Technology as system: towards an autopoietic theory of technology

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Abstract: This contribution develops a new notion of technology based on core ideas of Niklas Luhmann's sociological system theory. Technology will be conceptualised as a self-making, self-referencing system, distinct from society and the human individual. Its basal operation is information in the medium of operativeness, processing along the binary code of work/fail. Through close coupling with social systems as well as with human developers and users of technology, technological evolution is ensured as a co-evolutive network of technology and society. Thereby technology irritates society in a way that social reality is created by technology and all progress in technology as well as in society is now decided through technological means. This has great effects when dealing with the ecological crisis and the need for sustainable development. This will be illustrated with the example of the automobile in past, present and possible futures.

Keywords: system theory; technology; co-evolution; sustainability.

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1 Introduction

There is no non-technological mediated reality – this is one of the key axioms of Max Bense's philosophy (Bense, 1949). Everything we conceive as 'the world' is constructed via technological means. In George Spencer Brown's words, we create a universe by drawing a distinction (Spencer Brown, 1969). That distinction is drawn by technology, and with 'technology' we mean not just the skilled application of a certain branch of knowledge – what eventually is denoted in the conflated Greek terms *téchne* and *logia*. What we also mean here with technology is its almost hidden hard core, the technological artefact itself. It is the hammer and the wedge, which are enabling and determining the process of carving the sculpture out of the stone. It is the design of the artefact that couples it to its various environments, extending from a pure physical design towards ever complex architectures invoking the human user and society. All these elements – the technological artefact, the physical and social environment and the human user – co-evolve and there is no linear causality between technology and its development. What we argue here is that technology establishes a circular and recursive relationship between itself and its environments – the physical world, society and human beings. The image of the engineer designing technology is seen in this contribution as a more or less convenient illusion, a 'beautiful lie' to ensure the engineer, and in fact all human users of technology and their social communication about technology, that technology is manageable and the one last domain claiming predictability in our ever more contingent and insecure world.

In this contribution we will try to abandon this lie and construct an image of technology as technology – and not as a mere derivative of engineering or social construction. The conceptual instrument to do so is a second-order, i.e. self-referential type of system theory as developed by Niklas Luhmann (1995, 1997). This instrument is chosen due to its provision of a precise language for dealing with phenomena of recursiveness and co-evolution. At the same time Luhmann's theory abandons the fixation on the human individual, which in our view lies at the heart of the problem of contemporary descriptions of technology. When conceptualised with the human individual in focus, any approach to technology develops a tendency to orbit around the 'design fallacy' (Dennett, 2008), the view that everything designed needs a somewhat conscious designer, however dependent that designer is on what is already designed. Instead of discussing issues like what is the object or subject of technology, the system theoretical view dissolves all of them and concentrates on technology as system, its internal logic and its coupling mechanisms towards its social and physical environment. In the end not only a new piece of theory about technology as system is given, but also is substantiated and illustrated by some remarks about the implications of sustainability for technological and social development.

2 Conceptual 'premarks'

Before using Luhmann's system theory, several brief clarifications about its core ideas have to be made. First of all, the notion of system and elements of what Heinz von Foerster (1981) termed 'second-order cybernetics' were applied by Luhmann to the question of how to build a theory of society, especially modern society. The notion of 'second-order' denotes a situation where, e.g. in the case of cybernetics, cybernetic reasoning is turned towards cybernetics itself, i.e. thinking about feedback control in terms of feedback control. The main question of first-order cybernetics is: how to control a system through feedback of its own past states in its present calculations? Observation of the system of interest from its outside was the road to answering this question. The main question of second-order cybernetics is: how are cyberneticians constructing feedback models of cybernetic systems? The attention is now turned towards the observer and the act of observing systems. Taken to its extreme, this line of reasoning sees systems as observers who are observing themselves.

