THE CONCEPT OF BOUNDARY CONDITIONS

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ABSTRACT

The concept of boundary conditions stems from physics. Boundary conditions in physics are only *conceptual* and *instrumental tools* in the hand of physicists; existentially they are not parts of the physical universe. Every boundary condition *can be reduced* to initial conditions, and, of course, to physical laws and material substance. There are two main types of boundary conditions beyond physics: *structural* boundary conditions can be found in the field of chemistry and *control* boundary conditions in that of biology. Boundary conditions, rather than physical laws and material substance, are in the focus of these sciences, and because of their significantly different nature they can be reduced only in absolutely *different* ways (*synchronically* and *diachronically*). On the one hand, structural boundary conditions—which existentially are simply material—are conceptual tools in our hands to describe structures, shapes and every other secondary property, and structural evolving processes of things. On the other hand, control boundary conditions—which existentially are not material—are real, emergent, evolving things in our evolutionary system. The concept of boundary conditions establishes the possibility of a new, non-physicalist but non-dualist, philosophical understanding of life and human culture.

Keywords: boundary condition, initial condition, emergence, reduction, system theory, physics, chemistry, biology, Howard H. Pattee, Michael Polanyi.

1. Preface: The Emergence of Boundary Conditions

In the second half of the 20th century the concept of boundary conditions emerged from physics into the territories of cybernetics, life sciences, and philosophy. Several authors applied the concept to solve problems concerning some specific features of life, e.g. Ron W. Ashby (1957), Howard H. Pattee (1973), Michael Polanyi (1969), Robert Rosen (1991), Jerome Rothstein (1979), Stanley N. Salthe (1985), or more recently Korn (2005). Moreover, one of them explicitly stated that life was nothing else but a specific hierarchy of boundary conditions. Polanyi (1969) I think that the fact that an application of boundary conditions proliferated from that time on is not accidental. I also think that the questions of why they use boundary conditions and

what a boundary condition is can and have to be answered. Nevertheless, I believe that these questions cannot be answered only by a detailed analysis of the works of the authors or comparing them to each other; I will rather focus on the historical and philosophical background of the concept itself.

It was not an accident that I mentioned Polanyi distinctively. The exact reason of why he is so important is that he is the only one who uses the concept of boundary conditions as a fundamental pillar of an entirely new philosophy. He is the only one who, in a sense, really tries to find a path back to the times before modern physics and its influence on philosophy, so he is the only one who instead of only employing the concept of boundary conditions as it is used within physics tries to give a fundamentally *new meaning* to it. This point of view which I will follow I hope will help us to understand the philosophical significance of the concept of boundary conditions at the end of the paper.

The concept of boundary conditions stems from physics; there are several types of them (e.g. *fixed boundary condition*s, *linear boundary condition*s, *symmetric boundary condition*s, *time varying boundary condition*s, *special boundary condition*s, etc.). The differences between them are not relevant for the present purposes, only the two philosophically important, *main types* of them (from which follows the general concept of boundary conditions), and, more specifically, the reason why physicists apply boundary conditions in their work. Hopefully, the origin of boundary conditions in physics will shed light onto the historical background and philosophical significance of the concept.

As mentioned above, in the second half of the 20th century several authors took over the concept of boundary conditions from physics. Nevertheless, some of them did not apply the term boundary condition but call it *constraint* (e.g. Ashby, Pattee). Let's compare, for example, Pattee's structural and control constraints to Polanyi's test-tube and machine type boundary conditions.

Pattee differentiates two types of constraints. (Pattee 1973) The first type is called *structural constraint*. Structural constraints are *passive*, they do not control or govern the lower level (at the end, physical) processes. Pattee's example for structural constraints is a structure of a crystal or a balloon which is expanding due to the ascending temperature of the gas inside. Here, higher level constraints are simple *consequences of lower level processes*, that is, the balloon's expansion is a consequence of an ascending temperature (faster moving of the particles) of the gas. The second type is called *control constraints*. These constraints are active, they *control* and *govern* the lower level (at the end, physical) processes. Pattee's typical examples for control constraints are specific structures of living beings as e.g. how an organism controls the functioning of its organs.

