imagine advanced intelligences which are not able to produce universes but to annihilate them or transforming them for whatever reason (e.g., destroy complexity by initiating a vacuum phase transition). One could even speculate that such cosmic selectors want to be unique or not sharing cosmic resources and try to prevent other life-forms in their accessible multiverse.

Our universe might simply exist because they did neglect it by chance, forgot to pestle it, or failed to recognize its capacities early on (Jenny Wagner, personal communication). This may sound strange and awkward, but it can serve as an extreme illustration for the fact that CAS speculations might easily go astray and/or that we simply do know nothing about alleged cosmic engineers and their intentions. It can also motivate educated guesses about the ubiquity and extension of cosmic altruism (cf. Smart 2012; Vakoch 2014 for some optimistic arguments).

Fourth, there is a crucial question: If there are cosmic engineers at work, perhaps some of them having fine-tuned our universe, how did they emerge in the first place? In other words: *What or who created the creator(s)?* – To avoid an infinite explanatory regress, it seems most probable that they arose naturally in a life-friendly universe themselves. But this shifts the problem, because at least the creator's home universe should have formed without any intentional fine-tuning and CAS cannot apply here. Thus, either its origin was pure chance or the outcome of cosmological natural selection or evo devo coevolution or the result of a multiverse "generator" according to some fundamental laws, etc. Therefore we are back at the beginning, i.e., the original question regarding fine-tuning. If our universe was created according to CAS, the fine-tuning problem is just shifted to the problem of explaining an earlier fine-tuned universe where the cosmic engineers evolved. Their home universe might have been physically simpler than ours, but not too simple either, otherwise such complex creators could never have emerged. So this is a major objection against CAS.

And, connected with it, there is a further problem: One might wonder whether CAS has any convincing explanatory force at all. Because ultimately CAS tries to explain something complex (our universe) with something even more complex (cosmic engineers and engineering). But the usual explanatory scheme is just the converse: The explanans should be simpler than the explanandum (cf. Byl 1996; Barrow 1998, p. 132). Furthermore, CAS adds something qualitatively new: While multiverse (including CNS) and fundamental law approaches to the fine-tuning problem postulate some new nomological regularities, CAS postulates an intentional cause *in addition*. CAS is therefore a mixture of explanations: physical and intentional. (Intentions are not, as such, nonphysical, and actions can be conceptualized as causes – as specific causes, to be more precise (Davidson 2001) – so pacem other opinions there is no reason to abandon naturalism here, but intentional explanations are nevertheless not epistemologically reducible to physical explanations.)

These arguments are not a knockout objection (for a defense in a broader, but much more speculative context, see Vidal 2010, 2012, 2014, pp. 178 ff). But they point out some severe difficulties with CAS. At least they show that CAS – like any other design scenario – cannot be the ultimate explanation (Vaas 2006a). However, this is not what CAS proponents (should) have in mind anyway. And if it were possible for us to carry out artificial cosmogenesis by ourselves, a strong case for CAS can be made even within its explanatory restrictions. From a philosophical and practical perspective, CAS might be very important indeed.

9 Is Life Incidental?

One of the most remarkable developments in human cultural history was the recognition of our tiny place in the vast universe (or perhaps multiverse), and that we are not obviously meant to be here. The overcoming of a naïve and infantile anthropocentrism, that the universe is there for us, and, strangely connected, that an all-compassing god is there for us too (and vice versa) was one of man's great – and still not fully accomplished – achievements: an "emergence from his self-incurred immaturity" (Immanuel Kant). The Darwinian theory of evolution suggested that man and indeed life itself are not ingeniously designed, but a result of self-organizing processes, a "fruit of chance and necessity," as Jacques Monod (1970) used to cite Democritus. Astrophysics, big bang theory, and, finally, the still speculative scenarios of quantum cosmology taught the same lesson albeit on much larger scales: The emergence of intelligence was more or less an accident, not something planned in a universe that is indifferent to life's concerns, goals, and values. However, in intelligent, self-conscious beings like humans, the universe at least became partly aware of itself, poetically speaking.

But self- and I-consciousness also revealed the absurdity of life in the face of chance, futility, and misery (Vaas 1995b, 2008a). The shirking of firmly believing in transcendent creators or in an almighty, omnibenevolent god, though perhaps consolatory for some (Vaas 2009b, c, 2013), cannot surmount absurdity because misery, injustice, and death would be even more scandalous; thus antitheism is a natural reaction (Vaas 1999). This is, of course, an existential perspective. From a distant perspective, misery and catastrophes can also foster immunity, progress, and adaptation (cf. Smart 2017, ch. 11).

Anyway, it is hard for intentional, goal-oriented beings to accept the sometimes sophisticated structures of nature as the result of "blind" self-organized processes. But exactly this is the scientific approach which dispensed with the need for design assumptions or teleological explanations. The only opposing trends were some quasi-idealistic interpretations of quantum physics (including the participatory anthropic principle; Wheeler 1975, 1977) and the discussion of the so-called anthropic coincidences or fine-tuning of fundamental constants and some boundary conditions in particle physics and cosmology, sometimes taken as evidence for a cosmic design(er) or teleological force (strong or teleological anthropic principle). These issues are highly controversial from a scientific and philosophical point of view (Vaas 2004a). But if CAS were true, basic features of our universe, and even its very existence, could indeed not be explained without reference to intentionality. If cosmological artificial selection was involved, it must be part of such an explanation though it cannot be the full explanation.

Apart from explanatory issues, an attractive psychological feature of CAS might be, at least for some adherents, that it could hold life in high regard. If there is no omnibenevolent god, CAS might point toward a slender substitution after all. So, in the face of blank absurdity, CAS could be seen as a way out for some deeply frustrated would-be-believers, wanting to restore human grandeur and an ultimate meaning to everything.

But note that CAS does not necessarily mean that our universe was carefully designed with respect to every law and constant (or specific initial conditions). An engineered (ingenious) blueprint might have been realized, and such ideas are the basic of some "best of all possible worlds" beliefs. But it could also be the case that our universe was just cobbled together, perhaps with many others. Or it might even be an accident, for example, in a cosmological or particle collider experiment, i.e., an unintended by-product or collateral damage of an otherwise intended action. Although it is hard to imagine, one might even think of many different universes, originated completely naturally, with some of them, including ours, being intentionally picked – like fertilized eggs for uterus implantation in assisted reproductive technology – and activated to develop. (Of course this artificial selection could also have been a purely virtual process within a computer simulation to find out the right world-making recipe, as with iterative numerical calculations employed when there are no compact analytical solutions – after deriving a successful formula, then only the desired universe(s) would have been realized.) These different possibilities are not mutually exclusive by the way. For example, cosmic engineers might create any baby universe – and if it is capable of eternal inflation, then anything physically possible might ultimately evolve from it. Given the right laws, constants, and boundary conditions, even an infinite number of copies of their own universe (including Doppelgänger of the engineers themselves!) would emerge and any possible variation of it. Thus, as in CNS or eternal inflation scenarios, life and intelligence might be inevitable, although still accidental in some sense. So a kind of radical contingency remains. And of course one can still argue that life is absurd if anything that can happen will happen – and with any possible variation as well and infinitely often. Indeed exactly that was the point made by Friedrich Nietzsche when discussing eternal recurrence – but it is now an issue of modern cosmology too (Ellis and Brundrit 1979; Garriga and Vilenkin 2001; Tegmark 2004; Knobe et al. 2006; Vilenkin 2006b; Vaas 2001b, 2012b).

