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TECHNOLOGICAL DESIGN AS AN EVOLUTIONARY PROCESS

The evolution of technical artifacts is often seen as radically different from the evolution of biological species. Technical artifacts are normally understood to result from the purposive intelligence of designers whereas biological species and organisms are held to have resulted from evolution by natural selection. But could it be that technology, too, is really the outcome of evolutionary processes rather than intelligent design? Recent decades have seen the emergence of evolutionary theories of technology, which use concepts and principles drawn from evolutionary biology to describe and explain processes of technological innovation and technological change. In this chapter, I will focus on three prominent theories, by George Basalla, Joel Mokyr and Robert Aunger, and I will investigate to what extent these theories present a truly evolutionary account of technological innovation and change. In the end, I aim to analyze how these theories construe technological design: as a blind evolutionary process, a purposive activity of designers, or a mixture of both.

1. DESIGN AND EVOLUTION

Before evolutionary theory presented an alternative viewpoint, it was almost universally believed that biological organisms are creations of an intelligent maker – a God. For centuries, this belief played a central role in a major type of argument for the existence of a God, the Argument from Design. Arguments from Design come in different forms but all revolve around the belief that there must be a God or Intelligent Creator because organisms in nature are too complex and sophisticated to have occurred randomly or naturally.

The most famous Argument from Design is the Watch Argument presented by theologian William Paley in 1802. Paley's argument starts with the premise that living organisms and organs have the same kind of complexity and purposiveness as designed artifacts. An eye, for example, is an intricate organ for vision in precisely the same way that a telescope is an intricate artifact for assisting vision. Paley next argues that if one finds complex artifacts like a telescope or watch on the ground, one would not believe for a moment that it was the product of natural forces, but rather believe that it must have had a maker. But, Paley argues, since human organs and organisms have the same kind of complexity and purposiveness as such human-made artifacts, it is only plausible to assume that they, too, must have had a designer, or maker, who intentionally created them and gave them a functionality or use.

In his famous exposition of the theory of evolution, *The Blind Watchmaker*, Richard Dawkins explains that the theory of evolution by natural selection provides a compelling alternative to Paley's account. The complexity and functionality found in living beings, Dawkins argues, can be explained as the outcome of a long process in which less complex organic systems gain complexity and functionality in a series of steps involving small variations and selection of the fittest (best-adapted) systems. Dawkins concludes that an explanation of organic life requires no appeal to a creator or designer, but only to blind processes of natural selection. Natural selection, he claims, is completely different from purposive design since it "has no purpose in mind. It has no vision, no foresight, no sight at all. It does not plan for the future. It has no vision, no foresight, no sight at all. If it can be said to play the role of watchmaker in nature, it is the *blind* watchmaker." (Dawkins, 1986, 5). The theory of evolution is now well-established in science, and the Argument from Design has become discredited as a result, although it is still used in religious theories of biological life, as in creationism, creation science, and more recently, the theory of Intelligent Design (Dembsky, 1999).

As a result of the new scientific orthodoxy, the origins of organisms and of artifacts are nowadays seen as radically different: blind natural selection versus the purposive, forward-looking, and intelligent activity of designers. In this chapter, I will question whether this radical difference in origins can be sustained. I will not do this by revisiting the Argument from Design, but by questioning whether designed artifacts are best explained as resulting from purposive design rather than evolutionary processes. Recent decades have seen the emergence of evolutionary theories of technology, which use concepts and principles drawn from evolutionary biology to describe and explain processes of technological innovation and technological change (see Ziman (2000) for an overview). In what follows, I aim to investigate to what extent these theories present a truly evolutionary account of technological innovation and change and to analyze how they construe technological design: as a blind evolutionary process, a purposive activity of designers, or a little bit of both.

2. EVOLUTIONARY THEORIES OF TECHNOLOGY AND EVOLUTIONARY BIOLOGY

To start my investigation, I will begin with an analysis of what it means for a theory of technology to be evolutionary. I will do this by identifying the main principles of the theory of evolution and by then asking to what extent these should be present in a theory of technology for it to be evolutionary.