In accordance with Pattee—but independently of him—Polanyi states that we can distinguish two different types of boundary conditions. One of them is the *test-tube type* which *has no influence* on the elementary processes taking place within; and the other, the *machine type* boundary condition which has the function

of *controlling* and *harnessing* the elementary physical and chemical processes for the sake of some kind of *purpose*. (Polanyi 1969)[1] The test-tube in which different chemical processes are observed has no significant effect on the processes. There cannot be such influence because the function of a test-tube is making these processes *observable* by isolating them from their natural environment; it is purposeful only in this (relevant) sense. In contrast, the structure of a machine has not got the function of making the elementary physical and chemical processes observable—these processes are interesting only in the case if the machine fails—but it utilizes these elementary processes for the *purpose* of some kind of work. Accordingly, Polanyi emphasizes that "living mechanisms are classed with machines" (Polanyi 1969:226) because living beings have the function of *controlling* and *harnessing* the elementary processes for the sake of different purposes too. This does not imply that living beings are machines. Living beings only form another, natural subclass of machine type boundary conditions beside the subclass of artificial machine type boundary conditions.

The main difference between test-tube and machine type boundary conditions is as follows (for details, see Section 3). The structure of a crystal is simply a *consequence of the physical-chemical processes* of the crystal—as the balloon's expansion is that of the ascending temperature—in accordance with the lower level physical and chemical principles. (Polanyi 1997:286) In contrast, the structure of a machine is not a consequence of the physical-chemical processes of that machine but is shaped by humans in accordance with higher level principles of engineering. (Polanyi 1997:287)

It follows from the above that structural constraints and test-tube type boundary conditions, just as control constraints and machine type boundary conditions, have close and essential similarities. But there are also several differences in the details. As shown above, Polanyi's test-tube type boundary conditions have only one purpose: making some specific experimental processes *observable*. Its role as a test-tube is entirely *epistemological*. Similarly to a test-tube, the structure of a crystal has an important and necessary *epistemological role* in observing and analyzing the lower level physical-chemical processes of any crystallogenesis because without a comprehensive structure simply no one can observe and analyze these lower level processes as processes of a crystallogenesis (see in details in Section 2). Furthermore, like a test-tube does not control and harness the lower level processes taking place within the test-tube the crystal also does not control and govern its physical-chemical processes, on the contrary, the structure of the crystal is entirely the consequence of these lower level processes. The most important difference between test-tube tube type boundary conditions and structural constrains is that the formers are *artificial* devices.

[1] It is his famous, well-known paper, "Life's Irreducible Structure", which was originally published in Science, 160 (1968), 1308-12.

The strong similarities between machine type boundary conditions and control constraints are more obvious. *Both* of them are controlling, harnessing and governing their lower level processes for some kind of *purpose*. This means in Polanyi's point of view that they as comprehensive structures have ontological nature, that is, they are not the consequence of their lower level physical-chemical processes (see in details in Section 3). The most important difference is that in Polanyi's concept there are artificial machine type boundary conditions too, that is, machines and not just natural living beings.

So, there are two main types of boundary conditions: *epistemological* and *ontological*. Pattee's control constrains and Polanyi's machine type boundary conditions are equivalent: these are ontological control boundary conditions.[2] (The main difference is that in Polanyi's system there are two important subtypes of them.) However, the structural constrains and test-tube type boundary conditions are not equivalent but the two main *subtypes* of epistemological structural boundary conditions: *natural* and *artificial*.

2. Boundary Conditions from Physics

The concept of boundary conditions stems from physics, or more exactly from Galilean and Newtonian mechanics. Take a simple physical experiment, for example from Galilei, in which balls are rolling down on a slope. The aim of the experiment is to establish the physical laws of acceleration, or as it was understood at the time of Galilei, to settle what the correlation between weight and acceleration was. Galilei chose a slope for the experiment because on the slope it was much easier to measure the acceleration of the balls than from the top of the Leaning Tower of Pisa. He supposed there to be no connection between the angle of the slope and the interdependence of the weight and the acceleration of the balls, so the angle of the slope was *not* derived (in fact cannot be derived) from the laws of mechanics, but was chosen *arbitrarily*.[3] That is, the angle of the slope was a random *boundary condition*, and although it had important role in the experiment—it made much easier to determine the actual speed of the balls—at the end, from the aspect of the mechanical laws in question, it hadn't got any importance. As a determining factor it simply *fell out* from the equations.

