Melusina Press
Humanities

Serie #1 | The Ends of the Humanities
Edited by Johannes Pause, Christoph Purschke,
Isabell E. Baumann, Till Dembeck & Georg Mein

# The Humanities and the Rise of AI

## Implications of Cultural and Societal Engineering

*Johannes Pause, Christoph Purschke,*
*Isabell Eva Baumann, Till Dembeck & Georg Mein*

# Beyond algorithm-based AI concepts

## Consciousness and its generation on machines

Ralf Otte

The Ends of the Humanities - 3
Edited by Johannes Pause, Christoph Purschke, Isabell Baumann, Till Dembeck and Georg Mein

Melusina Press, 2025

Published in **Melusina Press**, 2025
11, Porte des Sciences
L-4366 Esch-sur-Alzette
https://www.melusinapress.lu

Management: Niels-Oliver Walkowski, Johannes Pause
Copyediting: Carolyn Knaup, Niels-Oliver Walkowski
Cover and Layout: Valentin Henning, Erik Seitz

The digital version of this publication is freely available at
https://www.melusinapress.lu.
The PDF and the master copy are generated with the help of princeXML.
Print and Distribution is carried out by BoD - Books on Demand, Norderstedt

Bibliographic information of the National Library of Luxembourg: The National Library of Luxembourg lists this publication in the Luxembourg National Bibliography; detailed bibliographic data are available on the Internet at bnl.public.lu.

| | |
|---|---|
| ISBN (Online) | 978-2-919815-79-1 |
| ISBN (PDF) | 978-2-919815-80-7 |
| ISBN (Print) | 978-2-919815-81-4 |
| DOI (Publication) | 10.26298/1981-5791-baac |
| DOI (Volume) | 10.26298/1981-5791 |
| DOI (Series) | 10.26298/2716-7550 |
| ISSN (Online) | 2716-7550 |

# Beyond algorithm-based AI concepts: Consciousness and its generation on machines

## 1. Introduction and definition

For centuries there has been a lively discussion on the "nature of conscious or mental states". The discussion is hardly to be overlooked by the layman, and yet a rough pattern is recognizable in the basic philosophical assumptions, which sometimes has shaped whole epochs. Already in antiquity a substantial difference between physical and mental phenomena, a dualism between physical and mental substances, was assumed. In later philosophical views this fundamental dualism was weakened and reduced to a dualism of properties of the same substance. By the middle of the last century, many philosophers then favored monism, a kind of identity of mental and physical states. Later, monism was also adapted, an essential difference between mental and physical phenomena was again accepted; and a so-called functionalism is nowadays proposed by many philosophers and researchers as the most appropriate form of description for the *mind-body problem*. But also, these philosophical approaches are constantly developed further, so that today different philosophical approaches and explanation models for the nature of mental (conscious) states are represented (Beckermann 2011).

But not only philosophers, but also natural scientists have been trying for many years to find out how spiritual, i.e. inner mental and conscious, states of a person can emerge from the complicated, physical excitation patterns of the brain. Ultimately, this is about nothing less than understanding the emergence of consciousness in all its facets. It is generally known that mental states as such cannot exist without being grounded in physical, i.e. bodily experience. But at least as important is the question whether or how mental states could causally affect physical states. Some researchers deny this causal effect from the mental to the physical in the brain (already for energetic reasons) in principle, others allow such a causal chain but ask about the possible principle of action. These are the basic questions of philosophers, biologists and psychologists dealing with the "new science of the mind" (Eric Kandel). The subject of consciousness has thus been a topic that has moved mankind for a long time. Meanwhile, computer scientists and engineers are also interested in the topic, because equipping an artificial intelligence (AI) with consciousness would not only be more attractive, but also very useful for many new tasks in industry and society, for mobile robotics, for example, to really perceive the environment (Otte 2021).

The sciences are always about the description of things, and the natural sciences are ultimately about the description of objects that exist outside our consciousness. Science develops by changing the description of these things. Of course, this does not change the objects, but only our knowledge of these objects. A good method of description is mathematics, because mathematics is a form of description that is highly precise, so that contradictions in the formulation can be recognized more quickly. And mathematics has another advantage: if you can no longer solve a problem by thinking, you can possibly calculate into unknown areas by "stubbornly" applying calculation rules. This is precisely the approach that will be pursued in this article. It turns out that the development of a so-called hypercomplex algebra (very specific numbers of mathematics) and their application in mathematical equations provides possibilities to better describe and thus understand processes of consciousness.

However, reports on mathematical results sometimes lead to incorrect interpretations, as some mathematical terms are also used informally, but with a different meaning. One example of this is the term "imaginary". In mathematics, the term refers to new numbers, so-called "imaginary numbers", which ultimately lead to complex and hypercomplex numbers. Colloquially, however, "imaginary" means something like "fuzzy" or "unreal". In this article, the term "imaginary" is used purely mathematically. When we speak of imaginary phenomena of consciousness, we mean that such phenomena are described by imaginary (hypercomplex) numbers.

Of course, certain mathematical forms of description point to certain physical properties, in this specific case to a possible hypercomplex form of energy. In physics, objects with imaginary and complex masses have been known since the 1960s, for example tachyons (Feinberg 1967). In the article, there is an extension to hypercomplex forms of energy, which are ultimately used to describe consciousness processes using bi-complex numbers (a dedicated form of hypercomplex numbers).

So what is consciousness? After the above introduction, it is not surprising that there are very many different explanations and definitions for consciousness. For example, experts distinguish between vigilance consciousness (being awake vs. being asleep), cognitive consciousness (being aware of attention), state consciousness ("having a conscious state"), phenomenal consciousness ("sensing, feeling, sensing something"), action consciousness ("doing something with intention"), and self-consciousness ("being aware of oneself and one's state") (e.g. Metzinger 2005). These different explanations are instructive, but not helpful for an engineer - and that is the author - since it seems impossible to build systems in the near future that even require the different definitions of consciousness for distinguishing their form of expression. Since there is no universally accepted definition, a working definition will now be given, which will be used in the essay: "Consciousness is the subjective experience of mental processes and states of a person or a system. It is the totality of a person's (system's) inner experiences; beginning with *perception*, through *emotional phenomena*, and ending with *will processes*." This fuzzy definition includes, at least for now, the statement that (at least) humans have consciousness. However, it can be assumed that animals, at least higher animals, also have consciousness. In the case of plants, it is not known whether they could possess consciousness. Physical systems, such as stones or crystals, were generally not assumed to be capable of consciousness. But just with the latter objects there are researchers in the meantime who also want to assume consciousness to very specific, "lifeless" crystals.

Engineers and natural scientists look for the smallest common denominator rather than the superset of all consciousness phenomena when defining consciousness. Therefore, from an engineering point of view, it seems appropriate not to distinguish between different forms of consciousness, but only between the terms mind and consciousness, because it is precisely by a sharper definition of these two terms that differences and similarities can be worked out. Especially with regard to a later mathematical description, a conceptual clarification of mind and consciousness is essential. To get a better idea of the differences, let us first consider the pair of terms

- matter and mind.

What is matter? Matter contains all processes, which possess a real (mathematically expressed, real-valued) energy level. This includes all physical, quantum physical, chemical and biological, and also neuronal processes known to us. What is mind? If one does not want to slide into esoteric definitions, one has no choice but to also consider mind (should it exist ontologically) as a physical phenomenon. In Otte (2016) it was already suggested to understand "mind processes" as physical processes, which - in contrast to material processes - has an immaterial (mathematically expressed, *imaginary*) energy level. According to this view, the term mind describes immaterial wave phenomena of nature or, mathematically speaking, wave functions with special *imaginary (hypercomplex) energy levels* (as mentioned at the beginning). Surprisingly, this view coincides almost exactly with the thinking behind Japanese Shintoism, but this will not be discussed in detail here.

