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Formal Similarities between Cybernetic Definition of Life and Cybernetic Model of Self-Consciousness: Universal Definition/Model of Individual

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The previously proposed cybernetic definition of a living (biological) individual and the cybernetic model of a psychical individual (a self endowed with subjective consciousness) are extended and compared, and their formal similarities are isolated and highlighted. It is argued that the emergence of the biological level of reality from the physical level and of the psychical level from the biological level is closely analogous. The (biological or psychical) individual is constituted by a network of elements (negative feedbacks/regulatory mechanisms or neurons/concepts, respectively) that possesses the following common properties: 1) it is intentional (in the operational sense); 2) its elements signify (have sense) by connotation (through relations to each other); 3) it contains an instrumental representation of (some aspects of) the world and 4) it is self-referential i.e. recurrently directed on itself (its own reproduction or representation, respectively). Thus life and self-consciousness have deep, formal, structural similarities when viewed abstractly. The cybernetic definition/model of an individual is also referred to societies/states, companies and other systems. It is postulated that this definition/model is a universal one and can be applied to all possible systems/objects existing in the Universe or constructed in the future by humans.

Keywords: Definition of Life; Model of Mind; Consciousness; Cybernetics; Self-Reference; System Complexity

Introduction

Life and consciousness are phenomena of immense scientific and philosophical interest and significance. Their nature and the kinds of functional organization of matter underlying them still remains a matter of hot debate. They are usually, explicitly or implicitly, regarded as being of completely different natures. However, revealing any formal similarities between them would help to understand their essence and origin. Such formal similarities can be specified within the formal science dealing with regulation, signal transduction, information transfer and generally purposeful interactions between different elements of a system-cybernetics.

Many different definitions of the phenomenon of life have been proposed. The majority of them stress reproduction combined with identity inheritance and the ability to evolve (Maynard Smith & Szathmary, 1995; Muller, 1935; Ganti, 1975). In this context, researchers often mention chemical composition based on organic carbon compounds, metabolism, complex structural and functional organization, growth, adaptation and response to stimuli. Particular definitions/characterizations of the phenomenon of life take into account various such features and their combinations. Biological systems are certainly systems of hierarchically organized dissipative structures (Prigogine, 1980; Prigogine & Stengers, 1980) or, in more general terms, low-entropy systems significantly displaced from thermodynamic equilibrium (Schrödinger, 1992). Life is also defined as a self-sustained chemical system capable of Darwinian evolution (Joyce, 1995) or self-reproduction with variations (Trifonov, 2012). Sometimes a more abstract set of properties is regarded as sufficient for the phenomenon of life to be separated from the inanimate world. For example, Program, Improvisation, Compartmentalization, Energy, Regeneration, Adaptability, and Seclusion (PICERAS) were suggested to be the "seven pillars of life" (Koshland, 2002). For a review of different definitions of life, see (Popa, 2004).

I believe that it may be useful to adopt a different strategy, namely to attempt to formulate a minimalistic definition of the essence of life. I formulated such definition in cybernetic terms. According to this definition, a living individual is a network of negative feedbacks (or, in broader terms, regulatory mechanisms and signal transduction pathways) that are subordinated to (are at the service of) an over-arching positive feedback (corresponding to reproduction) (Korzeniewski, 2001, 2005). In my opinion, this is the most minimalistic definition of life that manages to remain valid. Although it is very abstract, all other fundamental properties of living systems can be derived from this simple formula, when it is confronted with the real world (Korzeniewski, 2005). This cybernetic definition is expressed in the terminology of formal sciences (cybernetics, information theory), which makes it "objective", for instance, for physicists. It is sufficiently general to be potentially applicable to possibly

very different forms of life that may exist in the Universe. The cybernetic definition of life will be further discussed below.

The mind-body (spirit-matter) problem—i.e. the problem of the relation between the subjective psyche and (self-)consciousness and the objective external reality—is one of the most important philosophical problems in the history of humankind. Within the framework of philosophy, various forms of monism (materialistic and idealistic) and dualism were proposed. Some of them are more radical, others less so. In this article, there is no room to provide a detailed review of particular conceptions, most of which are commonly known anyway. The position presented here is based on the scientific paradigm. Science naturally tends towards materialism, although not necessarily towards primitive reductionism. The rapid development of neurophysiology and cognitive science provoked numerous attempts at explaining the origin and nature of consciousness based on the dynamic structure of neural connections in the brain or on other physical and biological features (Crick, 1995; Dennet, 1997; Damasio, 1999; Macphail, 1998; Cairns-Smith, 1996; Greenfield, 1998; Penrose, 2002; Koch, 2004; Llinas, 2002).

I proposed my own, cybernetic model of the psychical individual (Korzeniewski, 2010). According to this model, self-consciousness emerges when the "cognitive center" in the brain becomes recurrently directed onto itself, receives and processes signals from itself and creates its own model within itself. This center is most probably dispersed across large areas of prefrontal and frontal cortex. In animals devoid of subjective psyche and self-consciousness, it receives and processes signals from sensory cortex. In a self-conscious brain, the cognitive center receives signals also from itself. Therefore, in my cybernetic model, the essence of a psychic individual is based on the relation of self-reference. This model will be presented below in greater detail.

