INAUGURAL LECTURE

Prof Dr Ben van Lier CMC

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Thinking about ecologies of autonomous cyber-physical systems and their ethics

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Thinking about ecologies of autonomous cyber-physical systems and their ethics

Inaugural lecture

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Preface

The world around us is changing rapidly as a result of technological developments. In contrast to previous technological advances, technologies and ensuing technological applications such as the smartphone are now increasingly interconnected (cyber-physical systems) and have an increasing level of autonomy in the execution of their tasks (autonomous systems). As a phenomenon, technology is part of our day-to-day lives and work activities in the technology-based applications that we use, such as Siri and unmanned drones. These applications influence our perceptions and actions as human beings, changing how we experience reality. We seldom stop and think about the development or manifestation of technology in our era, or about how the technology actually works and could potentially work. Especially since technology has become an instrumental part of our daily lives and working practices, new knowledge about this subject is of crucial value in preparing us for a future where technological developments will become even more instrumental for humans. New knowledge can help us humans better deal with the technological developments that are emerging across the globe and rapidly approaching the Netherlands and Europe as well. However, new knowledge is created only through observation and analysis of these new and interconnected technological developments and their potential impact. The results of such an inquisitive approach will, in turn, be helpful in the development of new theory that can help us better understand this new whole, help us learn to deal with it, and, if possible, even help us influence its functioning. The possibilities of new technology can, in turn, be identified by building simulations, demos, or pilots of possible applications produced out of the new whole of humans and technology, and the resulting changes. Any experiences thus gained will lead to new insights that will prove useful in the design and manipulation of new technological developments. No matter how clear-cut this process seems, today's technology will be different tomorrow, and any kind of certainty based on existing knowledge will be replaced by the uncertainty brought by new developments, as we will find it hard to get the measure of the correlation and technical and social impact of these developments. This interplay between humans and technology in a new socio-technical whole therefore also calls for a rethink of how we develop new insights and acquire new knowledge. The rapid development of technology is not so much a revolution as an evolution, and every one of our observations, big and small, of the developments in technology and their potential impact on humans, organisations, and society will help in the development of new knowledge that we, as individuals, organisations, and society, need to define our human existence in an uncertain future. Hopefully, the contents of this book will help change the way we think about technology and its impact on us as humans, and will be considered and experienced as a cognitive exercise and analysis of the phenomenon of technology in general. In this book, the phenomenon of technology will be approached and analysed from the perspective of natural ecology. And finally, it will address the question of how the autonomy of technology is shaped and what this could potentially mean for humans. This book will close by going into the question of whether our existing ethical beliefs will continue to be adequate considering what these systems will do to us as humans.

Acknowledgements

This book is the result of continuing thought and research processes that deal with the development of interconnected technologies. As per usual, the process of research and production was a long journey of falling, getting back up, and starting over again, a draining process that required lots of perseverance. Especially since I mostly do my research work at home, thinking, reading and consulting online sources, while also having a regular day job, my family tends to bear the brunt of this process of thinking and writing. Without the love and support of Hedwig and my children Joost, Liese, and Sofie, I would have found it a lot harder to persevere with this process. I therefore owe them a great debt of gratitude for standing beside me and supporting me in producing these results. Without the support of my employer, Centric, and specifically Centric's chief executive Karim Henkens, I would simply not have been able to conduct this research alongside my regular work in this time span. My colleagues Richard, Karin, Ilse, Yvonne, and others were also indispensable in publishing and raising awareness of the results of this process in a dignified way. Thinking about the phenomenon of technology is not something I can do on my own in isolation. I am extremely grateful to my colleagues and the students at Rotterdam University of Applied Sciences' Creating010 knowledge centre for lending me their ears to bounce ideas off them and for the many discussions about this subject. I would also like to thank my colleagues at Steinbeis University in Berlin and Stuttgart, and Prof Löhn, Prof Meck, and Prof Lasi in particular, who placed their trust in me and provided support in the thinking and writing process that went into the production of this result, for which I am eternally grateful to them. My hope is for this book to be a new (intermediate) step in the continuation of my personal development and the ongoing research process. The research process will continue and will, I hope, lead to new results in the future, circumstances permitting.

I. Methodology

The changes that are currently happening in the world as a result of technology are making humans and technology increasingly interconnected and interdependent entities. The increasing digitalisation of everyday physical objects plays a key role in this development. Cyber-physical systems, for example, are objects that, thanks to software, can easily be interconnected in networks, while becoming more and more autonomous in their functioning, communicating between themselves, and possessing the ability to jointly make decisions. More than ever before, human and object are becoming interconnected because technology, as Cilliers (1998) put it, *"forms part of most of our tools; it infiltrates our social world and it is rapidly becoming the most important medium for communication" (1998:1)*. The rapid development of new combinations of human, object, and technology is coming up against the boundaries of our knowledge. The interplay between humans and technology in a socio-technical whole therefore calls for a rethink of how we develop new insights and acquire new knowledge. Back in the first half of the twentieth century, Schutz (1932) already argued that the world in which he lived and worked was far from homogeneous, claiming that the world of his day was actually made up of a complex whole of interconnected social perspectives. Schutz believed that it is up to social sciences to analyse and explain this complex and interconnected social whole, thus creating clarity and knowledge on the interrelations between the world's various social dimensions that we humans have created. Such analysis should, according to Schutz, be radical to be able to unearth the foundations of the scrutinised social reality and use the newly-acquired knowledge to shift or erase the identified boundaries between the various perspectives. An analysis down to the deepest depth of existing social relations would, as Schultz argues, lead to *'the ultimate source of meaning and understanding'*. Berger & Luckmann went on to define Schutz's views on the development of knowledge as the discipline of *'sociology of knowledge'*. Sociology of knowledge is, in their view, focused mainly on analysing the *'social construction of reality'*, i.e. the way in which reality is developed and experienced within these social constructions. For the further development of knowledge in the domain of our day-to-day lives and jobs, phenomenological analysis as a method of description of the phenomena in our world offers, according to them, sufficient basis for analysis and explanation of these phenomena. The explanations produced by phenomenological analyses and descriptions can be seen as not only empirical, but also as a source of knowledge through the continuous and ongoing objectivisation of the reality we experience. The world of Schutz and Berger & Luckmann was still one that consisted primarily of social relationships between humans. In their time, technology other than manually operated tools played only a minor role. It was one of Schutz's peers, Heidegger, who was the first to add a new interpretation of the phenomenon of technology to this social dimension. According to Heidegger (1977), the concept of technology as a means is no longer sustainable. He argued as follows: "*The current conception of technology, according to which it is a means and a human activity, can therefore be called the instrumental and anthropological definition of technology.*" In Heidegger's view, we may have to, after having gradually scrutinised what exactly the phenomenon of technology as a means entails, conclude that the function of technology as a phenomenon for us as humans is to reveal, expose, or unveil what we are as humans. Technology reveals the world to us and challenges us to further define what we as humans are (or want to be) with respect to the phenomenon of technology. In Heidegger's opinion, the essence of modern technology precisely manifests itself in the enframing of our thinking. Heidegger claims that the term 'enframing' denotes the consequences of technology, which create a framework for our daily lives and working practices that is engendered by everything that is at the disposal of technology, which leads him to state the following: "*Thus the question as to how we are to arrive at a relationship to the essence of technology, asked in this way, always comes too late. But never too late comes the question as to whether we actually experience ourselves as the ones whose activities everywhere, public and private, are challenged forth by Enframing. Above all, never too late comes the question as to whether and how we actually admit ourselves into that wherein Enframing itself comes to presence*" (1977:24). This latter point forces us, according to Heidegger, to keep thinking about the essence of the phenomenon of technology. In his opinion, this essence can in no way be referred to as human. On the other hand, it cannot be called technological either. Heidegger (1954) argues that the essence of technology is found "*in what from the beginning and before all else gives food for thought. It might then be advisable, at least for the time being, to talk and write less about technology, and give more thought to where its essence lies, so that we might first find a way to it*" (1954:22). Heidegger writes that thinking about the essence of technology and the analysis thereof based on which we humans develop technology, use technology, and let technology penetrate all aspects of our existence, is a crucial step for our existence in the world. In our current age of rapid technological changes, Heidegger's thoughts on thinking in terms of the essence of technology are more relevant than ever. As humans, we are increasingly interconnected with technology and technological applications, and we have views on technology in terms of the way we physically experience it in the moment. Technological applications are, however, increasingly networked and able to communicate, interact, and autonomously make decisions in these networks. It is a development that we no longer experience as a physical one or even as a development at all, as we are preoccupied only with the end result. Communication and interaction are making new technology even smarter and increasingly able to autonomously make decisions on our behalf. The central focus of this book is on the increasing interconnectedness and autonomy of systems, both in a biological and a technological sense. In the words of Feyerabend (2003): "*the history of science, after all, does not just consist of facts and conclusions drawn from facts. It also contains ideas, interpretations of facts, problems created by conflicting interpretations, mistakes, and so on*" (2003:50). This study, too, has looked for historic links and facts that could prove significant in understanding the developments described. In Feyerabend's view, the development of knowledge from a historical perspective is not a series of self-consistent theories that converges towards an ideal view. He also argues that it is not a gradual approaching of truth either, but rather "*an ever increasing ocean of mutually incompatible alternatives, each single theory, each fairy-tale, each myth that is part of the collection forcing the others in greater articulation and all of them contributing, via this process of competition, to the development of our consciousness*" (1975:60). The research results presented in this book are also a collection of current insights on subjects such as ecology, autonomy, independent communication and decision-making through the technological development of cyber-physical systems. Towards the end of this study, I will go into the ethical aspects of this new ecosystem of autonomously functioning cyber-physical systems for us as human beings. The human experience, Feyerabend argues, is what an observer observes under normal circumstances and describes in terms that are aligned with the facts that everyone can understand. The human experience, and consequently also the scientific experience, presents itself, according to Feyerabend, along with theoretical and scientific assumptions and does not precede them. Scerri claims that science, from a sociological perspective, progresses if we consider it the result of a whole that comes out of a social entity. Scerri argues that "*science proceeds by almost imperceptible small steps in an evolutionary fashion, not so much through the genius and brilliance of individual scientists but more by a process of trial and error, chance and sheer stumbling around. Above all, I claim that science is a collective enterprise, but not consciously so*" (2016:4). In Scerri's view, the widely acclaimed heroes of science are not the only ones driving scientific progress, as he widens the scope by stating that all scientists whose research is contributing to scientific progress in their respective fields are the real heroes. Scerri argues that every scientist plays a fundamental and equally important role in the progress of his or her respective scientific discipline. In Scerri's words, "*all participants are integral parts of one underlying whole and so it makes little sense to distinguish them in the first place*" (2016:9). Applied research conducted at the University of Applied Sciences is therefore, in terms of its approach, analysis, and application of the phenomenon of technology, one of the participants that take part in the development of new knowledge and insights into what new developments in technology can mean for humans. The vision that Scerri supports is that of an organic development of scientific knowledge ensuing from an "*interconnected organism, a living Gaia-like creature possessing many tentacles, branches and sub-branches. In this view there are no winners or losers in the race to arrive at a better description of nature. And there are no abrupt scientific revolutions*" (2016:10).

II. Introduction

The Merriam Webster dictionary defines ‘autonomy’ as *“the quality or state of being self-governing”*. Being autonomous creates the possibility of existing, functioning, or operating separately from others and without external control or support. Being autonomous therefore also means that a form of freedom is created to execute tasks or achieve predefined goals independently or together with others. In essence, the development of autonomic computing is based on the concept of autonomy, which originates from the combination of the words ‘auto’, which means ‘self’, and ‘nomos’, which means ‘law’ or ‘governance’. In autonomic computing, the concept of autonomy refers to a development where individual or collaborating systems acquire a growing level of freedom to perform tasks or achieve goals independently and without external control or support, such as by humans. The development towards collaborating autonomous systems marks a new phase in the development of traditional and independent objects. Knowledge is needed to be able to answer questions about the factual knowledge of systems’ autonomy, the shaping of systems’ autonomy, and the mutual collaboration of autonomous systems in the performance of tasks and realisation of predefined goals. According to German philosopher Heidegger (1927), objects or systems are always what he calls equipment, i.e. a structure that makes the object what it is to us. Heidegger argues that an object never manifests itself to us as a stand-alone entity, but always as a whole of equipment that is bound together in a context. The equipment ensures interconnectedness between the object and its environment, while also determining how we perceive the object in this environment. The whole of the equipment that exists between human and object determines how we, as humans, can or want to use the object within the whole of which it is a constituent part. According to Heidegger, an object is therefore never a stand-alone entity, but rather part of multiple forms of equipment that are, in turn, also interconnected. Each specific combination of an object that is connected in its equipment and in how we deal with this whole makes that the specific object acquires a manifestation for us that Heidegger refers to as a tool. We, as humans, assign a specific functionality or meaning to this tool or whole, which allows us to use the object to perform actions or have the object perform certain actions with some level of autonomy. The whole of what we experience or perceive of the functioning of the object thus, as Heidegger claims, manifests itself as a stand-alone whole. This manifestation is what Heidegger refers to as a phenomenon. Technology and interconnected technological applications are the phenomenon of our current time. As humans, we connect to networked, stand-alone objects, such as smartphones, smart TVs, electric vehicles, or personal assistants such as Apple's Siri. Although separate objects do manifest themselves as physical and stand-alone objects, they are now enriched with new possibilities through the addition of combinations of algorithms and software. The algorithms and software are making it possible for the object to connect to networks and communicate and interact with other connected objects. Communication and interaction between objects through the exchange and sharing of data and information are revealing new functionalities of the individual object on the one hand, while on the other jointly creating a new whole that offers more capabilities than the sum of its constituent parts. This way, exchanging and sharing data and information through networks not only creates new capabilities for the object itself, but also for the functioning of jointly operating objects. The use of algorithms and software does not change the manifestation of the object itself. But what does change is the functionality and functional autonomy of traditional objects as used and perceived by humans. The interconnections, communication, and interaction between people and objects lead to increasing possibilities of autonomous performance of actions by the object. The increasing interconnectedness in networks within which people function together with objects, algorithms, software, and information is not only changing the functionality of the object, but also our relationship with the object or the joint objects and our perception of the functioning of these objects in their equipment. As objects' autonomy continues to grow within a specific context, the two-way relationship between humans and autonomous objects will change drastically within that same context.

