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Artificial Intelligence and Contemporary Philosophy
Heidegger, Jonas, and Slime Mold

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1. Frame Problem

In this paper, I provide an overview of today's philosophical approaches to the problem of "intelligence" in the field of artificial intelligence by examining several important papers on phenomenology and the philosophy of biology.

There is no clear definition of artificial intelligence. Margaret T. Boden writes in her recent book *AI: Its Nature and Future* that an artificial general intelligence could have general powers of "reasoning and perception—plus language, creativity, and emotion." However, she does not forget to add that "that's easier said than done."[1]

Boden's concept of "artificial general intelligence" resembles John Searl's "strong AI," which was coined by Searl in 1980. According to Searl, while "weak AI" is a computer that can behave as if it were thinking wisely, "strong AI" is a computer that actually thinks like humans. Searl writes, "according to strong AI, … the appropriately programmed computer really *is* a mind, in the sense that computers given the right programs can be literally said to *understand* and have other cognitive states."[2] The theme of strong AI was frequently discussed in the late 20th century; however, it became clear that in order for a computer to be a strong AI, it must resolve various difficult problems. The most difficult philosophical problem was the "frame problem."

The frame problem is the problem that an AI cannot *autonomously* distinguish important factors from unimportant ones when it tries to cope with something in a certain situation. This problem arises, for example, when we let AI robots operate in the real world. The frame problem was proposed by John McCarthy and Patrick J. Hayes in 1969. This is considered a philosophical problem that cannot be merely reduced to a technical problem. Boden writes in 2016 that

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[1] Boden (2006), p.22.

[2] Searl (1980), p.417.

"[c]laims that the notorious frame problem has been 'solved' are highly misleading,"[3] which shows that, even now, many specialists think that the frame problem has not been solved.

Although there is no consensus about the definition of the frame problem, we could say that this is a problem centered around the question of how we can make an AI memorize the "tacit knowledge" that almost all human adults can have in a given context. Imagine a waiter robot that serves meals and drinks for customers in a restaurant. This robot must learn a series of knowledge and movements necessary for serving. How much knowledge does this robot need to have to be able to adequately serve in an actual setting? First, the knowledge that "when pouring too much water in a glass, the water overflows" is necessary for serving. And the knowledge that "when we move a tray on which there is a glass, the glass also moves together with the tray" is necessary as well because, without such knowledge, the robot cannot remove the used glass and the tray simultaneously. Moreover, we must input the knowledge such that when a robot moves the glass, the liquid inside the glass also moves with it. However, we do not have to input the knowledge that the liquid never evaporates by friction heat caused by the movement of the tray because this knowledge has nothing to do with the robot's serving task.

Considering this, it becomes clear that there is an infinite amount of knowledge the robot must memorize when serving, and there is also an infinite amount of knowledge it does not have to memorize. Who can make such a list of knowledge, and how is it possible to make the robot memorize them? The reason why this happens is that, when a robot encounters a new situation that it has never experienced, it cannot autonomously judge what kind of coping would be important to itself and what kind of coping would not, and therefore it cannot adequately solve the problem it faces. It is interesting that humans seem to be able to solve this kind of problem. A high school student can serve in a restaurant without problem if we give her a basic set of simple instructions. She will carry a tray back to the kitchen with an empty glass on it without any special instructions. Even if there occurs a new situation, she will try to solve the problem by taking a flexible approach on a case-by-case basis.

Concerning this topic, Hitoshi Matsubara had an interesting discussion in 1990. He wrote, "A subject that has a limited capacity of data processing,

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[3] Boden (2016), p.55.

including computers and humans, can never reach a complete solution of general frame problems, however, in everyday settings, humans seem not to be annoyed by the frame problem. Considering this, what we have to think deeply about should be the question of why humans look to be free from the frame problem."[4] This is the question of why in many cases human intelligence appears to successfully cope with unanticipated events in an open context, although humans do not have an enough capacity to completely solve the frame problem.

I believe that human intelligence has the following special characteristics as compared with machine intelligence: (1) when humans encounter unknown situations, they can make an adequate judgement using "tacit knowledge" and perform a certain action even if they do not have the complete list of knowledge necessary for performing it [*tacit knowledge*], (2) they can make an autonomous judgement about what kind of coping is truly important when they face an unknown situation and have to survive it [*importance judgement*], (3) they can choose a certain action and instantaneously perform it, violently ignoring other possible alternatives [*ignorance*]. It seems that artificial intelligence cannot have the above three characteristics. For artificial intelligence to have those characteristics, it must have the capacity to solve the frame problem we have discussed so far.