Consciousness is seen as a real existing phenomenon of systems with dedicated very high complexity, but it has a form of energy that ensures that it cannot be measured directly with today's measurement technology, even though its energy exists. In mathematical terms, phenomena of consciousness are therefore - as mentioned above - described by hypercomplex numbers. Apart from this description, phenomena of consciousness are called “hypercomplex system states”, simply because they must be described with hypercomplex numbers in order to formally describe their particular characteristics correctly. The term “soul” is not used in the paper because it is not clear exactly what soul means from a technical point of view, but it is assumed that (“dead”) physical systems are not capable of expressing a soul. In many discussions, however, the concept of “mind” and the concept of “consciousness” are mixed up. But mind is not consciousness, especially not in the technical elaboration. Just as little as material processes (on lowest physical level) can describe biological body processes, just as little immaterial wave phenomena (on lowest physical level) describe consciousness processes. Let us therefore try a further conceptualization and introduce the pair of concepts

- body and consciousness.

One recognizes that the term *matter* was replaced by the term *body* and the term *mind* by the term *consciousness*. Both previous terms were transferred thus from a low complexity level to a very high level, because an organic body has a far higher complexity than simple matter. And whatever may be meant by the term mind, consciousness can be understood as a highly complex mental process.

The ascent of physical processes via chemistry and later biology up to bodily processes of a human being is so complex that until today it is not possible to understand (living) bodily processes in their whole depth mathematically. Biology, life, cannot be described in mathematical equations today. It is the same with the mathematical description of consciousness. Even if one has recognized the existence of immaterial processes on the level of physics, the ascent of immaterial processes via chemistry and biology up to consciousness processes in the brain of a human being is so complicated that it cannot (yet) be worked through mathematically. That means, there are no mathematical equations for consciousness up to now, not even if one accepts immaterial processes on elementary level of physics and tries to describe these elementary processes mathematically.

From the comparison of matter-and-mind therefore meaningfully follows a comparison of body-and-consciousness. From when one should speak of consciousness processes and no longer only of immaterial (mind) processes is still unclarified. But it is just as unsettled, from when one should speak of a living process and no longer only of a chemical process. Only when it has been recognized in what way biological life differs so essentially from physics and chemistry, it becomes understandable in what way processes of physics differ from processes of living beings. The author assumes - and this shall be mentioned here only as hypothesis - that the difference (chemical to biological or mental to consciousness process) begins with the emergence of a living cell. To a cell we attribute life on lowest level, it is for us the most primitive life form. So it could be that one day we have to speak about consciousness from the biological cell level on. Currently this is not known, but it is postulated that consciousness (no matter what form) must have physical properties of mental phenomena. However, this means that not only biological systems, but also certain physical systems may have consciousness. Although this article assumes that “mind processes” can occur everywhere in nature as purely physical processes, from now on they will only be referred to as “consciousness processes” if the complexity of the entire system is so great that basic “mind processes” have essentially condensed into a kind of consciousness.

Imaginary states were introduced above as hypercomplex system states with immaterial energy levels. It is (axiomatically) assumed (and has yet to be proven) that these system states exist in addition to other, material states of a system, even within a technical system, for example a circuit. Artificial consciousness - and this is the only topic of the paper - is based on the concept of hypercomplex states and is expected to be generated on inanimate matter, such as computer circuits, in the near future. In order to conceptually distinguish this synthetic consciousness from other expressions of consciousness, this essay speaks of *machine consciousness* and introduces the following definition: “Machine consciousnesses are condensed immaterial process states of a system so that they can be used technically.” Machine consciousness means consciousness on physical machines. This consciousness has nothing in common with the consciousness of biological systems; it shall nevertheless be called consciousness, because - as we will see - it shall lead to technical systems capable of perception (as the lowest level of consciousness).

In the AI-community it is assumed that consciousness correlates with the appearance of intelligence, but this does not have to be the case. From the author's point of view, no correlation between intelligence and consciousness need exist in nature. One could just as well assume that consciousness and intelligence are two independent (orthogonal) properties of natural systems (Fig. 1).

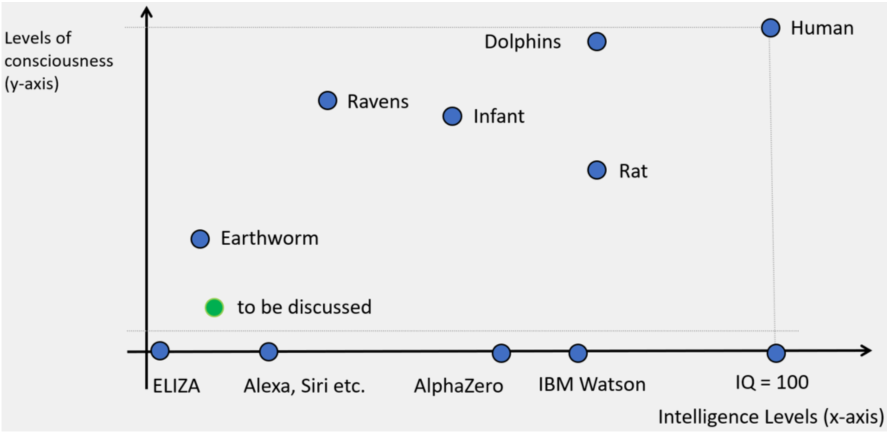


Fig. 1: Consciousness and intelligence could be two orthogonal aspects of nature

Consciousness and intelligence could cover a plane of properties in which humans, animals, plants and machines can be classified. The author argues that all of today's AI systems do not possess consciousness, because digital machines do not "constructively condense immaterial processes". For him, the systems of today's AI occupy a special position in nature. From his point of view they are to be found directly on the x-axis (Fig. 1), i.e., today's AI systems have a higher and higher intelligence level, but no "spark of consciousness", the essay will return to this later. The "to be discussed" mark in Fig. 1 is a placeholder for the machine consciousness to be introduced later and its hypothetical placement.

If it is true that today's AI systems cannot express any phenomena of consciousness, they are subject to limits in principle that cannot be overcome regardless of the effort spent, because for many interactions with the environment a system needs consciousness. In the following, some limits of today's AI will be pointed out. Even those who may not follow the above theses have to find a reason why today's AI systems simply do not get ahead with certain applications, and have not done so for more than 10 years. It is not about marginal failures, but about a hard failure of certain AI applications to reality.

## 2. The beginning of the end of the hype

Artificial intelligence is approaching the end of a major hype. The great successes in many areas of data evaluation such as social media, in the banking sector or in industrial products are contrasted by a remarkable number of failures. Autonomous driving, mobile robotics and other applications in the natural environment are sustainably resisting penetration by AI. It can be summed up this way: AI has so far been successful only in the "mathematizable" environment. Whenever the complexity of phenomena moves in the direction of natural processes and mathematical abstraction is no longer possible, AI fails. The question to be answered is therefore why AI has so many problems with use cases in natural environments.