This essay will focus primarily on the development of objects' increasing autonomy. The development towards such increasing autonomy will be addressed based on the description of the development of the concept of ecosystem. Within an ecosystem, autonomously operating and interconnected organisms and non-organisms play, within a specific context, a role in the conservation and development of this complex whole. In 1926, holistic philosopher Smuts described this ecological whole as a synthesis or a structure arising from underlying and interconnected components. Smuts describes this whole as follows: *"A whole is then a synthesis or structure of parts in which the synthesis becomes ever closer so as materially to affect the character of the functions or activities which become correspondingly more unified or holistic"* (1926:118). According to Smuts, it is important to establish that this synthesis is not a stand-alone new element that exists above the separate components that create the synthesis or the whole. Instead, he argues, a synthesis or new whole is created by *"the parts in their intimate union, and the new reactions which result from that union. But in that union the parts themselves are more or less affected and altered towards the type* *represented by the union, so that the whole is evidenced in a change of parts as well as a change of resulting functions"* (1926:118). Although Smuts' concept of synthesis dates back to roughly the same time as Heidegger's work, both independently developed the idea of interconnected components that form a new whole. In both cases, the whole is more than the sum of its constituent parts and the whole determines the functionalities that are created. Without doubt, Smuts' concept of a whole plays a major role in the development of the concept of ecosystem in biology. In the first part of this essay, I will therefore also go into the origins of the biological concept of ecosystem and how it has developed over the years. Based on my analysis of the concept of ecosystem, I will compile a profile of a biological ecosystem that is made up of organic and non-organic elements that are interconnected and determine the functioning of the biological whole. One key feature of this profile is the principle of homeostasis. Homeostasis is a property of a natural system that enables it to adapt itself and the interconnected components within it to changes in their environment. The ecosystem keeps organising itself in response to changes in its environment. Homeostasis and other properties of a biological ecosystem will be the basis for the next part of this essay, where the focus will be on the development of a digital ecosystem of networked autonomous objects that have the capacity to communicate between them, jointly make decisions, and interact with other systems based on information transactions. This development is creating a new whole, i.e. a digital ecosystem that is made up of autonomously collaborating cyber-physical systems. A new whole, or tool as Heidegger calls it, which is made up of new combinations of hardware, algorithms, software, data or information that determine systems' increasingly uninhibited ability to work together with ever more autonomously operating objects and people. Intercommunication and interaction are enabling people and objects to both separately and jointly execute a decision-making process. Based on the resulting decisions, joint actions or activities can be performed, which will, in turn, ensure that the whole adapts to changes emerging from its environment.

In the mid-1900s, the foundation for the thinking about interconnecting systems was laid by scientists such as psychiatrist and cybernetics pioneer W. Ross Ashby. He built a system that was made up of four interconnected machines, calling it the homeostat. After observing the functioning of his homeostat, Ashby (1956) concluded that one of the fundamental properties of systems is that components that together make up one single machine or machines as a whole, which are interconnected, can jointly form a new whole. The properties or functionality of the new whole created out of the interconnections exceeds the sum of its constituent parts. This leads Ashby to state that *"such complex systems cannot be treated as an interlaced set of more or less independent feedback circuits, but only as a whole"* (1956:54). Ashby's whole shows clear similarities to the thinking about biological ecosystems and can in this context be used within the current development of, for example, the (Industrial) Internet of Things or the development of cyber-physical systems that can interconnect to form a new whole of a system of systems. In the development towards cyber-physical systems, more and more objects are designed, developed, produced, and controlled that function in networks. Interconnection in networks and the possibilities offered by algorithms and software enable such objects to communicate and interact with each other. Intercommunication and interaction between distributed systems creates entirely new wholes in the form of systems of systems that are similar to biological ecosystems. After all, systems of systems are temporary or permanent combinations of people and autonomously functioning objects that are interconnected in a specific context, which are independently able to engage in intercommunication, interaction, and decision-making, and thus able to autonomously perform information transactions with other systems based on the decisions made. From the perspective of an ecosystem, the development of systems of systems is a development that calls for greater autonomy for the connected objects. The autonomous functioning of a cyber-physical system within a new whole of a system of systems requires these autonomously operating systems to have the capacity to self-adapt to changes arising within the system of systems or emerging in the environment within which the whole exists. A new whole of a system of systems, i.e. a digital ecosystem, will develop more rapidly as more autonomously operating objects acquire a greater capacity for self-adaptation, while also being able to take part in decision-making processes relating to these adaptations and to autonomously implement the required adaptations. Decision-making on when and how to adapt to changes in the environment can therefore potentially significantly help boost the autonomy of such systems of systems. Jointly through their interconnections, autonomous systems are contributing to the development of the whole of which they are constituent parts. The third part of this essay will mainly go into the issue of systems' autonomy and how to shape the increasing autonomy of these systems without jeopardising the stability of the whole or the system of systems. Autonomy of cyber-physical systems of systems is here defined as the self-regulating capability of the whole and the way in which a decision-making process takes place within this whole about collaboration and adaptation to changes of individual systems or the system as a whole. A system of systems' self-regulating capability is needed to secure the stability of the whole. According to Ashby, regulating stability is a central functional property of the whole. He argues that a system's stability is a given that is always connected to *"the fact that the presence of stability (as contrasted with instability) always implies some co-ordination of the actions between the parts"* (1952:55). Coordination of the actions within the system ensures, so Ashby claims, that variables that are essential for the functioning of the system remain within the physiological boundaries of the system as a whole. Ashby argues "that the living organisms use the principle of ultrastability as automatic means of ensuring the adaptiveness of its learned behavior" (1956:103). This is how coordination and alignment between separate parts of the system of systems ensure functional stability for the whole, while such stability, in turn, creates a basis that enables adaptation of the system as a whole to changes in its environment. Realising stability and adaptation to the environment does, however, in Ashby's view, require communication and interaction between the separate parts and independence or autonomy of these parts in being able to make decisions about how they want to respond to changes. The increasing autonomy, interconnectedness, communication, and autonomous decision-making by interconnected systems throws up new questions about the ethics of such new wholes, especially when these new wholes make decisions and perform actions that directly or indirectly affect us as humans. The final part of this essay will therefore specifically focus on how to develop a new ethics framework that can help us humans assess the functioning of these new ecosystems of interconnected and autonomously operating cyber-physical systems.

III. Biological ecosystems

This section of the essay will go into the development of our thinking about biological ecosystems in the previous and current centuries. One specific point that will be addressed is a special property of ecosystems that is called homeostasis.

A. Ecosystems

As I pointed out in the introduction, Smuts (1926) defines a whole as a *"synthesis or structure of parts in which the synthesis becomes ever closer so as materially to affect the character of the functions or activities which become correspondingly more unified or holistic"* (1926:118). Smuts adds, and this is a very important point to him, that the whole that is created by the synthesis of the various parts is not something that stands alone or above the parts that make up the whole. They are and continue to be, according to Smuts, separate parts that form one single new whole through their interrelations, and that further develop this new whole. In Smuts' view, the separate parts are still influenced in their interrelations to varying degrees, or they adapt to a form that is represented by the whole *"so that the whole is evidenced in a change of parts as well as a change of resulting functions"* (1926:118). The whole, according to Smuts, turns out to develop itself as a clear force of regulation and coordination of the interconnected parts. Smuts considers regulation and coordination as the most notable properties of organisms, which ensure *"that they involve a balanced correlation of organs and functions. All the various activities of the several parts and organs seem to be directed to central ends; there is thus cooperation and unified action of the organism as a whole instead of the separate mechanical activities of the parts. The whole thus becomes synonymous with unified (or holistic) action"* (1926:118). Thinking from the perspective of the whole transforms, according to Smuts, the concept of causality. When an activity takes place that arises from the whole's environment, the ultimate consequence of this external activity can no longer be traced back to what caused it, because the cause is constantly changing. Smuts sees this holistic transformation occur in all organic processes that involve stimulus-and-response mechanisms. The organic whole fuses the actions of its parts into a synthesis, a new unit that is truly different from what the result would be of the separate actions of each of the parties. The science of ecology—which was new at the time—is, in Smuts' view, based on this holistic perspective of a whole as a supplementation of the principle of natural selection. Smuts argues that "*the environment has a silent, assimilative, transformative influence of a very profound and enduring character on all organic life*" (1926:218). Botanist and ecology pioneer Tansley (1935) takes a different view, one that simply considers the constituent parts of the whole, together with the physical factors influencing them, as systems. Tansley concurs with Smuts' ideas on holism, calling his basic principles useful and acceptable. He agrees with Smuts' argument that the developing whole makes up a new entity. However, Tansley adds that we must take a broader view of this new entity, which he describes as "*the whole system (in the sense of physics), including not only the organism-complex, but also the whole complex of physical factors forming what we call the environment of the biome –the habitat factors in the widest sense*" (1935:299). Tansley claims that it is mainly human prejudice that is causing biological organisms in these systems to be seen as the most important parts. But non-living materials or materials derived from non-living systems are equally essential parts of the whole. In Tansley's opinion, a whole system cannot exist without these non-living parts. He argues that "*there could be no system without them, and there is constant interchange of the most various kinds within each system, not only between the organisms but between the organic and the inorganic. These ecosystems, as we may call them, are of the most various kinds and sizes*" (1935:299). The concept of ecosystems makes it possible, in his view, to include all kinds of combinations of organisms and non-organisms and their interrelations in the study of more specific ecosystems. We cannot, Tansley argues, base the concept of an ecosystem only on "*the so-called natural entities and ignore the processes and expressions of vegetation now so abundantly provided us by the activities of man*" (1935:299). Only when both elements are equally represented in the concept of ecosystems can we speak of a fundamental concept for a biome. A biome is, in Tansley's theory, a collection of plant species, animal species, and other organisms that live in a certain territory where conditions are the same for all. Within the concept of an ecosystem, Tansley claims, "*the organisms and the inorganic factor alike are components which are in a relatively stable dynamic equilibrium. Succession and development are instances of the universal processes tending towards the creation of such equilibrated systems*" (1935:306). According to ecologist Lindemann (1942), a more bio-ecological approach to distributed species would lead to recognition of plants and species as "*co-constituents of restricted 'biotic' communities in which members of the living community co-act with each other and react with the non-living environment*" (1942:399). Lindemann, too, considers an ecosystem a whole, a whole that he defines as a superorganic entity that is not made up only of plants and animals that jointly "*form biotic communities but also between the biota and the environment*" (1942:400). His view ties in with, he claims, Tansley's fundamental ecological entity, which according to

Lindemann can come in different sizes. He formally defines ecosystem as "*the system composed of physical-chemical-biological processes, active within a space time unit of any magnitude i.e. the biotic community with its biotic plus its abiotic environment*" (1942:400). For Lindemann, the basic process of such an ecosystem is made up of '*trophic dynamics*', i.e. the food pyramid that takes care of the transfer of energy from one place to another within the ecosystem, which leads him to the following statement: "*All function and indeed all life, within an ecosystem, depends upon the utilization of an external source of energy, solar radiation*" (1942:400). American ecologist Odum (1969) also considers an ecosystem to be a unit that is formed by a biological structure or organisation. He argues that changes in the structure or the organisation of the ecosystem are enabled by the organisms that are present in a certain territory and the interrelation and interactions between these organisms and with their physical environment. Odum argues that changes within an ecosystem over time are enabled by three parameters. The first is that changes occur according to an "*orderly process of community development that is reasonable directional and, therefore, predictable*" (1969:262). The second parameter is, according to Odum, that, within an existing ecosystem, the realisation of changes "*results from modification of the physical environment by the community; that is succession, is community-controlled even though the environment determines the pattern, the rate of change, and often sets limits as to how far developments can go*" (1969:262). And thirdly, Odum states that the realisation of changes in an ecosystem "*culminates in a stabilized ecosystem in which maximum biomass (or high information content) and symbiotic function between organisms are maintained per unit of available energy flow*" (1969:262). According to Odum, changes that are made consciously and with the help of these parameters within an existing ecosystem can be considered short-term changes. They are basically comparable to change processes that arise in the long term as a result of the evolution of species within the ecosystem or of the ecosystem as a whole. In both cases, such changes within the ecosystem lead to an increase in control, i.e. homeostasis with the ecosystem's physical environment. By adapting to changes, the species within the ecosystem develop maximum protection against disruptions from their environment. Fitzsimmons (1996) argues that these changes actually mean that ecosystems can be any shape or size: "*Ecosystems may be thought of as being of any size or shape from a drop of water to the entire planet. They are understood to change constantly in time and space*" (1996:79). Changes in terms of time and place also lead to a change to the boundaries between the various ecosystems. According to Fitzsimmons, these changes lead to overlapping and/or intertwined ecosystems. The interconnection of organic systems, their physical environment, and the threats and changes coming out of the environment are what makes it clear, according to Odum, that an ecosystem is a complex whole. Odum phrases it as follows: "*While one may well question whether all the trends* *described are characteristics of all types of ecosystems, there can be little doubt that the net result of community actions is symbiosis, nutrient conservation, stability, a decrease in entropy, and an increase in information*" (1969:266). Blew (1996) takes this one step further, claiming that communication and interaction between the various living and non-living elements within the complex whole of an ecosystem are partly responsible for the development of new properties within the whole, which leads him to state that "*the effects of the actions of organisms will bring about certain emergent properties which are the result of instruction or guidance arising from the whole of the community acting as a cause*" (1996:172). In his opinion, new properties emerging from the whole are based mainly on the interrelations and ensuing interactions between the various living and non-living organisms within the whole. Communication and interactions could, according to Blew, actually have a greater bearing on the properties of an ecosystem than the separate elements in that ecosystem. In Blew's view, an ecosystem can also be defined from the perspective of an important organism or system within an ecosystem. Levin (2005), however, adds to this that ecosystems "*self-assemble from components shaped by evolution, and self-organize as those components reproduce and express phenotypic plasticity*". To him, ecosystems are complex adaptive systems, i.e. "*heterogeneous assemblages of individual agents that interact locally and that are subject to evolution based on the outcomes of those interactions. This evolution may simply involve changes in individual behaviors, such as animals that alter their bearings in group dynamics, or economic actors in the marketplace; alternatively, it may involve differential production of offspring, representing heritable change by descent*" (2005:1077). Viewed from a perspective of complex adaptive systems, a holistic approach only is no longer adequate, according to Levin, as each individual system is able to trigger an evolutionary change from the basis of the system. Every single change can lead to a change to the system as a whole, and each of these changes can develop from "*the interplay among processes at diverse scales of space, time, and complexity*" (2005:1076). Levin argues that learning to understand the complexity of ecosystems and the development of this complexity based on interrelations, communication, and interactions between the various agents and systems should be one of the central focuses of research into ecosystems. According to Anand (2010), the development of ecological knowledge is increasingly drawing on definitions from information theory, such as the Shannon entropy, which can be used to measure diversity within the ecosystem. In his view, too little progress is being made, however, to be able to actually use this knowledge and these definitions from information theory to measure the complexity within an ecosystem. When it comes to the options and benefits of collaboration between these scientific disciplines, Anand states the following: "*The latter, which include adoption of concepts of algorithmic complexity and mean information gain, could help to integrate concepts such as cross-scale interactions and change into static measures of complexity*" (2010:401). Over the decades that passed between Smuts and Anand, the concepts of ecology and ecological systems became everyday and widely used concepts. And yet, there is little focus on the fact that an ecology can be considered a Heideggerian phenomenon, i.e. a whole that is autonomous and manifests itself to us as a whole. A whole that is created by interrelations, communication, and interaction between living and non-living organisms. And a whole that is constantly changing as a result of interrelations within the whole and with the whole's environment. The boundaries and shape of an ecosystem are therefore not static. The boundaries of the whole change following constant changes within the whole. In this sense, an ecosystem is a complex, living, and constantly changing whole that develops based on the interconnections, communication, and interaction between all organic and inorganic elements in the ecosystem.