The main objective of this article is to point out the similarities between the essence of life and (self-)consciousness as defined within the cybernetic paradigm. I will use the previously formulated cybernetic definition of the living individual and the cybernetic model of the psychical individual. I will significantly extend and broadly discuss this definition and model. I will focus on parallels between the emergence of the biological level of reality from the physical level, on the one hand, and the emergence of the psychical level from the biological one, on the other hand. I will attempt to demonstrate that from the formal, abstract point of view, the mechanism of emergence of a higher level from a lower level is in principle identical in both cases. I am referring here to the emergence both in the diachronic sense, during the evolution of the Universe and biological evolution, and in the synchronic sense, when we climb up through particular levels of the hierarchy of complexity and pass from atoms, molecules and macromolecules to living cells and (complex) multi-cellular organisms, as well as from neurons and their sets to complex neural networks that are the "carrier" of psyche.

Cybernetic Definition of a Living (Biological) Individual

Let us start with the essence of life. I believe that a living individual (and not organism) is the basic unit of life (as well as the subject of evolution, a unit of selection). I proposed a cybernetic definition of a living individual (Korzeniewski, 2001, 2005). I also referred it to a possible artificial supra-molecular life (Korzeniewski, 2011). Cybernetics (in the narrow sense of the term) is primarily a science of regulation and control in purpose-oriented systems (aimed at realizing some pre-determined goal). Negative feedback and positive feedback are two basic concepts of cybernetics.

Negative feedback is aimed at maintaining the value of a parameter at a pre-set level that is beneficial for the functioning of the entire system. In the case of biological systems, there are multiple parameters of the type, for instance: temperature, the rate of a chemical reaction, the concentration of a compound, a specific color in a specific place of an organism, the intensity of functioning of an organ, humidity (e.g. inside an anthill), exposure to sunlight, the size and shape of a specific structure or of the entire body at a given moment of embryogenesis, precision of an image produced on the retina, the optimum hunting strategy and many more. Negative feedback eliminates any deviations from the pre-set value of a parameter, caused by various disturbances occurring outside (or inside the organism), and it does so by triggering an action that leads to a modification of the relevant parameter value that counteracts the deviation. Maintenance of constant temperature in a fridge or corrections of the course deviation of a rocket from the pre-set trajectory are examples of negative feedback in the inanimate world.

Positive feedback operates in the opposite manner: it leads to the faster divergence of a parameter value from a specific value (often, this is simply zero), the more the current value of the parameter deviates from that specific value. Thus, this mechanism enhances something that is already present to some degree (therefore it is called "positive"). In other words, the parameter value moves away from the "preset" value the faster, the further away it is already removed from that reference point. Therefore, while negative feedback is a stabilizing mechanism that maintains a system in the vicinity of a specific state (although this optimum state may change, depending on the conditions), positive feedback leads to instability and explosive and/or chaotic behavior (while a combination of positive feedbacks and negative feedbacks may lead to oscillation of parameter values). The chain reaction during a nuclear blast and an avalanche of stones are examples of positive feedback in the inanimate world.

The mechanism of negative feedback regulates the value of a given parameter by maintaining its value near the "pre-set" value that is the optimum value with respect to some pre-defined goal. For instance, a fridge maintains the temperature of its interior sufficiently low to prevent food from going bad, while it is also sufficiently high to reduce power losses (and avoid deep freezing). In this case, a suitable detector (thermostat) continuously measures (detects) the value of the parameter to be regulated (temperature). If the temperature increases above the pre-set value, the detectors sends a control signal that triggers an appropriate effector (a cooling device) that counteracts the parameter deviation from the pre-set value, i.e. it compensates for the disturbances caused by the impact of the environment (the temperature returns to the optimum pre-set value). The entire discussed sequence of cause and effect (namely: increase of a parameter value above the pre-set value-measurement-detector-control-effector-compensation-decrease of the parameter value down to the pre-set value) is called the control loop. As stated above, the operation of positive feedback—as its name indicates—is opposite to that of negative feedback. It has a highly destabilizing impact. It moves a parameter value from the pre-set value the stronger, the further away the parameter value is from the pre-set value. As a result, the pa-

rameter value moves rapidly (exponentially) to infinity and the resulting effect may be termed: anti-regulatory or explosive.

As I have mentioned, the nuclear chain reaction is an example of positive feedback in inanimate world. An unstable nucleus of a radioactive isotope, e.g. uranium U^{235}, undergoes fission and emits three neutrons. Each of the neutrons collides with another unstable nucleus, which leads in each case to releasing yet another three neutrons. Thus, after some (very short) time, the number of neutrons is tripled. We have the following series: 3, 9, 27, 91… of neutrons. This process may repeat itself for an infinite number of times, at least potentially (in practice, it is limited by the amount of the unstable isotope). Other examples of the positive feedback can be found in chemical compounds that catalyze their own formation from other compounds (so-called autocatalysis) and in a stone avalanche, where a rock rolling down a slope sets more and more rocks in motion.

Let us return, however, to negative feedback. In live organisms, there is a plethora of regulatory and controlling mechanisms, and negative feedbacks are among the most prominent of them. When viewed in terms of their function and regulation, biological systems are practically made of a hierarchically organized network of mutually intertwined and conditioned negative feedbacks. Generally speaking, this entire network formed during biological evolution constitutes, in a sense, a functional and operational *reflection of both the external and internal environment of a given individual* (together with the variability of this environment in time and space) and it is aimed at the survival and reproduction in an ecological niche (physical and biological environment) occupied by this individual. On the other hand, negative feedbacks and other interactions between living individuals within an ecosystem are not aimed at the survival of the ecosystem, because the relations between different individuals (of the same or different species) are usually antagonistic and not cooperative (see discussion in Korzeniewski, 2011).