The theory of social systems is the result of what happens when a self-referential type of system theory is applied to the sociological problem of a theory of society. The theory is self-referential insofar as it takes into account the observer as the pivotal starting point of any observation, scientific or otherwise, and thus not only giving a theory of society if observed as made up of systems, but also a theory of society that contains itself, i.e. gives a coherent and complete description about how, in "the science of society" (Luhmann, 1992), theories are created. At the same time, this application of system thought to society yields insight for a more general approach to system theory, namely the clarification and conceptualisation of a descriptive language for self-referential systems. All complex systems that we can observe as such today are of a self-referential nature, i.e. they recur on themselves in order to evolve and change. This of course creates paradoxes, the greatest of them maybe the fact that A can be $\neg A$. What is meant by this seemingly contradictive equation is that any system can change from a state A to a state $\neg A$, given time for change. Spencer Brown (1969), who was already mentioned, developed a calculus for self-reference, further developed by Francisco Varela (1975), that enabled a three-valued logic for dealing with paradoxes emerging from self-referential systems. Luhmann very loosely used this idea, drawing a distinction between his type of system theory and existing theories of society, especially those theories that focused on the human individual as a starting point of theoretical reasoning.

What often irritates the reader about the theory of social systems is its 'inhumanity' (Viskovatoff, 1999), meaning that the human individual is not given the place of the main building block of society. If society is conceptualised as a self-referential system, everything that matters to society has to be neither physical nor made up of thoughts but inherently social. The basic social element in Luhmann's theory is communication. Society operates on, with, and through communication. In fact society can be observed as the totality of communication. Everything that is not communication is not society or a social system. Communication is thereby the result of a threefold selection process:

- selection of a content of information against a backdrop of other possible information ('what is communicated?')
- selection of an utterance of this content against a backdrop of other possible utterances ('is this communicated?')
- selection of a meaning constructed from this uttered information against a backdrop of other possible meanings.

Information is viewed as "a difference that makes a difference" (Bateson, 1972). You can picture this selection process of communication by ascribing it to human-centred *alter-ego* interactions: there is *alter* uttering information, and *ego* who understands that his information is meant for her thus realising communication. But when looking into social reality, you can easily describe all forms of communication without reference to human individuals. Communication in the economy can be observed in price changes on markets, turned into news headlines in the system of mass media and effecting legislation in the political system. The habit of using the human individual as anchor for communication is reflected in social system theory as 'social address': in order to ensure stability and longevity of communication, social addresses are communicated along, e.g. 'the CEO', 'the President' or 'the scientist'. It is clear that these addresses do not refer to the full complexity of a human being, its entire real of thoughts, feelings or metabolic activities. It only refers to its usefulness for communication in social systems. In other words: whatever goes on in your mind, whatever happens in your stomach at this moment, it does not influence society unless you manage to turn it into communication. It is important to note that this 'turning into' is not some kind of transfer of ontological units, i.e. a thought becomes communication. To frame it more colloquially: you cannot say what you can think; you can only say what you can say. This is pointing to language as the coupling mechanism of the human mind and society. Whatever thought can be expressed in language forces social systems to process it and vice versa. Social communication expressed in language is forcing a knowledgeable human individual to think about what is communicated (e.g. the latest election polls, football scores or articles on the nature of technology). In placing the human individual in the environment of society, thus drawing a distinction between them, the coupling of both realms becomes important.[1] This may be the greatest heuristic benefit of the theory of social systems: it demands the question of how things couple while working with totally different rationalities.

What is important for the further argument developed here is that distinct realms, in fact distinct systems, develop their own distinct core processes and codes of conducting them. In order to exert some influence over another, a mutually agreed upon mechanism needs to evolve. In the language of system theory this is called structural coupling. For example, the metabolism of an organism is structurally coupled to its food environment and vice versa. The food cannot change the structure of the metabolism; it can only be digested according to the metabolism's rules. It can of course kill the metabolism but this is merely it. However, both co-evolve through a phylogenic, as opposed to ontogenic, coupling and adapt to each other – the metabolism's organism looks for conditions that are beneficial for the food that is beneficial for its metabolism and the food evolves features for just that. But neither the rules of the metabolism nor the rules of the food interfere with each other; they remain distinct.