B. Homeostasis

One of the main properties of an ecosystem, homeostasis, merits closer scrutiny in this essay. Homeostasis is the property of an ecosystem that determines the ecosystem's ability to adapt to changes caused by communication and interaction between the systems in the ecosystem or with other systems in the environment. Homeostasis is a stage that is similar to a period of stability during which little to no evolutionary change happens within the ecosystem. Homeostasis can be considered a special property of a system as a whole that enables it to achieve inner balance and to maintain that balance as the normal outward condition. This makes homeostasis a capability of ecosystems to actively integrate new variables within the internal functioning of the whole without this affecting the stability or functioning of the whole. In the words of Odum (1969): *"In a word, the strategy of succession as a short-term process is basically the same as the strategy of long-term evolutionary development of the biosphere – namely, increased control of, or homeostasis with, the physical environment in the sense of achieving maximum protection from its perturbations"* (1969:164). Morgan, Ernest and Brown (2001) link this capability of homeostasis to a form of *'community compensation'*. They define community compensation as *"the tendency of coexisting, competing species to exhibit negative co-variances in population dynamics, so that variables that reflect resource use, such as total population size or biomass, are more stable than would be expected from random shifts in species composition"* (2001:2119). American biologists Morgan, Ernest, and Brown point out that both community compensation and homeostasis have a long tradition in their respective sub-disciplines of ecosystem theory. They consider homeostasis to be *"the tendency of an ecosystem to maintain the approximate stability of certain properties, such as productivity, energy or nutrient flux, or biomass, despite abiotic environmental perturbations or changes in biotic composition"* (2001:2119). Morgan, Ernest, and Brown argue that homeostasis is maintained by the compensation mechanisms within the ecosystem. Homeostasis and compensation mechanisms are interconnected in their execution within the ecosystem, enabling the ecosystem as a whole to respond to major and minor changes originating from within or outside the ecosystem. Morgan, Ernest, and Brown therefore also argue that an ecosystem is thus enabled to respond to seemingly minor changes, such as changes in temperature, PH values, or an invasion by a competing system, which "may cause substantial changes in the abundance of individual species, and create the opportunity for compensatory changes in other species, without significantly altering overall productivity or resource availability" (2001:2119). Health scientist Hegyi and her companions, however, conclude that life in general is based on energetic open systems, whereby conditions and circumstances in the immediate environment determine the equilibrium of the whole. For Hegyi et al. (2012), realising the equilibrium of a living system is the same as the capability of homeostasis. She claims the following: "*The living equilibrium is the homeostasis. The actual homeostatic state is definitely 'constant' despite its energetically open status. The normal healthy state of any living system is in homeostasis, which is not static, but dynamically changes in time, forming a relatively stable state*" (2012:64). Hegyi et al. argue that the capability of homeostasis is determined by numerous negative feedback loops that are responsible for the simultaneous creation of both microstructures and macrostructures, which are jointly responsible for shaping the equilibrium. As a result, so they claim, homeostasis can be considered "*the equilibrium of the living complexity*" (2012:70). Giordano (2013), on the other hand, sees homeostasis primarily as a property on a micro level, i.e. the level of cells that create an organism that drives "*the interplay of composition and functions in response to the pressure exerted by the environment to modify the status quo. For this reason, unicellular organisms often offer the best examples of homeostasis multifaceted nature*" (2013:93). Dyke and Weaver (2013) argue that homeostasis is the result of "*biological feedback on the abiotic environment*" (2013:1). By abiotic environment, they mean both the physical conditions and the inorganic resources that are instrumental for living organisms in terms of growth, health, and reproduction. The biological feedback loops on our planet with an abiotic environment that jointly lead to homeostasis give rise to the question why stabilising negative feedback loops are able to dominate the destabilising positive feedback loops. Dyke and Weaver answer this question as follows: "*If life is both affected by and affects its environment, then this coupled system can self-organise into a robust control system that was first described during the early cybernetics movement around the middle of the twentieth century*" (2013:2). Dyke and Weaver invoke, among other things, the works of Wiener and Ashby. Wiener is considered one of the fathers of cybernetics theory. According to Wiener, the theory of cybernetics covers the entire field of "*control and information theory, whether in the machine or in the animal*" (1948:19). In his theory, he introduces the concept of control and operation through information feedback, which comes with the benefit "*that the compensator may be adjusted to give stability for every type of constant* *load"* (1948:134). Maintaining stability in the form of homeostasis is, according to Wiener, an essential factor for the continuation of life. Back in 1954, Ashby defined homeostasis as follows: *"a form of behaviour is adaptive if it maintains the essential variables within physiological limits"* (1954:57). He further detailed this definition as follows: *"Some external disturbance tends to drive an essential variable outside its normal limits; but the commencing change itself activates a mechanism that opposes the external disturbance. By this mechanism the essential variable is maintained within limits much narrower than would occur if the external disturbance were unopposed. The narrowing is the objective form of the mechanism's adaptation"* (1954:60). Although Ashby's description refers to living organisms' capability of learning from this feedback, he adds the following to his description in 1956: *"A fundamental property of machines is that they can be coupled. Two or more whole machines can be coupled to form one machine; and any one machine can be regarded as formed by the coupling of its parts, which can themselves be thought of as small, sub-machines"* (1956:48). Ashby claims that such interconnected and complex systems cannot be considered merely a combination of more or less autonomously operating feedback circuits, but must be considered as a whole in their interconnectedness. He therefore argues that when the relationship between two separate entities becomes conditional on the status of a third entity, there is a necessary form of organisation for the functioning of the whole. Ashby: *"If conditionality is an essential component in the concept of organization, so also is the assumption that we are speaking of a whole composed of parts"* (1962:258). Ashby concludes that such a whole could be considered self-organising if *"a change were automatically made to the feedback, changing it from positive to negative; then the whole would have changed from bad organization to a good one"* (1962:267). According to Ashby, this reasoning makes it possible to consider every machine as being self-organising, because *"it will develop, to such degree as its size and complexity allow, some functional structure homologous with an adapted organism"* (1962:273). To test his theoretic assumptions, Ashby built a machine to confirm his theory of ultra-stable systems. The machine, which he called Homeostat, was made up of four similar entities. Ashby interconnected these four machines *"so that each sends its output to the other three; and thereby each receives an input from each of the other three"* (1952:95). His experiment showed that the stability of the interconnected whole existed on a higher level than that of each system separately. Ashby's Homeostat proved that interconnections between systems and the communication and interaction possibilities this offers enables the separate systems to respond to outside stimuli. The system as a whole helps the individual system assimilate changes and thus contributes as a whole to the stability of both the functioning of each of the four separate systems and the stability of the whole. The whole of an ecology self-organises and self-regulates, which gives it its own physical and biological laws. One of these laws is homeostasis, which enables the system as a whole to respond to changes arising from within itself or from its environment. The combination of autonomy and homeostasis allows for an ecology as a whole to keep developing, as well as to adapt to any changes that occur. This is how the ecology creates itself, and with that the properties we humans perceive as emergent properties of this whole.

IV. Digital ecosystems

In the previous section, the analytical focus was on what the key properties of a biological ecosystem are. Specifically, the focus was on one of the main properties of a biological ecosystem, i.e. homeostasis. Homeostasis is the property of an ecosystem that provides it with the ability to adapt to changes as a whole. In this section, we are going to look into the possible development of a digital ecosystem. This development will be analysed based on concepts such as autonomy, self-adaptation, and communication.