A leading (and relatively simple) example of the negative feedback in live organisms at the biochemical level is found in the regulation of the synthesis of an amino acid by the current concentration of this particular amino acid (Umbarger, 1978). Such amino acid inhibits (by lowering the activity of the relevant enzyme as a result of binding the molecule of this amino acid to the corresponding regulatory center) the first enzymatic reaction on the metabolic pathway that leads exclusively to its synthesis, so that the concentration of the amino acid in question is maintained at a relatively constant level. If the concentration of the amino acid drops (due to its low supply from digested food or/and its increased consumption, e.g., caused by synthesis of proteins), the enzyme is unblocked and the rate of synthesis of the amino acid increases, which results in an increase of its concentration. Otherwise, the synthesis of the amino acid is blocked. Without such regulation, the pool of a given amino acid would be exhausted very quickly or, on the contrary, an excessive amount of the amino acid would be accumulated, which would disturb the functioning of a cell (e.g. by increasing osmotic pressure).

Another example at the metabolic level is found in production of ATP—the universal energy carrier in a cell—in the process of oxidative phosphorylation in mitochondria. In the resting state, a high concentration of ATP inhibits the metabolic pathway producing this compound. A sudden increase in ATP consumption—for instance, due to muscle contraction (mechanical work requires energy consumption)—results in hydrolysis of ATP into ADP. An increase of the concentration of the latter activates production of ATP and compensates partly for the drop of its concentration (Chance & Williams, 1956) (although this is not the only mechanism that maintains homeostasis of ATP and ADP—see below).

As far as the components of a live cell are concerned, the synthesis of particular proteins, and enzymes among them, must be adapted to the rate of their decomposition (for instance, due to their damage by free radicals), so that their concentration is maintained at a constant level. This problem also applies to other cell components, e.g. lipids and membranes made of them, polysaccharides, as well as structures of a higher order, namely ribosomes, cytoskeleton and cell organelles. And the issue is not limited only to their degradation or synthesis de novo. For instance, the "amount" (surface area) of the cell membrane increases as a result of exocytosis, while it decreases as a result of endocytosis. Additionally, these processes lead to a change in the content of proteins and lipids in the cell membrane. Thus, regulatory mechanisms are indispensable to maintain a constant surface area of the membrane and to reconstruct the quantitative composition of membrane macromolecules. The composition and structure of a cell varies during the cell cycle as well. Volumetric growth of a cell (its cytoplasm), production of particular cell components, DNA duplication, formation of the karyokinetic spindle, condensation of chromosomes, etc. must proceed in an appropriate temporal sequence and at an appropriate intensity, while they are mutually correlated with each other. A complex network of cybernetic mechanisms—including negative feedbacks and signal transduction—is responsible for control and regulation of these processes.

The optimum concentration of a given protein may depend on the circumstances. Its regulation proceeds at multiple levels including the genetic level. For instance, in a bacterium cell that finds itself in the presence of lactose (and in the absence of other sugars) in the environment, production of enzymes responsible for taking up and decomposing this sugar is activated, while in other circumstances, these enzymes are not synthesized (the famous operon model) (Jacob & Monod, 1961). Consequently, a set value of a certain parameter (in this case: the concentration of enzymatic proteins) that functions as an element of a negative feedback at a lower level of the hierarchy (to ensure constant supply of a building material and energy, and thus to ensure a constant concentration of metabolites) may be changed by some other negative feedback at a higher level of the hierarchy (to reduce the expenditure of energy and building materials on the production of proteins that are not needed at the moment). In bacteria, the so-called alarmons and σ (sigma) factors play an important role in feedbacks responsible for appropriate reactions to varying external conditions.

In eukaryotes, and especially in multi-cellular organisms and organisms consisting of tissues, a highly complex and hierarchically organized regulatory system determines with exceptional precision which specific proteins are going to be produced in a given place, at a given time and in what amounts (Alberts et al., 2007) (this is of particular importance during embryonic development and the corresponding morphogenesis —see below). This regulatory system is based to a large extent on a network of negative feedbacks and other controlling mechanisms developed to transmit signals. Cells of different types consist of different proteins and varying amounts of common proteins. Cell differentiation consists primarily in selective

activation of the expression of certain genes and inhibition of the expression of others, which is reflected first of all in a specific protein composition of a cell (DeLeon & Davidson, 2007). Different protein composition is also required in different phases of the cell growth cycle, as mentioned above.