Evolutionary theories of technology have gained in prominence since the 1980s. Such theories use concepts and analogies from evolutionary biology to explain technological change and innovation. Part of the inspiration of these theories can be found in previous extensions of evolutionary theory into new realms, such as evolutionary economics (Andersen, 1994; Dopfer, 2005) and evolutionary epistemology (Hahlweg and Hooker, 1989; Callebaut and Pinxten, 1987). Another source of inspiration is found in the more general attempt to construct at a universal theory of evolution that transcends biological evolution. Such a theory, which incorporates ideas from evolutionary epistemology, has alternatively been called universal selection theory or universal Darwinism (Cziko, 1995; Dennett, 1995). The central claim of Universal Darwinism is that Darwinian principles of evolution by natural selection do not just underlie biological processes but underlie all creativity, and are key to the achievement of all functional order. So biological evolution is just a particular instance of a more general phenomenon of evolution by selection.

A prominent approach that incorporates ideas of universal selection theory is the memetic approach to cultural evolution initiated by Richard Dawkins (1976) and since then developed by a number of advocates (Blackmore, 1999; Aunger, 2000; 2002). According to memetic theory, human culture is realized and transmitted through cultural units called memes, which are units of meaning that can express any culturally determined idea, behavior, or design. Memes are like genes in that they can replicate and can be transmitted, and they compete with other memes for survival according to Darwinian principles.

A variety of evolutionary approaches to technological change and innovation now exist. Some of these approaches are more explicitly evolutionary, whereas others make use of concepts of evolutionary biology in a loose way. The influential SCOT approach in the science and technology studies (STS) is an example of the latter (Bijker, Hughes, and Pinch, 1987). In this approach, the development of technological artifacts is claimed to consist of semi-evolutionary processes of variation and selection, in which technology developers design and produce different kinds of artifacts and selection takes place between them by buyers and other actors.

More consistently evolutionary theories of technology make more systematic use of concepts and principles of evolutionary theory for the analysis and explanation of processes of technological change and innovation. In the subsequent three sections, I will analyze three prominent evolutionary theories of technological change and innovation, that have been developed by George Basalla, Joel Mokyr, and Robert Aunger, respectively. Before this, however, I will first briefly outline the main concepts and principles of the theory of evolution itself, as it has been developed in evolutionary biology.

The contemporary theory of evolution adheres to three basic principles and assumes that biological species evolve through natural selection. Evolution is the increasing adaptedness of species to their environment, and natural selection is the process by which natural conditions favor hereditable traits of organisms that confer the greatest fitness to the organisms that carry them. This idea of evolution by natural selection is often claimed to rest on three principles: phenotypic variation, heritability, and differential fitness.

1. *Phenotypic variation.* This is the idea that all individuals of a particular species show variation in their behavioral, morphological and/or physiological traits –

their 'phenotype'. For example, individual wolves may differ in their hair color, tail length, bone density, aggressiveness, sexual prowess, visual acuity, and so forth.

2. *Heritability.* This is the idea that a part of the variation between individuals in a species is heritable, meaning that some of that variation will be passed on from one generation to the next. In other words, offspring will tend to resemble their parents more than they do other individuals in the population. For example, if visual acuity is a heritable trait in wolves, then the offspring of a particular wolf with high visual acuity will have a higher than average tendency to have high visual acuity.
3. *Differential fitness.* This is the idea that some individuals of a particular species are better adapted to their environment than others and therefore have greater chances of survival and reproduction. That is, individuals in a species differ in their fitness, or their propensity to reproduce (leave offspring). For example, wolves with high visual acuity will tend to leave more offspring than wolves with low visual acuity because high visual acuity is a trait that leads to better adaptation to the environment by wolves, and therefore the trait of high visual acuity will tend to proliferate in future generations of wolves.

The result of these three principles, then, is evolution by natural selection: traits that enhance fitness proliferate in future generations, and individuals in a species are increasingly equipped with such traits. This is assuming that the local environment in which selection takes place remains the same. If the local environment changes, then traits that were previously fitness-enhancing may become less so, and other traits may come to enhance fitness. Such a change in the environment merely alters the course of evolution; the same underlying principles of natural selection remain at work.

The above three principles are the core principles of biological evolution formulated by Darwin in his Origins of Species (1859). Two additional principles specify underlying mechanisms for the processes described in these three principles. One specifies the underlying mechanism of heritability, which, genetics has taught us, is genetic reproduction:

4. *Genetic reproduction.* Inheritance of traits takes place through reproduction of genes.