A. Autonomy

The modern development in the thinking about the functioning of interconnected systems starts with Norbert Wiener's (1948) description of cybernetics. He describes cybernetics as the science of *"control and communication in the animal and the machine."* Cybernetics not only studies concepts such as the autonomy of biological and other systems, it also looks at control of and communication between these interconnected systems. Heidegger (1964) claims that the development of cybernetics will have major repercussions for science in general and for our thinking about technology in particular. Writing about this new science of cybernetics, he states the following: *"No prophecy is necessary to recognize that the sciences now establishing themselves will soon be determined and guided by the new fundamental science which is called cybernetics"* (1964:376). According to Rid (2016), the science of cybernetics as developed by Wiener and Ashby actually enables an elegant link-up between *"electronic engineering and the life sciences, blurring the line between living and non-living systems"* (2016:66). The experiences of Ashby in the realm of cybernetics show how systems, which in Ashby's case were machines, can be interconnected and thus be able to stabilise themselves, both separately and as a whole. The stability in the functioning comes about through intercommunication and interaction between the interconnected systems. Feedback loops also help create a functioning, stable, self-adaptive whole. Horn (2001) draws attention to the fact that the development of the Internet in particular is something that takes us, as human beings, to new heights of complexity. The Internet uses interconnection, intercommunication, interaction, and the associated feedback loops to form a new synthesis based on new combinations of humankind and technology. This new level of complexity is the result of, among other things, the interconnection of computers as objects in networks, and in Horn's words, *"to connect – some might say entangle – this world of computers and computing systems with telecommunication networks"* (2001:4). In Horn's view, what people generally consider a positive development is that the new whole acquires an ability to self-organise. This positive experience leads Horn to the following observation: *"That's why we need a systematic approach that follows for coordination and automatic management across entire networks of computing systems - systems built on various platforms and owned (or even shared) by various entities. Autonomic computing is thus a holistic vision that will enable the whole of computing to deliver much more automation than the sum of individually self-managed parts"* (2001:11). Autonomic computing, as referred to here by Horn, is based on the concept of autonomy, a word that comes from the Greek 'autos' and 'nomos', which mean 'self' and 'law' respectively. The concept of autonomy thus refers to a form of self-government or self-regulation of individually or jointly operating systems. Horn's vision of a development of a form of autonomous computing does, however, directly lead to the question of what autonomy of computer systems can or should look like and what fundamental properties autonomous systems in principle need to have to be able to collaborate in networks. In Horn's theory, autonomous systems should have a basic ability to organise and manage their own processes. Collaborating autonomous computer systems will, in his view, have differentiating elements at more specific and higher levels. In Horn's words: *"To be autonomic, a computing system needs to know itself – and comprise components that also possess a system identity"* (2001:20). An autonomously operating system will need to be able to recognise and differentiate itself among other systems to be able to function on different levels. Aside from that, the system will have a continuous need for detailed knowledge from its constituent components, as well as knowledge of the status of these components and the functioning of the autonomous system as a whole. The autonomous system will, based on the information collected, determine the maximum capacity available to the system as a whole to perform its tasks. Besides this capacity, the autonomous system needs to be able to collaborate with other systems and jointly make decisions in mutual consultation. And finally, Horn's theory attaches great importance to an autonomous system having an independent ability *"to know the extent of its owned resources, those it can borrow or lend, and those that can be shared or should be isolated"* (2001:21). To be able to use all these capabilities simultaneously, an autonomous system needs to have some kind of awareness of the functioning of the whole. This is necessary according to Horn, because: *"a system can't monitor what it doesn't know exists, or control specific points if its domain of control remains undefined"* (2001:21). Through a form of overall self-awareness of its own functioning and that of its surroundings, the whole needs to be able to (re)configure itself amidst changing and unpredictable conditions for the performance of a specifically assigned task. Mitchell (2005) defines such a form of self-awareness as *"information contained in a system about its global state* *that feeds back to adaptively control the system's low-level components*" (2005:1). When the whole of a system is made up of multiple distributed entities, this whole will also have to be able to use images and/or data to restore its operability following faults in local parts of the network. For such a whole to be able to deal with these kinds of disruptions itself, what is needed according to Horn is that "*adaptive algorithms running on such systems could learn the best configurations to achieve mandated performance levels*" (2001:22). In Horn's thinking, such a form of self-learning capability enables the autonomous whole to recover or self-configure, or in Horn's words, "*to recover from routine and extraordinary events that might cause some of its parts to malfunction*" (2001:24). The creation of learning and self-healing mechanisms will make two things possible for autonomous systems. They will find or develop alternative operating methods or they will determine how to (re)configure themselves, so as to be able to permanently guarantee the functionality of the system as a whole. The development and application of such self-healing capabilities requires, according to Horn, that systems be aware of the environment in which they have to perform their tasks. For Horn, the potential set of capabilities such as self-awareness, self-organisation, self-healing, and self-(re)configuration is comparable to the capabilities of organisms within an ecosystem, which he describes as follows: "*In nature, all sorts of organisms must coexist and depend upon one another for survival (and such biodiversity actually helps stabilize the ecosystem*" (2001:27). According to Ganek and Corbi (2003), Horn's set of capabilities basically creates an autonomous system similar to the human '*nervous system*'. They conclude the following: "*The autonomic nervous system frees our conscious brain from the burden of having to deal with vital but lower level functions*" (2003:7). They go along with Horn's reasoning that a development is needed where systems acquire even greater autonomy, arguing that systems need to become "*self-configuring, self-healing, self-optimizing and self-protecting*" (2003:7). For Ganek and Corbi, the development towards autonomous computer systems is merely a new and logical step that follows "*these past trends to address the increasingly complex and distributed computing environments of today*" (2003:7). The need to develop increasingly autonomous computer systems is, according to Ganek and Corbi, prompted by a combination of rapid changes in the scale, scope, and requirements for application in mission-critical conditions. Kephart and Chess (2003), too, claim that as the diversity of systems increases, "*architects are less able to anticipate and design interactions among components, leaving such issues to be dealt with at runtime*" (2003:41). The solution would, in their view, be to create more autonomous systems that are able to operate themselves in fulfilling the tasks that have been assigned to the system. In Kephart and Chess' thinking, the term autonomous system symbolises "*a vast and somewhat tangled hierarchy of natural self-governing systems, many of which consist of myriad interacting, self-governing components that in turn comprise large numbers of interacting autonomous,* *self-governing components at the next level down*" (2003:41). Kephart and Chess furthermore believe that inspiration can be drawn from available knowledge on self-governance of social and economic systems, but certainly also from available knowledge of biological systems. Like biological systems, autonomous computer systems will, in their view, "*maintain and adjust their operations in the face of changing components, workloads, demands and external conditions and in the face of hardware or software failures, both innocent and malicious*" (2003: 42). For Parashar and Hariri (2004), a computer system that has an autonomous ability to adapt its behaviour to changes in its environment is a homeostatic system. They describe such a system as follows: "*Such a system reacts to every change in the environment, or to every random disturbance, through a series of modifications that are equal in size and opposite in direction to those that created the disturbance. The goal of these modifications is to maintain internal balances*" (2004:248). A form of self-adaptability is something that Parashar and Hariri feel is necessary to ensure the stability of the system as a whole. They refer back to Ashby (1952), who stated that "*adaptive behaviour is equivalent to the behaviour of a stable system, the region of the stability being the region of the phase-space in which all the essential variables lie within their normal limits*" (1952:64). Like Salehie and Tahvildari, Parashar and Hariri identified the same four characteristics as Ganek and Corbi, which they abbreviated as the CHOP properties. These four CHOP properties are self-configuring, self-healing, self-optimising, and self-protecting. They claim that these properties play a role in adapting to changes that enter the system from the system's environment and are likely to affect the system's behaviour. Salehie and Tahvildari define self-configuring as "*the capability of adapting automatically and dynamically to environmental changes*". Self-healing is, according them, "*the capability of discovering, diagnosing and reacting to disruptions*". They define self-optimising as "*efficiently maximizing resource allocation and utilization for satisfying requirements of different users*". And finally, their definition of self-protection as a system capability is "*the capability of reliably establishing trust, and anticipating, detecting and recovering from the effects of the attacks*". According to Agarwal and Harrod (2006), the developments outlined here, as well as the above properties, will propel the development of more organically functioning computer systems. These systems will, in their view, fundamentally differ from today's more procedurally oriented computer systems. This difference is caused by the fact that it is impossible in autonomous operation to preconfigure all tasks in a system into possible scenarios, which leads them to conclude that "*the organic computer also implements learning and decision-making engines in judicious combination of hardware and software to determine the appropriate actions based on given observations*" (2006). Huebscher and McCann (2008) argue that autonomous execution of tasks by a system of systems is possible only when these systems collaborate to achieve an objective. This notion of collaboration of individual elements to realise a shared objective is, according to Huebscher and McCann, a fundamental aspect of research into possible forms of collaborating multi-agent systems. They conclude that the development of collaboration between different systems requires a process of mutual alignment and decision-making. This process can take place based on mutually agreed consensus rules for decision-making. The decisions will lead to joint performance of a specific action or transaction for the realisation of a shared objective. We can safely say that systems are increasingly connected to networks. These connections enable autonomous systems to communicate and interact. Communication and interaction between systems open up new avenues for autonomous performance of tasks and activities. Further development of autonomy, self-regulation, or self-governance makes it necessary for autonomously operating systems to differentiate their own functioning from that of other systems. By differentiating the system itself from its environment, autonomous systems are enabled to develop capabilities such as self-configuration and self-reconfiguration, self-healing, and self-optimisation for the task that is to be performed. They are then also able to protect themselves against unwanted influencing from the outside. To develop and apply these 'self-capabilities', the focus needs to shift from the system as an isolated physical object to a physical system that is networked. This physical system can apply these capabilities by combining them with the possibilities offered by algorithms and software. As a result, this new whole increasingly resembles a biological ecosystem as described above.

B. Self-adaptive

Autonomy in the functioning of systems increases as they become better able to adapt to changes emerging from within them or from their environment. This capability of autonomous systems is also referred to as self-adaptiveness, which will be detailed in the following. Based on a form of awareness of itself as a whole, a system is able to adapt to changes emerging from within itself or from its surroundings. This ability can be considered the system's adaptive capability. An autonomously operating system's ability to adapt to changes or change its behaviour without human intervention is what we refer to as self-adaptation. The development of this ability to self-adapt to changes arising from a system's environment is an initial and necessary precondition for the autonomous operation of any random system. According to a report published by the United States Department of Defense (DoD), *"autonomy is a capability (or a set of capabilities) that enables a particular action of a system to be automatic or, within programmed boundaries, self-governing"* (DoD 2012:1). This report was published back in 2012, when the Department of Defense still believed that all autonomous systems are in one way or another under the responsibility of human operators. The report does recognise, however, that alongside these human operators, there are algorithms and software that regulate the behaviour of an autonomous or semi-autonomous system. According to Mitchell (2009), the term algorithm generally refers to *"steps by which an input is transformed to an output"* (2009:129). Steiner defines the core of an algorithm as *"a set of instructions to be carried out perfunctorily to achieve an ideal result. Information goes into a given algorithm, answer comes out"* (2012:54). Steiner argues that the value of an algorithm is determined by the speed at which it can perform the requested tasks. According to him, this speed is determined largely by the hardware on which the algorithms operate. According to the DoD in 2012, autonomous systems still use algorithms and software in which humans have specified boundaries within which the autonomous system operates autonomously, is able to make decisions, or execute delegated actions. In the above description, the autonomy of a system is more than an intrinsic property of an isolated and unmanned system. The autonomy of a system should, according to the DoD, also be considered an outcome of a process of collaboration between human and system(s), both in the development and in the execution of tasks or actions. The new combination of object (hardware), rules based on which this object operates (algorithms), and the way in which the object performs its tasks (software) is what determines, together with humans, the boundaries of autonomy within which the system is able and allowed to operate independently. This new combination of hardware, algorithms, software, and humans controls the execution of tasks and actions by the object or objects. The US DoD added in 2012 that the increasing complexity of interconnected humans, algorithms, software, and hardware creates a great variety of challenges, both in the area of interaction between interconnected systems in dynamic environments and in collaboration between human and system. The greatest challenge to the autonomous functioning of the system is, however, the required shift in focus from system hardware to the algorithms and software. In 2016, the DoD observed that the development of system autonomy had up to then produced a result that ensued from the transfer of competencies from human to system to enable the system to perform actions independently within predefined boundaries. The restriction imposed by these boundaries basically curtails or even eliminates the system's possibilities of operating outside these boundaries, thus also constituting a restriction of the system's autonomy. To be able to operate with a far-reaching level of autonomy, the US DoD argues that *"a system must have the capability to independently compose and select among different courses of action to accomplish goals based on its knowledge and understanding of the world itself and the situation"* (2016:4). Further development of system autonomy therefore requires such autonomy to be embedded in an increasing number of algorithms and interconnected software entities. To inspire stakeholder confidence in decisions made by systems individually or jointly, the question of how to regulate this decision-making process must be addressed at an early stage in the design process for these procedures. Getting designers and stakeholders together at an early stage to have them come up with possible conditions that this decision-making has

to meet will create the possibility to apply *"adequate indicator capabilities so that inevitable context-based variations in operational trustworthiness can be assessed and dealt with at run-time"* (2016:14). According to Scharre et al. (2016), an essential dimension of autonomous systems is thus increasingly created by the level of complexity of the system itself and the environment within which the system has to operate. In Scharre's words: *"Complexity matters because it affects the human operators' ability to predict the behavior of the system"* (2016:11). The complexity created by interconnections, intercommunication, and interaction within the system and between the system and other objects in its environment will reduce the transparency of the system's functioning, making it harder for human stakeholders to fathom the system's operations. The result of such increasing complexity could, according to Scharre, be that: *"predicting the system's behavior, particularly when operating in complex and unstructured real-world environments can be more challenging"* (2016:11). Work on the algorithms and software that are needed has been ongoing for years. Laddaga (1999) argues, among other things, that for a system to be self-adaptive, it needs to be capable of self-evaluation of *"its own behavior and changes in behavior when the evaluation indicates that it is not accomplishing what the software is intended to do, or when better functionality or performance is possible"* (1999:27). In this same context, Laddaga argues that for algorithms and software to be able to give an autonomous system the ability to self-adapt, the software needs to be able to implement any changes on the fly. Laddaga and Robertson (2004) conclude that this basic premise means that *"we design and code an application as a control system. The runtime software is treated like a factory, with inputs and outputs, and a monitoring and control facility that manages the factory"* (2004:1). The algorithms and software that autonomous systems need should, according to Laddaga and Robertson, consist of parts that jointly control and monitor the whole.
Self-adaptive software will play a major role in the development of all kinds of embedded software for use in areas such as robotics, manufacturing, aerospace, self-driving cars, and sensor systems. Laddaga and Robertson: *"As such, self-adaptive software is an ideal framework for building pervasive computing systems"* (2004:2). In the view of Sheng et al. (2004) control systems consist of at least two components, i.e. a controlled object and a controller. They believe that the controller takes care of implementing changes in the object's behaviour *"by delivering control signals (called control inputs) which force the controlled object to achieve a desired goal (called set point)"* (2004:1). Salehie and Tahvildari (2009) argue that when you take a system of software components that are able to regulate themselves and the behaviour of other systems as the starting point, you need interoperability of information between these parts. They state the following: *"Interoperability is always a concern in distributed complex systems for maintaining data and behavior integrity across all constituent elements and subsystems"* (2009:50). As result of the fact that, according to Brun et al., algorithms and

software have *"become the bricks and mortar of many complex systems (i.e. systems composed of interconnected parts that as a whole exhibits one or more properties (behaviors among the possible properties) not obvious from the properties of the individual parts)"* (2009:16), algorithms and software are now basically de facto essential factors in the development of self-adaptive systems. Brun et al. claim that self-adaptive systems that both operate in a distributed manner and work together differentiate themselves through their self-organising capability. These systems use their self-organising capability to jointly perform activities on a local level while adhering to simple rules. This led Brun et al. to the following argument: *"The global behavior of the system emerges from these local interactions. It is difficult to deduce properties of the global system by analyzing only the local properties of its parts. Such systems do not necessarily use internal representations of global properties or goals; they are often inspired by biological or sociological phenomena"* (2009:50). To enable interaction between the systems involved, a feedback loop is a minimum requirement. According to Brun et al., such a feedback loop is made up of at least four activities, namely collecting, analysing, deciding, and acting. The feedback cycle starts with the collection of relevant data from the sensors in the system's environment. Such sensor data is subsequently enriched with data and information from other sources. The system then analyses the data and information collected. The outcome of the analyses made by the system is subsequently used as input for proposals for the decision-making process. The decision that is ultimately made by the system will be focused on adapting the system to a new target status. To implement the decision that has been made, Brun et al. argue, *"the system must act via available actuators or effectors. Important questions that arise here are: When should and can the adaptation be safely performed?"* (2009:53). Brun et al. claim that such feedback loops will be instrumental in controlling the uncertainty that exists between systems and their environment. Feedback loops not only need to be fit for purpose, they also need to be visible. Visibility of feedback loops will, so Brun et al. argue, make it possible to identify which parts of the feedback loops have an important impact on the functioning of the system as a whole. Cheng (2009) also considers the feedback loop a central element in control theory, *"which provides well-established mathematical models, tools, and techniques to analyze systems performance, stability, sensitivity, or correctness"* (2009:14). The increasing interconnectedness of algorithm-based and software-based autonomous systems does, however, lead to an increase in complexity as well, according to Cheng et al. This complexity is, in turn, already leading the software engineering community to invest in new ways of developing, implementing, and managing the interconnected landscape of software-intensive systems and services. One of these new ways is described by Baudry and Monperrus (2012), who are tying in with the concept of biological ecosystems. In their view, the concept of the biological ecosystem makes for a good basis for an approach to the development of these complex and dynamic systems. Based on the previous, we can conclude that a digital ecosystem is made up of new and continuously changing combinations of hardware, algorithms, software, data, information, and humans. Communication and interaction between objects themselves and between objects and humans are what make the digital ecosystem a complex whole. Any changes to a component can, within a specific context, lead to changes to the part in question, but also to the system as a whole. Parts are able to adapt to changes from the outside thanks to the application of algorithms and software in the new combination of hardware and software. Collaboration on various levels between interconnected autonomous systems creates a need for the development and stability of the whole and simultaneously of the functioning of the part.