Boundary conditions in physics are important because they can help us to find

[2] In the followings, I will use the centaur terms *structural* and *control boundary conditions*, because I believe that these express the essence of the concept the best, from which I like to speak about. So, as I mentioned, there are more of them than these two, but these two are the main types of boundary conditions which will lead us beyond physics to chemistry and biology; the others are only subtypes of these two, so there is no need (and place) to deal with them here.

[3] It does not mean that it was chosen randomly but by other important (higher level) principles, e.g. in accordance with the features of the experiments' instruments, the method of the measurement, etc. rather than the principles of physics.

out the physical laws of nature, e.g. the correlation between weight and acceleration. However, these boundary conditions, at least in physics, are never in the focus of interest. Galilei was also not interested in the angle of the slope (it had only subsidiary role as Polanyi would say). The focus is on the crucial physical *laws,* the material *substance* and its *properties* hiding behind them. There is no strict correlation between the boundary conditions and the laws of physics. Boundary conditions are random conditions of an experiment or a natural process. Therefore boundary conditions in physics are only *conceptual* and *instrumental tools* in our hands to reveal the deeper physical reality of nature.

In a physical universe, more exactly in the universe conceived by the notion of physicalism, existentially there are only physical laws, material substance and its properties. The question is what the source of boundary conditions is, if (existentially) there are nothing but material substance and physical laws. Let's accept now that in this kind of (only) physical universe physicists (and thus persons or minds) do exist, applying the conceptual tools of boundary conditions in their work as Galilei did. Why do they have to use these tools?

First of all, because they have no absolute knowledge like a Laplacean demon who *per definitionem* knows every physical law and who can observe the whole material substance of the Universe. Secondly, it follows that a human physicist who does not know every physical law can conclude these laws, the actual material substance of things and its properties *only by* relying on her previous knowledge of boundary conditions which make the material structure of things *observable* for her.

For example, with the help of a test-tube or a Petri dish as a boundary condition they *can observe* the material processes taking place within which otherwise cannot be *separated* from other material processes as it is in nature. Or with the help of the knowledge of the specific shape of a crystal as a boundary condition they *can conclude* the exact material processes shaping the structure of that type of crystal inside. This principle stands behind Galilei's experiment, the angle of the slope as a boundary condition helps to determine a physical law. Without this higher level comprehensive knowledge we can identify *neither* the specific type of a crystal *nor* those particular material processes which were shaping it; as a matter of fact, we cannot establish that the thing in our hands is a crystal at all. Nevertheless, in physics we are interested *only* in the physical laws and properties of material substance which determine the crystallogenesis and not in the actual processes or the angle of the slope.

However, the main question is what the *source* of epistemological structural boundary conditions is since it is fundamentally different from the origin of control boundary conditions (machines and living beings). As shown in the previous section, there are such Polanyian test-tube type artificial epistemological boundary conditions, e.g. the test-tube, a Petri dish, a slope, etc., which are human-made tools and machines. In this sense they seem to belong to the other category. However,

the well-separated initial compound in a Petri dish is, of course, not a man-made machine but a carefully chosen and observed structure of a kind of material.

In the case of crystallogenesis, the specific shape of a crystal as a natural epistemological boundary condition is a consequence of the material processes taking place within. These processes are consequences of the physical laws and properties of material substance. However, it is true of every crystallogenesis and every other physical process that they are determined by the physical laws and properties of material substance, and still there are different crystals and different boundary conditions. Then what is the difference between different crystallogenesises?

The answer is that although the physical laws and the material substance are the same in each case but there are differences between the *initial conditions*. In two different Petri dishes the physical laws and the material substance are necessarily the same—there are no other laws and substance in the universe—but there can be differences in the number, type, arrangement, etc. of material particles. *These* initial differences lead to different crystallogenesises and thus to different crystals as structural boundary conditions. So, the answer is that the source of different boundary conditions is the different initial conditions of material substance. In a physical universe, existentially there are only physical laws and material substance but there *can be* differences in the initial conditions of material substance.

At this point one can say that initial conditions are also boundary conditions; there is no important difference between the two. A reason for this may be that although our crystallogenesis example is very illustrative, it is also a little bit misleading. In the case of different Petri dishes there are no *real* initial conditions; in fact, in this example the two Petri dishes are the initial *epistemological* boundary conditions which determine the different crystallogenesises. It is the arbitrary choice of the chemist—like the angle of the slope was Galilei's—what determines the exact contents of the dishes which form a sharp boundary between the inside and the outside processes. More exactly the choice is determined by the actual interest of the chemist. For example, she intends to create the compound of a chemical. This choice is not determined by the physical laws of a chemical process, it is simply not part of the process, and thus at the end it can be left out of the results.