Recently, a series of stimulating approaches to the frame problem have come out of the interdisciplinary field between artificial intelligence research and contemporary philosophy. In the following chapters, I will examine two important discussions on this topic: Hubert Dreyfus's "Heideggerian AI" and the biological approaches influenced by Hans Jonas's idea of "metabolism." The former pays special attention to "Dasein" and "the body," which has a close relationship with today's phenomenology. The latter pays special attention to the form of "life" or "organism," which has a close relationship with today's philosophy of life and the theory of artificial life.

2. Heideggerian AI

Hubert Dreyfus is a Heideggerian who has long philosophically criticized artificial intelligence from the inception of AI research. Here I would like to examine his 2007 paper "Why Heideggerian AI Failed and How Fixing It Would

[4] Matsubara (1990), p.179.

Require Making It More Heideggerian."

Dreyfus also argues that the reason why artificial intelligence faces the frame problem is that it does not understand what kind of knowledge is important to itself in a given situation. An event or an object has meaning only when it is placed in a concrete situation.

However, the traditional AI research has presupposed the Cartesian model that our mind puts value onto the world that is made up of meaningless objects and events. Dreyfus stresses that this kind of research will never make artificial intelligence human intelligence or solve the frame problem. He pays special attention to Martin Heidegger's distinction between "Vorhandenheit" (presence-at-hand) and "Zuhandenheit" (readiness-to-hand) in the book *Sein und Zeit*.[5] For example, seen from the Cartesian perspective, a hammer in front of me appears as an objectified tool in the state of presence-at-hand. On the contrary, if that hammer appears as an already-encountered intimate tool that is interwoven in the web of meaning, which is made up of the apparent and hidden relationship between the hammer and the person (me) who uses it, we can say that the hammer appears to me as an intimate tool in the state of readiness-to-hand. The traditional artificial intelligence lacks the capacity to understand this kind of readiness-to-hand. While every person can understand that when she exists in the world she is always immersed in this kind of web of meaning, traditional AI could not understand it.[6]

Dreyfus argues that, for the traditional AI to have the capacity to solve the frame problem and become a true artificial intelligence, it must become the "Heideggerian AI" that could implement the dimension of readiness-to-hand. He examines several studies by AI researchers in that direction, but he concludes that none of those have realized Heideggerian AI.

First, he examines the robots of Rodney Brooks. Brooks is the inventor of "subsumption architecture," an insect-like hierarchical and dispersed system that is now used in the vacuum cleaner robot Roomba. Brooks's robot moves itself by "continually referring to its sensors rather than to an internal world model."[7] However, his robots "respond only to *fixed features* of the environment, not to context or changing significance,"[8] so we must say that his robot does not have

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[5] Section 18 and others.
[6] Dreyfus (2007), pp.248, 251.
[7] Dreyfus (2007), p.249.
[8] P.250. Italic original.

the capacity to solve the frame problem.[9]

Next, he examines Phil Agre and David Chapman's program *Pengi*, which developed into *Pengo*, a video game in which the avatar of a human player and Penguin characters throw snowballs to each other on the screen. According to Agre, when they programmed this game, they referred to Heidegger's *Sein und Zeit* and introduced the concept of "deictic intentionality" in the game. Deictic intentionality does not point to a particular object but to "a role that an object might play in a certain time-extended pattern of interaction between an agent and its environment."[10] This game has come to be able to treat the object that the agent reacts to as a function. [11]

Dreyfus is critical of Agre and Chapman's approach. For example, when I put my hand on the door knob to leave the room, I am not experiencing the door as a mere door. In such a situation, I am pushed toward the possibility of going outside the room through this door, and the door solicits me to go outside through it. Agre and Chapman's artificial intelligence did not program this kind of experience in which the agent is solicited by affordance activated in a given situation. This shows that they ended up with objectifying the functions they introduced and the importance of the situation for an agent. Dreyfus says that, in this sense, Agre and Chapman's artificial intelligence did not have the capacity to solve the frame problem.[12]