C. Communication

As should be clear from the previous, the development of entirely autonomous systems and their mutual collaboration requires a lot more research. New steps in this development are currently already being taken with the development of what are known as cyber-physical systems (CPS). This section will focus primarily on the capacity for communication between cyber-physical systems and between people and cyber-physical systems. The US National Institute of Standards and Technology (2016) has defined cyber-physical systems as *"smart systems that include engineered interacting networks of physical and computational elements"* (2016.xiii). According to Geisberger and Broy, cyber-physical systems are *"the product of the ongoing development and integrated utilization of two main innovation fields: systems containing embedded software and global data networks like the internet, featuring distributed and interactive application systems"* (2015:23). Lee (2006) points out that integration of physical processes and IT is not a new phenomenon, arguing that the existing combinations are captured by the concept of *'embedded systems'*. Further development of embedded systems is possible by connecting them in networks. Such networking, however, is conditional on a radical transformation of the available knowledge about the existing combinations of hardware and software. In Lee's words: *"However, the applications we envision demand that embedded systems be feature-rich and networked, so bench testing and encasing becomes inadequate"* (2006:2). Poovendran (2008) notes that: *"tomorrow's CPS must be able to adapt rapidly to anomalies in the environment and embrace the evolution of technologies while still providing critical assertions of performance and other constraints"* (2008:1365). Ragunathan (2010) claims that the new combination of cyber-physical systems requires a property to bridge the gap between the *'cyber world of computing'* and communication of these cyber-physical systems and the physical world. He states the following on this: *"Cyber-physical systems (CPS) are physical and engineered systems whose operations are monitored, coordinated, controlled and integrated by a computing and communication core. This intimate coupling between cyber and physical will be* *manifested from the nano world to large-scale wide-area systems-of-systems"* (2010:1). The essence of cyber-physical systems is such systems' ability to connect to networks in their environment and to communicate and interact with other systems in the network using algorithms and software. Communication between cyber-physical systems consists in the exchange and sharing of data and information in the form of messages between networked systems. If a random cyber-physical system is able to receive, store, and process data and information from its environment, it is enabled to assign its own meaning to the information received, whereby the meaning assigned determines what other activities the system must perform. After all, the meaning assigned supports the system in choosing tasks and how to perform them. The continuing cycle of receiving, processing, assigning meaning, and execution between a diverse range of cyber-physical systems can be seen as a process of communication, feedback, and interaction. Networking cyber-physical systems will ultimately lead to the development of a new whole, such as a cyber-physical system of systems that operates as a whole and develops based on intercommunication and interaction. It therefore resembles the processes in a biological ecosystem. Communication is the basis for new interactions between systems and processes of joint decision-making between collaborating cyber-physical systems. Mutual alignment through decision-making processes is necessary for (self)-adaptation of individual systems, to changes from the environment. This process of communication and adaptation between random systems is what is often referred to as interoperability of information, which Van Lier (2009, 2010, 2013) defines as *"the realization of mutual connections between two or more systems or entities to enable systems and entities to exchange and share information in order to further act, function or produce on the principles of that information"* (2010).

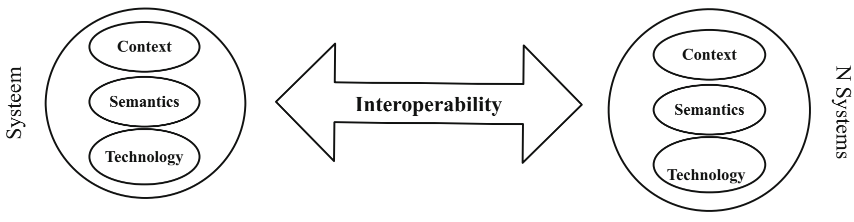

Figure 1 Interoperability

The principle of assigning meaning to data or information received for the selection and execution of further tasks is, according to German sociologist and systems theorist Niklas Luhmann (1995), an essential addition to the work of American mathematician Shannon (1948). Luhmann claims that Shannon's restrictions to the metaphor of sending and receiving undervalue the required communication between interconnected systems. In Luhmann's view, an element of communication is made up of at least three different parts. It is, in the first place, a selection of information originating from a sending system. This selection is, secondly, enriched with an utterance of the information. And finally, the way in which the information is to be interpreted by the recipient system is, according to Luhmann, the third essential component of an element of communication. Production of a synthesis in the form of an element of communication, based on the selection, utterance, and presupposed understanding of the message can, in Luhmann's view, be considered a form of autopoiesis. Autopoiesis is a term from biology that means self-reproduction. The system reproduces itself in the synthesis of the communicative element. The basic problem with autopoiesis in relation to the communication between systems lies, according to Luhmann, *"in the question how does one come from one elemental event to the next. Here, the basic problem lies not in repetition but in connectivity"* (1995:36). To be able to communicate effectively, systems need, so Luhmann argues, to be interconnected and *"define their specific mode of operations or determine their identity by reflection to be able to regulate which internal meaning units enable the self-reproduction of the system and thus are repeatedly to be reproduced"* (1995:34). Luhmann goes on to argue that this form of autopoietic production therefore relies on *"an adequate homogeneity of systems operations, and these define the unity of a determinate type of system"* (1995:49). Due to this basic principle, interconnected cyber-physical systems need to know of each other who or what they are, and also know the technological capabilities with which each recipient system takes part in the joint operation. The recipient system still has the option to either reject or accept the incoming communication element. When accepting, the recipient system gives the communication element permission to be part of the internal complexity of the recipient system. Acceptance of the communication element thus simultaneously also creates an interconnection in the development of the systems involved. The process of assigning meaning by the recipient system is what Luhmann calls a process of interpenetration, which he defines as follows: *"Interpenetrating systems converge in individual elements—that is they use the same ones—but they give each of them a different selectivity and connectivity, different past and futures"* (1995:16).

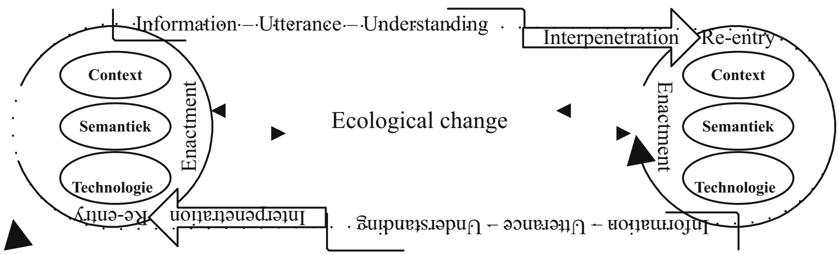

Figure 2 Intepenetration

Luhmann uses the concept of interpenetration to make it clear that systems that are interconnected and exchange and process communication units mutually contribute to the development of other systems in their environment. This means that interpenetration of communication units is more than a general relationship between the system and its environment. Instead, it should, Van Lier claims, be seen as an intersystem relationship between two or more systems that create a temporary but shared environment. Van Lier words this as follows: "*The concept of interpenetration is Luhmann's answer to the question of how double contingency between different systems is enabled, and a new system based on communication comes into being with sufficient frequency and density. Making connections between two or more systems leads to the evolutionary creation of a new and higher form of system formation. This new system formation consists of interlinked autonomous and self-referential systems, and is basically a higher form of interlinked systems that only manifests itself as it comes into being, i.e., as it enters into and maintains a communicative association*" (2013:77). The process of intercommunication and interpenetration of data and information leads to forms of interaction between interconnected and intercommunicating cyber-physical systems and other systems in their environment. From a systems theory perspective, this creates a circular communication process within the whole that shapes itself in reality. The process leads to the development of a new whole that shapes itself and is constantly subject to changes.


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V. Digital ecosystems and ethics

Interconnectedness of systems in networks boosts the development of autonomy, self-adaptiveness, and communication between cyber-physical systems and between these systems and humans. These new capabilities of cyber-physical systems enable them to work together and jointly make decisions. Autonomous decision-making by collaborating systems throws up a series of ethical questions about the jointly made decisions, especially when these decisions affect other systems or even humans.

A. Collaboration

This section will mainly analyse the capability of joint decision-making, viewing it in light of the ethics of interconnected systems. The process of communication, interpenetration, and interaction is the basis for new self-adaptation, self-configuration, or self-reconfiguration capabilities for an individual system or group of systems. This process also enables systems to make decisions jointly or in larger groups to (self-)optimise the functioning of one or multiple interconnected systems. They can also jointly make decisions on the recovery after faults in systems that impede the individual or collective functioning. And finally, joint decision-making can help protect the functioning of one single system or groups of systems against external attacks. The ability to jointly make decisions is conditional on a reliable communication system for information transactions between separately operating and distributed systems. The communication system as a whole will have to be robust or fault-tolerant, i.e. the system must always be able to keep functioning, also when constituent systems are not working or not working adequately. When distributed systems in the form of cyber-physical systems perform information transactions in direct partnership with each other, they must first reach consensus on the meaning to assign to the information transaction to perform. This jointly assigned meaning must lead to a reliable transaction or joint acceptance and processing of the information involved. It must be possible for every autonomous and distributed cyber-physical system to record a jointly performed transaction, so that the origins of the information transaction can always be traced without the information having to be available in a central location. Finally, there has to be a protocol in place that specifies all conditionalities for consensus on decisions and distributed recording of these decisions. Lamport defines such a distributed system as *"a collection of distinct processes which are spatially separated and which communicate with one another by exchanging messages"* (1978:558). And he goes on to define the communication process as a system of events with a predefined order, or as he phrases it: *"we assume that sending a message is an event in a process"* (1978:559). Lamport assumes that every system is capable of sending these communication elements directly to other processes, and of receiving similar elements directly from other processes. The ability to send and receive mutually reliable messages between different processes requires distributed algorithms that must ensure that each process follows similar rules for the sending and receiving of messages, meaning that there is no longer a need for centralised synchronisation or storage of these messages. Such a direct form of sending and receiving communication elements between random cyber-physical systems is, according to Lamport, conditional on the active participation of all processes involved in the application of the distributed algorithms that are needed for it. Such active participation is possible, Lamport argues, when all processes *"know all the commands issued by other processes, so that the failure of a single process will make it impossible for any other process to execute State Machine commands, thereby halting the system"* (1978:562). Random and distributed systems' interconnectedness and dependency on communication processes mean that a system of systems must be able to keep functioning without problems in one or multiple separate systems or components of systems leading to the system of systems malfunctioning or not functioning at all. This means, in Lamport's view, that we have to think about fault-tolerant systems. He considers the concept of a disruption of one or multiple processes within a system meaningless without a notion of time, arguing that: *"we can only tell that a computer system has failed ('crashed') when we have been waiting too long for a response"* (1978b:96). Another condition that has to be met to make fault-tolerant systems possible is that *"each machine must maintain its own copy of the user machine state"* (1978b:109). In Lamport's view, communication between systems that function as part of a greater whole can be considered secure when it is impossible, or at least difficult, to disrupt the required communication between the systems through, for example, unauthorised activity. For distributed systems to ultimately be able to jointly form a fault-tolerant system, Pease, Shostak and Lamport (1980) claim that what is needed is an ability to absorb the effects of faulty functioning or non-functioning of distributed systems by using *"voting schemes involving more than one round of information exchange; such schemes might force faulty processors to reveal themselves as faulty or at least to behave consistently enough with respect to the non-faulty processors to allow the latter to reach an exact agreement"* (1980:228). Lamport assumes that distributed systems will have to autonomously be able to reach consensus on transactions that can lead to, for example, self-adaptation. This means, however, that distributed algorithms will have to be developed that can regulate the consistency of the required voting schemes. In his opinion, the ability to maintain an interactive form of consistency between separate systems is a fundamental precondition for the design and development of distributed systems, where executive control is also distributed. Lamport (1998) describes the procedure to obtain this kind of consistency by using the analogy of the functioning of a parliament in an ancient civilisation, the Paxon parliament. He uses this description as the basis for a decision-making algorithm that is focused on reaching consensus between the part-time members of this parliament, who are not all able to be present for the required decision-making procedures at the same time. The key requirements behind this algorithm are, firstly, fundamental trust between the entities involved and, secondly, consistency where *"each Paxon legislator maintained a ledger in which he recorded the numbered sequence of decrees that were passed"* (1998:2). Important conditions for the use of such individual ledgers by individual systems are described in what is known as the Paxos protocol. An example of that would be to record every decision using indelible ink, so that decisions that have been adopted cannot be changed at a later date. The Paxos protocol is focused primarily on consistency in recording decisions in the respective distributed ledgers to prevent saving of contradictory information. The Paxos protocol also includes rules to ensure that decision-making procedures are initiated, ballots are conducted, quorum is set for these ballots, and options on how to reach consensus between separate systems on decisions are clear. Furthermore, the protocol provides rules on the manner in which the decision made is to be recorded in the respective ledgers. Once a decision has been recorded by all involved in their own distributed ledger and can no longer be changed, this decision can be considered to be a shared block that appears in all distributed ledgers. In a group of interconnected cyber-physical systems, consensus would then enable decision-making on joint activities or transactions by random systems. The decisions made are securely recorded in distributed ledgers, which creates new opportunities for learning from previous decisions, while also leading to a higher level of security because the whole no longer depends on central storage of decisions by a trusted third party. Lamport (2002) claims that such an approach to the process of decision-making based on votes and consensus also offers the possibility of having systems learn from previous decisions. To make this kind of learning happen, a learner node needs to be included in the network that serves specifically to facilitate learning from jointly made decisions, where, in Lamport's words, *"a learner can learn what value has been chosen"* (2002:3). Interconnectedness in networks thus facilitates not only communication and interaction, but also a form of joint decision-making about the use of capabilities such as self-adaptation, (re)configuration, self-recovery, optimisation, and self-protection by groups of cyber-physical systems. Autonomy and self-awareness of interconnected cyber-physical systems thus automatically grow as their new capabilities for intercommunication, interaction, and decision-making develop. This way, cyber-physical systems form a