In the case of growth and reproduction of cells of unicellular organisms, the series of events at the base of these processes is generated in an endogenous (intracellular) way. Appropriate negative feedbacks ensure the series does not deviate from the set sequence of changes. In multi-cellular organisms, growth, division, differentiation and migration of cells during embryogenesis are to a large extent induced in an exogenous way (from the outside of a cell—see below). The series of events—especially in the case of differentiation of cells—covers hierarchically and cascade organized regulation of gene expression. It means that the activation/inhibition of a regulator gene (activation/blocking of the synthesis of the regulator protein coded by this particular gene) at a higher level of the hierarchy results in the activation/inhibition (through the mediation of the above-mentioned regulator proteins) of multiple regulator genes at a lower level of the hierarchy (DeLeon & Davidson, 2007; Gilbert, 2006). These, in turn, may activate/inhibit regulator genes at yet lower level of the hierarchy. There are several such levels of the hierarchy (occasionally, there may be over a dozen). Finally, at the lowest level of the hierarchy, the synthesis of proteins by the so-called structural genes is activated or inhibited. These proteins do not regulate gene expression, but participate in the creation of the structure and functions of (a given type of) a cell. Their synthesis must proceed at the right place, the right time (and in the right temporal order) and in appropriate amounts. In higher organisms, there are several hundred different types of cells and a specific gene-expression regulatory cascade corresponds to each type. As such cascades are hierarchically organized and they consist of multiple stages and involve hundreds and thousands of genes, they are very susceptible to disturbances and chaotic behavior. It means that even a minute change in the expression of a regulator gene at the top of the cascade or at higher levels of this hierarchy will result in massive accumulation of errors at lower levels of the hierarchy and, finally, it may lead to a sequence of events that is quite different from the expected one. Even a small divergence from the right amount of regulator proteins produced at a given level of the hierarchy (not to mention their type) would change completely the expression of genes at a lower level of the hierarchy. Consequently, a totally dysfunctional cell may be created. Such cell will be unable to fulfilll its original function. To avoid this, the cascade that regulates gene expression during cell differentiation must be subjected to extremely precise control. We do not know any mechanism that could be responsible for this process other than negative feedback. A complex set of such feedbacks must verify on the run, whether a sequence of events in a cell corresponds to the intended sequence (originally determined by evolution) and counteract any deviations from that sequence. The same potential instability is inherent in the complex choreography of morphogenesis at the level of an entire organism (see below).

Another example of negative feedbacks at the genetic level is found in the correction of DNA damage or errors in DNA copying, in particular: replacement of erroneous nucleotides in a descendant DNA strand with correct nucleotides that are complementary to the matrix—the original strand (Alberts et al., 2007).

Reactive oxygen species (ROS) produced by the respiratory chain in mitochondria damage many cell components: DNA, proteins, lipids and so on. The rate of ROS production strongly depends on the proton gradient across the inner mitochondrial membrane. An increase in ROS level activates uncoupling protein 3 (UCP3), which increases the proton leak into mitochondria and thus decreases the proton gradient and ROS production (Echtay et al., 2002).

At the physiological level, two hormones—namely insulin and glucagon—constitute antagonistic signals in the loop of a negative feedback that maintains a constant concentration of glucose in blood (insulin reduces the concentration, while glucagon increases it) (Cryer, 1991). This parameter is so important that its precise regulation requires several complementary control signals. Another hormone—namely adrenaline—increases the rate at which the heart pumps blood to increase the supply of oxygen and nutrients to tissues during physical exercise and/or stress (Mitchell, 1990; Rowell et al., 1996). The elevated skeletal muscle work is associated with an intensive O_2 and respiratory substrate (e.g., glucose, fatty acids) consumption by oxidative phosphorylation, which can lead to a substantial decrease of their concentration in blood. The accelerated heart beating increases the delivery of oxygen and respiratory substrates to skeletal muscles and thus counteracts the decrease of their level. Physical exercise causes a rise in the CO_2 (carbon dioxide) level in blood (in the result of the respiratory substrate combustion). This rise is detected by chemoreceptors in the brainstem (in particular in *medulla oblongata*) and, through a neural negative feedback, increases the ventilation of the lungs and thus O_2 uptake (Coates et al., 1984) and the heart work (the latter effect cooperates with the effect of adrenaline) (Mitchell, 1990; Rowell et al., 1996).

By changing the diameter of the pupil, iris muscles regulate the amount of light entering the eye, depending on the needs and circumstances, to ensure sharp vision in strong light and the ability to see anything at all in weak light (Malmström & Kröger, 2006). Here, the optimized parameter is a possibly good vision at a given light intensity. On the other hand, muscles that stretch the lens may change its curvature and maintain in this way sharp vision, when the eye passes from the observation of remote objects to the observation of close objects, and vice versa (the phenomenon of accommodation) (Malmström & Kröger, 2006). Therefore, a sharp vision is maintained despite the "disturbance" consisting in passing attention between remote and close objects.

Blood coagulation (based in itself on a positive feedback that supports a network of negative feedbacks—see below), wound healing, regeneration of damaged tissues and body parts, fighting parasitic infections—all these processes obviously restore the general condition of an organism (defined by multiple parameters, e.g. amount of blood) to the "set value", i.e. they restore the organism's health.

At the behavioral level of an entire organism, exhaustion of the reserves of nutrients (fats, saccharides) in the body of an animal after a long period of starvation stimulates the activity of the animal, so that it undertakes appropriate actions aimed at taking up food. This negative feedback helps to maintain a proper level of respiratory substrates and building substances within the individual's body. Realization of this task involves numerous negative feedbacks that regulate the operation of the nervous system and the locomotor system.