Another one elaborates the underlying mechanisms driving variation:

5. *Mutation and recombination.* Two principal factors are responsible for the creation of variants: mutation, accidental changes in genomes, and recombination, the crossing between alleles, on which genes are situated, during meiotic cell division.

A sixth important principle of evolutionary biology is already implicit in the previous ones:

6. *Blindness.* Variation and selection are blind processes, meaning that they do not depend on foresight or learning. Put differently, they are nonteleological processes, not the result of any goals or aims but merely the result of conditions in the natural environment.

With these principles, we can now see what it would take for a theory of technology to be an evolutionary theory in a direct sense. Obviously, the evolution of technology is not a biological process since technical artifacts are not biological species. So an evolutionary theory of technology cannot be part of evolutionary biology. Instead, a theory of technology can only be evolutionary in an analogous sense: by assuming that technological change and innovation depend on principles that are strongly analogous to the principles underlying biological evolution. That is, there must be a structural similarity between the two processes through which most or all of the above principles apply to technological change, albeit in a modified form. The more principles apply, the more strongly evolutionary the theory is. The most important principles are the first three, because they are the core principles of evolutionary theory. Theories of technology that employ at least two principles that are analogous to these three core principles may be called weakly analogous to biological evolution, whereas theories that employ all three and at least one of the three peripheral principles may be called strongly analogous.

3. GEORGE BASALLA'S THEORY

In his book *The Evolution of Technology*, historian of technology George Basalla presents an evolutionary theory of technological change that aims to explain technological innovation, including the emergence of novel artifacts, and the process by which society makes a selection between available artifacts (Basalla, 1988). Basalla considers his notion of technological evolution to be an "analogy" or "metaphor". He claims "Metaphors and analogies are at the heart of all extended analytical or critical thought." (1988, 3). Basalla holds that metaphors and analogies can be helpful in constructing novel scientific analyses and explanations.

Basalla argues that the proper object of analysis of a theory of technological change is the artifact, since artifacts are normally the outcome of innovative technological activity. He then likens artifact types to species and individual artifacts of a particular type to members of a species (1988, 137). Artifacts are hence to be likened to phenotypes. He claims that variation within artifact types clearly exists: there are many different kinds of hammers, steam engines, or automobiles. There is also a kind of inheritance between artifacts, Basalla claims. That is, artifacts may be followed by subsequent generations of the same artifact, or similar artifacts. The main difference here is that artifacts do not reproduce; they are reproduced by human makers. However, Basalla holds the resulting process of reproduction to be similar to the process of inheritance. Basalla also claims that selective pressures operate on artifacts, and that some are selected to be used and reproduced, whereas others are discarded. He believes that this process of selection can be analyzed with reference of traits of artifacts that make a better or poorer fit to conditions in their environment. He argues that four kinds of factors are involved in the selection of artifacts: economic, military, social, and cultural. These factors do not operate on artifacts directly, but on humans who select artifacts. Their actions are determined by "economic constraints, military demands, ideological pressures, political manipulation, and the power of cultural values, fashions, and fads." (139). It can hence be said that artifacts have a differential fitness relative to such constraints.

Basalla holds that the mechanism by which new variants of artifacts are created is not the mechanism of mutation and recombination. It is usually a mechanism involving conscious human choices. Likewise, the selection of artifacts is not a blind process, as it also involves human choice. Basalla claims that the selection of artifacts is similar to artificial selection, the selection of phenotypes in animal and plant breeding, and less similar to natural selection. As he claims, "Variant artifacts do not arise from the chance recombination of certain crucial constituent parts but are the result of a conscious process in which human taste and judgment are exercised in the pursuit of some biological, technological, psychological, social, economic, or cultural goal." (1988, 136). It must be admitted that human choices are constrained by economic, military, social, and cultural factors over which human beings do not have complete control. Even so, Basalla holds that the involvement of conscious, goal-directed choices by human beings introduces a disanalogy between technological and biological evolution. Another disanalogy exists, Basalla holds, regarding the notion of species and interbreeding. Artifact types can be combined quite easily to produce new types, meaning that artifact types can interbreed easily, whereas different biological species usually do not interbreed (1988, 137). A final disanalogy between Basalla's theory and the theory of evolution is that there is no unit of reproduction similar to the gene in Basalla's theory; it is artifacts, or phenotypes, rather than genes, and genotypes, that are reproduced.