However, in the case of the *whole physical universe* there are *real* initial conditions. They are *not* determined by the laws of physics *either*. Ultimately every now existing boundary condition is the *consequence* of these real initial conditions in the same way as the shape of the crystal as a boundary condition is the consequence of the former "initial" conditions of material substance in the Petri dish. This means—and this is very important—that *every boundary condition can be reduced to these first and real initial conditions* plus physical laws, material substance and its properties.[4]

[4] It follows that "reduction" here is not a specific correlation between laws (there are no strict laws of boundary conditions) or between different scientific disciplines, etc. but *between boundary (and initial) conditions*. Nevertheless, in this paper there is no place for a detailed investigation of this specific kind of reduction.

The main goal of modern physics is to find out the exact physical laws of nature and the exact properties of material substance. In order to do so, real initial conditions can *also* be left out from scientific inquiry. It is *cosmology* and not physics itself that is interested in the real initial conditions. If initial conditions had been different, physics would be the same but not cosmology.

According to ideal mechanical knowledge, the knowledge concerning the initial conditions and boundary conditions are not parts of the knowledge of Laplace's demon. As a matter of fact, according to this ideal, there are no real initial conditions, time is eternal.[5] For Laplace's demon there is only the real actual state of material substance and the knowledge of physical laws. For him initial conditions (if there is any) and boundary conditions are not relevant. What is even more important, the demon *does not need* any boundary condition to conclude physical processes. He observes the exact physical state of the crystal in the Petri dish and he can conclude the exact physical processes of the crystallogenesis. For him, contrary to us, *neither* the final shape of the crystal *nor* the initial boundary conditions of the Petri dish chosen by the chemist are necessary for doing so. Moreover, for him the boundary conditions have no significance and meaning at all (Polanyi 1959: 48-9)[6]; he observes the physical processes of the body of the Petri dish *in the same way* as the processes inside of it. He is not a human being or a person. For him *there is no difference* between the crystal and the body of the Petri dish; all he observes is the same structure and physical process of quarks and electrons, etc.; that is, the same process of material substance. The knowledge of initial conditions and boundary conditions is simply *not part* of his ideal (fundamental) physical knowledge as they are not parts of (ideal) physics. This is the main reason why initial conditions and boundary conditions are random and can be left out of fundamental physical

[5] It might be surprising but Newton's theory of gravity which presupposed an existing material force was the first step against this mechanical ideal. It follows from the hypothesis of the gravitational force that by time the whole material substance will assemble at the gravitational centre of the universe. (See it's physical (and ethical) problems e.g. in Newton's first letter to Bentley. (Turnbull 1961)) So, even if time is eternal the material universe has to have a beginning and an end. This, then, makes room for real initial conditions and cosmological interest.

[6] „Assume, for the sake of argument, that we posses a complete atomic theory of inanimate matter. We can then envisage the operations of a Universal Mind in the sense of Laplace. The initial positions and velocities of all the atoms of the world being given for one moment of time, and all the forces acting between the atoms being known, the Laplacean Mind could compute all future configurations of all atoms throughout the world, and from this result we could read off the exact physical and chemical typography of the world at any future point of time. But we now know that there is a great and varied class of objects which cannot be identified, and still less understood, by establishing their complete physical and chemical topography, for they are constructed with a view to a purpose which physics and chemistry cannot define. So it follows that the Laplacean Mind would be subject to the same limitation: it could not identify any machine nor tell us how it works. Indeed, the Laplacean Mind could identify no object or process, the meaning of which consists in serving purpose. It would ignore therefore the existence not only of machines but also of any kind of tools, foodstuffs, houses, roads and any written records or spoken messages." (Polanyi, 1959:48-9)

investigations. The final (but inaccessible) goal is having that kind of ideal physics. The boundary conditions as *conceptual* and *instrumental tools* are necessary *only for the human* physicist and *for human* physics but they are not and *cannot* be part of ideal physics. It is worth emphasizing that philosophy and physicalism lean on this ideal (fundamental) physics rather than real human physics.