Strict control of the contraction and tensioning of muscles to

ensure smooth movements is indispensable for the performance of so complex actions as locomotion, precise hand manipulation or speech articulation. It suffices to remember, how much time a child needs to learn how to walk, perform manual operations or talk. The decision to move, and thus to contract particular (groups of) muscles originates in the brain (in the frontal cortex and the motor cortex, among others). Interoceptive receptors (proprioreceptors) measure the tonus of particular muscles and send return signals to the brain (to the cerebellum, among others). In case of any deviation of this parameter (or the rate of its changes, which is also a parameter) from the set value, the brain sends a controlling signal that rectifies this value and restores the right "trajectory" of muscle activity (Kawato, 1999). The movement trajectory can be also optimized by negative feedbacks involving visual control (Desmurget et al., 1998).

Broadly understood perceptive and cognitive functions of living organisms are elements of an extremely rich network of negative feedbacks and signal transduction mechanisms that is involved in the transformation (often in a highly mediated manner) of stimuli originating from the environment into behavior of an animal, which finally leads to satisfying its various biological needs. This is so, because the immense variability of environment in space and time requires a living individual to react appropriately, in order to maintain the values of parameters related to its internal homeostasis (e.g. appropriate temperature, levels of saccharides, fats and amino acids used as the source of energy or construction material, or concentrations of mineral salts) as constant as possible and to realize its reproductive functions (satisfaction of the sexual drive). The changes in the environment in space and time are disturbances that require a proper behavioral response in order to maximize the individual's chances of survival and reproduction. Negative feedbacks involved in the generally understood perception and cognition may comprise, on the one hand, such simple phenomena as the (already mentioned) lactose operon and eye accommodation and, on the other hand, so complex mechanisms as the operation of the brain aimed at coordinating the current and future behavior of a living individual with past, current and anticipated properties of the environment and events occurring around the individual. This activity comprises, among others, perception of stimuli coming from the environment, integration of sensory data into complex neural/mental properties and objects, association of various features, objects and aspects, detection of regularities and relations in sets of sensory data, formation and use of memory records, planning and decision-making, as well as others. Creation and strengthening (or else elimination or weakening) of the so-called associative structures in the network of neural connections (Korzeniewski, 2010) (see below—the functional structure of the neural network) is one of the leading examples of negative feedbacks in the behavioral and cognitive domain. These feedbacks optimize the present and future behavior of an individual in response to different "disturbances" coming from the (physical and biological) environment that varies greatly in space and time. However, even a simple unconditional reflex, for instant withdrawal of a hand after touching a hot object, constitutes a good example of negative feedback in which the nervous system is involved.

Finally, as already mentioned above, a rich network of negative feedbacks controls the course of morphogenesis (structure formation) during embryogenesis. This process is based on morphogenetic centers and gradients of morphogens. An appropriate combination of the concentrations of the latter constitutes the so-called positional information that determines what structure and tissue will be formed in a given place of the embryo. The set of morphogenetic centers/morphogens is organized hierarchically. Those at the higher hierarchy levels are responsible for the formation of bigger body structures, while generating secondary morphogenetic centers, together with their morphogens, that control the formation of smaller (more detailed) body structures. The entire process is referred to as the morphogenetic cascade. It leads to the formation of a particular living individual with a specific structure and function (Gilbert, 2006; Wolpert et al., 2002). Differentiation of particular cells into different cell types (epithelial cells, muscle cells, nerve cells, etc.), in turn, is associated—as mentioned before—with a hierarchically organized cascade of gene expression regulation within a cell. (DeLeon & Davidson, 2007; Gilbert, 2006; Wolpert et al., 2002). Apart from regulator proteins, production of particular structure/function-related proteins is controlled by the so-called miRNA (micro-RNA) (Bartel, 2009). Morphogenetic gradients control not only differentiation, but also migrations of various types of cells and apoptosis (programmed cell death). The entire set of processes that lead to the generation of complex and hierarchically organized structure and functions of a full-grown living individual must be regulated with exceptional precision. When this regulatory process—presumably based on a highly complex network of negative feedbacks and other cybernetic mechanisms—fails (when the multi-dimensional "trajectory" of morphogenesis deviates from the set path), functionally handicapped individuals are born at best, freaks—at worst. In the face of the vast complexity of the system constituted by a living individual, it is impressive that the network of controlling mechanisms so rarely fails to fulfill its role correctly.

For the sake of accuracy, it should be added that negative feedbacks do not exhaust the list of cybernetic mechanisms responsible for controlling the functioning and formation of the structure/functions of living individuals. For instance, subordinate positive feedbacks "integrated" into a network of negative feedbacks are responsible for "decisions" made according to the principle of "all or nothing", e.g. during irreversible differentiation of embryo cells into particular cell types or during determination of the sex of an embryo (Gilbert, 2006) (and, most probably, for action-related choices made by the brain). In this case, when a cell or an entire developing individual enters a certain development path, continuation of the development along this path is progressively strengthened. Otherwise, there could appear, for instance, hybrid cells that combine features of a nerve cell with those of a muscle cell or intersexes, i.e. individuals exhibiting features that are intermediate between a male and a female. Both growths would be dysfunctional from the biological point of view. The cascade of blood coagulation is another example of a subordinate positive feedback built into a network of negative feedbacks. It is a typical chain process, where a signal is highly enhanced (amplified) at each stage.