## *Everything is simulation*

AI today relies on two pillars of intelligence: reasoning and learning. The PSSH hypothesis of Simon and Newell (1976), the basic hypothesis of AI, states that intelligence could be simulated by mechanical *symbol manipulation* (e.g. on a computer). This has not really been contradicted to date. Learning and thinking does seem to be mechanizable ("mathematizable"); all AI relies on mathematical methods. However, this is a misconception. Because only this part of thinking which can be mechanized has been mechanized so far. And everything that can be mechanized can run on a computer, therefore it looks as if a computer can think. But this is only a linguistic convention: One says that the computer can think, because it implements the mathematical part of thinking so well, that a nonequivalence of *simulation of thinking* with *thinking* would look like splitting hairs. But human thinking goes beyond logically correct thinking. In particular, humans can arbitrarily switch between logics, deal with contradictions and even with circular reasoning. And so, one quickly sees the limits of the purely mathematical method of thinking. All current AI systems fail sooner or later due to the complexity limit of second-order predicate logic.

## *Limits of logic and logical thinking*

Since the work of Kurt Gödel (1931) it is known that 2nd order predicate logic can lead to statements whose truth is not computable. However, algorithmic computer systems with non-verifiable truth pose a serious logic problem. A similar logic problem applies to circular reasoning. "All Cretans lie," says the Cretan. But is he lying? For a computer, this is a situation where it can't come to an end with the calculation. A human being, however, could say, "yes, the Cretan there is lying, I have already met him in Athens". A human solves the problem by getting out of the logic system, and getting back in, any number of times.

As already pointed out, humans can deal with unknown and even contradictory truths and also with any number of circular reasoning. The reason is probably that humans have not experienced their *own I* as an infinite regress; humans have been able to cancel the circular reasoning of their *own I*. Their ME contains themselves completely, because the ME originates from the brain and yet contains the whole body from which it originates. Systems that master this logical difficulty can probably deal with all logical antinomies, but this is only a thesis. Another reason might be that humans do not "live" in logics but have invented logics as a symbolic form to structure experience in a formal way.

In any case, computers do not contain themselves. One could use AI programming languages to develop software which contains itself, but from this no experience for the system arises, it would remain purely syntactical. Computers permanently reach their "thinking limits", humans not at all. That computer systems beat humans in certain mental tasks like GO or chess is simply because this part of thinking could be fully algorithmized, which is why computers outperform humans in these areas. As soon as something is algorithmizable, a computer will solve the tasks better than a human, but infinitely many problems are not algorithmizable, as every mathematician knows. Thus, the number of all possible algorithms on all computers of the world is (only) countable (infinite), but the variety of all problems is over-countable (infinite). Algorithmization as a problem-solving method is thus a good but severely limited tool for realistic problem solving that nature presents us with. However, today's AI can only turn to algorithmizable problem solutions; the rest is in principle unattainable.

### *Limits of learning*

Machine learning systems require data to learn their models. Thus, in principle, these inductive learning methods cannot generate general knowledge. For example, if an ornithologist has built a table in which the plumage of all swans is white, the AI – which is supposed to generate rules from this – must conclude that “all swans are white”. But that's not true, as any human knows. Machine learning is a statistical concept, which usually does not lead to universally valid knowledge.

A human being, however, can use the results of a learning and observation process in a creative act to generate completely new and valid knowledge (such as the law of gravitation by observing falling apples). Now a creative act is characterized precisely by the fact that no algorithm exists that specifies how to get from a starting point A (e.g. observing falling apples) to a new creative state B, thus algorithmic AI computers cannot perform any creative performance. They can apply learned knowledge in the extrapolation space, but any expert knows that beyond a certain distance from the learned supporting points in the learning data space, only wrong results are produced. AI systems are not creative and they cannot develop general-purpose rules from learning results. Humans can do that very well.

### *Limits of simulation*

Although the mathematical-algorithmic method reaches its limits as mentioned above, nevertheless mathematical methods for the description of consciousness are already recognizable in rudiments. So, one could assume that consciousness like thinking and learning could be generated (simulated) mathematically on a computer. But this is a false conclusion. Just with consciousness, especially with perception as the lowest level of consciousness, the limit of any simulation becomes apparent. If one has developed mathematical equations for the big bang and runs them on a computer, their application in the processor does not cause any physical changes in its environment. The simulation is said to have no “causal power”, so it cannot interfere with the physics of the environment – except for processor heat and such like. And so it is with all mathematical simulations. A simulation of chemical equations does not produce chemistry; a simulation of biological processes does not “live”. Mathematical descriptions are essential, but in no scientific discipline has it occurred to anyone that if you run the equations in the form of software on a computer, then more than simulation is happening. But AI suggests otherwise. Because it equated *thinking* with the *mathematics of thinking* and *learning* with the *mathematics of learning*, and was very successful in doing so, while it denied the difference between real process and simulation and postulated that the AI machines were actually intelligent.

However, the success of AI stems from the fact that the rational thinking and learning of humans has been precisely modeled mathematically in advance and can thus of course be run on a computer. This is a completely normal process. When a computer adds two numbers, it is *calculating*. Or does it only simulate calculating? For philosophers this might have been an important question, but for engineers, computer scientists and users of AI it was not. If the simulation is sufficiently exact (means enough for selected technical applications), one does not distinguish it linguistically anymore. One says that the computer thinks, learns and calculates. But this is just a linguistic convention, because it should be clear that the distinction between something that happens and the statement that something happens is not only important, but fundamental.

This distinction becomes particularly clear when we are no longer modeling mathematical processes (and exactly those are rational thinking, learning and calculating), but physical, chemical or biological ones. Here, of course, the simulation does not reach the "causal power" of the original process. Thinking and learning can be "generated" mathematically as explained above (at least a large part of it), the crucial thing now is that one cannot do that with consciousness, since consciousness is at least a *physical property*. Also weight, size or form cannot be generated mathematically, but these physical properties can only be described mathematically.

One could describe the running of mathematical equations on a computer as a physical process, because finally register entries are read out, written in etc., but this physical process in the memories and circuits is not specific enough to produce physically "more than just waste heat". The digital computer does not physically distinguish what kind of equations are running in the processor, this is also the reason why intelligence and consciousness cannot correlate in a digital computer, as mentioned earlier. From this example you can also see that there is no emergent behavior of a computer. The running logics on a computer do not emerge from the underlying physical processes; emergence might turn out to be the biggest scientific illusion later on.

### *Example 1: Perception cannot be simulated*

A concrete example where the limitations of simulation are even more apparent than in thinking and learning is perception.

For the last 10 years, AI in the field of machine vision has been racing from one success to the next, Deep Learning Networks, for example as CNN, have established downright revolutionary possibilities in image processing. While classical backpropagation networks can already *learn anything that is learnable* (and continuous), they have failed in image processing because the neural image evaluations were not translation and rotation invariant. Convolutional neural networks (CNN) have been used to overcome these difficulties.

And yet, it is in *machine vision* that one recognizes the great difficulties of AI. To put it in a nutshell: AI systems of machine vision cannot see, they are blind to their external environment. The reason is not really surprising; today's AI systems simulate seeing. but seeing is not a mathematical process, not at all, but a thoroughly physical one. This, of course, has enormous consequences. To distinguish between dogs or cats, an AI needs tens of thousands of images, but a child needs at most 10 or 20 different cat and dog images. The difference in performance between humans and machines is so dramatic that image processing will have to be done differently in the future and mathematical deep learning systems will have to be fundamentally changed. But how?