3. Boundary Conditions in Chemistry and Biology

It has been shown in the previous section that the concept of boundary conditions stems from physics but boundary conditions are only conceptual tools in the hand of human physicists to help to find out the physical laws and fundamental properties of material substance. Boundary conditions can be reduced to initial conditions, physical laws and material substance, and they can be and must be left out at the end of the investigations. Boundary conditions are simply not part of ideal fundamental physics. Now the question is what happens when one focuses on boundary conditions.

There are two fundamentally different possibilities. The first and simpler one is the case of chemistry and cosmology which we have already seen in the previous section in the case of crystallogenesis and different questions of cosmology. Contrary to physics, cosmology is not interested in physical laws and properties of material substance but supernovas, comets, extrasolar planets, etc.; it simply accepts and uses the achievements of physics for its own purposes *in order to define and explain cosmological phenomena*. Similarly, chemistry is not interested in physical laws and properties of material substance but in *chemical* processes, reactions, connections, forces, properties, etc. at a higher level. When a chemist sets an experiment in a Petri dish concerning crystallogenesis she is interested *only* in the chemical processes (e.g. the relations between initial conditions and the structures of the evolving crystals) and not in the physical laws and properties of material substance, contrary to physics, they are in a subsidiary role, as Polanyi would say. Moreover, the chemist applies the knowledge of physical properties *at the level of chemical elements* and she is not at all interested in equations of quantum mechanics or string theory. So, both the chemist and the cosmologist intend to study and explain a *higher level* phenomenon in contrast to the substantial matter of physics. Since these disciplines are interested in higher level phenomena, in these disciplines scientific knowledge consists of *higher level* principles, laws, forces, properties, etc. concerning higher level *boundary conditions*.

The second and more complex case is that of biology and engineering. Biology is not interested in physical laws or properties of material substance but in species, organs, and biological processes as digestion, reproduction, etc. In the same way as seen above, when it is possible or necessary biology also accepts and applies the achievements of physics to define and explain biological phenomena. Similarly,

engineering is interested in nothing else but higher level mechanical processes, correlations, structures and properties. So, as in the case of cosmology and chemistry, a biologist or an engineer also study and explain *higher level* phenomena. Thus scientific knowledge also consists of *higher level* principles, laws, forces, properties, etc. concerning higher level boundary conditions.

As seen in the first section, two main types of boundary conditions can be distinguished as Polanyi or Pattee did. Test-tube type boundary conditions or structural constraints can be identified in chemistry or cosmology and machine type boundary conditions or control constraints in biology or engineering. Now, the question is what the exact difference between the two is and whether it is a well–established differentiation. The fundamental difference between boundary conditions in biology and chemistry is intuitive; just compare e.g. a crystal with a frog. But between chemistry and engineering, the difference is less obvious. Moreover, it might be even counter-intuitive that boundary conditions in engineering are in the same category as biological boundary conditions.

As seen, both Polanyi and Pattee state that the fundamental difference between structural and control boundary conditions is that the latter *controls* and *harnesses* the lower level processes taking place within while the former does not. Think about, for example, a piston that transforms the energy of exploding petrol into rotary motion or a water mill that does the same with the energy of flowing water. In these cases the lower level processes do not go freely, according to their lower level principles only, but the specific structure of the piston (or the water mill), according to their higher level engineering principles, govern (control) and harness these lower level, at the end, physical processes in several distinct steps in order to move a car or to grind the wheat, etc.

> "Engineering and physics are two different sciences. Engineering includes the operational principles of machines and some knowledge of physics bearing on these principles. Physics and chemistry, on the other hand, include no knowledge of the operational principles of machines. Hence a complete physical and chemical topography of an object would not tell us whether it is a machine, and if so, how it works, and for what purpose. Physical and chemical investigations of a machine are meaningless, unless undertaken with a bearing on the previously established operational principles of the machine." (Polanyi 1967:39)