Parallel activation—that could also be termed "feed-forward activation"—is also quite common. For instance, during the passage from rest to physical exercise, the central nervous system (cerebral cortex) activates not only contraction of skeletal muscle cells in limbs, but also increases, through medulla oblongata, the rate at which the heart operates (the so-called "central control") (in the latter case, the discussed adrenaline- and

CO_2-driven activation cooperates with neural activation) (Mitchell, 1990; Rowell et al., 1996). This is aimed at enhancing oxygen supply to muscles in parallel to increased oxygen consumption in muscles (involved in the production of ATP in the process of oxidative phosphorylation). Protein kinases activate numerous proteins through their phosphorylation within target cell in response to different hormones and other factors (Reece & Neil, 2002). Within a muscle cell, not only ATP consumption for mechanical work performed by myosin and actin filaments is activated by Ca^{2+} ions, but—most probably—a factor/mechanism related to these ions also leads to direct activation of particular enzymes of oxidative phosphorylation and other components of the cell energy system responsible for ATP production (Korzeniewski, 1998). This mechanism dominates in the cardiac muscle and cooperates with the above—discussed negative feedback that operates on the basis of the concentration of ADP (a product of ATP decomposition) in skeletal muscles (Korzeniewski, 2007).

All negative feedbacks are hierarchically organized and mutually interconnected (directly or indirectly). In other words, their functioning conditions the functioning of all other negative feedbacks and, inversely, the functioning of other negative feedbacks conditions the functioning of a given negative feedback. For instance, insulin and glucagon that regulate the level of glucose in blood are proteins. Therefore, their synthesis is dependent (among others) on the above-mentioned negative feedbacks responsible for the regulation of the synthesis of amino acids, of gene expression and protein production. A similar relation is found between the regulation of muscle contraction, of energy (ATP) production and of taking up—together with food—respiratory substrates for ATP production. The food acquisition involves, among others, movement coordination and perception and behavior control (e.g., eye accommodation, forming associative structures related to object recognition and generating/stopping particular actions). Muscle contraction and brain operation require energy in the form of ATP, and the rate of ATP production is adjusted to the present ATP demand of these organs by the negative feedback acting through ADP concentration. ATP production requires respiratory substrates that are taken up from digested food and O_2 breathed in by lungs. These substances are distributed among different tissues by blood. Adrenaline, CO_2 and neural signals from cerebral cortex elevate the heart rate during exercise and thus accelerate blood circulation and transport of nutrients and O_2. CO_2 speeds up the ventilation of lungs and thus O_2 uptake from the atmosphere. Acquisition of food requires the network of negative feedbacks involved in coordination of muscle contraction and in perceptive and cognitive functions. The elevated heart work requires faster nutrient delivery to and faster ATP production within cardiac myocytes. So the negative feedbacks controlling ATP production, heat rate, food acquisition, muscle contraction, cognitive functions and behavior form a sort of a vicious circle or, more accurately, "vicious network". This is an example of a "causal closure", so characteristic for living individuals. Many similar examples can easily be found. The mentioned negative feedbacks are of course functionally related, directly or indirectly, to thousands other negative feedbacks that constitute the cybernetic identity of a cybernetic individual. Generally speaking all negative feedbacks in a living individual form a coherently organized network. All feedbacks within the network are mutually dependent and they condition each other. For instance, the approximately constant level of glucose in blood could not be maintained by the negative feedbacks involving insulin and glucagon (being proteins) without the negative feedbacks controlling amino acid synthesis, protein synthesis, coordination of muscle contraction, behavior (e.g., food acquisition, hunting strategy) and many, many others. Negative feedbacks involved in wound healing and immunological system activation maintain the integrity and health of the whole individual, and thus support all other negative feedbacks and other regulatory mechanisms it is equipped with. Wound healing needs collagen—the production of this protein involves negative feedbacks regulating gene expression as well as amino acid and ATP production. And so on, and so forth. Therefore, the purpose—in functional, regulatory terms—of each particular negative feedback is determined by the context of the entire complex of negative feedbacks of a given living individual. Negative feedbacks of living individuals do not act in void—they enable and support the existence and functioning of other negative feedbacks, and at the same time their existence and functioning depends on the action of those other negative feedbacks. For instance, ATP, particular amino acids and proteins are not just produced with a strictly controlled intensity—they are produced for *some purpose*. From the cybernetic point of view they constitute a source of energy and constructing substances for other negative feedbacks (regulatory mechanisms). Thus, it can be said that the functional sense of each negative feedback is realized by *connotation*, by its relation to other negative feedbacks.

Generally speaking, mutual co-conditioning of the functioning and genesis of various parts (e.g. cell components, cells, organs) of an organism is one of the most characteristic features of living individuals. They constitute a certain self-supporting whole (in specific environmental conditions). Living individuals are capable of self-generation (reproduction and development in the process of embryogenesis, repair of their bodies, reconstruction of their components). This is based on the recurrent network of component production at different levels of the hierarchy (the metabolic, genetic, cellular, physiological levels). The discussed co-conditioning (of the genesis) of elements is frequently called "causal closure". Living individuals are organized in space and time in a circular way. The regulatory purpose of living individuals related to cybernetic mechanisms is "active", as opposed to the "passive" purpose related to the "static" structure and function (Korzeniewski, 2005). In this sense, the heart structure and function (blood pumping) is passive, while the regulation of the heart rate by CO_2/adrenaline/central control in response to exercise/stress is active. Moreover, cybernetic (regulatory) information is not the only one that is related to live systems. One can also distinguish structural and functional information (related, for instance, to cell architecture and to metabolism) and genetic information (related to the sequence of nucleotides in DNA/RNA and the transcription and translation mechanisms that translate it into a sequence of amino acids in proteins, while the latter sequence determines to a large extent the target three-dimensional structure and functions of the proteins). However, the need for a living individual to have metabolism and a genetic record/apparatus (as well as a number of other features, e.g. that of being a dissipative structure, or a hierarchically-organized system of dissipative structures) results from the confrontation of the abstract cybernetic definition of a living individual with the real world and its elementary properties (Korzeniewski, 2005). Moreover, the cybernetic regulation and transfer of signals constitutes the most