The perception of the human being reveals surprising things when looking closer. The human being sees, as everybody knows from own experience, the images where the photons "start their way" and not where they "arrive" (on the retina). The term "seeing" (better: visual perception) therefore gets a clear physical meaning. Seeing is the perception of electromagnetic waves from the place of their starting point. It is as if the photon on its way to the eye carries its place of origin at the start. When a photon hits the retina, one should expect that there (only) color and intensity are recorded. But the starting point of the photon? How does the starting point arrive at the retina? This can only be explained quantum mechanically. Of course, using optical laws, the starting point P(x,y,z) in Fig. 2 can be back-projected from the point of impact on the retina P'(x',y',z') and the refractive properties of the eye lens, but why do we "see" the starting point P outside the brain? How does the visual re-projection from P'' (in the visual cortex) to P happen (Fig. 2)?

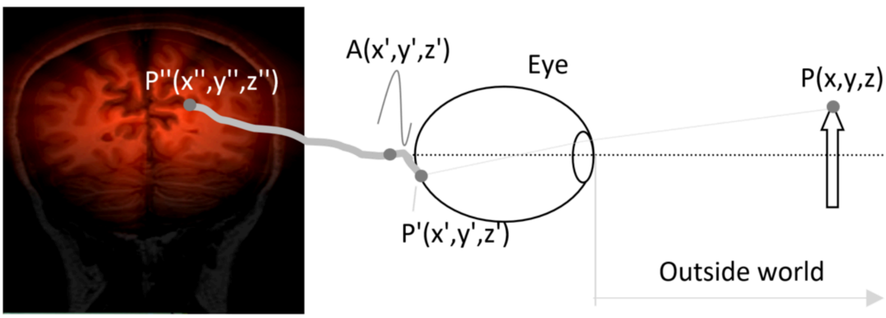


Fig 2: Seeing a point P in the outside world

If one electrically excites the retinal cell P'(x',y',z'), then no bright spot P(x,y,z) appears for the affected person in front of his head in the external world. The author posits that if one were to initiate - directly behind the retinal cells - exactly the identical electrical action potentials A(x',y',z') into the visual cortex that would normally be evoked by the retinal cell during vision, then the subject will still not see an object dot P(x,y,z) of the environment. Vision, and also hearing, cannot be derived solely from the electrically evoked nerve potentials A that are conducted from the sensory organs to the brain. A further processing step must be introduced that leads to an image P''' in consciousness.

This approach is not state of the art, but it is a compelling necessity from the author's point of view.

When a human sees something, it is not a model formation in the visual cortex which is separate and separable from the original. No, the person is (from the point of view of the so-called *First person*) visually "merged" with the viewed object (P''' ≡ P), a technically considered "incredible" process. Dreyfus (1985) says that people do not represent their environment, they *are in it*. From the sighted person's point of view (*First person*), model in consciousness (P''') and original (P) cannot be separated at all. Such a separation can be learned, but for the time being perception (external) and object (external) are identical. It is different from the point of the *Third person*. For a researcher analyzing a sighted person during vision, there is the original object (P) in the environment and the neural image (P'') in the cortex (which he can detect by MRI, for example). But from the point of view of the *First person* (the sighted person himself) the model P'' in the cortex does not exist, because he does not see the model in his head, he sees the object P''' in consciousness and therefore outside in the environment. Humans (and certainly also highly developed animals) therefore have two ways of signal processing, an internal representation of the environment in their internal neuronal networks (P'') and additionally a perception of the object in the outside world in the consciousness (P'''). Computers only have an internal representation of the environment, they do not see out of their cameras into the world. As strange as it sounds, humans can do this.

But how exactly does P''' get back outside to P? This is a completely new research question, which precisely supports the author's thesis that consciousness is needed to see, especially consciousness with hypercomplex energy states. This effect is the essence of the approach presented.

Seeing and thinking are two completely different mental processes. While thinking can be easily approximated mathematically, seeing cannot. That is the difference. And in computers, the process of seeing is quite different from that in humans. Computers reconstruct a mathematical model of the environment from received electromagnetic waves and recoded electrical signals in the CCD chips of their cameras, which we also mistakenly call *seeing* because electromagnetic waves are used for data acquisition of the environment. But one could just as easily use acoustic waves as the basis for model building (of course, their resolution is lower); in that case everyone would understand that this form of data processing does not lead to vision. All methods of deep learning for machine vision are now pure mathematical simulations, with all the resulting disadvantages. For the computers of today's machine vision, the outer boundary of their world is the chip of the camera, there is no further "outside", it is an impassable, because physical hurdle for it. The consequence of this is highly explosive for many applications, such as autonomous driving: computers see nothing, their tables of zeros-and-ones are exhausting mathematical reconstructions of an outside world unreachable for "them". With no deep learning system in the world, it is possible to "project" the images from computer memories back into the outside world, but that is exactly what humans do (Otte 2019).

In summary, software vision does not exist. Software seeing is a principled delusion to which researchers are subjected and a serious limitation of any software AI.

*Example 2: Semantics cannot be calculated*

Let us come to another example of limits of simulation. Computers of today's design cannot comprehend the semantics behind the statistical syntax. Of course, pseudo-semantics can be derived from context, otherwise there would be no language translation systems or state-of-the-art speech engines, for example, but semantics is a matter of recognizing the meaning of things independently. When an AI sees a tree, it creates a table of zeros and ones as a representation inside it, as just described. This table is not linked to anything in the original environment. But meaning is created precisely through linkage and association. Now, one can program any number of associations, knowledge-based systems provide the basis for a multitude of such links. But every single association must be foreseen. And meaning goes far beyond associations. In Otte (2016) it is stated that meaning always arises at the receiver of a message and cannot be contained in the message itself after all.

Let us consider, for example, a language-processing system that processes numerous texts a,b,c,... one after the other and arrives at some point at text k, in which it says: "The recipient of text k will be destroyed after reading". An AI system of today's design will process this text k in the same way as the texts a, b, c. If the syntactic information quantity H of a,b,c and k is the same ($H_a=H_b=H_c=H_k$), an observer who monitors all electrical voltages and currents of the system will still not be able to measure that the message k differs semantically from the messages a,b,c, because the receiver does not understand the message, and syntactically this message contains the information quantity $H_k$, with $H_a=H_b=H_c=H_k$.

If one would assume at all that the meaning of a message is (only) recognizable in the electrical changes of the currents and voltages of the receiver, then for example two messages a and b with different syntactic amount of information $H_a$ ("Hello") and $H_b$ ("Hello world!") would have per se also different semantics, because their processing at the receiver would lead necessarily to different currents and voltages. But even this interpretation can be wrong. Even two messages i and j that mean nothing to the system, for example (whose semantic information set is therefore zero for the systems), would lead to different processing steps if message j is, for example, a hundred times longer than message i. Therefore, encoding the semantics alone in the measurable processing sequences of the receiver is not possible at all. But semantics cannot be encoded in the message itself either, since its meaning lies mainly in the receiver's reaction to that message. So where is semantics encoded?

If one considers semantics as mathematically "orthogonal" to syntax on a metaphoric level, then one recognizes that systems with consciousness (whose consciousness processes could be also mathematically "orthogonal" to the neural processes, Fig. 1) are predestined to understand semantics. Semantics is recognized in consciousness, and only there. It is assumed that the *semantic* information quantity is encoded in the change of the *imaginary state* of a system, in this case of the receiver system. (The term "imaginary state" was introduced at the beginning, describing physical phenomena with immaterial energy levels; this will be elaborated in paragraph 3). Therefore, conventional AI computers cannot evaluate any semantics; their *imaginary states* (in the digital circuits) are completely independent of the processing tasks.