In conclusion, CAS is neither restricted to a careful and complete world design nor does it imply that every law, constant, and/or initial condition was intentionally selected. Creating life (let alone human beings!) need not be the goal of this art of world-making either. Perhaps life was just allowed for – or even an accident or mistake. If so, CAS would not prevent (our) life from being incidental. (Though at least we would have someone to blame for all the blunder.)

Even if one accepts CAS, without further knowledge, it is impossible to tell anything about the intentions of the creator(s). They might work in mysterious ways their wonders to perform. This is, of course, another problem for CAS. An intentional explanation without explaining the intention might be considered as a shortcoming. But this is not a refutation. And speculations are possible too.

For example, it was suggested that the creators – not taken as god(s) but as technologically very advanced, though nevertheless limited, cosmic engineers – are simply curious; so they might be trying hard to figure out ways of universe formation (an engineer's proverb, taken from Richard Feynman, states that one only understands something if one is able to make it). Then life might be an accident indeed.

Another possibility is that those cosmic engineers created their own universal soap opera for entertainment (perhaps even with sadistic intentions). Life would not be incidental then, but something like a zoo inhabitant or gladiator. Furthermore, our universe might soon become too boring for its spectators and therefore suddenly be deleted . . .

Much more serious is the assumption that the cosmic engineers face their own death too and the forthcoming end of their universe. Thus they might try to escape into a kind of rescue universe or at least transmit something of their knowledge lest they will not be forgotten completely. Death might be seen as an ultimately salvation, but it also marks the ultimate absurdity. To fight futility, self-conscious life gets the urge to endure and to intellectually grow endlessly. If this takes infinitely many (infinite?) universes, why not try to make them, if this is possible?

10 Is Life Ultimately Doomed?

It is an age-old question, whether the universe is infinite in time and space – or at least part of a larger system which is – and what this means for the ultimate prospects of life. In a branch of modern cosmology, sometimes called *physical eschatology*, this question can be discussed within the framework of (albeit speculative) scientific reasoning (Table 2).

The fate of the universe and intelligence depends crucially on the nature of the still mysterious *dark energy* which probably drives the accelerated expansion. Depending on dark energy's – perhaps time-dependent – equation of state, there is now a confusing number of mutually exclusive models. They are popularly called big whimper, big decay, big crunch, big brunch, big splat, big oscillation, big brake, big freeze, big rip, big trip, big hit, big hole, big resurrection, etc., and they envisage many different avenues. Most of them are dead ends for life – and this is also true for other cosmological models without dark energy. Thus, the ultimate future of our universe looks deadly dark (Ćirković 2003, 2004; Vaas 2006b).

But many self-conscious individuals want to fight absurdity and overcome death. If cosmological boundary conditions or creative minds – not necessarily god(s) – beyond it (see, e.g., Leslie 2001; 2008 for a far-reaching proposal), do not support this, mortals must try to take their fate into their own hands, prolonging their life and even searching for a “physics of immortality” (cf. Tipler 1994). Can CAS provide some help here?

11 Dark Energy Is Bad for Life

Going along with the externalization of memory and computation through the invention of writing, computers etc., a remarkable, accelerating increase of cultural complexity started on earth (and perhaps at many other places in the universe), a

Table 2 Exploring destiny: Scientific speculations concerning the very far future are bold but not unbound. One must keep some important presuppositions and open problems at the back of one's mind, however. With respect to cosmological artificial selection and artificial cosmogenesis, the possible role of intelligence influencing the fate of the universe is crucial

Presuppositions for physical eschatology and foundational queries	Comments
Ontological naturalism: Nonphysical entities do not exist (or have causal effects); no epistemological idealism or radical illusions about the universe	Scientifically unprovable, but strong philosophical arguments in favor
Ontological status of space and time?	They might be an illusion or not fundamental, but even so predictions and extrapolations are not meaningless and could be rephrased
No compact topology of space	Otherwise there are different boundary conditions
Weak determinism (at least); limited effects of chance (acausality)	There might be completely acausal events (like quantum effects), even on macroscopic scales, but no predictions are possible if a weak (moderate, average, or statistical) form of determinism doesn't hold
Relevant laws of nature are known	Quite questionable; how will new discoveries change the future and our view of it, are the established scientific methods sufficient at all, and what are the implications of a valid theory of quantum gravity?
Fundamental laws and constants of nature do not vary	But: Possibility of phase transition; perhaps there are no fundamental laws at all (but could effective regularities suffice?); signs of a time-dependent fine-structure constant ($\alpha = e^2/2hc\varepsilon_0 \approx 1/137$) already discovered?
Problems of infinity	Is actual infinity possible in nature? Is it realized? How to deal with infinities in theory (calculations, paradoxes) and research (only finite measurements possible)?
Restricted access?	Limited observations in space and time (particle horizon) and finite accuracy of measurements (especially of crucial parameters like Ω and w)
The universe as an open or closed system?	Problems for thermodynamics and conservation laws; are there interactions with other universes?
Limitations of explanations and predictions?	Even with (weak) determinism and all relevant laws and boundary conditions known, there might be strong restrictions due to nature's complexity and, perhaps, the incompleteness theorems
Role of intelligence?	Influencing destiny on cosmic scales?

tendency to do ever more work and to require ever less time, space, and energy (Fuller 1969; Chaisson 2001; Smart 2008; Vidal 2008). This is an excellent prospect for realizing CAS. However, the accelerated expansion of space leads to an universal limit on the total amount of information that can be stored and processed in the future (Krauss and Starkman 2004): This restricts the technology and computation capabilities for any civilization in principle, because there is access to only a finite volume, even after an infinite time. (On the other hand, the total amount of computational diversity at the universal scale might be increased because of galactic supercluster isolation due to the accelerated expansion of space, cf. Smart 2012.)