With these 'premarks' on some of the key thoughts of the theory of social systems, we dive into the options arising from them for conceptualisation of technology as system. In doing so, some of these premarks can be substantiated and explained in their consequences in more detail. First, technology can be conceptualised as a function system of society. Modern society structures itself into function systems that are independent from each other, e.g. the economy or politics or science. All function systems evolve their own code of conduct, e.g. the economy runs on a code of paying or non-paying whereas politics uses the code of government (power) or opposition (no power). Codes of today's function systems come as binary in nature. These codes enable function systems to take decisions, with one side of the code being the preferred one. In the economy it is always much more preferred to being able to pay than not being able to pay, unless this inability will lead, through the mean of investment, to an increased ability to pay in the future. The ability to pay of course is what is termed as liquidity. All codes do not operate in thin air but through a medium of communication. The media of communication in function systems are highly specialised and generalised. They have to be so in order to cope with the proliferating amount of complexity in society. What investment decision should we take? Which product should we make or buy? Of course the ones that ensure our ongoing liquidity would be the economic answer. But how to measure this as unambiguously as possible in order to ensure security in taking the decision – and not refrain from decision and stop processing? The answer for the economy is money. Money is one highly specialised and generalised communication media, the dominant medium in the economy and on which the code of liquidity/illiquidity can be exercised smoothly. For politics the medium is power, for science it is truth and so on (Luhmann, 1995; Luhmann, 1997).

Returning to technology, it can be conceptualised system-theoretically in three different ways. The first possibility is that of technology as a function system. Technology can then be observed as a social system operating on communication as its basal element. There would be no physical artefacts involved, but the factual dimension of meaning construction in this particular system would act as a social proxy for physical aspects of technology. The code of technology can be conceptualised as the binary form of *work/fail*: the decision taken within technology circles around this question and the preferred side of the code is clearly 'work'. The medium on which the code can act and around which communication in social systems could form may well be the medium of *operativeness*.[2] With both medium and code, multiple forms of technology can emerge while at the same time the vast insecurity regarding technological trajectories is reduced with using the work/fail code on the medium of operativeness: technology either works, then it is selected, or it does not, then it is neglected. Within the system of technology, other social systems can emerge, most notably organisations of technology, e.g. standardisation organisations (consortia, networks, formal organisations) or formalised innovation projects. On a smaller scale within and across these organisations, interaction systems could form around processes underlying the working of these organisations, e.g. in R&D team meetings or at conferences dedicated to technological issues.

Second, technology can be conceptualised as a part of one or more function systems, maybe connecting these function systems, e.g. science, economy and politics. Technology is then observed as a secondary primary system (Fuchs and Schneider, 1995). Most of what has been said above holds for this form. Such a secondary primary system of technology would have the same code and medium as technology as a function system, but there is no need to develop internal organisations or interaction systems. These would still remain within the logic of their function systems, but technology as secondary primary system provides assistance and direction for communication, especially in interaction systems processing technological issues in communication, taking decisions regarding technology development or use while at the same time being influenced by the actuality of existing and the potentiality of to be technologies. Both solutions to conceptualisation would place technology within society, as a part of society acting on communication, thus dealing with the same 'currency' as the rest of it. This may well seem beneficial enough for social analysis of technology and the way you can connect thoughts on operativeness as medium to more action-oriented approaches like the social construction of technology (Bijker et al., 1987). Even the exclusion of the physical side of technology need not be problematic, as Halfmann's (1996) double-edged view on technology as medium and installation shows. However, both conceptualisations of technology from a system theoretical point of view do not actualise the full potential inherent in it.

Thus, we turn to the third possibility to conceptualise technology as system: technology as an autopoietic system distinct from society and the human individual. 'Autopoiesis' means 'self-making' (Maturana and Varela, 1980) and was used by Chilean biologists Humberto R. Maturana and Francisco J. Varela to give an answer to Schrödinger's question 'what is life?' To call a system autopoietic implies that there is a unity of a network of components which interact within this network that produced them and in doing so realise this network as a unity distinct from its environment (Varela et al., 1974). This concept of a self-making network of components who recursively produce the basis of their own continuous existence has primacy over mere reproduction as a key feature of the living. In its abstract form, autopoiesis can be seen as "a general form of system-building using self-referential closure" (Luhmann, 1986, p.172). Luhmann continues that if we take this definition of autopoiesis serious, then "we would have to admit that there are non-living autopoietic systems, different modes of autopoietic reproduction, and general principles of autopoietic organisation which materialise as life, but also in other modes of circularity and self-reproduction" (Luhmann, 1986). We follow Luhmann here and take this abstract notion to technology as an autopoietic system. Such a system would not be 'social', as the other two conceptualisations would have been. Such a system is first and only 'technological'. Just as the human mind is distinct from its brain and its society, technology would then be distinct from all of these. Society as well as human beings constitutes the environment of technology, just as technology is constituting their environment. And just as, e.g., society proceeds with its business only according to its rules, technology does by proceeding along technological rules. But how do you turn technology into a proper autopoietic system of its own provenience and origin?