Lastly, Dreyfus talks about Michael Wheeler's theory. Wheeler writes in his 2005 book *Reconstructing the Cognitive World* that the embodied-embedded cognitive science that has been applied to artificial intelligence research resembles Heidegger's philosophy. But Dreyfus criticizes him, saying that he also looks in the wrong place when considering this subject. Dreyfus's point is as follows. Although Wheeler insists that such embodied-embedded artificial intelligence models are considered to be Heideggerian, it still remains inside the Cartesian model in which the events in the outer world are represented onto (the sensors of) artificial intelligence, and the AI's problem solving is performed based on this representation. However, this representation model itself is the problem. We cannot fully understand human intelligence by this Cartesian model. Dreyfus argues that Heidegger considers Dasein as "being-in-the-world," and there is no

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[9] PP.249-250.
[10] P.252.
[11] PP.251-252.
[12] P.253.

room for representations there. Dreyfus writes that "*being-in-the-world* is more basic than *thinking* and solving problems, it is not representational at all."[13]

When a person tries to solve problems, the boundary between that person and her tools disappears. That person has already lived inside the world, and for skilled copers, they "are not minds at all but *one with the world*."[14] In the most basic sense, we are "absorbed copers."[15] It is very hard to clearly say whether the absorbed problem solving is performed inside oneself or in the world because the distinction of inside and outside is not an easy thing to do.

The basis of Heideggerian AI should be Dasein's being-in-the-world. An artificial intelligence should be Dasein, and its way of existing should be being-in-the-world. An artificial intelligence that does not have this mode of existence should not be called "Heideggerian," and therefore it cannot have the capacity to solve the frame problem.

In the case of humans, they can improve their skills of coping with important changes in the world by their embodied capacity of problem solving. For example, when we are in a room, we usually ignore many changes therein, but if the temperature goes extremely high, the windows of the room solicit us to open them, and we react to that solicitation and open the windows. In this case, the problem solving is made by reacting to the affordance of the environment. Dreyfus writes about the reason why humans can solve the frame problem as follows. "In general, given our experience in the world, whenever there is a change in the current context we respond to it only if in the past it has turned out to be significant, and when we sense a significant change we treat everything else as unchanged except what our familiarity with the world suggests might also have changed and so needs to be checked out. Thus, a local version of the frame problem does not arise."[16] In the case of humans, "our familiarity with the world" is always activated tacitly in our cognition, and what is important to us is automatically distinguished from what is not important to us. This function deters the frame problem from arising.

When we must change the context ourselves, the frame problem again emerges. When can we recognize the fact that the problems existing in the peripheral area come to the center of our problem-solving tasks? Dreyfus says,

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[13] P.254. Italics original.
[14] P.255. Italics original.
[15] P.255.
[16] P.263.

referring to Merleau-Ponty, that such a recognition is caused by "summons" from the affordance.[17] In essence, when something very important to us happens, we can recognize it by solicitations or summons made by the world we live in, and without accepting this kind of model we can never solve the frame problem. Dreyfus concludes that for artificial intelligence to acquire such capacity, "we would have to include in our program a model of a body very much like ours with our needs, desires, pleasures, pains, ways of moving, cultural background, etc."[18]

It seems that Dreyfus's Heideggerian AI should have a human-like "body" and live in that body from the inside. However, is it possible for current AI robots made up of silicon chips, metals, and plastic to satisfy such high requirements? In the next chapter, we examine biological approaches, which are completely different from Heideggerian AI.

3. Artificial Intelligence and Metabolism

There is a group of researchers who think that for artificial intelligence to have the capacity to solve the frame problem, it should be a kind of "organism," or a life form, before it can acquire a human-like body. When facing fatal difficulties, organisms try to survive by using every possible measure. Organisms have such innate capacities. Those researchers believe that these innate capacities that organisms have for survival must be the foundation needed for the resolution of the frame problem.

Hans Jonas, who was once a disciple of Heidegger, stressed the importance of the concept of "metabolism" in the field of philosophy of biology, and this concept has made a huge influence on the above approaches. Jonas published the book *The Phenomenon of Life* in 1966 (and its German edition *Organismus und Freiheit* in 1973) and established an original philosophy of biology. He thinks that "freedom" came into existence when ancient microbes with cell membranes emerged on the earth. These microbes take in nutrition through the membrane and excrete waste out through the membrane. By this kind of continuous intake and emission of tiny particles through the membrane, the microbes can maintain their lives. As time passes, all the materials forming the cell are replaced. Nevertheless, the living cell maintains its identity on a different dimension. Jonas sees here the liberation of life from the dimension of matter. This liberation is, Jonas thinks, the

[17] P.264.
[18] P.265.