For a universe, dominated by a cosmological constant Λ (the simplest candidate for dark energy with the energy density ρ_Λ), which approaches asymptotically a de Sitter phase where the scale factor a increases exponentially, $a(t) = a_0 e^{Ht}$ with $H = (8\pi\rho_\Lambda/3)^{0.5}$, there is a maximum amount of energy $E_{max}(r)$ that will be received by harvesting matter out to a distance r: $E_{max}(r) = \Omega_m c^5/128GH$ where Ω_m is the dimensionless matter density, the sum of both baryonic matter (quarks and leptons) and dark matter. $E_{max}(r)$ has a maximum at $Hr/c = 1/2$, the de Sitter horizon is located at $Hr/c = 1$. The accessible energy is only 1/64th of the total energy located within the de Sitter horizon at the present time. With a flat metric ($k = 0$), a matter density $\Omega_m \approx 0.3$, and a Hubble constant $H_0 \approx 70\ kms^{-1}Mpc^{-1}$, one finds $E_{max} \approx 3.5 \times 10^{67}$ J. This is comparable to the total rest-mass energy of baryonic matter within today's horizon. Dividing $E_{max}(r)$ by $Tk_B \ln 2$, where T is the noise temperature and k_B Boltzmann's constant, a minimum energy loss yields a limit on the number of bits that can be processed or information that can be registered. It is smaller than $\pi\Omega_m c^5/64\hbar GH^2 \ln 2 = 1.35 \times 10^{120}$. (Therefore, by the way, Gordon Moore's law, which assumes that the computer power doubles every 18–24 months, cannot continue unabated for more than 600 years for any technological civilization in our observable universe.)

In contrast to a simple eternally expanding universe (big whimper scenario with $\Lambda = 0$), a universe ruled by Λ leads to an everlasting expansion with dismal prospects for life. This is due to quantum effects at the cosmic horizon (analogous to Hawking radiation at the horizon of a black hole, but in de Sitter space the horizon surrounds the observer). Because of these the universe cannot cool down to (almost) 0 K. It has a total entropy S and, hence, a final temperature, the de Sitter T_{dS}, which will be reached within a few hundred billion years (Gibbons and Hawking 1977): $S = A/4 = 3\pi/\Lambda$ and $T_{dS} = 1/2\pi l$ with $A = 4\pi l^2$ and $l = (3/\Lambda)^{0.5}$. Here, A is the area of the de Sitter horizon at late times and l the curvature radius of that closed universe. T_{dS} is approximately 10^{-29} K (corresponding to 10^{-33} eV). It means the end for any living system because then it cannot radiate away waste heat – and there is no life without an energy gradient (Krauss and Starkman 2000).

Other scenarios look also more or less disappointing. But if our universe and every living being in it would be finally doomed, there could be infinitely many other universes and/or our universe might *recycle* itself due to new inflationary phase transitions out of black holes (Smolin 2006) or out of its high-energy vacuum state, where new exponential expanding bubbles should nucleate at a constant rate, growing to new universes elsewhere with new thermalized regions (Lee and

Weinberg 1987; Garriga and Vilenkin 1998), and cut their cords, metaphorically speaking. They probably will give rise to new galaxies and civilizations. It is not possible, however, to transcend these boundaries or to send a device with the purpose to recreate a follow-up of the original civilization in the new region or to transmit at least a kind of cosmic message in a bottle. It is not possible (Garriga et al. 2000), because the device or message will almost certainly be intercepted by black holes, which nucleate at a much higher rate than inflating bubbles, namely in the order of $\sim \exp(10^{122})$.

12 Wormhole Escapism and Designer Universes

If our universe is ultimately determined to die, or if at least the sufficient conditions for any possible information processing system disappear, the only chance for life would be to leave its universe and move to another place. Therein lays the prospect for an everlasting future of civilizations, and this is a strong motivation for CAS. So if the new universes are meant as new homes for their creators, because the universe they live in will run out of free energy and life-friendly conditions, the laws and constants of those successor homes will probably be intended to remain fixed – otherwise the cosmic engineers would cease after moving in. And, as mentioned above, their relocation must happen without quantum tunneling. Because of extremely small tunneling probabilities, all mechanisms that involve quantum tunneling are probably doomed to failure. However, there are bold speculations about *traversable wormholes* leading to other universes (Visser 1996; Krasnikov 2018; Vaas 2018c). This seems to be possible at least in the framework of general relativity. Perhaps wormholes could be found in nature and modified, or they could be built from scratch. If so, life could switch to another universe, escaping the death of its home.

And if there is no life-friendly universe with the right conditions (physical constants and laws), an advanced civilization might even create a sort of replacement or rescue universe on its own. In fact, some renowned physicists have speculated about such a kind of world-making (Farhi and Guth 1987; Frolov et al. 1989; Farhi et al. 1990; Fischler et al. 1990; Linde 1992; Crane 1994/2010; Harrison 1995; Merali 2006; Ansoldi and Guendelman 2006, 2008).

At a Grand Unified Theory energy scale of 10^{14} GeV, a universe might emerge from a classical bubble which starts out with a mass of only about 10 kg. By means of quantum tunneling, the bubble mass could be arbitrarily small, but the formation probability of a new universe would be reduced very much. Of course the main problem is to concentrate enough energy in a tiny volume. It has been suggested to try a coalescence of two regular magnetic monopoles (with below critical magnetic charge), producing a supercritical one which then inflates giving rise to a baby universe, or to take just one monopole and to hurl mass onto it, using a particle accelerator or a cosmic string (Borde et al. 1999; Sakai et al. 2006). The new bubble filled with a false vacuum is an extremely warped patch of spacetime and would create its own space: It undergoes an internal exponential inflation without displacing the space outside of the bubble itself (the negative pressure inside, zero outside, and the positive surface tension prevent the bubble from expanding into its mother universe). On the contrary it disconnects from the exterior region: The wormhole, which acts like an umbilical cord between the mother and child universe, collapses. (From the perspective of the mother universe, the disconnected bubble hides inside a microscopic black hole which will not appear to grow in size but evaporates quickly, while from within the bubble, the creation event is seen as a white hole-like initial singularity. Mathematically, the bubble can be described as a de Sitter spacetime embedded in a Schwarzschild spacetime, joined by using the Israel junction conditions.) The new universe might be detectable nevertheless because of modifications to the Hawking radiation.

It remains unclear, however, whether one could pass a message to the future inhabitants of the created universe (Hsu and Zee 2006) – due to inflation they would live in a tiny corner of a single letter, so to speak. Perhaps it could be encoded within the value of a fundamental constant. It remains also unclear, whether one could even travel into the descendent universe via new wormholes. If such an interchange of universes is possible, life might continue endlessly.

While such bold speculations easily sound awkward or technocratic or as the ultimate megalomania, they at least offer an interesting change of perspective (from observation to experiment), which questions the passive point of view when dealing with cosmological problems and the limits of observations due to the restrictions imposed by the spacetime structure on the causal relations among objects. This perspectival switch is another advantage of CAS.