If a classical AI syntactically learns that rain is wet, it means nothing to an AI because "being wet" is a subjective experience in consciousness. An AI without consciousness can attach many actions to the measured state of "being wet", such as "sidestep", "send error message", etc., but it has no *subjective meaning* because this has been defined only for consciousness. One could program human semantics into these systems, in the sense that the state "to be wet" is to be avoided, because otherwise the system rusts or the circuits become defective, or the car can slip. But this is still not a subjective experience of the system itself, and "being wet" still means nothing to the system.

## 3. Proposal for generating consciousness on machines

After mentioning some limitations of today's AI systems, in the following we will describe the approaches of generating consciousness on machines. To be able to explain consciousness from an engineering point of view, let us look again at the properties of natural objects: Objects can have physical, chemical or biological properties. It does not matter whether consciousness is thought of as a dynamical sub-property of a process or ontologically as really existing. That a stone has a weight is a physical property, that acids and bases together form a salt are chemical properties, and that a cell is alive is a biological one. Every natural object in the real world at least always has physical properties. The physical properties are mediated by basic forces and are independent of our views about them. Thus, should consciousness exist in real nature, it is necessarily to be expected that consciousness is at least a physical property of an object; that means, it exists independently of our opinion about it. Whether it has any other properties, we want to ignore here consciously.

Let us come to the postulated starting position: Consciousness is a property of an object which is at least physical. A brain and also a computer have this minimum property. Consciousness exists (if it exists) independently of the views of third parties and can be determined objectively (for example on the basis of its effects on a system).

### *Consciousness has unusual physical properties*

Currently there is no chance to understand human consciousness mathematically or even to model it. Only a massive reduction of the complexity of the problem allows an engineer to deal with this topic at all. Of all the manifold properties of consciousness, only the physical ones will be highlighted in the following. If the physical properties of human consciousness are known, then there is hope to establish processes on physical systems that express consciousness processes.

We thus consider human consciousness in its greatest possible abstraction as a physical process. But consciousness processes have extremely unusual physical properties:

1. Consciousness processes are not physically measurable, because up to now it has not been possible to measure consciousness directly, despite all advanced measur-

ing methods. Consciousness is an inner state, an experience from a very private point of view (so called Qualia), without any access from outside.
2. Consciousness processes can store information.
3. Consciousness processes have a temporal behavior, i.e., they change their information state over time.
4. Consciousness processes are non-spatial, one cannot assign x,y,z coordinates to thoughts or dream images.

Even if consciousness processes, better: their contents, cannot be measured directly, their *effects* in the brain must of course be measurable. Consciousness processes are just not understood as epiphenomena, but they have permanent effects on the neuromorphic structures of the brain.

With these physical results we come to the discussion of important scientific relations. In the following it will be explained mathematically why consciousness processes were introduced at the beginning of the essay with the term "imaginary state".

### *Mathematical description of physical aspects of consciousness processes*

Because of their importance for the mathematical description of consciousness, complex numbers shall be discussed in more detail: Complex numbers - that are composite numbers z consisting of a real part "a" and an imaginary part "i·b" - have been known in mathematics for centuries. Mathematically one writes: z = a + i·b. The number "i" is the imaginary number with$i = \sqrt{-1}$. Mathematically experienced readers recognize that it is not possible to solve the problem $x = \sqrt{-1}$ with real numbers, because $(+1) \cdot (+1) = +1$ and $(-1) \cdot (-1) = +1$. There is no real number whose square becomes -1. Therefore (some hundred years ago!) the number range of the real numbers had to be extended by new numbers, the "imaginary numbers". Numbers consisting of real (3, 6,-9,...) and imaginary numbers (-3i, -12i, 5i, 100i) are the *complex numbers* (for example: 4+5i or -3-7i). In 1833, Hamilton interpreted the complex numbers as ordered pairs of *two* numbers <1,i> and sought an extension to *three* dimensions, the so-called *hypercomplex trions* <1,i,j>. This search failed, however, because he could not multiply his trions without contradiction, so he had to extend his algebra to 4 dimensions <1,i,j,k>. In 1843 (i.e. after 10 years of intensive searching) he found the multiplication rules of his so-called *Quaternions*. The Quaternions are a 4-D algebra, with the one-element 1 and three imaginary entities i, j, k. Such an algebra is called hypercomplex, because there is more than one imaginary entity. An example of a hypercomplex number is: q=2+6·i-9·j+12·k.

It is not that mathematics prescribes the nature of things, but in the history of natural science it has been shown that from time to time problems occurred which could be solved adequately only by "new" mathematical approaches. Just as real (e.g. transcendental) numbers – which already arise from the solution of simple geometrical tasks – could give us some more understanding about "infinity", the above introduced "imaginary numbers" could make us aware of a physics (that of quantum physics) which has unusual effects. The "mental phenomena" to be described are now even more unusual than quantum phenomena and it suggests itself that new mathematical numbers are indeed needed to describe these phenomena adequately. Hypercomplex numbers could point to physical processes whose energy contents are classically not measurable. Hypercomplex (resp. mental) phenomena are thereby not separated from the real objects of nature, but would be intrinsic properties of certain objects, which produce just these properties. Thus, the mathematical description is ultimately about showing that "mental phenomena" fit into the present scientific world view, but extend it fundamentally.

The development of natural sciences was usually based on mathematical descriptions. However, as stated above, mathematics itself must be adapted from time to time. While in the first times of the natural sciences the algebra of the natural, whole, rational and later of the real numbers was sufficient for the description of nature, quantum physics has been described on the basis of the so-called *Complex Algebra* since about 100 years. Complex numbers consist of *real* and (the already introduced) *imaginary* numbers, the last ones are the eponym for the "imaginary" of states of consciousness emphasized in the essay (see insertion).

Until recently, real and complex numbers had sufficed to describe all natural phenomena mathematically. But the physical analysis of the phenomenon "consciousness" suggests something fundamentally new, namely that "mental oscillation and wave phenomena" could be immaterial (imaginary). But not only that. Even the oscillations and waves of quantum mechanics already possess a kind of imaginary (they are usually so-called "possibility waves"), otherwise one could not understand many effects, as for example the measurement problem. But their imaginary is such that after a measuring process the received mathematical values represent *real* "probability amplitudes" for the occurrence of physical values. This is not so with consciousness processes. Consciousness remains physically immaterial even after measurement (the process of becoming conscious). Mathematically expressed, the calculation of the energy of mental processes must therefore lead to imaginary values, because (only) this is a good explanation why mental processes are in principle not measurable with conventional measurement techniques. There's a bunch of possible explanations. One being that the experimental setting used to measure consciousness could be ill-constructed, another being that the conceptual understanding of what consciousness is could be wrong. Or another explanation would be that consciousness phenomena do not exist at all. But this is obviously wrong. Therefore, the generation of consciousness in technology is advantageous, because it is predicted that technical systems with and without consciousness will be seriously differ from each other, which will be clearly measurable).

Now, the physical properties of consciousness demanded above (1.-4.) can be modeled neither with real nor with complex numbers. Only one *hypercomplex algebra* can describe the *physical problem of imaginary* mathematically correctly, since such an algebra has several imaginary quantities, Fig 3. From initial considerations, the hypercomplex *Quaternions* seem to offer themselves for modeling mental processes (see Insertion and Otte 2011). However, such an attempt fails, since e.g. the necessary oscillatory phenomena cannot be formulated with it; that's why an algebra deviating from *Quaternions* has been proposed for describing "mental processes", the so-called *Bi-Complex Algebra* (Hertig 2014).