3 How to systemise technology proper?

In order to systemise technology in the way Luhmann systemised society into social systems, we need to answer the question whether technology is physical or non-physical, having either a physical operation or a non-physical operation at its core. Technology can easily be observed in its material artefacts and accordingly it would be easy to see it as something physical and place all its non-physical aspects in the social realm. However, this would then be one of the options sketched above. The argument taken here is that technology is neither physical nor social; it is above all technological. Its material artefacts are not technology itself just as the human bodies observable all around are not identical with the human beings they belong to. To be human is not a physical feature or anything that could be decided physically alone. It was exactly this fuzziness of the concept of the human individual that took Luhmann to abandon it altogether and separate it into the three different realms of biology (body/brain, physical activities), psychology (mind, thoughts) and sociology (social systems, communication). Constructing a theory that observes technology as inherently technological is, just as constructing a theory that observes society as inherently social, demands a precise definition of a non-physical, non-social basal operation of technology, of its non-physical, non-social medium of internal evolution, its general code, and the way it actually evolves and, connected to that issue, how it couples with its environment, especially with society and the human individual.[3]

The only feasible contender for a non-physical, non-social basal operation appears to be information in a slight rephrased Batesonian sense. *Information shall be understood here as a pattern that influences the formation and transformation of other patterns. A pattern shall be understood as an order of any sort*. The carrier of the pattern is of no importance, it "has an integrity independent of the medium by virtue of which you have received the information that it exists" (Buckminster Fuller and Applewhite, 1975). Information thus has a synchronic and diachronic nature: the pattern is timeless insofar as it is as it is – an order like 1-2-3-4-5 – but as to become information it needs to influence other patterns thus creating a before and after the information. Imagine a vinyl disc and the pickup. The state of information on the disc is synchronic; Luhmann (1995, 1997) would call it potential and Giddens (1984) virtual. The movement of the pickup over the disc – or the movement of the disc under the pickup – changes the state of information into a diachronic form, a before and after is observable. Information becomes actual. The transformation process of the engraved physical pattern into mechanical and electrical patterns is in itself information. It turns the uncertainty of what might be on the disc into the certainty of hearing Bob Dylan. One could argue that there is no surprise in technology as technology eliminates surprises by information and to inform is to order. The reader should be aware that this process does not need consciousness, at least no human form of consciousness. The engraved biochemical pattern in our DNA does not need it; it only needs a pickup able to fit the pattern.

Regarding the general medium of technology, we argue here that *operativeness* can act as one, just as meaning acts as the general medium for social systems (and in fact also the mind). All information in technology circles around information on operativeness of technology, just as all communication in social systems circles around communication of meaning in and about those systems. In social systems there is hardly a general code, unless you take the code of sense/nonsense as given. This is, however, a strange code as there is not so much a preferred side but the non-preferred side is non-existent. Meaning cannot be contradicted unless in a meaningful way and there is no nonsense unless it makes sense to mark something as nonsense. But regardless of this strange feature of meaning, the code sense/nonsense does work in the way depicted here: it enables communication to mark itself as meaningful or not, even though it remains meaningful also in the nonsense case. Furthermore, this general code acts as a backdrop to which other codes can be checked: is paying/non-paying a meaningful code for the economy, i.e. does it make sense to use it in an economic circumstance? So, if operativeness is the general medium of technology as system, the code *work/fail* might also be applied as a general code to which other technological codes can be checked. The evolution of technology as system is then driven by information about the working or failing of technology, with working as the preferred side and with failing as useful information into which directions not to go. *Technology will then move into a direction, which produces more information about what works, i.e. more patterns that have the ability to form and transform other patterns*. If there are transformational patterns working on themselves and actually work in transforming themselves and give rise to new and stable transformational patterns, we speak of technological evolution.