Like dark energy, however, wormholes violate some fundamental energy conditions. And a violation of the weak energy condition (WEC) is also necessary to create new inflating regions without quantum tunneling and to go there or send messages into it, for instance, a blueprint of the engineering civilization. The required magnitude of the negative energy density is in the order of $-\rho \geq \mathrm{H}_{\mathrm{inf}}{}^{-2}$, where $\mathrm{H}_{\mathrm{inf}}$ is the inflationary expansion rate. Because WEC violation is in conflict with quantum inequalities (Ford and Roman 1997; Borde et al. 2002; Ford et al. 2002), it should be investigated how seriously this constraint is to be taken, since it is unclear to what extent these inequalities apply to interacting fields.

13 The Case for CAS?

The hypothesis of cosmological artificial selections does not only address (1) the origin and apparent fine-tuning of our universe but also (2) the possible value and meaning of life and (3) its ultimate future. However, all these complex issues provide eminent problems for CAS. One might argue that although CAS is based on three weak points, putting them together they make the case for CAS stronger, i.e., strengthen its stability under load like a tripod. Indeed, cosmic fine-tuning, meaning, and survival are fancily linked together in the CAS scenario and form a coherent picture. But this does not make the CAS proposal true, of course. And, indeed, the three points are qualitatively distinct: Fine-tuning is about explanation, meaning about evaluation, and survival about action and construction. Therefore it is questionable whether one can really strengthen the others, although explanation might be a necessary condition for construction (or vice versa?) and (the search for) meaning a crucial motivation for explanation and action. Nevertheless, all three points and, thus, CAS remain an open issue at the moment. Related are genuine philosophical and existential questions, which may strengthen the case for CAS, but are beyond the scope of this essay (for further discussions, see Vidal 2014).

CAS is (or at least starts out as) a metaphysical speculation. And there is nothing wrong with metaphysical speculations if they are not confused with or advertised as scientific results. What's more, (some) metaphysical speculations have a heuristic value and might even boost the formation of scientific hypotheses. And philosophy is, among other things, thinking in advance. Both the challenge of escaping cosmic doomsday and searching for penultimate explanations – really ultimate explanations are excluded (Vaas 2006a) – surely need unconventional input and encouragement. But CAS is or can be seen also as a scientific speculation. Like multiverse scenarios in general, it fulfills many criteria of science (Vaas 2008b, 2010) and could even be testable – or realizable – in the future. CAS might be judged as unlikely or far-fetched, but it is worth exploring and is a serious candidate to produce adapted complexity via evo devo processes (Smart 2017, ch. 11). "Just as life's incredibly adapted complexity self-organized over many evo devo cycles, and just as everything that is complex and adaptive inside our universe is a replicating system, it is most parsimonious to assume that our universe is a replicating evo devo system as well. If it is, its evo devo intelligence will always remain a limited and incomplete aid to selection, not a" godlike "designer" (http://evodevouniverse.com/wiki/Evolutionary_development_(evo_devo,_ED)). It extends the realm of both cosmological problems and possible solutions and, thus, challenges other approaches – constructive competition is always good for science and philosophy, and criticism is a gift for further developments.

Summing up, it seems doubtful whether the hypothesis of cosmological artificial selection is correct – at least in the stronger sense as the cause of our universe: First there are simpler and more probable explanations for the fine-tuning of our universe (or for getting rid of the anthropic coincidences altogether); second psychological urges for overcoming human contingency are no argument for the truth of scientific hypotheses, and CAS is far from being an analgesic against absurdity; and third it seems unlikely that an advanced civilization within our universe can intentionally start the creation of new universes either by simulating them (because of the finite computational resources both in size and in time) or by physically producing them (because this might either be too difficult or it happens naturally much earlier and more often anyway). Certainly we don't know enough to assign a probability or likelihood of CAS's truth yet.

If CAS is possible in principle, our successors or any other much further advanced civilization within our universe might be the very first to fully realize it. If this occurs as a simulation or emulation, its contents – as complex as they might be, perhaps including even self-conscious beings – ultimately would be doomed if the simulating hardware breaks down. And within our universe, this seems to be inevitable. Thus, such simulated universes cannot endure forever. (If we ourselves would live within a computer simulation, or rather be one, the show might stop very soon . . . without any prospect for a cosmic reset.) If, on the other hand, somebody within our universe can artificially create offspring universes and even transmit the recipe for doing that – either as a message or as a physical necessity, for instance, by starting Doppelgänger universes which inevitably will repeat history – then a potentially infinite chain of successor universes might begin. Eternal life could become a reality, even if it is not necessarily an eternal *continuing* life.

Assuming that such a giant chain of being is actually possible, however, it seems nevertheless quite unlikely that our universe is the very first one to accomplish this. Furthermore, this would be a violation of the Copernican principle because our location in spacetime, in this case the multiverse, would be very special. Therefore one should conclude that, given the CAS framework was correct indeed, our universe is a result of cosmological artificial selection (or simulation) too – one link within the probably future-eternal chain. If so, the spark of life may endure endlessly indeed. And even if we or our successors were not be able to pass it on, being then a tiny dead end within a flourishing realm of evolution, we will at least have envisioned it.

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References

Aguirre, A. (2001): The Cold Big-Bang Cosmology as a Counter-example to Several Anthropic Arguments. Phys. Rev. D 64, 083508; arXiv:astro-ph/0106143

Aguirre, A. (2007): Eternal Inflation, past and future; arXiv:0712.0571

Ansoldi, S., Guendelman, E. I. (2006): Child Universes in the Laboratory; arXiv:gr-qc/0611034

Ansoldi, S., Guendelman, E. I. (2008): Universes out of almost empty space. Prog. Theor. Phys. 120, 985–993; arXiv:0706.1233

Baláz, B. A. (2005): The cosmological replication cycle, the extraterrestrial paradigm and the final anthropic principle. Diotima 33, 44–53.

Barnes, L. A. (2012): The fine-tuning of the universe for intelligent life. Publications of the Astron. Soc. of Australia 29, 529–564; arXiv:1112.4647

Barrabès, C., Frolov, V. P. (1996): How many new worlds are inside a black hole? Phys. Rev. D 53, 3215–3223; arXiv:hep-th/9511136

Barrow, J. D. (1998): Impossibility: The Limits of Science and the Science of Limits. Oxford University Press: Oxford.

Barrow, J., Tipler, F. (1986): The Anthropic Cosmological Principle. Oxford University Press: Oxford.

Barrow, J. D., et al. (eds.) (2008): Fitness of the Cosmos for Life: Biochemistry and Fine-Tuning. Cambridge University Press: Cambridge.

Borde, A., Ford, L. H., Roman, T. A. (2002): Constraints on Spatial distributions of Negative Energy. Phys. Rev. D 65, 084002; arXiv:gr-qc/0109061

Borde, A., Trodden, M., Vachaspati, T. (1999): Creation and Structure of Baby Universes in Monopole Collisions. Phys. Rev. D 59, 043513; arXiv:gr-qc/9808069

Bostrom, N. (2002): Anthropic Bias. Routledge: New York, London.