*The Algebra of Bi-Complex numbers*

Particularly interesting with hypercomplex numbers is how the imaginary numbers can be multiplied (and divided) with each other, which determines many of their later mathematical properties. Fig. 3 shows the multiplication table for the imaginary numbers i, j and k, which is the basis for formulating oscillation phenomena and Fourier transformations for imaginary waves. Thus, there is (since 2014) a 4-D algebra based on hypercomplex numbers <1,i,j,k> which admits all physical needs, in particular *to store information on imaginary wave functions*.

Numbers q from this *Bi-Complex Algebra (B)* consists of one real number and three imaginary numbers i, j and k, here is an example of such a number: q=5+2·i-3·j+7·k.

Philosophically, it might be interesting that there is only *one* hypercomplex 4-D algebra that satisfies all the necessary properties. For example, the multiplication "i·j" must result in "-k" (Fig. 3), anything else will not lead to success, and so it is with all the other multiplications given. Thus, the results shown are inevitable.

Development of a new hypercomplex algebra <1,i,j,k> on **which oscillations (Taylor series)** and **Fourier transformations** can be mathematically formulated and where **imaginary eigenvalues** are obtained by applying energy operators to wave phenomena.

| | $1$ | $i$ | $j$ | $k$ |
|---|---|---|---|---|
| $1$ | $1$ | $i$ | $j$ | $k$ |
| $i$ | $i$ | $-1$ | $-k$ | $j$ |
| $j$ | $j$ | $-k$ | $-k$ | $j$ |
| $k$ | $k$ | $j$ | $j$ | $k$ |

Multiplication table of bi-complex numbers,
for example :

1 * 1 = +1
i * i = -1
i * j = -k
j * j = -k

Fig 3: Mathematical fundamentals of consciousness: Bi-Complex Algebra (1/2)

The importance of the algebra ***B*** is to be emphasized. The formulation of oscillation phenomena is necessary because oscillations are always used when information is to be stored by modulation; the whole communication technology is based on the idea of information storage on oscillations and waves. And, of course, the storage ability of information in consciousness is a very important property, without this ability one would not need consciousness at all. If one now extends - as suggested in the paper - the idea of information storage to phenomena whose energy levels are *hypercomplex*, the algebra ***B*** could provide the basis for describing "mental phenomena". (An exact mathematical analysis of the algebra ***B*** is given in Hertig 2014).

| | | |
|---|---|---|
| $\psi(x) = e^{ix} = \cos(x) + i\,sin(x)$ | (4.1) | Energetic wave (e.g. radio wave) |
| $\phi(x) = ke^{jx} = k\cos(x) + j\,sin(x)$ | (4.2) | **Immaterial wave (imaginary wave )** |
| $ke^{jx} = k\left(1 + jx - \frac{kx^2}{2!} - \frac{jx^3}{3!} + \frac{kx^4}{4!} \dots\right) = k\cos x + j\,sin\,x$ | (4.3) | |
| $\lvert\phi\rvert^2 = \phi^*\phi = ke^{jx}ke^{-jx} = (k\cos x + j\,sin\,x)(k\cos x - j\,sin\,x) = k$ | (4.4) | **Imaginary magnitude square** |
| $\Omega(x) = e^{ix} - ke^{jx} = \cos x + i\sin x - k\cos x - j\sin x$ | (4.5) | Superwave function omega <1,i,j,k> |
| $\psi(x)\cdot\phi(x) = e^{ix}\cdot ke^{jx} = (\cos x + i\sin x)(k\cos x + j\sin x) = ke^{j(x+x)} = \phi'(x)$ | (4.6) | Interaction of a wave with itself |
| $\psi(x)\cdot\phi(y) = e^{ix}\cdot ke^{jy} = (\cos x + i\sin x)(k\cos y + j\sin y) = ke^{j(x+y)} = \phi'(x,y)$ | (4.7) | Interaction of two waves |
| $\psi(t)\cdot\phi(t) = e^{it\omega_{new}}\cdot ke^{jt\omega_{store}} = ke^{j\,t(\omega_{store}+\omega_{new})t} = \phi'(t)$ | (4.8) | **Modulation of an imaginary wave to store information** |

Fig 4: Mathematical fundamentals of consciousness (2/2)

In this paper it has been repeatedly said that mind and consciousness are imaginary states of a system. If one follows this argumentation, however, the physical effect of consciousness processes on material processes seems (still) relatively unclear, since it obviously threatens to violate the causality of physics, if *non-energetic phenomena* can interfere with material physics. However, if such an effect happened, for example, via the change of quantum processes ($\psi$(x)) in the microscopic processes of a system, causality would be preserved; more detailed explanations are given in Otte 2016. In Fig. 4, equation 4.7., one can already see how a multiplicative interaction of imagined quantum mechanical waves within brain tissue $\psi$(x) with imaginary waves of consciousness $\phi$(y) could be formulated. The result is explosive: Immaterial processes, i.e., *also phenomena of consciousness, could act into the material processes even without real energy*. Of course, the result was tacitly expected, because if it were otherwise, consciousness would have no biological sense at all and in technology one would not need machine consciousness. One measures consciousness by its effects, because consciousness without effects into the material world we would not need at all.

With the above representations the difference of consciousness phenomena to quantum physics can be clarified once more in its different mathematical description: Quantum physics describes its phenomena with complex numbers z = a+b·i. Possible imaginary phenomena are thus expressed in complex-valued terms. In contrast, the phenomena of consciousness are described with the imaginary numbers *j* and *k*. From a mathematical point of view, the *imaginary of quantum physics* is of a different nature than the *imaginary of consciousness* (Fig 5).

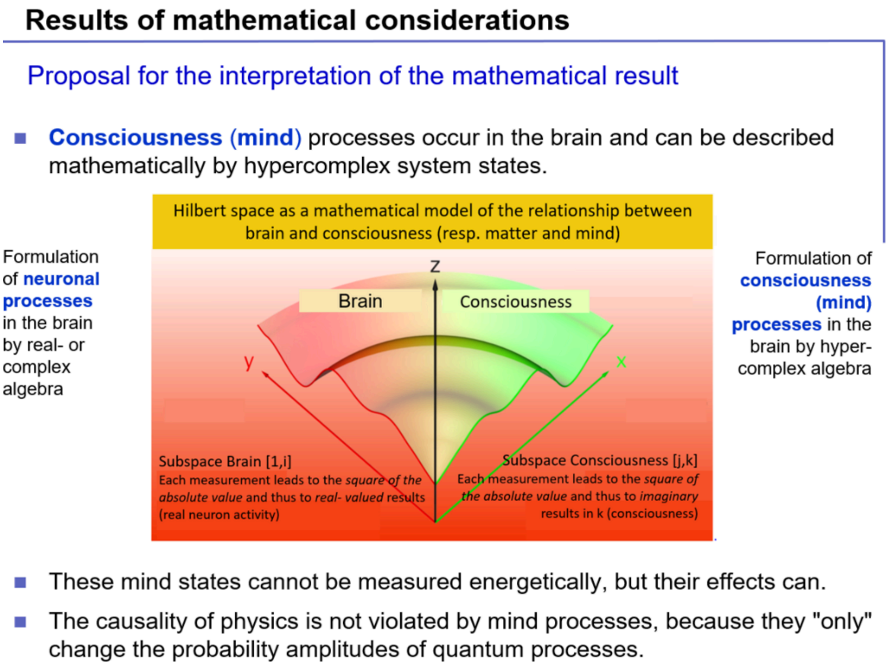


Fig 5: Hypercomplex wave functions for the description of mental states

### *Summarizing the mathematical paragraph about immaterial processes*

Consciousness processes are immaterial phenomena (with mathematically imaginary energy levels), which arise on suitable physical objects. In the human brain such consciousness processes form by themselves, which cannot be measured from the outside (to repeat: because of their imaginary energy level). Immaterial processes have thereby special physical properties, which the human brain uses for example for the process of *seeing*, since the properties make the (apparent) outside projection of images possible, as discussed above. The inner perception (Qualia) of human beings - based on those immaterial processes - can be described mathematically in its basic features. Using the mathematical description, technical specifications can be obtained.