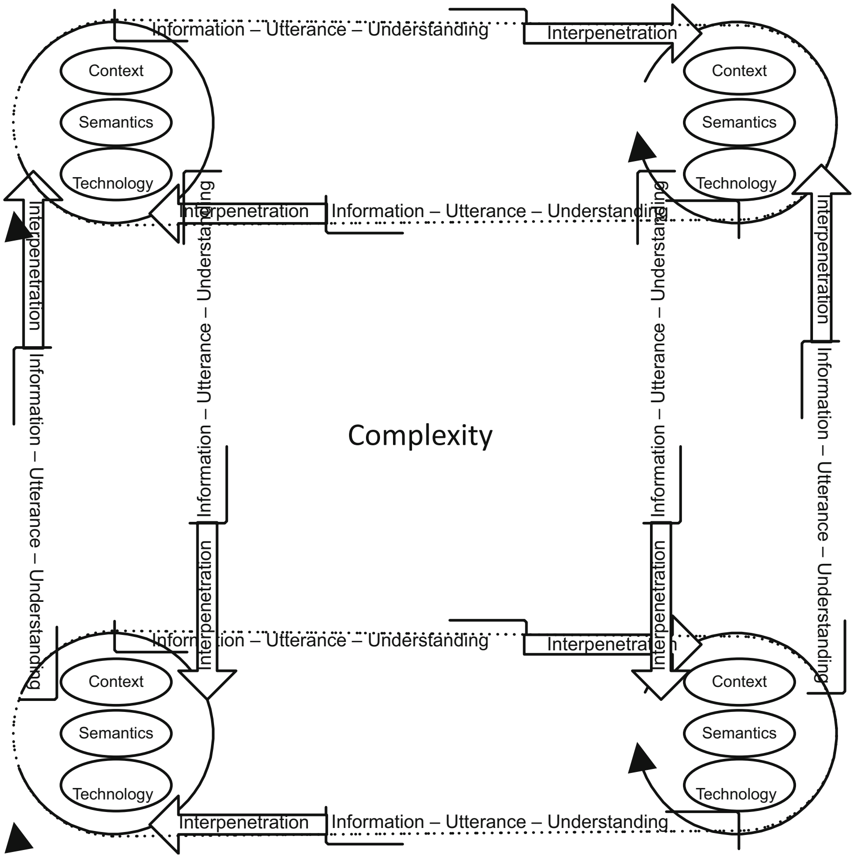

Figure 3 Collaboration

new and stand-alone whole, i.e. a synthesis of networked interconnected hardware and software, which is also referred to as a cyber-physical system of systems. The new whole of cyber-physical systems will, as Van Lier (2017) argues, *"continue to evolve as more cyber-physical systems are networked and start communicating and interacting based on algorithms, software, and information"* (2017:708). Maier (1998) argues that such a new whole of collaborating cyber-physical systems must be considered to be a system of systems when: *"its components fulfil valid purposes in their own right and continued to operate to fulfil those purposes if disassembled from the overall system, and the component systems are managed (at least in part) for their own purposes rather than the purposes of the whole"* (1998:268). Boardman (2006) argues that making connections between networked cyber-physical systems will create new relationships between and with other autonomous cyber-physical systems. For Boardman, these new relationships mean that each of these systems *"will have to be persuaded of the value of all this - to change, to render service, and to collaborate with other systems"* (2006:119).

Olfati-Saber et al. (2007) point out that, in a network of agents in the form of autonomously operating cyber-physical systems, it is important *"to reach an agreement regarding a certain quantity of interest that depends on the state of all agents. A consensus algorithm (or protocol) is an interaction rule that specifies the information exchange between an agent and all of its neighbors on the network"* (2007:215). For Jamshidi (2008), systems of systems are first and foremost *"large-scale integrated systems which are heterogeneous and independently operable on their own, but are networked together for a common goal. The goal, as mentioned before, may be cost, performance, robustness etc"* (2008:ix). Dahmann (2009) claims that a cyber-physical system of systems is characterised by a joint *"set or arrangement of systems that results when independent and useful systems are integrated into a larger system that delivers unique capabilities"* (2009:2). Samad and Parisini (2011) consider the correlation of decentralised and distributed networked compositions of heterogeneous and (semi-)autonomous elements the defining feature of a system of systems. In their view, the aspect of autonomy within this new whole is key, because *"autonomy is inherent in SoS – not just in the function of the SoS but also in the function of the component systems"* (2011:1). The freedom of autonomous systems and systems of systems as a whole thus also leads to a new and exceptional challenge in terms of governance and control. Jaradat and Polinpapilinho (2011) point out that the behaviour of this new whole cannot be understood by *"micromanaging individual systems, autonomy at management and operations levels of individual systems"* (2011:6). All of this leads Mens and Grosjean (2015) to suggest that the development of interconnected, intercommunicating, and interacting systems such as cyber-physical systems and the intrinsic dynamics of these developing and hardware-based, software-based, and connection-based wholes cannot yet be adequately analysed and therefore not be fully grasped in their development. Mens and Grosjean claim that accepting biological theories and methods of analysis can be helpful in finding new research strategies that will allow us to view the effectiveness and robustness of these wholes more as new digital ecosystems. According to Baudry and Monperrus, concepts such as ecology and ecosystem, which became popular from the late 1980s and early 1990s, are now mainly used *"simply to refer to a set of heterogeneous entities evolving in unpredictable environments"* (2012:3). They prefer to define ecology in this context as 'ecological networks', a term that allows them *"to capture different forms of direct and indirect interactions between species and species or populations (nodes) and represent and essential structure to explain ecosystem dynamics and robustness"* (2012:4). The development of cyber-physical systems of systems as a new whole and a combination of physical and non-physical components that can be interconnected in networks calls for new knowledge and insights, especially where these cyber-physical systems are equipped to autonomously establish connections, and to communicate and interact based on these connections. This allows them to autonomously and jointly make decisions about the tasks they need to perform jointly. The capability for autonomous functioning and implementation of adaptations to itself or to other systems in its environment undeniably increases cyber-physical systems autonomy. As cyber-physical systems' level of autonomy increases, the autonomy of humans in arrangements of mutual collaboration and joint performance of tasks and actions will reduce relatively. The new coherence that is created in a cyber-physical system of systems closely resembles the functioning of a biological ecosystem. The digital equivalent of homeostasis could be formed through intercommunication, collaboration, and joint decision-making that engenders activities of self-adaptation, recovery, optimisation, and protection. Concurrently, the process of joint decision-making can take care of regulation and control of the activities of the jointly operating cyber-physical systems. From this perspective, a cyber-physical system of systems can be seen as a cyber-physical ecosystem—an ecosystem produced by a collaborating whole of interconnected components, the nature and function of which forms a holistic whole, which is more than the sum of its constituent parts. Within this ecosystem, not only do the technological parts drive the whole, but so do humans who are part of the whole and use it in their daily lives and for work. An ecosystem is not a simple whole, as it can vary in terms of place, time, composition, and how it develops and functions. A new whole as a cyber-physical ecosystem that functions in concert with humans calls for new knowledge of this new whole. This knowledge can come from a combination of existing knowledge of a holistic view of biological ecosystems and new and holistic knowledge of a rapidly increasing number of networked combinations of cyber-physical systems.

B. Ethics

The evolution of a new holistic whole of interconnected, intercommunicating, and interacting cyber-physical systems into an ecosystem, which develops, exists, and collaborates with humans as a whole, also throws up ethical questions about the development and operation of the separate components, but also of the system as a whole. Questions about, for example, the way in which these autonomous systems function and make decisions as a collaborating whole, which can have major consequences for us humans in our lives and jobs. And questions about what these wholes mean to us, as humans, and the way we deal with them. Although the focus on these kinds of ethical questions is growing, we are only just starting to develop a thinking on an ethical theory that can help us define what we consider good or bad in the development and functioning of this new ecosystem. According to Driver (2004), a theory on the ethical side can provide us with "*criteria for evaluation of actions and character. If a theory does not give us answers that go beyond intuitions, then the theory is not doing any independent work for us, and this would be a drawback*" (2016:9). The ethics we need will have to lay a foundation for what humans consider good or bad in the functioning of such a whole of interconnected systems that make decisions for us that can have a major impact on our daily lives and work. We will have to assess, evaluate, and perhaps even control the new whole, and not only the separate parts of the new whole, in its development and functioning, using an ethical theory. Control of the whole would then be focused on adjusting the functioning of the whole and the underlying components, in their intercommunication, interaction, and decision-making, as well as the ensuing consequences for humans and other systems. New and developing wholes that incorporate humans and technology are seen in, for example, technological implants in humans, such as hearing devices (cochlear implant) or brain implants in cases of Parkinson's disease. Cars are using connectivity and software to give advice on the best route to take, while also letting the owner know when maintenance is due and where to go for the next service. TVs and devices that can autonomously show us the kind of content we like are recommending further viewing based on our Netflix viewing behavior, for instance. Soon, the fridge will tell us we have run out of milk, where to buy more milk, and what we could have for dinner, based on our preferences and what we have in the fridge. Also in our jobs, software is becoming more and more dominant, such as the diagnostics system that a car mechanic plugs into a car to find out what is wrong with it. Surgeons perform high-precision procedures using a software-operated surgery robot, and we often have no idea whether we are talking to a human or a software robot when calling a company's customer service department. Our day-to-day lives and work are continuing to fuse with technology, without us even being aware of it, and at an increasing pace, leading Van Lier, Roozendaal, and Hardjono (2014) to state the following: "*The new hybrid world in which we live and work emerges naturally around us and demands a holistic approach to the developing and all-embracing system in its entirety*" (2014:348). The new hybrid world in which we all live together, amidst an ecology of autonomous cyber-physical systems, leads to new and as yet unknown dilemmas. We must ask ourselves if we, in this world, are going to hang on to, what Heidegger phrases as, "*the current conception of technology, according to which it is a means and a human activity, can therefore be called the instrumental and anthropological definition of technology*" (1977:5). The question is whether such a traditional view would not lead to a world where people, as Arendt puts it, "*are surrounded by machines whose doings we cannot comprehend although we have devised and constructed them*" (1977:264). In our current time, and given the state of development of technology and the way we deal with it, we may already have arrived at a new and specific moment in time, which, according to Arendt, "*unlike the world and the culture into which we are born, can only be indicated, but cannot be inherited and handed down from the past, each new generation, indeed every new human being as he inserts himself between an infinite past and an infinite future, must discover and ploddingly pave it anew*" (1977:13). Can we, in this moment in time between past and present in which we now find ourselves, hang on to the principles that currently determine our lives, and which are rooted in our tradition and history? Is it wise, given this development, to approach technological developments from a perspective that says that *"autonomy in the ethically relevant sense of the word can therefore only be attributed to human beings"* (2018:9) as the European Group on Ethics in Science and New Technologies has claimed? Such a perspective not only makes it impossible to better understand the developing whole, but also fails to do justice to what Braidotti (2013) calls the developing co-presence between humans and technology, *"that is to say the simultaneity of being in the world together defines the ethics of interaction with both human and non-human others"* (2013:169). For acceptance of this co-presence in our thinking and actions, she argues, *"we need new frameworks for the identification of common points of reference and values in order to come to terms with the staggering transformations we are witnessing"* (2013:196). The idea of an ethical framework that thinks in terms of wholes instead of components is not new. As far back as in 1675, Spinoza formulated such a framework for the world around him. Heidegger took Spinoza's Metaphysics as an example of a theory on ethics that relates to wholes. Heidegger argues that Spinoza's Ethics is a whole in its own right, because *"the sole completed system which is constructed all the way through in its foundational connections"* (1985:33). By 'sole completed system', Heidegger not only refers to the theory itself, but also to Spinoza's basic principles. Spinoza writes, among other things, that he takes our world as a substance, or, in his own words: *"I understand that which is in itself and is conceived through itself: that is, that, the conception of which does not depend on the conception of another thing, from which conception it must be formed"* (2017:57). Spinoza argues that reality or the being of this whole is shaped for us by the quantity of attributes or properties that we can or want to assign to this whole. His line of thought on the substance as a whole leads Spinoza to the conclusion that it allows us to qualify something as good when we are sure that it is useful to us. Based on this claim, we can say that when a whole of a cyber-physical system helps us in our day-to-day lives and jobs, and we generally experience this support as good, it can or will ultimately be qualified as good. When the possible functioning of a whole impedes us in general from getting hold of a good, Spinoza classes it as 'bad'. This could happen when the functioning of the cyber-physical system as a whole does not enable us to realise or serve a predefined common good. The qualification of whether the functioning of the ecosystem as a whole is good or bad therefore not only depends on the functioning of the system itself, but also on the way in which we, as humans, perceive and experience this whole or its utterances in our day-to-day existence. According to Spinoza, we humans are highly inadequate in our ability to assess whether something will be able to be qualified as good or bad in the future. In his opinion, this inadequacy is caused by our limited power of imagination of the future based on knowledge from experiences in the present. This leads Spinoza to the conclusion that our knowledge of good and bad can only ever be of an abstract and general nature, and, in Spinoza's words, *"the judgment which we pass on the order of things and the connection of causes, with a view to determining what is good or bad for us in the present, is rather imaginary than real"*. (2017:433). Kant (2017) called such a causal link a synthesis, about which he writes the following: *"we can represent nothing as combined in the object without having previously combined it ourselves, and that among all representations combination is the only one that is not given through objects but can be executed only by the subject itself, since it is an act of its self-activity"* (2017:184). It is Heidegger who links the concept of synthesis with being and the being of things. Heidegger argues that a synthesis does not consist solely in the connecting or associating of representations but departs from *"letting something be seen in its togetherness with something, letting it be seen as something"* (1927:33/56). Heidegger argues that the interconnection between human and objects creates a kind of equipment that we use to produce, and where our responsibility is to reveal the being of the equipment. The equipment is analysed or unravelled, according to Heidegger, based on prior demarcation of what makes equipment equipment, or in Heidegger's words 'the determination of tool-being'. Due to our limited power of imagination, we will have to acquire thorough knowledge, through analyses and continuous investigation, of the functioning of the whole, its components, and their interconnections. Only based on questions, analysis, and discussion will we be able to acquire thorough knowledge of the whole, its components, and their connections. At the same time, this means that we have to think and ask questions about our position as humans in relation to the whole, and what this means for our assumptions regarding the functioning of the technology and our prejudices or assessment with regards to the technology. From the previous, we can infer that the development of a theory about ethics in connection with the development of an ecology of interconnected cyber-physical systems is an issue to which we can only find answers through continuous investigation, analysis, and debate. These answers will also be found on the interface between past, present, and future, and the dividing line between humans and technology. On this topic, Heikkerö (2012) argues the following: *"Even if the ideas of technological determinism and the autonomy of technology are proven unfeasible, in a more limited sense the ethical political character of technological artifacts still remains to be reflected upon. The artifacts act as parts of our social contexts"* (2012:23). Sandler (2014) also believes that: *"ethical theories are systematic accounts of what, why and how things matter, particularly as they relate to deliberations about actions, practices, and policies. For these reasons, the ethics of emerging technologies – both in general and with respect to particular technologies - often involves discussion of ethical theory more generally"* (2014:20). As regards the development of new and developing technology, we owe it to ourselves to think about the essence of this technology and the ensuing effects, without being immediately able to influence these effects. Essentially, there is nothing human about technology, as pointed out above, but it is not purely something technological either. The essence of technology lies, according to Heidegger, mainly in "*what from the beginning and before all else gives food for thought*" (2004:22). To be able to formulate a new ethical framework, we therefore need to think about the essence of technology and the ensuing effects of a co-presence of humans and technology. Moving forward, such a new ethical framework, which is based on the idea of a whole of autonomously functioning humans and cyber-physical systems, needs to be able to fulfil the basic principles that allow us to evaluate, assess, and control the moral functioning of this new whole. In this context, Van der Poel and Royakkers (2011) argue that ethics in its essence is a systematic reflection on morality. They consider that morality in turn consists of opinions, decisions and actions that are expressed by an individual or a group of people concerning what they consider to be right or wrong. Standards are formed by the rules that prescribe necessary, desirable or prohibited action within a specific context. Or as Abney suggests: "*Morality always involves an "ought (not)" – it is about the way the world ought (or ought not) to be, as opposed to the way it actually is*" (2014: 36). For Floridi, it is essential that the ethical discourse not be limited to individual agents, because this will hinder "*the development of a satisfactory investigation of distributed morality, a macroscopic and growing phenomenon of global moral actions and collective responsibilities resulting from the invisible hand of systematic interactions among several agents at a local level*" (2013:137). In view of these descriptions, Anderson and Anderson (2007) argue that "*the ultimate goal of machine ethics is to create a machine that itself follows an ideal ethical principle or set of principles*" (2007:15). This objective brings us, according to Gunkel (2012), to a new boundary where we as human beings are confronted with new and fundamental challenges to our moral philosophy. The fact that we as human beings develop and use ever more intelligent and autonomous machines means that the machines will each time present us with new questions concerning the fundamental human assumptions at the basis of the question as to who or what shapes being a moral subject or, in the present case, a moral object.