What is left now is the entire complex of how technology couples itself to its environment and how it ensures co-evolution with that environment. Three environments can at least be identified: the natural environment, the human individual and society. In a strict Luhmannian sense, the human individual would need to be differentiated into a biological system (body and brain) and a psychic system (the mind). The biological aspects of the human individual would then mostly belong to the natural environment of technology, whereas the human mind would be a distinct environment. We start with the coupling towards the human body. The mechanisms for coupling are technological tools, characterised and determined by their physical shape and causal features. The physical shape of technology does not only couple with the human body in the sense of how to fit, but also carries information about its use. A hammer mimics the human hand and with its shape ‘explains’ what can be done with it. This design of the tool can become complex and transcend its physical shape, e.g. in the form of an operating system on a computer.

The design of the hammer is not only useful for coupling with the human body, but it is also connected to the human mind insofar as it is easy understandable. In other words: it makes sense. However, the design focus is mainly on the physical interaction of tool and body, whereas the design focus of an operating system is the complex interplay of manual manipulation and cognitive activities. Take the operating system of the iPhone along with its touch screen hardware and there you have technology coupling itself to the human individual in its totality. The coupling to society can be twofold. The easiest way is via the human individual, using its couplings to society, i.e. language. The vast amount of media coverage and small talk about the iPhone speaks evidence about this way of coupling. The task for technology would then be to attract the attention of the human individual, be practical for physical application and attractive for cognitive processes, thus force the human individual to turn technology into a communicative theme for society. The returning feedback from society is sales in the economy (paying) enabling Apple to pay engineers and designers to create more and newer iPhones. More difficulties arise if technology tries to couple directly to society. Up until now, everything that is communicated in society has been brought in via the coupling of society and human beings. 'Brought in' is thereby metaphorical and does not denote an ontological entity somehow miraculously jumping from a human mind into a social system. It just means that a thought has been expressed in language and thus forced a social system to process it as communication. From then on, it can feedback and force a human mind to process it as a thought again (Luhmann, 1997). With the advent of internet search engines, this has changed significantly. A search engine is an algorithm searching any form of database and orders information according to its internal structure and the search phrase. The result is a new structure of information presented to the one who is searching. However, this 'one who is searching' is itself influenced by past searches or input from other sources. One can think of a human individual reading a news site on the internet, then searching for some background info on the issues discusses there, being presented this info, which turns into a new issue on which it processes another search and so on. As soon as this process starts, looking for a 'first search' or 'first information' that triggers the beginning of the search becomes meaningless. In fact, the search phrase itself becomes meaningless in this sense or in other words: a search engine is a pattern that influences other patterns, including the initial search phrase as well as itself. *This is a recursive loop with no vestige of a beginning and no prospect of an end* – unless someone pulls the plug. The more societal communication is taking place via automatised and 'technologised' platforms, e.g. Google+, the easier it is for technology to couple directly to society. It only needs to provide an automated generator of language, the trigger for all communication in society. On a side note, this clearly does not involve any form of artificial intelligence; intelligence is not a feature of autopoiesis and not necessary for it.