That is, the fundamental difference between the two main types of boundary conditions is that structural boundary conditions are simply consequences of the *lower level physical processes and principles* while control boundary conditions are consequences of *higher level processes and principles*. Think about e.g. an evolving solar system in contrast to an evolving species or a crystal in contrast to a machine. In the language of cybernetics, the essential difference between the structural and control boundary conditions as systems is that the latter is closed to control and

information. (Ashby 1957) (But only to control and *not* energy flow or other simple physical parameters which exist in the case of structural boundary conditions too.)[7] This is the fundamental aspect putting artificial boundary conditions in engineering into the same category with natural biological boundary conditions. Both of them are closed to control, that is, they are specific structures (or rather hierarchy of structures) determined by complex higher level external processes and principles, such as human activities and evolutionary processes of Earth. Therefore, boundary conditions in chemistry (or cosmology, geology, meteorology and similar disciplines) are much easier to study and explain with the help of physics than boundary conditions in biology (or in similar disciplines like psychology, sociology, economics, history, etc.), because in chemistry one *can bound* a concrete process for exact examination, for example, in a Petri dish but one can hardly do the same in biology. The boundary conditions of chemistry are simple physical systems *without* control thus we can set simply physical parameters on the boundaries. In other words, structural boundary conditions are simple one-level systems without complex relations of higher level systems. This is not true of a frog, for example. The whole evolutionary system cannot be brought into the laboratory.

So, the structure of a machine is not the consequence of the elementary physical processes of the machine but of higher level external processes that are *contingent* upon these processes of the machine. This, at the same time, might suggest that when an engineer plans and creates a machine she violates the fundamental physical laws and principles of nature. Moreover, the fact that the purpose of a machine as an ontologically higher level boundary condition is to control and harness the lower level physical-chemical processes could also strengthen this impression.

However, a machine can control and harness the lower level processes *only via its material parts* in full accordance with the fundamental laws and principles of physics. The fixed walls of a piston while controlling and harnessing the flow and explosions of petrol do nothing against the fundamental laws and principles of physics. Higher level *emergent* boundary conditions are not independent vital forces or Cartesian substances. Higher level *emergent* boundary conditions do not work on their own, that is, against their material conditions but on the contrary: they lean on their material conditions and work by them in full accordance. A piston is a boundary condition shaped into its material fundaments by man according to higher level emergent principles. The interaction between the piston as a higher level boundary condition and the controlled and harnessed lower level physical-chemical processes

[7] It is important that both structural and control boundary conditions as systems are open to physical processes and while in the case of the former there is *no* control the latter is closed *only* to control. Physical processes at the boundaries can be defined as simple physical parameters. However, as I will mention below, control boundary conditions as systems—due to their nature—are not only in physical but other specific relations with the external world or other systems. Nevertheless, these relations cannot be defined with simple parameters but concepts like functions, information, mechanisms, etc.

inside the piston *can be understood only at the lower level*. It is necessary since the fundamental physical processes in accordance with their nature exist only at the fundamental, lower level. Therefore they can interact only at that level. It follows that a higher level emergent boundary condition can control and harness the lower level physical-chemical processes in its body only via its own material conditions. Accordingly, the engineer who plans and creates the piston also shapes the piston via her material conditions, her physical body, as the piston does with the petrol and not by some mysterious mental force or by something magical. So, contrary to first impressions, neither the engineer nor the higher level emergent structures violate the fundamental physical laws and principles of nature.

This means that in the case of control boundary conditions where there is some kind of shaping process from outside there is *also* only material substance and physical laws at the end of the determining process. Merely the system will be much bigger and complicated in space and time in which we have to take into consideration the initial conditions of material substance for the sake of the reduction. In this case we have to take into consideration every other external system with which our control boundary condition as system is in relationship. For example, for reducing a frog we have to take into consideration every evolutionary process and higher level biological principle which has shaped this species, that is, essentially the *whole evolutionary system and its evolutionary history*. After all, *every* control boundary condition stems from the evolutionary process of Earth. Before life and evolution there were only material substance and structural boundary conditions. This difference of origin draws the line between structural and control boundary conditions; and this is the main reason why it is impossible to reduce a frog or any other living being to present or quasi present material processes. Not because it is irreducible just because it is irreducible to *present* processes, moreover, it is irreducible only to *its own* present processes inside the boundary since it leaves out the external shaping processes.

So, neither structural nor control boundary conditions are vital forces or Aristotelian forms or other substantially different entities. They are emergent, higher level structures shaped by fundamental processes according to higher level principles of biology, engineering, etc., thus they are in the focus of higher level sciences. We *can* reduce every boundary condition to physical laws, material substance and initial conditions. In the case of structural boundary conditions, this is a more simple process. "It can take place within a Petri dish", while in the case of control boundary conditions, this is a much more complicated, multileveled process. After all, somehow we have to take into consideration the whole evolutionary system and its billion years history. I call the first as *synchronic reduction* (because of its relative simplicity) and the second as *diachronic reduction* (because of its necessarily evolutionary aspect).