C. Ethical framework for digital ecosystems

The development of a digital ecosystem of interconnected cyber-physical systems that are able to self-adapt to changes and intercommunicate thanks to algorithms and software is one that raises new questions. Especially when systems, enabled by algorithms and software, are able to jointly make decisions that affect us as humans, we will become interested in the rules based on which these decisions are based. Ethics teaches us that the difference between good and bad is an abstraction that is hard to fathom, especially when it concerns new and difficultly imaginable developments. This final section of the essay will try to outline a framework within which we can think about the unimaginable. To do so, concepts will be defined and described, and a diagram will be used to outline a procedure along which the functioning of these collaborating systems can be judged and, if necessary, controlled using feedback loops. As Van Lier states (2016, 2018), the software and algorithms used by these intelligent and autonomous machines thus form the new knowledge logics for humans, organisations, and society. Algorithms are becoming more intelligent, operate more independently and take more and more decisions. Algorithms are certainly not free of values and it is therefore advisable to focus more on the value-specific choices that have been and will be included in these algorithms. According to Steiner (2013), an algorithm is in essence merely a set of instructions developed by one or more people and intended to be performed by a machine such as a computer, a software robot, or a physical robot in order to realise an ideal result. Information is fed into the algorithm, after which it is checked and approved on the basis of the combination of rules. However, by definition, algorithms are not a stable unit. Genetic algorithms are an example of that. As described by Holland (1992), genetic algorithms can develop independently in an evolutionary manner and autonomously learn to solve new problems during this development in a way that even their developers find difficult to understand. In our modern society, algorithms have developed into a crucial element that enables us to control the ever increasing flow of information, according to Gillespie (2014). These algorithms also determine how information is perceived and used by end users, whether these are humans, machines or combinations of the two. These elements were not the most important reasons for Gillespie to further consider algorithms. He calls for more research into the *"multi-dimensional entanglement between algorithms put into practice and the social tactics of the users who take them up"* (2014). According to Gillespie, we should thus search for a mutual connection between algorithms and their creators and/or users and the considerations applied by them in the development and/or the use of these algorithms. He states that we should stop considering algorithms as merely a form of computer code, but we should rather consider these algorithms to be the current socially-constructed new knowledge logics that are used and controlled by organisations. According to Gillespie, research in this area should mainly focus on the complex operation of these new knowledge logics. This research is important because, as we have seen, algorithms are increasingly able to act, make decisions and process information without human intervention on a scale that is difficult to conceive. Kraemer et al. (2011) are of the opinion that algorithms are essentially value-specific if it is impossible to make a purely rational decision between two or more options, and ethical considerations play an implicit or explicit role in this decision. They consider developers morally responsible for the software they create if the developers of these algorithms are unable to prevent the algorithm from making such ethical choices in its selection of information. Kraemer et al. (2011) define such a value judgement as *"any proposition expressing a view on how things ought* *to be or not to be, or what is good or bad, or desirable or undesirable"* (2011:252). They are of the opinion that, if such implicit value judgements are or have been included in algorithms, these value judgements should be transparent and easily identifiable by the users. Allen, Wallach and Smit (2006) also draw attention to such value judgements that have been included in algorithms, intentionally or otherwise. System developers and software developers should at least be aware of whose values are involved and who contributed those values during the development of the algorithms. However, they also point to the fact that the modular design and the development of mutually connected technological systems means that it is no longer possible for a single person or a group of people to oversee the entire interaction or response that arises from the complexity of the new algorithms that are used. As part of a development in which we as human beings have ever higher expectations of algorithms and these algorithms become ever more autonomous in their actions, we cannot avoid including possibilities in these algorithms that enable ethical or further considerations. Crnkovic (2012) is of the opinion that such a form of artificial morality should be considered a skill on the part of machines to perform activities that we as human beings would have performed in the same way. In his opinion, the argument that such systems do not have a capacity that allows for a conscious form of intentionality is incorrect because defining what such a conscious capacity actually is or involves is generally problematic. Even for people, intentionality is described on the basis of observed behaviour, because we do not have direct access to how the human brain operates. Crnkovic states that we should see 'intelligent agents' such as algorithms more as parts or components of a larger socio-technical environment. From this perspective, responsibility is also a distributed and mutually connected whole, because within the overall socio-technical environment only part of the responsibility can be attributed to an intelligent agent such as a software robot or physical robot. According to Gunkel (2012), we can and should distinguish in both cases between moral ‘agents’ and moral ‘patients’. Moral agents can then be described in a general sense as a class of agents and patients that can qualify as a source for moral actions. Moral actions in this sense are a result of the complex communications and interactions among these interconnected agents such as described in the financial sector. As Floridi states: *"what we are discovering is that we need an augmented ethics for a theory of augmented moral agency"* (2013:160). This is contrasted by the moral ‘patients’, in other words, a class that is formed by ‘agents’ that can qualify in principle as receivers of these moral actions. According to King (1995), it can be determined from the perspective of intentionalism that the intention with which an action is performed by an agent is decisive for the moral value of this action. In order to be able to evaluate the actions that have been performed on the basis of their moral value, we should, according to King, search for the reason why the specific action was performed, and not limit ourselves to evaluating the action itself. For Scharre, autonomy of a machine or combinations of machines in its most simple form *"is the ability of a machine to perform a task without human input. Thus an autonomous system is a machine, whether hardware or software, that once activated performs some task or function of its own"* (2015:8). Tonkens (2009) states that in addition to the intentionality of the action performed by the agent, the agent's degree of autonomy when performing the action is also important. He is of the opinion that autonomy can be distinguished into a negative and a positive form of autonomy. Negative autonomy arises when the agent is restricted in its actions by an outside influence which determines what the agent should do. Positive autonomy exists if the agent is the only party that determines what rules are performed by it when performing its activities. The terms 'moral agent' and 'moral patient' and the terms 'intentionality' and 'autonomy' can be used as the basis for the development of an ethical framework that can be used to develop moral machines and the ensuing new interactions between human beings and machines. We can also start to think about what we as human beings consider to be moral action by cyber-physical systems within the emerging ecosystems of cyber-physical systems and humans on the basis of such a framework. The next step in developing this framework is to define 'actors' within this framework who perform activities within the digital ecology of cyber-physical systems, for example. According to Luhmann, the concept 'system' in its abstraction refers *"to something that is in reality a system and thereby incurs the responsibility of testing its statement against reality"* (1995:12). On the basis of this general description, human beings, organisations and the technology used by them for instance in the form of cyber-physical systems can be considered separate systems, as referred to by Luhmann. New systems that come into being in this larger whole, are different from the systems that already exist when considered from the traditional system perspective, because they focus on technology in their actions and use the activities that arise from this technology to trump the traditional possibilities of human actions within the financial sector. These new combinations of human beings and technology are referred to by Hissam, Klein and Moreno (2013) as socio-adaptive systems. They describe such socio-adaptive systems as *"systems in which human and computational elements interact as peers. The behavior of the systems arises from the properties of both types of elements and the nature of their collective reaction to changes in their environment, the mission they support, and the availability of resources they use"* (2013). This description allows us to also determine that, contrary to more traditional organisations, a socio-technical system satisfies the post-anthropocentric assumption of equality between human beings and technology and jointly uses the new ensuing possibilities to create the new possibilities previously mentioned. Systems are required to satisfy two essential criteria within the system concept developed by Luhmann, namely self-reference and autopoiesis. First and foremost, systems must have the capacity to establish relationships within the system itself (for example human technology) and be able to distinguish these internal relationships from the relationships established by the system with its environment. Luhmann refers to this power to distinguish as 'self-reference' (1995:13). The relationship between the system and its environment is not just an incidental and accidental relationship that merely serves as adaptation to impulses that arise from the environment, but is also a structural relationship without which the system could not continue to exist, according to Luhmann. The system distinguishes itself from other systems in its environment by the relationships established by the socio-technical system with its environment. The second criterion of the system concept formulated by Luhmann is the principle of autopoiesis. The term autopoiesis was originally formulated by Chilean biologists Maturana and Varela and was composed by them from the terms 'auto' which means 'self' and 'poiesis' which means 'create'. Luhmann uses the term to indicate that the communication elements used by the system are created by the system itself. These communication elements are, in turn, involved in the continued existence of the system itself and the relationships between the system and its environment. The activities that are performed by a system in its environment are therefore always related to the raison d'être of the system and the relationships that already exist within the system. Together, they form the basis for the intentionality with which the system performs it activities. Figure 1 shows the moral agent in diagram form.