active, "supervisory" aspect of live organisms, while the "stationary" (invariable in time) structure and functions—especially the "raw" genetic record—constitute subordinate elements that could be regarded as acted-upon objects, rather than acting subjects. At first sight, it may seem that negative feedbacks (or, in broader terms, all cybernetic mechanisms) constitute only a narrow sub-set of the entire set of functions realized by live organisms. And this is actually the case, in a sense. The regulatory/homeostatic aspect is one of numerous aspects of biological systems. Still, in another, very important sense, the network of negative feedbacks is superior with respect to the entire complex structure and functions of these systems. This is so, because it is precisely the network of negative feedbacks that supervises, steers and controls both the process of formation of the structure and functions, and their current maintenance (to sustain their existence). As mentioned before, this may be expressed at the cellular level by maintaining constant internal conditions, irrespective of various external disturbances, and by regenerating (creation in the case of cell growth and division) particular cell components from the already existing elements. In the case of complex multi-cellular organisms, this takes additionally the form of control over the course of the morphogenetic cascade, responsible for the creation of a fully-grown individual from a fertilized egg cell in the process of embryogenesis. From the formal and cybernetic point of view, all these processes are based on negative feedbacks (and other cybernetic mechanisms, e.g. subordinate positive feedbacks, signal transduction or parallel activation = feed-forward activation). Thus, one could venture a claim that it is negative feedbacks (or an appropriately organized set of such feedbacks) that "take care" of the creation of their structural and functional base. This would turn upside down the traditional, intuitive and commonsense view that it is the structure (and the "passive", non-regulatory function) of living individuals that "uses" feedbacks to support itself and to create a new structure (and function). Obviously, there is in fact nothing in living individuals that is subordinate or superordinate. Everything is mutually conditioned by everything else, according to the principle of the "vicious circle" or "causal closure". As it does not make sense to ask, whether an egg was first, or the hen, it does not make sense to ask, for instance, what is more important or primary: DNA or proteins. One could just as well say that genes code proteins that ensure their multiplication (as Dawkins (1976) would have it) and that a functionally integrated set of proteins records its identity in the form of a sequence of nucleotides in DNA.

All negative feedbacks forming the identity of the cybernetic individual constitute, direct or indirect, *operational representation of* (*different aspects of*) *the external* (*physical and biological*) *and internal* (*structure and function of the individual*) *world*. This regulatory, operational representation allows the cybernetic individual to survive and reproduce in its environment/ecological niche. The direct and indirect representations should be clearly distinguishes. Let us consider a few examples. The ON state of the lactose operon (which is turned ON by lactose) can be regarded as a direct representation of the presence of lactose in the environment (and of the absence of other sugars that turn it OFF). The turning off of the synthesis of lactose decomposing enzymes in the absence of lactose or in the presence of other sugars represents directly the absence of lactose in the environment and, less directly, the limited energy and amino acid resources necessary for the synthesis of these enzymes (and also the limited space within the bacterium cell). The regulation of the amino acid level/synthesis represents directly a lowered or elevated concentration of a given amino acid and indirectly the abundance of food, content of proteins in food, rate of protein synthesis by the organism, the fact that proteins are synthesized from amino acids and so on. The present diameter of the pupil represents the present light intensity and, less directly, the sensitivity of rods and cones to light and the laws of optics saying that the smaller the pupil diameter, the sharper the picture on the retina. The feedback signals participating in the regulation of locomotory muscle tension/contraction rate directly represent the deviations of these parameters from appropriate (pre-set) values and generally deviations of movement trajectories from the set trajectories "recorded" in motor programs in the central nervous system. These deviations result from the lack of perfect control of muscle tension/contraction only by feed-forward signals sent from the locomotory cortex of the brain and from e.g., disturbances caused by the unevenness (ups and downs) of the ground. Indirectly, the tight control of muscle contraction must represent e.g. the physical laws concerning movement (proper muscle contraction sequence must ensure effective locomotion in the real physical environment). The regulation of behavioral activity directed on acquiring food represents directly the present nutrient (fat, polysaccharides) stores within the animal's body (the food-acquisition activity is turned off in the state of satiety and turned on in the state of starvation). Indirectly, it represents the need for energy and building substances, the fact that living individuals are dynamic dissipative structures driven by energy dissipation and entropy production and generally the laws of thermodynamics. The optimization of hunting strategy represents the prey, its behavior and the topography of the surrounding area (e.g., presence of bushes favoring hunting from ambush or of high grass that can hide an approaching predator). Generally, the planning future actions and making decisions takes into account the general rules governing the physical and biological world, and constitutes a response to particular features of the surrounding area in which a given individual lives. The regulation of the movement and orientation of chloroplasts in leaf cells represents changes in the present light intensity. Blood coagulation, wound healing and activation of the immunological system constitute a direct representation of a damage of the body surface (skin and other tissues) and of the factor that caused this damage, and an indirect representation of elementary physical laws (blood flows out from broken blood vessels) and of the presence of parasitic microbes in the environment. The level of insulin and glucagon represents directly the present concentration of glucose in blood. Indirectly, the regulation of glucose level in blood represents the present abundance of food, the properties of glucose molecule as a source of energy, the physiological fact that excess of glucose can lead to diabetes/diabetic coma, while glucose shortage would mean respiratory substrate supply limitation to different organs, especially to the brain for which glucose is the only respiratory substrate. The tight regulation of embryonic development supervises a development of an organism that would be efficient in survival and reproduction in the external (physical and biological) world (in this sense, it represents the world itself) as well as functional internally. It also represents numerous possible disturbances in the complex hierarchically-organized developmental cascade causing a deviation of morphogenesis from the proper "trajectory". And so on, and so forth. Generally, as mentioned above, a representation can be