"freedom" the form of life acquires.

On the other hand, life is bound by the replacement process of the tiny particles through the membrane. If this replacement process stops, life is destined to disappear because it is by this replacement process that life can maintain itself. In this sense, life depends on matter. Jonas call this kind of freedom "dependent freedom" or "impoverished freedom (bedürftige Freiheit)."[19] Life's survival is always threatened by this potential risk. Life is destined to survive by performing the continuous replacement of its contents. If life neglects efforts to replace materials, it will face its own death. Life is essentially fragile because without continuous efforts to survive, it will soon perish.

When Jonas was thinking about the above idea, he was not imagining artificial intelligence. His thoughts on life and freedom were discussed only within a small circle of philosophers of biology at that time. However, after his death in 1993, Jonas's philosophy soon began to be discussed outside the field of biology.

One of the philosophers who shed a strong light on Jonas was Francisco J. Varela, who advocated the concepts of "autopoiesis" in the field of biology and "enactivism" in the field of phenomenology and artificial intelligence. In the seminal paper "Life after Kant" written by Andreas Weber and Varela published in 2002 (Varela's posthumous publication), they try to connect Varela's autopoiesis with Jonas's metabolism. They write that "autopoiesis is the necessary empirical ground for Jonas's theory of value"[20] and that these two ideas (autopoiesis and metabolism) are "not only contemporaneous but fully *complimentary*. Both seek a hermeneutics of the living, that is, to understand from the inside the purpose and sense of the living."[21] In both theories, the key terms were the membrane of a cell and its metabolism. Jonas and Varela tried to think that a single cell that has a membrane contains "intrinsic teleology" and this cellular organism has "a *basic* purpose in the maintenance of its own identity, an affirmation of life."[22] Varela's attention on Jonas's philosophy of biology, especially his emphasis on metabolism, made a huge impact on some of the researchers of artificial intelligence.

Tom Froese and Tom Ziemke's paper "Enactive Artificial Intelligence: Investigating the Systemic Organization of Life and Mind," published in 2008, is

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[19] Jonas (1973), S.150.
[20] Weber and Varela (2002), p.120.
[21] P.116.
[22] P.117.

an endeavor to develop Jonas's idea of metabolism in the field of artificial intelligence.

Froese and Ziemke interpret the frame problem as follows. It is the problem of "how it is possible to design an artificial system in such a manner that relevant features of the world actually show up as significant from the perspective of that system itself rather than only in the perspective of the human designer or observer."[23] They refer to Dreyfus's paper and stress that the frame problem has not been resolved, and they go on to say that contributions from phenomenology and theoretical biology are necessary for the solution of this problem.

Froese and Ziemke say that in recent years an "embodied turn" occurred in cognitive science. However, we still do not know how to teach an AI to understand important problems for itself "in an autonomous manner." They focus attention on Jonas's philosophy of biology. They write that "the existence of what could be described by an external observer as "goal-directed" behavior does not necessarily entail that the system under study itself has those goals – they could be *extrinsic* (i.e., externally imposed) rather than *intrinsic* (i.e., internally generated)…"[24] If an AI robot has its own "goals," they should be generated from inside the robot spontaneously. They argue that the question we should ask would be what kind of body the robot must have for it to accomplish such a task.

Froese and Ziemke refer to Jonas's idea of metabolism and discuss the difference between an artificial system and a living system. The mode of existence of an artificial system is "being by being." An artificial system can act, but this action is not necessarily done for its own survival. On the contrary, the mode of existence of a living system is "being by doing." A living system must engage in certain "self-constituting operations," that is, the continuous replacement of tiny materials through the membrane of the cell. If a living system stops the replacement actions, it will die. It disappears from the world. Doing or acting is necessary for a living system, but not so for an artificial system. This is the crucial difference between an artificial system and a living system, and this is exactly what Jonas wanted to stress by the words "dependent freedom." Jonas was discussing this topic against the backdrop of cybernetics and the general systems theory in the 1960s. Froese and Ziemke revived Jonas's idea in the age of artificial intelligence in the 21st century.

It is very difficult to make a metabolizing artificial intelligence. But they argue

[23] Froese and Ziemke (2008), p.467.
[24] P.472. Italics original.

that the fundamental reason why AI cannot solve the frame problem lies in the fact that AI does not have the biological way of being, “being by doing.” For example, even if we switch off an artificial intelligence, and after that we switch it on, it will continue to operate without any special problems. However, if it is a lifeform, once it dies, it will never live again.[25] This sense of urgency that when it dies everything is over characterizes the lifeform’s way of being. They argue that here lies the door to the solution of the frame problem.