To sum up, Basalla's theory of the evolution of technological artifacts exploits a number of similarities between biological and technological evolution while also admitting to a number of dissimilarities. Basalla appears to claim that analogous versions of the principles of variation, inheritance, and differential fitness apply to technological evolution, while the principles of genetic reproduction, mutation and recombination, and blindness do not apply. In his theory, technological innovation is hence weakly but not strongly analogous to biological evolution. Inheritance in artifacts is construed as the tendency of successive generations of artifacts to resemble previous generations. Variation and selection are not blind but involve conscious human agents making purposeful choices: choices regarding the creation of novelty and regarding the selection of artifacts.

4. JOEL MOKYR'S THEORY

Economic historian Joel Mokyr has presented an evolutionary theory of technology that does not focus on the evolution of artifacts, as in Basalla's theory, but on the evolution of technological knowledge (Mokyr, 1996; 1998; 1999; 2000a; b). More precisely, he has presented an evolutionary theory of techniques, or technological know-how, mirroring Gilbert Ryle's famous distinction between knowledge "how" and knowledge "that". Mokyr is critical of evolutionary approaches that take artifacts as the unit of selection, like Basalla's, because he holds that technological change is better analyzed as a change in techniques than as a change in artifacts. New techniques for washing one's hands, training animals, or navigating the stars may not involve any artifacts at all. Moreover, he claims, many artifacts are meaningless without specific instructions, and only gain their identity when a series of “how-to” instructions are attached to them. Mokyr’s theory has been inspired by developments in evolutionary epistemology, as well as by evolutionary approaches to economics. Mokyr’s aim is to develop an evolutionary framework that is helpful in analyzing the fundamental causes of technological change. Like Basalla, he believes that evolutionary biology provides a useful “analogy” or “metaphor” to this effect.

Following Gilbert Ryle, Mokyr makes a distinction between “how” knowledge and “what” knowledge. He argues that society has developed two basic kinds of knowledge to help it cope with the world. The first kind is what he calls “useful knowledge”. This is “what” knowledge that resides either in people’s minds or in storage devices from which it can be retrieved. Useful knowledge consists of observations and classifications of natural phenomena, and regularities and laws that make sense of these phenomena. It includes scientific knowledge, but also engineering knowledge, including quantitative empirical relations between properties and variables. Mokyr calls the total set of useful knowledge about the world in human minds and storage devices Ω (Omega). Next to useful knowledge, there are techniques, which are a form of “how” knowledge. Techniques are sets of instructions, or recipes, that tell the user how to manipulate aspects of the environment to attain a desirable outcome. Like “useful knowledge”, techniques reside in people’s brains and in storage devices. For example, a “how to” manual is a codified set of techniques. Many techniques, however, are tacit and unconscious. Mokyr calls the total set of techniques that exist in a society λ (Lambda). Mokyr believes in the primacy of “useful knowledge” over techniques, or of Ω over λ. That is, he believes that there usually is a dependency of techniques on what-knowledge that has made the technique possible. For instance, he believes that the technique of bicycle riding is in some way dependent on the mechanical principles of bicycle riding that made the production of bicycles possible. Techniques, in Mokyr’s analysis, are the end-product of knowledge in Ω. Ω defines what a society knows, and λ what it can do.

Mokyr likens “useful knowledge” to the genotype and techniques to the phenotype. He believes that an evolutionary theory of technology must in some way capture the genotype-phenotype distinction by including a distinction between some underlying structure that constrains a manifested entity. In technology, the underlying structure is Ω and the manifested entity is λ. There are mappings between Ω and λ when one or more elements in Ω give rise to one or more elements in λ. For example, the now-defunct humoral theory of disease gave rise to a series of medical techniques, including the bleeding and purging of patients suffering from fever. Mokyr admits that the relation between Ω and λ deviates in several ways from the genotype-phenotype relationship. For instance, a gene and the phenotypic trait it gives rise to must be part of the same carrying organism. But if an individual masters a technique, he need not be knowledgeable of the “useful knowledge” that formed the basis of it, and this knowledge may be stored in other minds or storage devices, or may even have been lost.