The moral agent intends to establish communication connections with other systems in its environment by means of the elements created by and of itself in the form of algorithms. The system's intention with these relationships is to collect

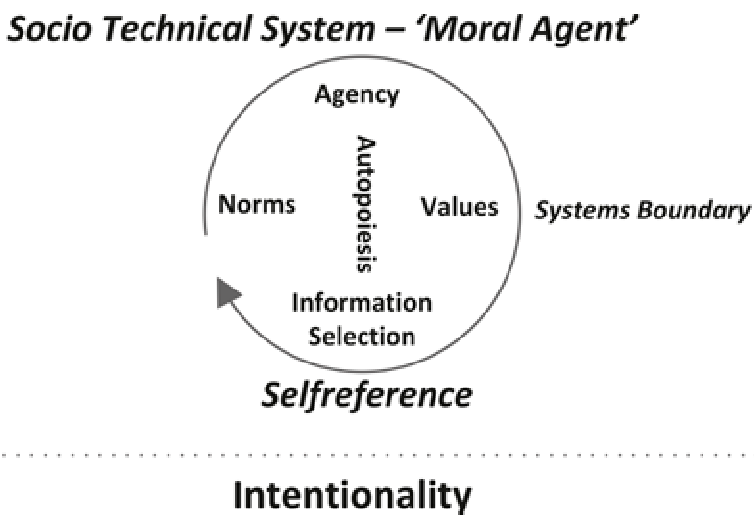

Figure 4 Moral agent

possible within a certain period of time. Luhmann states that the connection between two socio-technical systems that is created by means of communication in the form of algorithms is not the same as sending and receiving messages between a sender and a receiver as formulated by Shannon (1948). The metaphor of sending and receiving messages focuses only on the manifestation of sending and/or receiving the message, according to Luhmann (1995). This manifestation is defined by him as the ‘utterance’. To him, ‘utterance’ is merely a suggestion of a selection of information. According to Luhmann, communication connections between socio-technical systems can therefore be considered not just a selection process of information in which only two elements are involved, namely the sender and the receiver, but also as a three-part selection process. According to him, the synthesis that arises from the unity of the three elements of ‘selection of information’, the ‘utterance of information’ and the possible ‘understanding’ of the selected information that is included in the communication connection should be assumed for the communication connection between two or more systems. Communication can be considered successful if the receiving socio-technical system is able to attribute a correct meaning, as Van Lier (2013) states, to the synthesis that arises from the trinity of information, utterance and understanding, without further intervention. The information can be incorporated within the system's complexity and used for further action, operation or creation with the aid of the meaning assigned by the receiving system. It will be clear that the synthesis arising from the trinity of information, utterance and understanding can also form a possible basis for including moral considerations. The element of communication is depicted in figure 2.

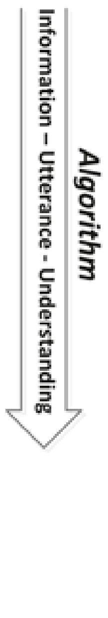

Figure 5 Communication element

When the communication element—consisting of the synthesis of the selection of information, utterance and understanding—arrives at the receiving system, in the present case a 'moral patient', the receiving system will be able to allow or refuse this communication element access within its system boundaries. The system performs selections in both situations in order to determine whether the communication element can be accepted and incorporated in the complexity of the receiving system itself or whether it should be rejected. Figure 3 presents the moral patient in diagram form.

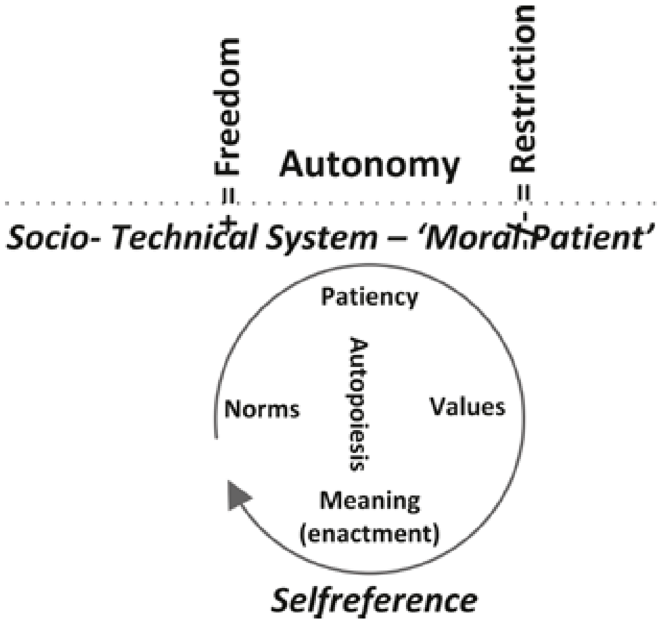

Figure 6 Moral patient

Access to the receiving systems and incorporation in the complexity within this system is described by Luhmann using the term 'interpenetration'. According to Van Lier (2010, 2013, 2013), Luhmann uses this term to indicate the special manner in which systems by sending elements of communication contribute to the design of the receiving systems in the environment. Luhmann does not apply the term interpenetration until the system makes its own complexity available for construction by another system.

The response that will be expressed by the receiving 'moral patient' (a new synthesis of information, utterance and understanding) to the communication element that it has received and given meaning to, can be considered from a cybernetic perspective as equivalent to a feedback loop as defined by Wiener. Feedback is, according to Wiener (1948), "*to return the information into the system, which the system can use for correcting its own action*" (1948:3).

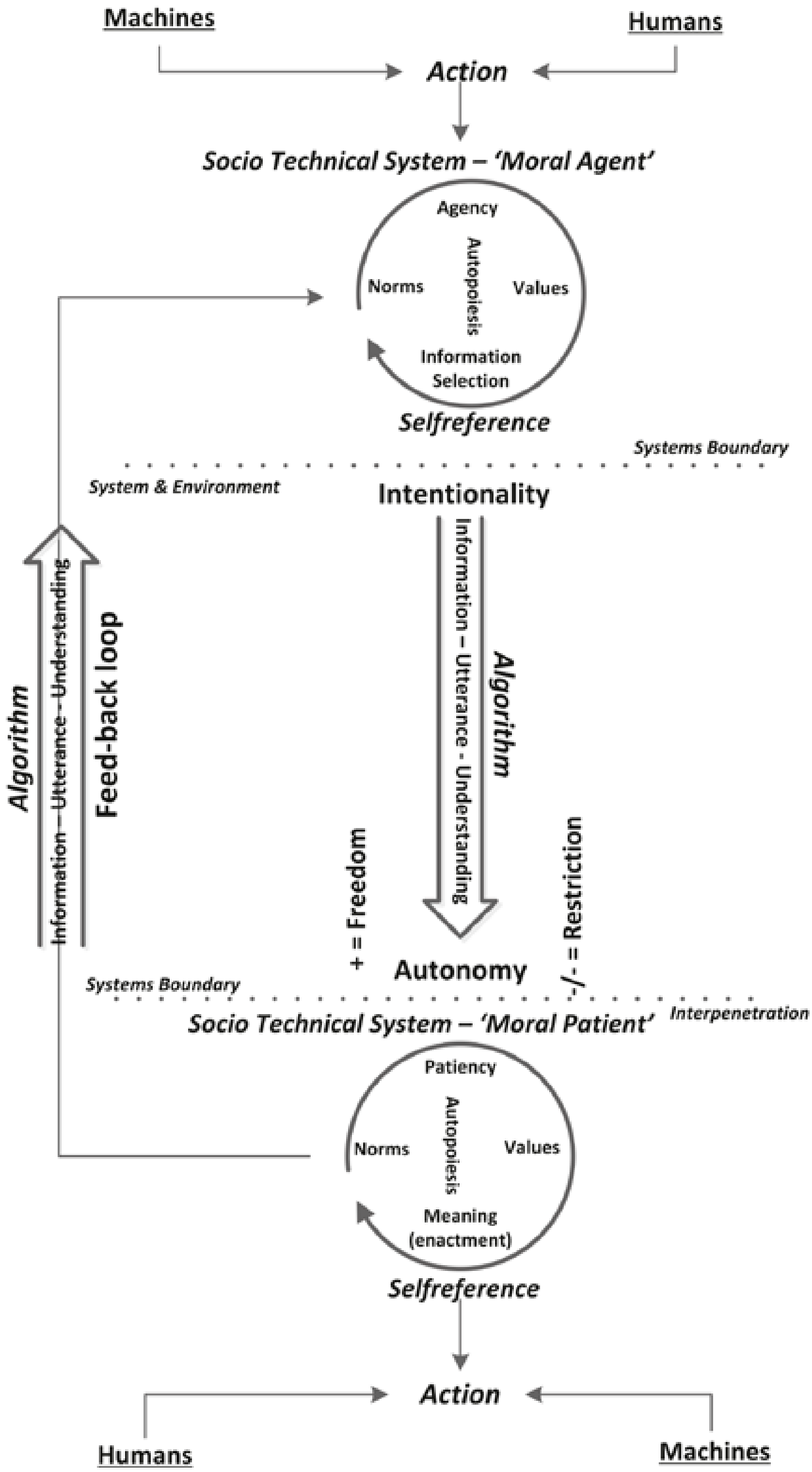

Figure 7 Feedback loop

The feedback loop can create a cycle of machine learning in which moral elements are simultaneously included. When represented in diagram form in figure 4, we then arrive at the full diagram on the basis of which further research can be carried out into the further expansion of an ethical framework for the possible development, management and maintenance of moral machines and algorithms. To summarise this section, we can conclude that software and algorithms are becoming increasingly autonomous and capable of making decisions by themselves. Decisions made by autonomous machines, software and algorithms within an ecosystem of communicating, interacting and decision-making cyber-physical systems could be seen as being ethically important. According to Van de Voort et al. (2015), a decision can be considered a moral decision when a person could have made a similar decision in the same situation. Ethical decisions made by autonomous humans or autonomous cyber-physical systems always have an intention which is decisive for the moral value of this action. The action performed by autonomous systems within the new emerging ecosystem of connected cyber-physical systems is usually a result of communication elements based on information and algorithms which could be accepted by other systems. By accepting these communication elements, they will interpenetrate the receiving system and the system's own complexity. Within this complexity, the accepting system will assign meaning to this communication element. The assigned meaning can be reused by the accepting system in a communication feedback loop that can help teach the sending machine to correct its own actions. This conclusion is in line with recent developments described by Deng (2015), who argues as follows: "*With this kind of 'machine learning', a robot can extract useful knowledge even from ambiguous inputs. The approach would in theory help the robot to get better at ethical decision-making as it encounters more situations. But many fear that the advantages will come at a price. The principles that emerge are not written into the computer code*" (2015:25). The increasing ability to learn causes the autonomy and intelligence of the machines connected within networks to increase further on the basis of the algorithms used. We therefore cannot avoid, as suggested by Coeckelbergh (2014), associating the notion of moral standing with "*interpretations of encounters and interactions between humans and machines*" (2014:67), especially where these connections also see machines make more and more decisions that have moral elements or consequences.

VI. Epilogue

This essay started by quoting Smuts' conclusion that interconnectedness of components of a system or the interconnectedness of whole systems leads to the development of a new whole or synthesis. Wiener and Ashby combine this observation with the concept of feedback. The synthesis in the form of the new whole develops and shapes itself around interconnections in networks and processes of intercommunication, which lead to interpenetration and interaction between them. These systems being or becoming autonomous therefore also means that an increasing degree of freedom is created to independently or together with others execute tasks or achieve predefined goals independently or together with others. The development of the term ecology shows that within this biological context, organic and inorganic elements make up a constantly changing whole through intercommunication and interaction. A whole that changes due to the interconnectedness of autonomous entities that autonomously self-adapt to changes arising from within themselves or from the environment of the ecosystem as a whole. The changes made further the development of the whole, creating new or emergent properties that cannot easily be traced back to underlying individual parts of the whole. Over the past few decades, more and more technology-based systems are developed in networks, which are combinations of hardware, algorithms, and software. Connection in networks enables these systems to communicate and interact with each other. The new combinations of cyber-physical systems make up new wholes in the form of systems of systems, which are also acquiring greater autonomy in the execution of tasks and realisation of specific goals. This is conditional on intercommunication and interaction that enables these interconnected systems to jointly make decisions for the execution of individual or joint activities. The decisions make an individual system or group of systems become able to implement changes, which, in turn, enables the systems involved to (re)configure, optimise, protect, or recover. As Van Lier states: "*mutual communication and interaction between intelligent machines and humans will inevitably play an important role in an interconnected world. In the development of this interconnectedness, feedback loops play an essential role in the process of communication and interaction. Feedback is the giving of a meaningful response based on data and information received and the meaning assigned to it. Feedback hence plays an essential role in the development of productive collaboration between man and intelligent machine*" (2016:93). Organic systems and cyber-physical systems thus acquire more and more freedom in their actions with respect to each other and to humans. The process through which interconnected systems create a new whole, within which humans also play a changing role, does not, according to Heidegger, mean that this whole is created as a whole, but rather that it is created and develops itself from an ongoing process of *"standing in creation as a becoming"* (1936:131). In Heidegger's view, the process towards a 'being' of these biological and cyber-physical wholes, which is bound to a specific time and place, is an ongoing process of the creation of this being. This process of creation of the being of a whole of interconnected systems and their continuously increasing autonomy and freedom of action raises questions that Heidegger considers part of the domain of metaphysics, i.e. these are questions about the being of the whole in the world, questions that are asked above the level of the whole. Thinking in such terms not only has the potential to help us better understand the being of these new wholes, it can also lead to a rethink of our being as humans in a world of autonomous and freely operating cyber-physical systems of systems. The latter point will provide ample material for further research over the coming years. Also in the years to come, this research will continue to be focused on the investigation, analysis and application of new manifestations of the phenomenon of technology. In collaboration with lecturers and students from different degree programmes at Rotterdam University of Applied Sciences, I hope, through practice-based research and context-rich learning, to be able to create greater insight into and a deeper grasp of the potential opportunities and threats that come with these new manifestations of technology for us as humans, for organisations and for society as a whole. This will predominantly materialise in the form of research projects to which I can contribute substantially through my expertise in areas such as the (Industrial) Internet of Things, cyber-physical systems, blockchain technology and cybersecurity. Such projects can be based at the Creating 010 research centre or other research centres at Rotterdam University of Applied Sciences, such as the Business Innovation research centre or the RDM Centre of Expertise. Alongside my research, I will continue to be dedicated, both at Rotterdam University of Applied Sciences and beyond, to sharing and spreading new technology knowledge and experiences by giving lectures and keynote speeches. By sharing knowledge and experience at a range of different events organised by Rotterdam University of Applied Sciences, at conferences for lecturers and researchers, but also at conferences across the business community, I hope to be able to contribute substantially to the deepening of insight into and the adaptation of the technological developments that will impact us humans, our organisations and society at large over the coming years.

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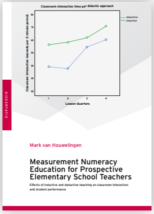

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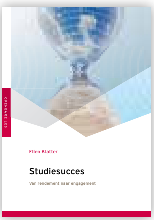

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