Given all these forms of coupling, how then does technology evolve and co-evolve? In the more traditional views on technology, technology evolves either by the work of the engineer or by its social acceptance (or non-acceptance). In either case, there is a 'someone' involved in developing technology, i.e. technology has no internal capability to change without external interference. If technology can be observed as an autopoietic system, the engineer, e.g., is clearly in the environment of technology, along with society. What can be said about the relation with the engineer is that both evolve in a structural coupling that is co-created through that relation. But technology would only operate along its own lines, its own medium and code; engineers can at best irritate technology. However, if something is formulated in a certain way technology has to process it just as a thought expressed in verbal or written language forces social systems to react on it, but only along their own lines of operation. So, engineers can only think about how they can properly irritate technology but what technology then does with this irritation is beyond the engineers' scope. The irritation can be done by creating a physical shape with causal determinations and/or a design interface. *This will force technology as system to process it as technology, operating the work/fail code in the medium of operativeness on the shape/design. And it is only the outcome of this operation that determines whether or not something is a (working) technology, able to evolve further, or not*. The engineer, on the other hand, then can only react on the outcome of this process and eventually try something else. One conclusion drawn from these remarks is that *technology can only progress technologically*, i.e. technology always needs technology to evolve. There is no technological evolution with, say a change in the behaviour of technology application. That is unless this change in behaviour irritates technology in a way that it reacts with a technological answer to that change, e.g. using the text message feature in mobile phones – a feature once only installed for maintenance purposes of telecom service personnel – did not propel the evolution of mobile phones unless it was turned from SMS to MMS and further to mobile emails, thus increasing the technological capacities of mobile phones. If there had not been the possibility to 'upgrade' text messages to more sophisticated technological means, this feature would have not had any effect on the mobile phone's evolution. However, as biological features once developed show the tendency to come up at different locations – the eye, e.g. was developed several times – text messages propelled the development of another technology, namely Twitter and its offsprings like Facebook wall postings, which in turn changed social communication habits and the rest, is history. Another outcome of this reasoning is that there are no technology leaps. Technology always needs technology and what kind of technology is decided by applying the work/fail code in the medium of operativeness. There can be a technological evolution that enables society to communicate radically different, as e.g. the mechanical printing press or the hypertext protocol did, but these leaps are social leaps, not technological ones – *Technologia non facit saltus*.

4 Reconstructing the case of the automobile

In order to illustrate this new type of theory about technology as an autopoietic system, the case of the automobile is chosen and its history and possible future will be reformulated in a system theoretical narrative. This narrative will concentrate on the evolution of the automobile as we know it today, some of its self-enforcing couplings with society, and the ecological challenge it faces in order to survive as a technology.

What can count as the history of the automobile can be dated back as far as 6000 years ago with the invention of the wheel among different cultures across the planet (Eckermann, 2001). However, the distinct character of this particular technology is a self-propelled vehicle without any reliance on human or animal assistance, in short, mobility without involving the living. The first empirical evidence for that can be found in 1674 with the construction of a reciprocating engine powered by gunpowder. The principles laid down here are archetypical for all combustion engines motoring automobiles today. The engineer of that age was the Dutch physicist Christiaan Huygens, but his name is of no interest to technology. What is of interest is his understanding of the physics of his time and his construction abilities that forced technology to process it as information about the working of the engine which was positively selected and thus able to evolve further. In order to evolve further, more technology was needed and as there are no leaps in technology, a steady evolution in technology had to occur. And occur it did, e.g. the various attempts to use steam as a means for powering self-propelled vehicles. Interestingly, the couplings with the engineer were a lot stronger and more elaborate for most of the automobile's evolution until the last century, so the main drive for its evolution was human curiosity, which in turn co-evolved with it. Needless to remark that the first couplings with society were established with the military in the 18th century, whose own logic of work/fail did not chose the steam automobile as a useful topic for communication. It was the invention of the petroleum fuelled combustion engine in the 1850s and its application in the automobile in the 1880s that truly mark the birth of what we now are used to when talking about cars. The coupling established with society was not via the military but the economy, more precisely the omnibus (technology) and omnibus services (organisation, social system) for commuting, which were already in place since the 1820s with steam-powered vehicles (Klapper, 1978). This coupling was increasingly successful because of the social evolution of the working class as an economic necessity in 19th century industrial development. The petroleum-powered combustion engine in the omnibus made omnibus services cheaper (paying/non-paying) and enabled commuting of workers over longer distances, which in turn separated living from working, which in turn made running a subsistence agriculture as a 'side job' to industrial work less possible, which in turn established the main work structures along with the division of labour in factories and across gender (women's work equals non-paid work at home) and so forth. This clearly is a recursive loop at the beginning of public transportation companies and the public-private sector of transportation industry.