Techniques, Mokyr claims, are subjected to selective pressures. When a technique has been used, its outcome is evaluated using a set of selection criteria that detemine whether it will be used again or not. This, he holds, is similar to the way in which selection criteria pick living specimens and decide whether they survive and reproduce. He does not hold it to be important whether this selection occurs by the same human agent who used a technique previously or by other human agents. Agents may again select techniques that they have used previously, and other agents may learn or imitate techniques, which is also a form of selection. When a technique is selected again, it is reproduced, in Mokyr's terminology. So reproduction of techniques may take place through learning and imitation, or through reselection by a human agent. Mokyr points out that the analogy between biological selection and the selection of techniques breaks down on an important point: selection of techniques is not blind, but is performed by conscious units, firms and households that do the selecting. Humans are, in this model, not the selected but the selectors. Mokyr claims there is also selection between elements of $\boldsymbol{\Omega}$. Here it is not their perceived usefulness but their perceived truth or veracity that determines whether they are conserved, and whether they are used to create techniques. Their truth is tested by established rules in society, for instance rules of science.

Mokyr is not fully clear on the conditions that create variation (or "innovation"). He calls the creation of new "useful knowledge" mutation, and defines such mutations as "discoveries about natural phenomena", but does not specify a mechanism for it. He does suggest that the creation of new techniques often results from new combinations of knowledge in $\boldsymbol{\Omega}$. He refers to the possibility of a general drive in human agents to devote resources to innovation, but does not develop this idea. Moreover, new techniques need not result from new (combinations of) knowledge. Techniques can also change through experience and learning by doing, or may emerge from "pure novelty" like mutations. The use of new techniques may also influence the set of "useful knowledge". For instance, the invention of telescopes impacted knowledge of astronomy, and early steam engines influenced the development of theoretical physics. So technological evolution, in Mokyr's theory, may also involve Lamarckian feedback mechanisms from phenotype to genotype, or from $\boldsymbol{\lambda}$ to $\boldsymbol{\Omega}$.

Mokyr's theory, like Basalla's, holds that the basic three ideas of Darwinism apply in some form to technological change. There is phenotypic variation between techniques, techniques have differential fitness, and there is some form of heritability in that subsequent generations of techniques tend to resemble their predecessors. Unlike Basalla, Mokyr upholds the genotype-phenotype distinction by putting what-knowledge and how-knowledge in those two roles and assuming there is a mapping-relation from what-knowledge to techniques. He is therefore able to adhere to some principle of genetic reproduction, according to which most techniques depend on underlying knowledge, and their reproduction often depends on the presence of this knowledge. Mokyr is also able, better than Basalla, to adhere to a principle of mutation and recombination. Mutations occur to $\boldsymbol{\Omega}$, through new discoveries, and knowledge in $\boldsymbol{\Omega}$ may be combined in new ways to yield new techniques. This analogy breaks down, to some extent, since techniques may also mutate and subsequently reproduce without any changes in underlying knowledge.

Mokyr thus takes the analogy between biological evolution and technological change considerably farther than Basalla, and presents an account on which technological change is strongly analogous to biological evolution, although disanalogies are also present. Mokyr does not adhere to the principle of blindness, since he holds that variation and selection are driven by conscious human agents. In Basalla's theory it was artifacts that were the object of variation, reproduction, and selection by humans. In Mokyr's theory, the object is techniques, which are a type of knowledge. In both cases, the trajectory of these objects may be described in evolutionary terms, but is nevertheless the immediate result of human deliberation and purposive action.

5. ROBERT AUNGER'S THEORY

Anthropologist Robert Aunger has developed an account of technological change within the context of memetics (Aunger, 2002). Memetics is an evolutionary approach to culture that was initially proposed by evolutionary biologist Richard Dawkins (1976). Dawkins claimed that culture might have its own evolutionary mechanism, separate from that of biological evolution, and that it is dependent on basic units of propagation similar to genes, which he called "memes". A meme is the basic meaningful unit of culture and the basic unit of cultural inheritance. Memes are akin to ideas. The religious concept of heaven, the Newtonian concept of gravitation, the notion of a scarf, the notion of a semicolon, the idea of a handshake, all these are memes, or complexes of memes. Memes are capable of reproduction, and are subjected to Darwinian processes of blind variation and selection. They compete with each other in an environment of other ideas, and human biological needs, that determine whether they will be selected and survive in their hosts, or be copied by other hosts and hence spread throughout a population. Importantly, memeticists believe that the basic selection mechanism for memes is not conscious, and involves forces that are beyond the control of individual agents.