Bostrom, N. (2003): Are We Living in a Computer Simulation? Phil. Quart. 53, 243–255.

Byl, J. (1996): On the natural selection of universes. Quart. J. Royal Astron. Soc. 37, 369–371.

Byrne, P. (1989): Natural religion and the nature of religion. Routledge: London.

Callender, C. (2004): Measures, explanation and the past: should 'Special' initial conditions be explained? British J. Phil. Sci. 55, 195–217.

Calmet, X., Carr, B., Winstanley, E. (2014): Quantum Black Holes. Springer: Heidelberg.

Carr, B. (2007): The Anthropic Principle Revisited. In: Carr, B. (ed.) (2007): The Universe or Multiverse? Cambridge University Press: Cambridge, pp. 77–89.

Carr, B. J., et al. (2010): New cosmological constraints on primordial black holes. Phys. Rev. D 81, 104019; arXiv:0912.5297

Chaisson, J. (2001): Cosmic Evolution: The Rise of Complexity in Nature. Harvard University Press: Cambridge.

Chaisson, E. J. (2011): Energy rate density as a complexity metric and evolutionary driver. Complexity 16 (3), 27–40; https://www.cfa.harvard.edu/~ejchaisson/reprints/EnergyRateDensity_I_FINAL_2011.pdf

Chaitin, G. (1987): Algorithmic Information Theory. Cambridge University Press: Cambridge.

Chaitin, G. (1992): Information-theoretic Incompleteness. World Scientific: Singapore.

Chaitin, G. (2001): Exploring Randomness. Springer: London.

Ćirković, M. M., Bostrom, N. (2000): Cosmological constant and the final anthropic hypothesis. Astrophys. Space Sci. 274, 675–687.

Ćirković, M. M. (2003): Resource letter: PEs-1: physical eschatology. Am. J. Phys. 71, 122–133; arXiv:astro-ph/0211413

Ćirković, M. M. (2004): Forecast for the Next Eon: Applied Cosmology and the Long-Term Fate of Intelligent Beings. Found. Phys. 34, 239–261; arXiv:astro-ph/0211414

Ćirković, M. M., Dimitrijević, J. (2018): Putting the Cart Before the Horse: Co-evolution of the Universe and Observers as an Explanatory Hypothesis. Found. Sci. 23 (3), 427–442.

Clifton, T., Linde, A., Sivanandam, N. (2007): Islands in the landscape. JHEP 0702, 024; arXiv:hep-th/0701083

Crane, L. (1994/2010): Possible Implications of the Quantum Theory of Gravity: An Introduction to the Meduso-Anthropic Principle. Found. Sci. 15, 369–373; arXiv:hep-th/9402104

Davidson, D. (2001): Essays on Actions and Events. Oxford University Press: Oxford.

Davies, P. C. W. (2006): The Goldilocks Enigma: Why Is the Universe Just Right for Life? Allen Lane: London.

Davies, P. (2007): Universes galore: where will it all end? In: Carr, B. (ed.) (2007): The Universe or Multiverse? Cambridge University Press: Cambridge, pp. 487–505.

de Chardin, P. T.(1955): The phenomenon of man. Harper & Row: New York 2008.

Dennett, C. (1995): Darwin's Dangerous Idea. Simon & Schuster: New York.

Dick, S. J. (2000): Cosmotheology: Theological implications of the new universe. In: Dick, S. J. (ed.) (2000): Many Worlds. The New Universe, Extraterrestrial Life and the Theological Implications. Templeton Foundation Press: Philadelphia, London, pp. 191–210.

Dick, S. J. (2003): Cultural Evolution, the Postbiological Universe, and SETI. Int. J. Astrobiol. 2, 65–74; http://history.nasa.gov/SP-4802.pdf

Dick, S. J. (2008): The Postbiological Universe. Acta Astronautica 62, 499–504.

Dick, S. J. (2009): The Postbiological Universe and our Future in Space. Futures 41, 578–580.

Duff, M. J., Okun, L. B., Veneziano, G. (2002): Trialogue on the number of fundamental constants. JHEP 0203, 023; arXiv:physics/0110060

Ellis, G. F. R., Brundrit, G. B. (1979): Life in the infinite universe. Quart. J. Royal Astron. Soc. 20, 37–41.

Ellis, G. (1997): A Darwinian universe? Nature 387, 671–672.

Ellis, G. F. R. (2015): Recognising top-down causation. In: Aguirre, A., et al. (eds.) (2015): Questioning the foundations of physics. Springer: Heidelberg, pp. 17–44.

Farhi, E., Guth, A. H. (1987): An obstacle to creating a universe in the laboratory. Phys. Lett. B 183, 149–155.

Farhi, E., Guth, A. H., Guven, J. (1990): Is it possible to create a universe in the laboratory by quantum tunnelling? Nucl. Phys B 339, 417–490.

Fedrowa, J. M., Griest, K. (2014): Anti-anthropic solutions to the cosmic coincidence problem. JCAP 01, 004; arXiv:1309.0849

Fischler, W., Morgan, D., Polchinski, J. (1990): Quantum nucleation of false-vacuum bubbles. Phys. Rev. D 41, 2638–2641.

Ford, L. H., Roman, T. A. (1997): Restrictions on Negative Energy Density in Flat Spacetime. Phys. Rev. D 55, 2082–2089; arXiv:gr-qc/9607003

Ford, L. H., Helfer, A. D., Roman, T. A. (2002): Spatially Averaged Quantum Inequalities Do Not Exist in Four-Dimensional Spacetime. Phys. Rev. D 66, 124012; arXiv:gr-qc/0208045

Frolov, V. P., Markov, M. A., Mukhanov, M. A. (1989): Through a black hole into a new universe? Phys. Lett. B 216, 272–276.

Fuller, R. B. (1969): Utopia Or Oblivion: The Prospects for Humanity. Overlook Press: New York.

García-Bellido, J. (1995): Quantum Diffusion of Planck Mass and the Evolution of the Universe. In: Occhionero, F. (ed.) (1995): Birth of the Universe and Fundamental Physics. Lecture Notes in Physics 455. Springer: Berlin, pp. 115–120; arXiv:astro-ph/9407087

García-Bellido, J. (2017): Massive Primordial Black Holes as Dark Matter and their detection with Gravitational Waves. J. Phys.: Conf. Ser. 840, 012032; arXiv:1702.08275

Gardner, A., Conlon, J. P. (2013): Cosmological natural selection and the purpose of the universe. Complexity 18, 48–56.

Gardner, J. N. (2000): The selfish biocosm: Complexity as cosmology. Complexity 5 (3), 34–45.

Gardner, J. N. (2003): Biocosm: The New Scientific Theory of Evolution. Inner Ocean: Makawao.

Gardner, J. N. (2005): Coevolution of the cosmic past and future: the selfish biocosm as a closed timelike curve. Complexity 10 (5), 14–21.