They say that we should pay attention to the fact that a lifeform actively generates and sustains “the systemic identity under precarious conditions.”[26] They call this mode of being “constitutive autonomy” following Varela’s naming. They say that “constitutively autonomous systems bring forth their own identity and domain of interactions, and thereby constitute their own ‘problems to be solved’ according to their particular affordances for action.”[27] They make a theoretical analysis of artificial intelligence with constitutive autonomy and try to find a possible combination between artificial intelligence and artificial life.

First, they point out the possibility of a “microbe-robot symbiosis.”[28] For example, if we can reflect the state of microbes that is incorporated into a robot onto the robot’s controller, the autonomous movement of the microbes could be inscribed onto the intelligence of the robot on a real-time basis. They also argue that by incorporating the principle of tessellation automaton into a robot, we might use their characteristic that although the production principle is not intelligent, the outcome looks intelligent when observed from the outside.[29] They stress that such a system has not been created by anyone and that “[i]n order to develop a better theory of the biological roots of intentional agency we first need to gain a better understanding of bacterium-level intelligence. Only by returning to the beginnings of life itself do we stand any chance of establishing a properly grounded theory of intentional agency and cognition.”[30]

It seems to me that their argument that to develop a spontaneous artificial intelligence we have to go back to the bacteria level is stimulating and reasonable. Margaret A. Boden also stresses the importance of metabolism by citing Hans Jonas and concludes that if metabolism is the necessary condition for mind, strong

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[25] P.485.
[26] P.480.
[27] P.481.
[28] P.492.
[29] P.494.
[30] P.495.

AI should be impossible because metabolism "can be *modeled* by computers, but not *instantiated* by them."[31] Jonas's metabolism model might be the deepest key for understanding artificial intelligence.

4. Slime Mold and Biocomputer

The endeavor to investigate intelligence by going back to the bacteria level has already begun. Among them, the slime mold computer, which has been studied by Toshiyuki Nakagaki and Ryo Kobayashi, is particularly worth mentioning. They discovered in 2000 that when putting food at two separate places on a small maze made of glass on the surface of which they have spread out starving slime mold, the slime mold slowly transforms its whole cell to make the shortest route between the two places.[32] The slime mold limbs that are on a dead-end route start to retreat from it, join the main route that is connected with the food, and help thicken the cross-section of the main route made by slime mold. In this way, slime mold makes a kind of calculation by itself, discovers the shortest route between the two places, and modifies its body into the most efficient shape for that route. This action performed by starving slime mold eloquently shows the fundamental mode that lifeforms seek to maintain their existence in a "precarious" situation.

In their 2011 paper "Performance of Information Processing in a Primitive Organism of True Slime Mold" (in Japanese), Nakagaki and Kobayashi argue that this kind of action for survival by slime mold is made by the "calculation" performed by the slime mold itself.[33] That is to say, the action for survival emerges inherently and spontaneously inside the slime mold, calculations searching for the most adequate solution are performed, and the slime mold transforms itself in accordance with the solution. This can be called a biological calculator, and I presume that the frame problem might be solved in this slime mold case. If we give the slime mold a new difficult task and track it down, it would certainly rethink its strategy for the new condition and try to transform its body toward a new adequate solution. The slime mold seems to have the capacity to continuously adapt itself to unknown changes in the environment by transforming its own body in an emergent way.

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[31] P.144. Italics original.
[32] Nakagaki, T. et al. (2000)
[33] Nakagaki and Kobayashi (2011), p.483.

Nakagaki and Kobayashi made a mathematical simulation model for tracing the movement of slime mold (physarum solver) and investigated its behavior. As a result, they discovered that the calculation the slime mold makes is not accurate and perfect but "rough and speedy." They argue that such a "rough and speedy" calculation is a "noteworthy characteristic of biological computation."[34] Although they do not mention this, I believe that this characteristic of biological computation might be the key to creating human-like intelligence – intelligence that, when encountering a new environment, can speedily judge which factor is most important to it and act violently, ignoring other non-important factors. This kind of intelligence is necessary for solving the frame problem.