The analogy between biological evolution and cultural evolution thus goes all the way: all six principles of biological evolution outlined in section 2 are also thought to apply to cultural evolution, in some form. However, there is debate on whether a genotype-phenotype distinction applies to memetics. Dawkins claimed that this distinction does not hold in memetics, because selective pressures operate directly on memes. Memes are like genes that carry phenotypic traits on their sleeves. Memetic evolution on this conception is Lamarckian, because it upholds the heritability of acquired traits (new memes). Others have claimed that a genotype-phenotype distinction is tenable for memes. If memes are ideas in the mind, then their phenotypic expression may be a realization or manifestation of this idea. This phenotypic expression may be an artifact or behavior. For example, a recipe for a cake in someone's mind is a set of memes, and a cake baked according to this recipe the memetic phenotype. Likewise, the remembered idea of a song may be a set of memes, while the performance of a song is the phenotype. On this view, selective pressures do not operate directly on memes, but indirectly, on their phenotypic expressions. In this debate, Aunger largely follows Dawkins's idea that memes are both genotypic and phenotypic. He moreover holds that memes are brain structures, or ideas in the brain.

Aunger holds that a theory of technological change should focus on memes and artifacts. He holds, like Basalla, that artifacts evolve. However, he claims they evolve through interaction with mental artifacts, or memes. Aunger hypothesizes a process of coevolution between memes and artifacts. He claims that this process of coevolution involves "two lines of inheritance working together, feeding off each other in a positive fashion," and that it is responsible for the "incredible dynamicism of cultural modification in modern Western societies" (2002, 277). Aunger emphasizes that artifacts do not have a single role in meme-artifact coevolution. Artifacts sometimes function as phenotypes, that are the focus of selective pressures. But they may also function as vehicles or interactors for memes, as signal templates, or even as replicators, as in computer viruses and nanites (self-replicating pieces of nanotechnology). Different relations with memes are established in these different roles of artifacts. In all cases, however, there is coevolution: memes give rise to artifacts, and artifacts may feed back to memes and alter them or generate new ones. Both memes and artifacts are subjected to their own selective pressures.

Aunger sums up his theory of technological change as follows: "New artifact types are created through *invention*, or random mutations in form. This starts a new evolutionary lineage. *Innovations*, on the other hand, are modifications of these inventions through the recombination of parts. ... Such single-step recombinations between artifact lineages ("combinatorial chemistry") can rapidly produce complexity. Over time, an artifact lineage can therefore show evidence of cumulative selection (variation with descent) and manifest an adaptive design with greater and greater power to transform the environment. Simultaneously there is a process of mental evolution in know-how that can be described as Darwinian." (2002, 299). Aunger holds that the production of artifacts is first simulated in the mind, in which different varieties of artifacts are "tried out" for their competitive advantage. This process of mental trial and error may recur at the level of research and development within a firm, and then again in the marketplace. So it is the interaction of two Darwinian processes, "of descent with modification in the body of knowledge available to a society relevant to the production of some artifact, as well as the embodied modifications in the artifact itself – that must be modeled for a complete understanding of technological evolution." (2002, 299-300). Aunger notes that precise models of the interaction between memes and artifacts will still have to be developed.

Aunger's theory incorporates an analogue of most principles of biological evolution, and he therefore conceives of technological change as strongly analogous to biological evolution. Auger adopts principles of variation, inheritance and differential fitness for memes and artifacts that strongly mirror those in biology. He holds that the relation between memes and artifacts sometimes resembles the genotype-phenotype relation, but claims that memes and artifacts may also have a different relation to each other. When this relation occurs, the principle of genetic reproduction seems to apply. Aunger moreover assumes that the invention of new memes and artifacts may be described as mutation, and that some process of recombination also occurs, when a combination of memes gives rise to new artifacts.

Unlike Basalla's and Mokyr's theories, Aunger adheres to the blindness principle: he holds that the basic processes of meme and artifact variation and selection are not properly understood as conscious and goal-driven, even if conscious decisions and goals play a role in them. This is, indeed, a basic tenet of memetics: the evolution of memes, or ideas, is not explained as the result of conscious cognitive processes and actions by human agents, but rather as a process of blind variation and selection of memes in human beings who function as passive hosts to this process. Memetics therefore takes Darwinism significantly farther than Darwin ever did: even the watch found by William Paley turns out to be not the result of conscious design but rather the result of blind variation and selection. Just like biological organisms, memeticists hold, human-made artifacts are the result of processes of evolution by natural selection.