Gardner, J. N. (2007): The Intelligent Universe: AI, ET, and the Emerging Mind of the Cosmos. Career Press: Franklin Lakes.

Garriga, J., Vilenkin, A. (1998): Recycling universe. Phys. Rev. D 57, 2230–2244; arXiv:astro-ph/9707292.

Garriga, J., et al. (2000): Eternal inflation, black holes, and the future of civilizations. Int. J. Theor. Phys. 39, 1887–1900; arXiv:astro-ph/9909143

Garriga, J., Vilenkin, A. (2001): Many worlds in one. Phys. Rev. D 64, 043511; arXiv:gr-qc/0102010

Gasperini, M., Veneziano, G. (2003): The Pre-Big Bang Scenario in String Cosmology. Phys. Rept. 373, 1–212; arXiv:hep-th/0207130

Gay, P. (ed.) (1968): Deism. Van Nostrand: Princeton.

Gibbons, G., Hawking, S. W. (1977): Cosmological Event Horizons, Thermodynamics, and Particle Creation. Phys. Rev. D 15, 2738–2751.

Gribbin, J. (2009): In Search of the Multiverse. Allen Lane: London.

Harnik, R., Kribs, G., Perez, G. (2006): A Universe without weak interactions. Phys. Rev. D 74, 035006; arXiv:hep-ph/0604027

Hartle, J., Hawking, S. W. (1983): The wave function of the universe. Phys. Rev. D 28, 2960–2975.

Harrison, E. R. (1995): The natural selection of universes containing intelligent life. Quart. J. Royal Astron. Soc. 36, 193–203.

Harrison, E. R. (1998): Creation and Fitness of the Universe. Astronomy & Geophysics 39 (2), 27.

Hempel, C. G. (1965): Aspects of Scientific Explanation and Other Essays in the Philosophy of Science. Free Press: New York.

Hogan, C. J. (2000): Why the Universe is Just So. Rev. Mod. Phys. 72, 1149–1161; arXiv:astro-ph/9909295

Hoyle, F. (1983): The Intelligent Universe: A New View of Creation and Evolution. Michael Joseph: London.

Hsu, S., Zee, A. (2006): Message in the Sky. Mod. Phys. Lett. A 21, 1495–1500; arXiv:physics/0510102

Hume, D. (1779): Dialogues Concerning Natural Religion. Dialogues Concerning Natural Religion and Other Writings. Cambridge University Press: Cambridge 2007.

Inoue, M., Yokoo, H. (2011): Type III Dyson Sphere of Highly Advanced Civilizations around a Super Massive Black Hole. J. Brit. Interplanetary Soc. 64, 58–62; arXiv:1112.5519

Jaffe, R. L., Jenkins, A., Kimchi, I. (2009): Quark Masses: An Environmental Impact Statement. Phys. Rev. D 79, 065014; arXiv:0809.1647

Johnson, B. (2009): Deism. Truth Seeker: Escondido.

Kane, G. L., Perry, M. J., Zytkow, A. N. (2002): The Beginning of the End of the Anthropic Principle. New Astron. 7, 45–53; arXiv:astro-ph/0001197

Kanitscheider, B. (2009): Darwins Theorie als Prototyp und Vorläufer einer Theorie der Selbstorganisation. Universitas 64 (751), 56–66.

Knobe, J., Olum, K. D., Vilenkin, A. (2006): Philosophical Implications of Inflationary Cosmology. Brit. J. Phil. Sci. 57, 47–67; arXiv:physics/0302071

Krasnikov, S. (2018): Back-in-Time and Faster-than-Light Travel in General Relativity. Springer: Cham etc.

Krauss, L. M., Starkman, G. D. (2000): Life, The Universe, and Nothing. Astrophys. J. 531, 22–30; arXiv:astro-ph/9902189

Krauss, L. M., Starkman, G. D. (2004): Universal Limits on Computation; arXiv:astro-ph/0404510

Lee, K. M., Weinberg, E. J. (1987): Decay of the True Vacuum in Curved Space-Time. Phys. Rev. D 36, 1088–1094.

Leslie, J. (1989): Universes. Routledge: London 1996.

Leslie, J. (2001): Infinite Minds. Clarendon Press: Oxford.

Leslie, J. (2008). Infinitely Long Afterlives and the Doomsday Argument. Philosophy 83, 519–524.

Lifton, R. J., Olson, E. (2004): Symbolic immortality. In: Robben, A. C. G. M. (ed.) (2004): Death, Mourning, and Burial: A Cross-Cultural Reader. Wiley-Blackwell: Malden, Oxford, Carlton, pp. 32–39.

Linde, A. D. (1987): Particle physics and inflationary cosmology. Phys. Today 40 (9), 61–68.

Linde, A. (1992): Hard Art of the Universe Creation. Nucl. Phys. B 372, 421–442; arXiv:hep-th/9110037

Linde, A. (2005): Particle Physics and Inflationary Cosmology. Contemp. Concepts Phys. 5, 1–362; arXiv:hep-th/0503203

Linde, A. (2006): Inflation and String Cosmology. Prog. Theor. Phys. Suppl. 163, 295–322; arXiv:hep-th/0503195

Linde, A. (2008): Inflationary Cosmology. Lect. Notes Phys.738, 1–54; arXiv:0705.0164

Linde, A. (2017): On the problem of initial conditions for inflation; arXiv:1710.04278

Linde, A., Vanchurin, V. (2010): How many universes are in the multiverse? Phys. Rev. D 81, 083525; arXiv:0910.1589

Lipton, P. (2004): Inference to the Best Explanation. Routledge: London, 2nd ed.

Lloyd, S. (2000): Ultimate physical limits to computation. Nature 406, 1047–1054; arXiv:quant-ph/9908043

Mahner, M. (2018): Naturalismus. Alibri: Aschaffenburg.

Manson, N. A. (2000): There is no adequate definition of 'fine-tuned for life'. Inquiry 43, 341–352.

Mayes, G. R. 2005: Theories of Explanation. The Internet Encyclopedia of Philosophy; http://www.utm.edu/research/iep/e/explanat.htm

Maynard Smith, J., Szathmáry, E. (1996): On the likelihood of habitable worlds. Nature 384, 107.

McGinn, C. (1989): Can We Solve the Mind-Body Problem? Mind 98, 349–366.

McGrew, T., McGrew, L., Vestrup, E. (2001): Probabilities and the fine-tuning argument: a sceptical view. Mind 110, 1027–1038.

Merali, Z. (2006): Create your own universe. New Scientist 2559, 32–35.

Mersini-Houghton, L. (2008): Birth of the Universe from the Multiverse; arXiv:0809.3623

Monod, J. (1970): Chance and Necessity. Knopf: New York 1971.