Kobayashi also writes in his 2015 paper "Autonomous Decentralized Control Found in Creatures: From Slime Mold to Robot" (in Japanese) that while most robots can move correctly in the anticipated environments, animals can move in a tough manner even if they encounter unknown environments. He argues that animals have the capacity to solve the frame problem,[35] and these animals include not only mammals and insects but also slime mold. Kobayashi argues that insects and slime mold can take spontaneous decentralized control over their bodies. This suggests that to solve the frame problem, the development of a spontaneously decentralized bodily system would be better than that of centralized control system like a central nervous system. Kobayashi says that his snake-like self-moving robot might have such a decentralized system, and he proposes the development of the control system that makes the environment its "friend."

These studies suggest that the inherent and spontaneous solution of the frame problem made by humans is performed not by the human central nervous system but by the decentralized control system located at every part of the body that is free from the control of the central nervous system. However, it should be noted that Brooks's subsumption architecture has not succeeded in solving it.

Froese and Ziemke's "microbe-robot symbiosis" might be a possible answer. They propose to insert a colony of microbes into the body of a robot, but isn't there another possibility in the opposite direction – the possibility to insert artificial objects such as super-micro artificial intelligence, super-micro robots, or the fragments of artificially structured DNA or RNA into the cells of microbes? It might be possible to create the symbiotic systems of a group of such super-micro artificial objects and microbes.

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[34] P.491.

[35] Kobayashi (2015), p.236.

Take the example of slime mold. We might give slime mold the capacity of calculation that is enhanced by super-micro robots, super-microprocessors, or artificially-made nucleic acids. Such artificially enhanced slime mold could not only solve the shortest path problem inherently and spontaneously, but it could also solve more difficult tasks by calculation. In such a case, we could suppose that this slime mold must have the capacity to discover the problem that is important for its own survival and to solve that problem by spontaneous calculation. As slime mold as an organism is considered to have the capacity to solve the frame problem, slime mold with the capacity of calculation that is artificially enhanced should also have the capacity to solve the frame problem. Artificially enhanced slime mold should be considered a kind of biocomputer. In the context of computers, biocomputers are the key to the solution of the frame problem. This is the provisional conclusion of this paper.

One philosophical problem emerging from our discussion is, if the frame problem is to be solved by an organisms's spontaneous decentralized control, then the frame problem could be solved without the realization of Heideggerian AI proposed by Dreyfus, which exists in the mode of being-in-the-world. The frame problem might not be the problem at the level of the central nervous system that executes symbol manipulations but the problem at the level of metabolism-based, spontaneously decentralized control systems. Since Dreyfus would have presupposed the control by the central nervous system, his idea could have been completely wrong. Some people say that the recent development of deep learning will perhaps succeed in solving the frame problem, but the capability of deep learning is still not clear. The above discussions depend on how we understand the essence of the frame problem. This is the question philosophers should tackle head-on.

As seen above, we have tried to give an overview of the connection between the frame problem, Heideggerian AI, metabolism-based AI, the spontaneously decentralized control system by slime mold, and a future possible solution of the frame problem by biocomputers. We find there several stimulating themes for contemporary philosophy. Researchers of philosophy will take interest in the fact that the names of Heidegger and one of his great disciples, Jonas, appear in our discussion of the frame problem. I am not an AI research specialist, so if there are any misleading expressions or incorrect uses of technical scientific words in this paper, please let me know.

There is tremendous risk in research on making artificially-enhanced slime mold. We must prevent the uncontrolled runaway of artificially-enhanced slime mold because this research intends to give slime mold high-level calculation capacities. If they are emitted into the environment, they might cause devastating damage to humans and ecosystems, hence the research ought to be carried out at the highest biosafety level in facilities that have the capacity for physical containment stipulated by the Cartagena Protocol. In the first place, we cannot imagine how slime mold would behave when its capacity of calculation is enhanced. There might be the risk that artificially-enhanced slime mold with high-level intelligence could proliferate on a huge scale and cover the whole earth searching for food. In the case of toxic microbes, research on giving them high-level calculation capacities should not be allowed.

This kind of research can also be seen as enhancement research using artificial objects with microbes as their targets. Therefore, this topic is connected with bioethical discussions on enhancement.

While artificial intelligence has supported biotechnological research in many ways, in the future there will appear a completely different situation in which AI research is directly combined with the manipulation of organisms in the field of biotechnology. We must have an intensive and interdisciplinary discussion before it becomes a reality. We can conclude that the gulfs between AI research, biology, and philosophy have become much shallower than before.

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