4. Boundary Conditions in the Light of Philosophy

We have seen that the concept of boundary conditions stems from physics but boundary conditions in physics are only *conceptual* and *instrumental tools* in the hands of physicists and they are *not parts* of ideal (fundamental) physics. They are neither material substance or its properties nor physical laws. At the same time, in chemistry or biology the boundary conditions are not only conceptual or instrumental tools but essential goals of scientific inquiry. Now, the question is what these boundary conditions really are.

We have seen that boundary conditions are in a close connection with the structures and shapes of things and the shaping processes (evolution) of things as well as different boundaries between things, processes, and systems. Even though boundary conditions stem from physics, the philosophical understanding of structures, boundaries, shapes and shaping processes of things is much older.

In Aristotelian philosophy the shapes of things are the consequences of substantial forms; and the shaping processes are the consequences of potential forms.[8] Therefore there are two, inseparable substantial parts of a thing: *matter* and *form*. *Every* terrestrial thing consists of these two; and every higher-level thing can be "reduced" to these two substantial parts, i.e., matter and form. However, in the Aristotelian philosophy the substantial parts (matter and form) do not "fill up" the fundamental level only but there are several *hierarchical* levels where higher-level (e.g. potential) forms *determine* (control) lower-level processes (joint lower level of matter and form). The difference between a crystal and a frog is that the crystal is a *homogenous* higher level entity while the frog is a *heterogeneous* one and different types of forms are determining the two.

In the beginning of the modern era everything was changed. In accordance with René Descartes' view, it was supposed that every higher level (or secondary) property (thus shapes and shaping processes and boundaries, etc.) is the consequence of *mechanical (physical) processes* of material substance, i.e., in Descartes philosophy, the *res extensa* (particles with one fundamental (or primary) property: extension). We have seen in Section 2 that this means that every higher level property of things can be reduced to (1) the properties of material substance and (2) physical laws *and* (3) to the initial conditions of the evolving processes of that given thing. There are *no* hierarchical levels. There is *no* significant difference between a crystal and a frog.

So, in Aristotelian philosophy, forms determine the boundaries of a thing and in the modern era, as seen in Section 2, after all the initial conditions—the other two necessary conditions are given. This means that in Aristotelian philosophy there is *no* question concerning what a boundary condition or an initial condition is. Simply there is *no need* of boundary or initial conditions; the notion of form

[8] E.g. the cause of the shaping process of a goat is the potential goat form in the zygote.

plays their role. Nevertheless, the Aristotelian form is a real *substantial* thing, but the initial conditions which are in the focus of our investigation are not, and, as we have seen that in Section 2, the knowledge concerning the initial conditions is *not* part of the ideal physical knowledge of Laplace's demon only *human physicists* see the shapes of things[9] and involve boundary and initial conditions in their physics as conceptual tools and instruments. They apply initial and boundary conditions as conceptual tools; they have to do so since they are human beings; for their physics is not ideal but *fundamental*.

However, in the Cartesian philosophy, there is a substantial *res cogitans* too. That is, human beings (and solely them) are not only mechanical material things but specific beings with *soul*. This is the classical dualist position. It implies that higher level properties of a human being (thinking, consciousness, etc.) cannot be reduced to the properties of material substance and laws of physics *and* the initial conditions of the evolving processes of that certain human being alone. Similarly to Aristotelian philosophy, in this specific case the higher level properties of things can be reduced only to the *two* substances (i.e., matter and soul) and the initial conditions, because the latter still cannot be left out from the mechanical evolving processes of material substance to conclude boundaries and shapes of things. It is clear from this that there is neither identity nor close connection between the shapes of things (boundary conditions) and the souls of human beings as there is in Aristotelian philosophy between the forms and shapes of things where the human soul is also a (specific sort of) form. The Cartesian soul only *recognizes* the shapes of things but he himself is not a shape, a form, or a boundary condition (as a matter of fact, the *res cogitans* has no extension at all). The Cartesian soul is the existing physicist who uses boundary conditions as *conceptual* and *instrumental tools* to conclude mechanical (physical) laws and material substance and its primary geometrical properties. Without substantial souls there are *neither* physicists *nor* boundary conditions but only fundamental processes of material substances, that is, particles and its primary properties.