Mosterín, J. (2005): Anthropic explanations in cosmology. In: Hajek, P., Valdés-Villanueva, L., Westerstahl, D. (eds.) (2005): Logic, Methodology and Philosophy of Science. King's College Publications: London, pp. 441–471; http://philsci-archive.pitt.edu/1658/

Okasha, S. (2012): Emergence, hierarchy and top-down causation in evolutionary biology. Interface Focus 2, 49–54.

Papineau, D. (2016): Naturalism. The Stanford Encyclopedia of Philosophy; https://plato.stanford.edu/archives/win2016/entries/naturalism/

Pitt, J.C. (ed.) (1988): Theories of Explanation. Oxford University Press: New York.

Poland, J. (1994): Physicalism: The Philosophical Foundations. Clarendon: Oxford.

Price, M. (2017): Entropy and Selection: Life as an Adaptation for Universe Replication. Complexity 2017, 1–4.

Rescher, N. (2000): The Price of an Ultimate Theory. Philosophia Naturalis 37, 1–20.

Ridley, M. (2004): Evolution. Blackwell: Malden, 3rd ed.

Rothman, T., Ellis, G. F. R. (1993): Smolin's natural selection hypothesis. Quart. J. Royal Astron. Soc. 34, 201–212.

Sagan, L. (1967): On the origin of mitosing cells. Journal of Theoretical Biology 14, 255–274.

Sakai, N., et al. (2006): The universe out of a monopole in the laboratory? Phys. Rev. D 74, 024026; arXiv:gr-qc/0602084

Salmon, W. C. (1998): Causality and explanation. Oxford University Press: New York.

Sandberg, A., Armstrong, S., Ćirković, M. M. (2016): That is not dead which can eternal lie: the aestivation hypothesis for resolving Fermi's paradox. J. British Interplanetary Society 69, 406–415; arXiv:1705.03394

Silk, J. (1997): Holistic cosmology. Science 277, 644.

Smart, J. (2000): Introduction to the Developmental Singularity Hypothesis; http://www.accelerationwatch.com/developmentalsinghypothesis.html

Smart, J. (2008): Evo Devo Universe? A Framework for Speculations on Cosmic Culture. In: Dick, S. J., Lupisella, M. (eds.): Cosmos and Culture: Cultural Evolution in a Cosmic Context. NASA: Washington, pp. 201–295; http://accelerating.org/downloads/SmartEvoDevoUniv2008.pdf

Smart, J. (2012): The transcension hypothesis: sufficiently advanced civilizations invariably leave our universe, and implications for METI and SETI. Acta Astronautica 78, 55–68; http://accelerating.org/articles/transcensionhypothesis.html

Smart, J. (2017): The Foresight Guide; http://www.foresightguide.com/

Smith, Q. (1990): A natural explanation of the existence and laws of our universe. Australasian Journal of Philosophy 68 (1), 22–43; http://www.infidels.org/library/modern/quentin_smith/natural.html

Smolin, L. (1992): Did the universe evolve? Class. Quant. Grav. 9, 173–191.

Smolin, L. (1997): The Life of the Cosmos. Oxford University Press: Oxford.

Smolin, L. (2004): Cosmological natural selection as the explanation for the complexity of the universe. Physica A 240, 705–713.

Smolin, L. (2006): The status of cosmological natural selection; arXiv:hep-th/0612185

Stenger, V. J. (2011): The Fallacy of Fine-Tuning: Why the Universe Is Not Designed for Us. Prometheus; Amherst.

Stoljar, D. (2017): Physicalism. The Stanford Encyclopedia of Philosophy; https://plato.stanford.edu/archives/win2017/entries/physicalism/

Susskind, L. (2005): The Cosmic Landscape. Little, Brown: New York.

Tegmark, M. (2004): Parallel Universes. In: Barrow, J., Davies, P. C. W., Harper Jr C. L., (eds.) (2004): Science and Ultimate Reality. Cambridge University Press: Cambridge, pp. 459–491; arXiv:astro-ph/0302131

Tegmark, M., et al. (2006): Dimensionless constants, cosmology, and other dark matters. Phys. Rev. D 73, 23505; arXiv:astro-ph/0511774

Tipler, F. J. (1994): The Physics of Immortality. Anchor Books: New York.

Tough, A. (1986): What role will extraterrestrials play in humanity's future? J. Brit. Interplanetary Soc. 39, 491–498; http://ieti.org/tough/articles/future.pdf

Vaas, R. (1993): Die Welt als Würfelspiel. In: Evangelische Akademie Baden (ed.) (1993): "Gott würfelt (nicht)!" Karlsruhe, pp. 108–162.

Vaas, R. (1995a): Reduktionismus und Emergenz. In: Die mechanische und die organische Natur. Beiträge zum Naturverständnis. Konzepteheft 45 des SFB 230. Stuttgart, Tübingen, pp. 102–161.

Vaas, R. (1995b): Masse, Macht und der Verlust der Einheit. In: Krüger, M. (ed.) (1995): Einladung zur Verwandlung. Hanser: München, pp. 219–260.

Vaas, R. (1998): Is there a Darwinian Evolution of the Cosmos? – Some Comments on Lee Smolin's Theory of the Origin of Universes by Means of Natural Selection. Proceedings of the MicroCosmos – MacroCosmos Conference, Aachen; arXiv:gr-qc/0205119

Vaas, R. (1999): Der Riß durch die Schöpfung. der blaue reiter. Journal für Philosophie 10, 39–43.

Vaas, R. (2001a): Why Quantum Correlates Of Consciousness Are Fine, But Not Enough. Informação e Cognição 3 (1), 64–107; http://www2.marilia.unesp.br/revistas/index.php/reic/article/view/715/617

Vaas, R. (2001b): Ewiges Leben im Universum? bild der wissenschaft 9, 62–67.

Vaas, R. (2003): Problems of Cosmological Darwinian Selection and the Origin of Habitable Universes. In: Shaver, P. A., DiLella, L., Giménez, A. (eds.): Astronomy, Cosmology and Fundamental Physics. Springer: Berlin, pp. 485–486.

Vaas, R. (2004a): Ein Universum nach Maß? Kritische Überlegungen zum Anthropischen Prinzip in der Kosmologie, Naturphilosophie und Theologie. In: Hübner, J., Stamatescu, I.-O., Weber, D. (eds.) : Theologie und Kosmologie. Mohr Siebeck: Tübingen, pp. 375–498.

Vaas, R. (2004b): Time before Time. Classifications of universes in contemporary cosmology, and how to avoid the antinomy of the beginning and eternity of the world; arXiv:physics/0408111

Vaas, R. (2006a): Das Münchhausen-Trilemma in der Erkenntnistheorie, Kosmologie und Metaphysik. In: Hilgendorf, E. (ed.) (2006): Wissenschaft, Religion und Recht. Logos, Berlin, pp. 441–474.