6. DESIGNERS AND TECHNOLOGICAL EVOLUTION

What, according to these three evolutionary theories of technology, is the nature of engineering design? I will start with answering this question for Basalla's and Mokyr's theories, which, unlike Aunger's, construe technological change as dependent on the conscious deliberation and foresight of human agents. On their view, then, evolutionary processes are not necessarily blind, and the design of technology is part of an evolutionary process while simultaneously involving foresight by designers. Their view seems to run counter to the blindness principle outlined in section 2. However, as I will now argue, this principle is too strong in its current form even for biological evolution and therefore needs to be modified. Evolutionary processes of variation and selection sometimes do involve foresight and conscious choice.

Natural selection is often contrasted with artificial selection, which is the selection by humans of animal and plant phenotypes, which creates new breeds within a species, and may even yield a species. The dog is a domesticated species upon which artificial selection has been worked for thousands of years, resulting in hundreds of different breeds. Clearly, these breeds are the result of processes of variation and selection that resemble natural selection in every way, except that they involve human foresight and choice working in conjunction with "natural" processes of variation and selection. Yet, does the dependency of the evolution of dogs on human foresight really differentiate it from ordinary, natural evolution?

Closer consideration shows that in natural selection, foresight and choice also frequently play a major role, because natural selection often depends on intentional, forward-looking actions by animals and humans. Animals select their mate, predators select their prey, and animals choose the immediate environment in which they live and the things and animals with which they interact, and parents choose which offspring they give the most food or are most protective of. These choices are generally guided by expectations about the future. They are a large factor in the processes of selection, variation, and reproduction that occur in natural selection.

It may be objected that there still is a major difference between artificial and natural selection: artificial selection is selection with the explicit aim to grow or breed certain species with predefined properties (phenotypic traits), whereas the foresight in natural selection is not similarly aimed at designing the traits of offspring. A rabbit breeder may successfully breed a rabbit with a white body, black head and red eyes, but it would seem that two rabbits in the wild do not mate because they aim to realize offspring with certain phenotypic properties. Rather, they mate because they lust for each other and desire to copulate.[1]

In spite of this difference, however, there is no reason why artificial selection could not be described using the same concepts and principles used in natural selection accounts. In both cases, selection involves both forward-looking intelligence and events that involve no foresight. A rabbit breeder cannot completely control the circumstances that determine the phenotype or genotype of new generations of rabbits, so his foresight is just part of the explanation of why a bred rabbit looks the way it does. Conversely, an explanation of why a certain generation of rabbits in the wild has the phenotypic traits it does may include, amongst others reference to the intentional states of parent rabbits, predators, and other animals that played a role in selection.

In the evolution of technology, a designer or maker has the same relation to technical artifacts as a breeder has to the animals he breeds. The designer attempts to create a certain artifact with desired properties, but is not in full control of the outcome. Concrete artifacts are a compromise between the designer's ideals and the contingencies of the physical and social world through and in which the designer operates. While a designer is not fully in control of the outcome of his designing activity, he is even less in control of the success of his artifact once let loose in the environment, i.e., the marketplace and the world of users. Once a certain brand of artifacts leaves the factory, it is the intentions and choices of sellers, users, regulators, and others, as well as random events, that determine whether it successful as a brand (or species) and whether it proliferates.

In the evolutionary process of variation and selection, the designer is the main agent of variation. He produces new types of artifacts, after which various selection constraints in the environment determine whether they are successful. In the production of these variations, forward-looking intelligence has a large role, much greater than it has in the production of new variants in biological evolution. In contrast, the designer's forward-looking intelligence normally has a much less significant role in subsequent selection. As many product designers have found out the hard way, it is often very difficult to predict or control which products will be successful in the marketplace.

A product designer may, however, attempt to control the selection process, by controlling the environment in which his products operate. He may for instance attempt to require or encourage that a certain type of product is only used in pre-specified contexts or by pre-specified users. He may also attempt to alter the contexts of use in which products operate, or alter the traits of users. He may for example offer training to users, or encourage such training, or he may recommend

[1] It may occur that humans consciously or unconsciously select a certain mate to generate offspring with certain phenotypic properties, but this does not seem to be a major factor in mate selection. Possibly, such considerations also play a role in mate selection by animals.

that adaptations are made to the environment in which the product is used. The designer's main ways of controlling the environment include the authoring of manuals and direct communication with suppliers or users. As such, a designer may project his forward-looking intelligence beyond the artifact itself to also influence the conditions under which selection takes place. His actions are like those of a parent who prescribes where his children can go and whom they can associate with, and who eliminates risks and dangers in the environment so that his children have the best chance of succeeding in the world.