This latter is the physicalist position of the modern era which left out Cartesian souls from the mechanical (physical) world view. The ideal physics of Laplace's demon does not need any conceptual and instrumental tools such as boundary conditions. The question is who recognizes the shape of things as boundary conditions and who uses boundary conditions as conceptual and instrumental tools if there are no forms and souls. There is no significant difference between a crystal and a frog, both of them being higher level boundary conditions, that is, conceptual tools and not existentially real things; and now there is no significant difference

[9] In the Aristotelian philosophy both a human philosopher and an ideal "Aristotelian demon" could see the shapes of things, because their knowledge contains a knowledge of forms. The problem mentioned above is entirely modern.

between a frog and a man, both of them as higher level boundary conditions are *only conceptual tools* and not existentially real things. Conceptual tools *cannot* recognize each other, as e.g. quarks and electrons can not. As neither Laplace's demon can recognize any higher level boundary conditions by his ideal physical knowledge. (Polanyi 1962:139-42) As a matter of fact, Laplace's demon, since the perfect and omniscient Cartesian soul of ideal physics does not exist in a physical universe, in accordance with meaning, it cannot recognize anything. This is the main reason for Polanyi to assume that control boundary conditions like humans (without perfect, explicit knowledge of ideal physics) are *existentially real things* capable of recognizing another higher level structural and control boundary conditions by our natural evolutionary tacit powers.

So, at the end of the modern era, in Michael Polanyi's post-critical philosophy—which partly tries to find a path back to the hierarchical world view of Aristotelian philosophy—once again a close connection has been established between the structures and shapes of things and human souls in order to answer the question who uses boundary conditions as conceptual and instrumental tools if there are no Cartesian souls. There is close connection not because human souls or the shapes of things are substantial forms but because *both of them are boundary conditions*. A crystal is a structural boundary condition that is the consequence of its material substance thus a crystal is existentially identifiable with its material substance while a frog or a man which are the achievements of evolution are (hierarchies of) control boundary conditions existentially not identifiable with their material conditions. The essential difference between a frog and a man is that human beings are not only biological beings but *also cultural* (also the consequence of the second main stage of evolution, that is, cultural evolution (Polanyi 1962:389)). However, both frogs and human beings consist only of *material substance* and a specific *hierarchy of boundary conditions*. In the Polanyian philosophy there is only *one substance*, the *material*; every real thing of higher levels is *real* not because it is substantive but because it is *emergent*. In the Polanyian universe, in contrast to Aristotle and Descartes', there are no necessary, infinite, higher level, non-physical, substantial real things such as forms and souls, there are only evolving emergent boundary conditions which can be reduced to material substances, physical laws and initial conditions.[10]

Nevertheless, since the control boundary conditions are the consequences of an emergent evolutionary development and they are in relationships with the whole earthly evolutionary system, in their case, the initial conditions can be found in a much wider range and, moreover, in the *far past*, at the time of "primordial inanimate matter" (Polanyi 1962:404), before the beginning of emergent evolutionary development; thus *they cannot be reduced in our times*. With Polanyi's words:

[10] It is worth noting that in the Polanyian universe there are not emergent laws either, contrary to e.g. the theories of the British emergentists (Alexander 1920; Morgan 1923; Broad 1925).

> "when I say that life transcends physics and chemistry, I mean that biology cannot explain life in our age [i.e. synchronically] by the current workings of physical and chemical laws." (Polanyi 1997: 294-5)

In my terms it means that they cannot be reduced synchronically *only diachronically*; and that they *significantly differ* from the things which are only structural boundary conditions.

So, boundary conditions have to be divided into two *significantly different* main types. First, there are *epistemological structural boundary conditions* which are existentially *material* (that is, they can be reduced synchronically) and which are only *conceptual tools* in our hands to describe the shapes and every other secondary property, and the structural evolving processes of things. Second, there are *ontological control boundary conditions* which are existentially *not* material (that is, they can be reduced only diachronically) and which are real *existential* (emergent) things in our evolutionary system from frogs via machines to human institutions. Therefore the concept of boundary conditions establishes the possibility of a new, *non-physicalist* but *non-dualist* philosophical understanding of human universe.

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