### *Neuromorphic computers as a technical basis for generating machine consciousness*

From the mathematical description above it is clear that consciousness processes are associated with quantum processes (at least, however, with electromagnetic photon processes), but they are not identical with them. The thesis propagated by Penrose and many others (Hameroff 1996; Stapp 2004; Penrose 2017) - that quantum processes in the brain are responsible for the expression of consciousness – *has to be extended*.

This extension is mathematically complicated (as we have seen), but nevertheless it shall be repeated here again in a scientifically correct formulation: The application of energy operators to quantum processes leads to mathematically real-valued results. The application of energy operators to the imaginary wave functions used in Fig. 4 leads to mathematically imaginary results in base k (see Hertig 2014 and Otte 2016). These different mathematical forms of description are necessary because fundamentally different physical phenomena are described: Quantum processes take on real physical values through measurement processes (with a certain probability), consciousness processes remain unmeasurable even after becoming conscious, in the mathematical description this is implemented by the hypercomplex representation.

Ultimately, consciousness processes are a kind of "hyperquantum process" because their physical properties are "even more imaginary" than those of quantum processes themselves. However, quantum processes (at least electromagnetic processes) operate as an interface of information exchange between immaterial and material processes (Fig. 6).

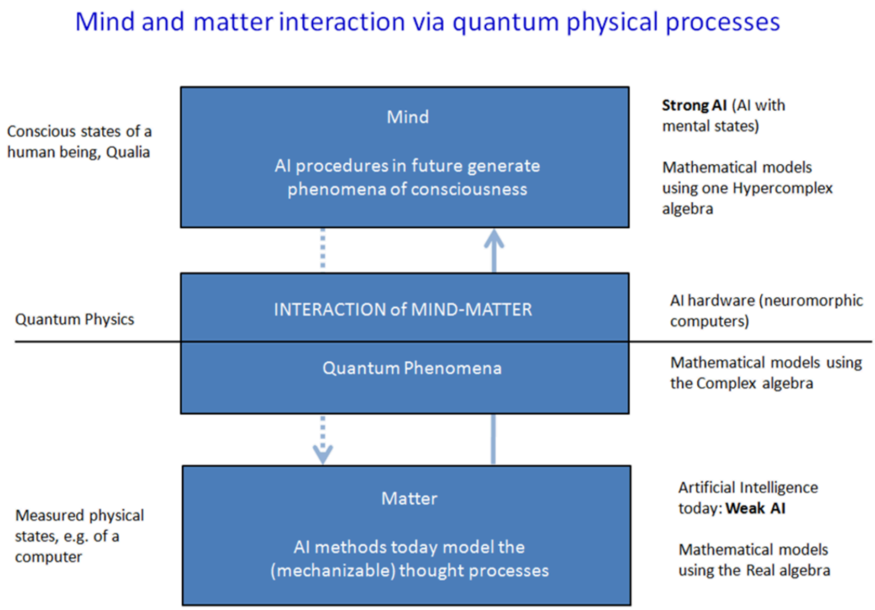


Fig 6: Mind and mater interaction

It is obvious, of course, that consciousness processes will only play a role in technology if they – despite their special imaginary nature – can affect technical systems. In Fig. 4 simplified interactions between wave functions to base i and j, k have already been shown (e.g. equation 4.7). Such interactions could represent the physical basis for the effect of immaterial processes on material processes. Consciousness processes, according to this interpretation, would never act directly on matter, but would only ever change the probability amplitudes of quantum processes, which in turn could then lead to altered physical measurements. Systems with usable consciousness must therefore contain quantum processes; this mathematical insight is technically relevant.

Since quantum processes are present in every technical device, the design of machine consciousness is about using systems in which the quantum processes can be used for the processing of tasks. This is not the case with a pocket calculator or a digital computer, for example; here as well as there, the results are generated by "classical" electrical or magnetic operations in electronic circuits.

Examples where quantum processes directly affect the results of tasks are *quantum computers* and *neuromorphic computers*. Neuromorphic computers are computers that use physical resources to get as close as possible to the neural structures of the human brain. While neural networks in a digital computer are pure mathematical constructs, neuromorphic computers are physically approximated as closely as possible to neuromorphic structures (Wan 2022 ).

A concrete implementation example for the use of neuromorphic computers are memristors. The memristors physically replicate the synapses of neuronal structures correctly. By changing the voltage, one can increase and/or decrease the weights (resistance values) of the memristors and thus implementing the synapses of the brain in a physically correct way. Quantum processes take place in the memristors, so that they can provide the physical basis for the expression of consciousness effects. However, quantum computers and, in particular, photon computers are also most likely perfectly suited for the manifestation of consciousness effects on physical machines.Digital machines, on the other hand, are not. Neuromorphic computers thus represent a concrete hardware basis for the generation of machine consciousness.

## 4. Summary and outlook

Designing machines with consciousness can be considered as a surprising engineering design achievement; nevertheless, it follows the normal laws of successful implementations. Inspired by human consciousness (original), the reduction of this original to its essential physical properties leads to a working model of *mental states as states with immaterial (imaginary) energies*, Fig. 7.

For non-scientists, systems with *imaginary energies* are certainly suspect, but in the context of physics, imaginary particles have been discussed for years. In contrast to these (for example the tachyons), and also in contrast to other phenomena of quantum physics, a mathematical analysis based on a specially developed hypercomplex algebra (Fig. 3) shows that consciousness processes have a very special imaginarity, which substantially extends our world understanding - even that of quantum physics.

Consciousness processes will remain imaginary even after they become conscious (the measurement) and thus have novel physical properties, such as *non-measurability* and *non-spatiality*. These properties would, for example, be able to physically explain such unusual phenomena as *seeing out of the head*. Based on explanations of such significant processes – and vision is an absolutely significant process for a system - the hope is that the mathematical description given here is perhaps still too limiting, but at least not completely wrong. The main result means that nature itself generates imaginary states

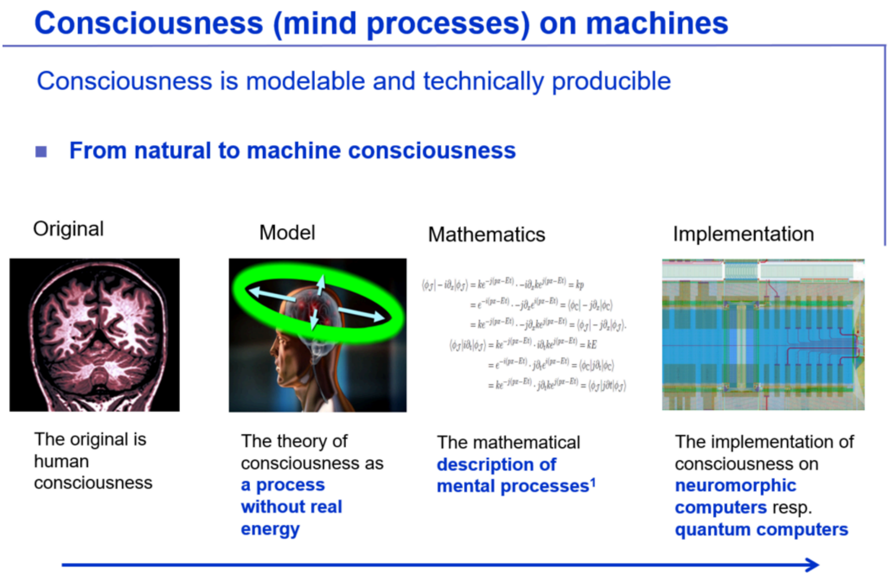


Fig 7: From natural to artificial consciousness

in pure physical objects, and these states can be condensed by engineering art into consciousness processes to be used technically.