Vaas, R. (2006b): Dark Energy and Life's Ultimate Future. In: Burdyuzha, V. (ed.) (2006): The Future of Life and the Future of our Civilization. Springer: Dordrecht, pp. 231–247; arXiv:physics/0703183

Vaas, R. (2008a): Aufrechtstehen im Nichts. Universitas 63 (749 & 750), 1118–1137 & 1244–1259.

Vaas, R. (2008b): Phantastische Physik: Sind Wurmlöcher und Paralleluniversen ein Gegenstand der Wissenschaft? In: Mamczak, S., Jeschke, W. (eds.): Das Science Fiction Jahr 2008. Heyne: München, pp. 661–743.

Vaas, R. (2009a): Die Evolution der Evolution. Universitas 64 (751), 4–29.

Vaas, R. (2009b): Life, the Universe, and almost Everything: Signs of Cosmic Design?; arXiv:0910.5579

Vaas, R. (2009c): Gods, Gains, and Genes. On the Natural Origin of Religiosity by Means of Biocultural Selection. In: Voland, E., Schiefenhövel, W. (eds.) (2009): The Biological Evolution of Religious Mind and Behavior. Springer: Heidelberg, pp. 25–49.

Vaas, R. (2010): Multiverse Scenarios in Cosmology: Classification, Cause, Challenge, Controversy, and Criticism. J. Cosmology 4, 664–673; arXiv:1001.0726

Vaas, R. (2012a): Cosmological Artificial Selection: Creation out of Something? Found. Sci. 17, 25–28; arXiv:0912.5508

Vaas, R. (2012b): "Ewig rollt das Rad des Seins": Der 'Ewige-Wiederkunfts-Gedanke' und seine Aktualität in der modernen physikalischen Kosmologie. In: Heit, H., Abel, G., Brusotti, M. (eds.) (2012): Nietzsches Wissenschaftsphilosophie. de Gruyter: Berlin, New York, pp. 371–390.

Vaas, R. (2013): Die neue Schöpfungsgeschichte Gottes – Herausforderungen einer Evolutionsbiologie der Religiosität. In: Fink, H. (ed.) (2013): Die Fruchtbarkeit der Evolution. Alibri: Aschaffenburg, pp. 133–172.

Vaas, R. (2014a): Wahrheiten auf hoher See. Maritime Metaphern vom Leben, Forschen und Untergehen. Universitas 69 (820), 42–71.

Vaas, R. (2014b): Vom Gottesteilchen zur Weltformel. Kosmos: Stuttgart, 2nd ed.

Vaas, R. (2015): Im Anfang war der Urknall – oder nichts, Gott, alles? Schöpfungsglaube gegen moderne Kosmologie. Universitas 70 (823), 44–76.

Vaas, R. (2017a): Bewusstsein X.0. Von digitalen Denkwürdigkeiten zur ungeheuerlichen Unsterblichkeit. Universitas 72 (854), 64–81.

Vaas, R. (2017b): Umzug der Menschheit? Vom Homo sapiens zum Homo spaciens und weiter ... Universitas 72 (856), 42–69.

Vaas, R. (2017c): Jenseits von Einsteins Universum. Kosmos: Stuttgart, 4th ed.

Vaas, R. (2018a): Superzivilisationen im All. bild der wissenschaft 7, 8–26.

Vaas, R. (2018b): Hawkings neues Universum. Wie es zum Urknall kam. Kosmos: Stuttgart, 6th ed.

Vaas, R. (2018c): Tunnel durch Raum und Zeit. Kosmos: Stuttgart, 8th ed.

Vakoch, D. A. (ed.) (2014): Extraterrestrial Altruism: Evolution and Ethics in the Cosmos. Springer: Heidelberg.

van Riel, R., Van Gulick, R. (2018): Scientific Reduction. The Stanford Encyclopedia of Philosophy; https://plato.stanford.edu/archives/sum2018/entries/scientific-reduction/

Vidal, C. (2008): The Future of Scientific Simulations: from Artificial Life to Artificial Cosmogenesis. In: Tandy, C. (ed.) (2008): Death And Anti-Death. Ria University Press: Palo Alto, pp. 285–318; arXiv:0803.1087

Vidal, C. (2010): Computational and Biological Analogies for Understanding Fine-Tuned Parameters in Physics. Found. Sci. 15 (4), 375–393; arXiv:0912.5508

Vidal, C. (2011): Black Holes: Attractors for Intelligence?; arXiv:1104.4362

Vidal, C. (2012): Fine-tuning, Quantum Mechanics and Cosmological Artificial Selection. Found. Sci. 17 (1), 29–38; arXiv:0912.5508

Vidal, C. (2014): The Beginning and the End: The Meaning of Life in a Cosmological Perspective Springer: Heidelberg etc.; arXiv:1301.1648

Vilenkin, A. (1995): Predictions from Quantum Cosmology. Phys. Rev. Lett. 74, 846–849; arXiv:gr-qc/9406010

Vilenkin, A. (2006a): On cosmic natural selection; arXiv:hep-th/0610051

Vilenkin, A. (2006b): Many Worlds in One. Hill and Wang: New York.

Visser, M. (1996): Lorentzian Wormholes. American Institute of Physics Press: Woodbury.

Vollmer, G. (2016): Im Lichte der Evolution. Hirzel: Stuttgart.

Vollmer, G. (2017): Gretchenfragen an Naturalisten. Alibri: Aschaffenburg.

Waring, E. G. (ed.) (1967): Deism and Natural Religion. Frederick Ungar: New York.

Weinstein, S., Fine, A. (1998): Book Review of Lee Smolin's The Life of the Cosmos. J. Phil. XCV, 264–268.

Wheeler, J. A. (1975): The universe as home for man. In: Gingerich, O. (ed.) (1975): The nature of scientific discovery. Smithsonian Institution Press: Washington, pp. 261–296

Wheeler, J. A. (1977): Genesis and observership. In: Butts, R. E., Hintikka, J. (eds.) (1977): Foundational problems in the special sciences. Reidel: Dordrecht, pp. 3–33.

Wheeler, J. A. (1980): Law without law. In: Medawar, P., Shelley, J. (eds.) (1980): Structure in Science. Elsevier: New York, pp. 132–154.

Wheeler, J. A. (1983): On recognizing law without law. Am. J. Phys. 51, 398–404.

Windsor, H. H. (1907): Cart before the horse, Popular Mechanics 4, 425.

Wittgenstein, L. (1922): Tractatus Logico-Philosophicus. Kegan Paul, Trench, Trubner & Co.: London.

Woodward, J. (2003/2009): Scientific Explanation. The Stanford Encyclopedia of Philosophy; http://plato.stanford.edu/entries/scientific-explanation/

Yurov, A. V., Martín Moruno, P., González-Díaz, P. F. (2006): New "Bigs" in cosmology. Nucl. Phys. B 759, 320–341; arXiv:astro-ph/0606529

Zimorski, V., et al. (2014): Endosymbiotic theory for organelle origins. Current Opinions in Microbiology 22, 38–48.