In Basalla's and Mokyr's approach, then, design is the process of creating variants in an evolutionary process of variation and selection. Designers use forward-looking intelligence in the creation of new variants, but new variants (artifacts) are not wholly determined by the designer's vision, but also by the everyday constraints under which designers operate. Designers and others may also use forward-looking intelligence in trying to influence the selection process. However, their efforts are ultimately part of an evolutionary process that cannot be controlled by any party.

In Aunger's memetic theory of technological change, neither variation nor selection involve forward-looking intelligence, as he holds that even design, or innovation, involves random mutation of form. This is the result of a radical vision of cognition according to which cognitive processes are themselves processes of variation and selection of memes over which human beings have no real control, since they are subconscious processes driven by the laws of memetics. In the language of memetics, designers are "meme fountains": along with artists and scientists, they are people who happen to be good at producing new memes or integrating existing ones. The new memes they produce are designs of technical artifacts.

Let me finally come to an evaluative question: which perspective on design and technological innovation is right? Is it Aunger's radical approach, in which designers are mere pawns in an evolutionary process? Is it the traditional, non-evolutionary approach in which designs spring from the creativity and intelligence of designers? Or is it Basalla's or Mokyr's approach, located somewhere in between? I want to suggest that there may be more than one valid conceptual framework in which to analyze design and innovation. If the purpose is to explain the presence of certain features or functions in an artifact, then it may be most useful to highlight the intentions of designers. For example, it can be explained that the panhandle is curved because the designer wanted the pan to have an easy grip. This kind of explanation is called an *intentional explanation*, as it explains things or events as the product of human intentions. If the purpose is to explain technological change, then too many constraints are at work besides the intentions of designers or innovators, and one should resort to a *causal* (or *structural* or *functional*) *explanation* that references to structural features or mechanisms at work in producing such change (Little, 1991). The claim of evolutionary theorists of technology are that such mechanisms are evolutionary, in a broad sense, and should inherit part of the vocabulary and laws of evolutionary biology.

In Basalla's and Mokyr's approaches, the resulting evolutionary explanations are underpinned in part by intentional explanations: they are macro-analyses that can be related to micro-analyses which include individuals such as designers and users who have intentions, desires and beliefs, and act on them. In Aunger's approach, however, the micro-level of analysis includes no intentional agents but agents with minds that are themselves subjected to blind variation and selection. Put differently, Basalla and Mokyr still treat the mind as an *intentional black box* (Haugeland, 1981), an entity that has intentions and generates ideas and requires no further explanation, whereas Aunger, correctly or incorrectly, reduces the mind to a non-intentional, non-forwardlooking process of meme variation and selection.

7. CONCLUSION

In this chapter, I aimed to examine whether the evolution of technical artifacts is radically different from the evolution of biological species, and whether designed artifacts are best explained as resulting from the purposive intelligence of designers or instead from a process akin to biological evolution. I discussed evolutionary theories of technology by George Basalla, Joel Mokyr and Robert Aunger, and examined whether they qualified as genuinely evolutionary theories. I concluded that on Basalla's account, technological innovation and change are weakly analogous to biological evolution, whereas on Mokyr's and Aunger's account, they are strongly analogous.

Although I have not demonstrated the validity of evolutionary approaches to technology, I hope to have convinced the reader that such approaches are worth taking seriously. Evolutionary approaches to technology present us with a vision of design in which the intentions and beliefs of designers and others are at best only part of the explanation of processes of technological innovation and change. They yield a conception of designers as initiators of new variants that then undergo selection in society. Designers are agents of mutation and recombination in the production of new variants. They have partial, but no complete, control over this production process. The success of the variants they produce in the subsequent selection process, or their fitness, can only be predicted or controlled by designers to a very limited extent. This perspective on design and innovation is worth developing further, as it may help us better understand the role of designers in technological innovation and the conditions under which technological innovation is successful.

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