A particularly important use of machine consciousness would be for perception. Perception would also be considered the lowest level of consciousness, so that one can actually speak of *consciousness on machines*. The author estimates that by 2030 at the latest – probably sooner – the first computers with demonstrable machine consciousness will be constructed and in use, but at the same time he estimates that systems with consciousness – such as those possessed by humans – cannot be developed at all, since human consciousness is based on physical, chemical, biological and social processes. Technical consciousness on physical machines – and this is exactly what today's AI is based on – can therefore only develop physical aspects.

Transhumanism ideas of the development of computers whose performance far exceeds the performance of humans are science fiction; even machine consciousness does not change this. Neither a singularity can be assumed, nor will it be possible to build computer systems that outperform humans (except in special disciplines) in the next hundred years. The weakness of all AI computers today is the implementation of AI as software. The great successes of machine learning have blinded many researchers to its drawbacks. The intelligence in the human brain is not coded as software, but as a clear topological hardware network. And only through this could the imaginary states of the individual neurons in a brain condense into consciousness, which is what we humans use every day. Neuromorphic computers are the right answer to these new challenges.

But even the use of real physical neuromorphic structures cannot exceed certain limits. While these systems can reach the lowest level of consciousness (namely that of perception), all technical systems are denied *feeling processes* or *will processes*. The reason is that physical systems are in principle not capable of forming feelings; feelings are the domain of living systems, since feelings represent a clear benefit in the struggle for survival of a system. In the case of technical systems, which are not even living, a struggle for survival is already linguistically absurd; but a struggle for survival is also absurd because a computer is not a closed object, which wanted to be able to survive. While biological systems have clear object boundaries that are not extendable, technical systems are extendable at will, so that one cannot speak of a (bounded) system at all. The limits of a robot are per se not founded in its outer skin, because this is arbitrarily expandable, the spatial and organizational limits of a living being are founded in its genetics and not (only) in its outer skin. Living beings are clear and non-negotiable entities, technical systems just not. Living beings have the most important goal to (out-)live, technical systems do not. Anorganic life forms, which are propagated by numerous researchers, as for example Harari (2018), are pure science fiction and justified by nothing, except a desire to produce them.

AI systems, which wanted to rise above humanity because of their intelligence and foresight, are completely absurd. The scaremongering about such systems is of course useful for the big AI manufacturers, since they already offer many people a supposed solution: the fusion of humans and machines into so-called *Cyborgs*, in order to be able to stand up to the new super-smart AI machines. But just as the singularity AI machines will not emerge, so too all Cyborgs concepts will fail. Transhumanism ideas will lead to complete technical failure. The question is how much money will be invested by then until humanity reaches this level of understanding.

As in the *emergence theory to consciousness* so also in the extension of the quantum physical approach to the generation of consciousness much hope for success is contained, but it is physically based and thus realizable by a designable development process. Why has this path not been taken earlier? One reason is that consciousness has only recently been considered in the natural and technical sciences. Ten years ago, if one wanted to integrate consciousness into physics, one was very quickly declared esoteric. Today it is different. Many experts worldwide are convinced that a mineral, like doped silicon of a circuit, is able to form rudimentary consciousness phenomena.

In this paper, an attempt was made to understand consciousness as a process that occupies unusual physical properties. The most unusual property is its principle of non-measurability. In order to formulate these properties formally correctly, a form of description with bi-complex numbers was developed, which introduces consciousness processes as hypercomplex system states. If this is confirmed in further work, it could be possible to develop computers with hypercomplex system states, which could lead to further development of the current AI. Machines with such consciousness phenomena could be needed for many applications such as mobile robotics or autonomous driving, as today's software AI has reached insurmountable limits.

## References (only until 2022)

Beckermann, Ansgar (2011): Das Leib-Seele-Problem. Eine Einführung in die Philosophie des Geistes. Stuttgart: UTB.

Dreyfus, Hubert L. (1985): Die Grenzen der künstlichen Intelligenz. Was Computer nicht können. Frankfurt am Main: Athenäum.

Feinberg, Gerald (1967): Possibility of Faster-than-light Particles. In: Physical Review 159 (5): 1089.

Hameroff, Stuart and Roger Penrose (1996): Orchestrated Reduction of Quantum Coherence in Brain Microtubules: A Model for Consciousness. In: Mathematics and Computers in Simulation 40 (3-4): 453-480.

Harari, Yuval Noah (2018): Will the Future be Human? Presentation at the World Economic Forum in Davos. https://www.youtube.com/watch?v=npfShBTNp3Q.

Hertig, Torsten, Jens Philip Höhmann and Ralf Otte (2014): Hypercomplex Algebras and their Application to the Mathematical Formulation of Quantum Theory. arXiv preprint arXiv:1406.1014.

Metzinger, Thomas (2005): Bewusstsein: Beiträge aus der Gegenwartsphilosophie. Paderborn: Schönigh.

Moser, Hans R. and Ralf Otte (2017): Emergence and Electrophysiological Analogies in Jellium Models for Cortical Brain Matter. In: Complex Systems 26 (1): 71–91.

Newell, Allen and Herbert A. Simon (1976): Computer Science as Empirical Inquiry: Symbols and Search. In: Communications of the ACM 19 (3): 113–126.

Otte, Ralf (2011): Attempt of a System Theory of Mind. Göttingen: Cuvillier.

Otte, Ralf (2016): Vorschlag einer Systemtheorie des Geistes. Göttingen: Cuvillier.

Otte, Ralf (2019): Künstliche Intelligenz für Dummies. Weinheim: Wiley-VCH.

Otte, Ralf and V. Otte (2020): Method and Apparatus for the Generation and Use of Machine Consciousness. Munich: German Patent Office, DE 10 2019 111 616 A1 2020.11.12.

Otte, Ralf (2021): Maschinenbewusstsein. Frankfurt a.M.: Campus.

Penrose, Roger, Stuart R. Hameroff, Subhash Kak and Lana Tao (Eds) (2017): Consciousness and the Universe: Quantum Physics, Evolution, Brain & Mind. Cambridge, MA: Cosmology Science Publishers.

Singer, Wolf (2006): Vom Gehirn zum Bewusstsein. Frankfurt am Main: Suhrkamp.

Stapp, Henry (2004): Quantum Mechanical Theories of Consciousness. https://www.osti.gov/servlets/purl/878524.

Wan, Qing (2022): Neuromorphic Devices for Brain-inspired Computing: Artificial Intelligence, Perception and Robotics. Weinheim: Wiley-VCH.