The automobile as the main carrier of individual mobility, however, needed more self-enforcing couplings than this. We will briefly mention two of them. The most obvious coupling was the large-scale production-line manufacturing of Ransom Olds and, more notably, Ford (1928). This did not only couple the product with the way of producing (technology) it, but it also coupled technology with a social system: the organisation. The evolution of the large-scale corporation became the dominant trajectory for all organisations in the 20th century, not only in the economy but also across all function systems, e.g. healthcare organisation, universities and governmental bodies. At the same time, this coupling also produced the manual worker of Taylor (1911), thus coupling the automobile for individual mobility with the just mentioned omnibus services and establishing a self-referential loop. Another important coupling, and one almost forgotten, was the introduction of the sidewalk in the late 1920s. There had been sidewalks before, but up until then roads within cities were joint places of meeting and living. With the proliferation of the automobile, these places were contested for dominance of use. Due to the high rate of accidents, automobiles were at first viewed as dangerous and a nuisance. There was a significant challenge for the automobile, as the drivers were labelled as 'street maniacs' or 'speed dogs', with sales numbers of Ford in the US declining from 1923 onward (Stengel, 2010). The coupling with the economy, however, proofed to be strong enough to set up a lobby for the automobile, relabelling pedestrians as 'jaywalkers' with newspaper articles and caricatures – coupling with the social system of mass media – as well as financing campaigns at schools for more road safety – coupling with the social system of education. This changed public opinion in the course of a few years. Additionally, politics joined this cause as the automobile established a coupling towards the political system via the means of taxes: the more automobiles, the more revenue from taxes on automobiles. By this multitude of couplings, and many more followed, the automobile managed to set up enough self-enforcing recursive loops to stabilise itself as the dominant technology for individual mobility, i.e. it resulted in more information about what works for the automobile technologically as well as socially. We have to stress this last point, because with this technology 'infused' its code of work/fail and its way of producing information, i.e. patterns to influence other patterns, into social systems. In other words, technology constructs social reality by adaptation of society to a techno-logic and this adaptation comes about by the multitude of couplings between technology and society.

For the last 40 years, the automobile encountered an increase in opposition, just as it did in the 1920s for being a hazard to pedestrians. The source for this opposition is the ecological crisis, socially communicated from 'Silent Spring' to 'Limits to Growth' and the latest reports by the Intergovernmental Panel on Climate Change. The earliest discussion was that on air pollution, triggered by studies on smog in Los Angeles in the 1950s which in turn triggered the technological development of the catalytic converter for petroleum-fuelled combustion engines (Houdry, 1957). The reaction of technology was a technological reaction, what else? What is more interesting is that society followed this reaction insofar as politics passed legislation demanding catalytic converters to be built in automobiles. It has to be noted that catalytic converters themselves are harmful for the natural environment due to the necessary addition of certain chemicals into fuel, the increase of fuel consumption and thus carbon dioxide emissions, and the use of highly toxic metals in building these converters. One could add that with the invention of the catalytic converter the automobile gained, at least for the time being, a 'green' status, i.e. that it could be used without the need to reflect on its harmful environmental impact. Technology and in particular the automobile managed to force society to process this problem of air pollution in a technological feasible way. Just as a reminder, in the 1970s after the oil shock there were car-free Sundays, e.g. in Germany. This could have been a reaction to the problem of the ecological crisis just as feasible, at least for society, as the invention of a technical artefact. However, for technology this would have been no option, no practicable trajectory for technological evolution. Today the most pressing aspect of the ecological crisis, at least in social communication, is climate change and the necessary reduction in carbon dioxide emissions. What is happening here? Again we can observe a move towards new technologies, namely engine technologies, be it the fuel cell, the electric motor or hybrid drives. However, it can be argued that the challenge of climate change cannot be tackled by focusing on technological solutions alone, as new technologies often lead to more consumption of resources instead of less. This is the so-called Jevons paradox (Alcott, 2005), explaining that an increase in technological efficiency in resource use equals a decrease in price for that resource which will lead ceteris paribus to an increase in resource demand. If this is the case then technology cannot play the leading role in addressing the ecological crisis. Nevertheless, technology can only – and will only – progress with (more) technology. However, as has been shown, technology established multiple couplings with society as well as with its human designers and users thus not only accelerating its own evolution but also the evolution of society. Moreover, technology managed to make social communication use its work/fail code as a secondary code in each function systems decision, i.e. society uses a technological logic to determine its present and future reality. This tight coupling, ensuring for technological and social co-evolution may as well hinder any non-technological solution to a problem like climate change or resource scarcity. As can be observed in current discussions, technological solutions dominate. There is one recent development though that may yield another option. The introduction of carsharing more than 20 years ago evolved into a new field for automobility and is taken up by economic organisations. Being for a long time only organised as associations with no intention to earn profits, and with little technological support for marketing their services, in recent years a significant change has begun. Carsharing is now done by large-scale companies even from the automotive industry. Daimler has started its own branch of carsharing with car2go in Germany and the USA (Reichel et al., 2009). At the same time, carsharing services became more and more 'technological', i.e. they used not only the telephone for booking but increasingly the internet also. The cooperation with new communication technology and the ability to access an automobile – for car2go there is even an iPhone application – turned this form of individual mobility into a technological processable solution. This twofold move, towards the economy and towards a fusion of technologies, turns the once sufficiency-oriented, ecologically aware consumption of non-owned but shared automobiles into something both society (her: the economy) as well as technology can continue to operate with. If this proves to be the positively selected technological way into the ecological future of the automobile, however, is uncertain. First, it is unclear whether or not this new form of using the automobile is really delivering less ecological impact. But this will now be decided technologically and that leads to the second uncertainty: whether or not this in fact new automobile technology will really be selected as the favoured future technological trajectory. This also will now be decided technologically – and only technologically. What can be said with the history of the automobile in mind is that the new automobile – or better: automobility – will be successful if it can establish strong and multiple couplings with different parts of society as well as with its human designers and users. Maybe the cleverest move of this technology of carsharing was the liaison with communication technology (mainly the internet) and the incorporation of its more appealing physical tools (mainly smartphones and their applications).

5 Conclusions and outlook

In this contribution, a new form of an autopoietic theory of technology has been sketched: technology as system. Its main characteristics are the self-referential description of technology as an independent and distinct realm in the environment of society and the human individual, especially as regards its medium (operativeness), its internal code (work/fail) and its evolution through a multitude of structural couplings with its environments. This has been illustrated with the example of the automobile and its history, retold in the light of this new approach. Although being in a *status nascendi* the theory of technology as system yields insights not only for understanding past technological developments and their success factors, but also for the present challenges of the ecological crisis. Technology has progressed through establishing multiple couplings with its environment: with the human designers and users of technology, but even more with society and its function systems. Clearly this progress is co-evolutionary and technology appears to have managed to infuse its code and internal conduct into society as well the mind of the engineer. Work/fail acts as a secondary code beneath or above other codes and this proves to be the strongest coupling we can observe today. Through this coupling society constructs reality through the lens of technology and there appears to be now way out of a technological trajectory for social evolution. This clearly is parting with the view of technology as being socially constructed. Quite on the contrary, technology as system is constructing social reality. Not only is the future of technology solely decided within and through technology, but the future of society is also decided technologically. The implications for the pressing needs of sustainable development in the light of the ecological crisis – climate change, overconsumption, resource depletion, loss of biodiversity – are irritating. Instead of focusing on behavioural change of lifestyles, the theory of technology as system points to a different directions: the technological change of lifestyles and society.

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Notes

1 In order to be system-theoretically precise, we would have to distinguish the biological system of the human body, including its brain, from the psychic system of the human mind, including the realm of thoughts. In social systems, the human individual would appear in communication as a person, which acts as a social address to which communication can be anchored. For ease of reading, we keep the notion of the human individual/being and confuse it for either its biological aspects or its psychic aspects.

2 Operativeness should not be confused for function or functionality, both being system-theoretical terms denoting the function of a system that is defined from what the system is not, i.e. its environment. Operativeness here just acts as the backdrop to the operations of the work/fail code, with technological artefacts, being physical like a hammer or non-physical like a computer operating system, as the forms through which the medium is realised.

3 The reader should not confuse the physical or non-physical artefacts of technology with technology as system. In a system-theoretical view, those aspects of technology could be described as allopoietic, i.e. they are not self-making but made by someone else. In the view detailed here, however, technology is not allopoietic and even its manifestations are better not conceptualised as such, not even as systems, but as mechanisms of structural coupling with technology's environments.