direct, as in the case of the representation of the presence of lactose by the ON state of the lactose operon or very indirect, as in the case the representation of physical laws and physiological state of an organism by numerous negative feedbacks. Generally, a direct representation refers rather to the present state of a given negative feedback, while an indirect representation—to the existence of this negative feedback at al.

The positive feedback that finds the strongest expression and is most characteristic and decidedly most important in the living nature is simply reproduction combined with inheritance, i.e. multiplication of one's identity in as many copies, as possible. It is always possible, at least potentially, to produce more descendant individuals than the total number of existing parents. For instance, when placed on a nourishing substance (medium), bacteria that reproduce by fission double their number in a specific unit of time (necessary for a cell to grow and double its mass), until the culture medium is filled up. If one starts with a single bacterium, one receives 1, 2, 4, 8, 16, 32, 64… bacteria in subsequent generations. Thus, until the capacity of the environment is unsaturated, the number of produced living individuals is the larger, the larger number of individuals have already been produced. When the capacity of the environment is limited and saturated, the number of individuals cannot increase and the positive feedback is expressed as the expansion potential. It may take the form of forcing other identities (individuals of the same or competitive species) out of the limited environment or of populating new areas. Reproduction and the correlated expansion potential are at the core of the essence of biological individuals.

My cybernetic definition of a living individual runs as follows: *A living individual is a network of negative feedbacks, subordinate to* (*at the service of*) *a superior positive feedback* (*reproduction*) (Korzeniewski, 2001). This definition is further significantly updated, extended and discussed in the present article. The entire set of negative feedbacks (or, in broader terms: regulatory and controlling mechanisms)—operating at different levels of hierarchy and representing the cybernetic aspect of the functioning of a living individual—is aimed at maintaining the identity of the individual (its survival). The only ultimate goal of this identity is, in turn, self-multiplication in as many copies as possible (realization of the superior positive feedback). From the cybernetic point of view, the identity of a given individual is precisely such-and-no-other, unique complex of negative feedbacks (regulatory mechanisms). At this point, we face a certain type of a (recurrent) vicious circle: the network of negative feedbacks is ultimately aimed at reproduction, while reproduction leads to multiplication of this particular network of negative feedbacks. Therefore, a living individual may be presented as a certain, dynamic system *oriented* purposefully *on itself*, its survival and reproduction. In this (functional and not psychic) sense, it is undoubtedly *intentional*.

A cybernetic living individual consists of all and only these negative feedbacks that are aimed at its reproduction that constitutes the leading positive feedback. Particular negative feedbacks cooperate with each other, in order to maximize the reproductive success. The overriding objective, the mother value does not consist in survival, in maintaining an individual's structure and function intact, as numerous authors would have it, but precisely in reproduction. We know tens of thousands of examples of parent individuals sacrificing their live to enhance the chances for possibly fast growth, survival and reproduction of their offspring. Of course, survival until the reproductive age (and the "sub-objectives" leading to this goal, such as acquisition of food, avoidance of predators, illnesses and injuries, etc.) is an indispensable condition of reproduction. Also, when there are no chances for progeny to survive (e.g., because a lack of food) a mother can eat its children in order to increase its own chances to survive and to produce progeny in the future. It should also be pointed out that the cybernetic individual does not only cover the fully-grown phase, but the entire life cycle. Therefore, a spore, for instance, constitutes a part (element, stage) of a living individual, although its life functions are quite limited. The same applies to viruses. A virion, i.e. a particle of a virus (nucleic acid, RNA or DNA, in a protein capsule called capsid) does not show traces of metabolism or any other activity outside the host cell. However, a virus "immersed" in the host metabolism, which is switched by an infecting virus from its normal course to the production of new viruses, behaves as a regular parasite and therefore it is unquestionably alive. Similarly, according to the cybernetic definition, cancer cells, especially those that are capable of infecting new hosts (as, for instance, in the case of canine transmissible venereal sarcoma (Barski, 1966) or the facial tumor affecting Tasmanian devils Bostanci, 2005)) or colonies of social insects (Wilson, 1971) should be regarded as living individuals. These problems are discussed in detail in my previous publications (Korzeniewski, 2001, 2005).

To sum up: a cybernetic living individual is a system of negative feedbacks (or generally: regulatory and controlling mechanisms) that signify by *connotation*, which constitutes an *intentional*, functional *representation of the* (physical and biological) *world*, and which is (recurrently) *oriented on itself*, on its own reproduction.

Cybernetic Model of the Psychical Individual (Subjective Self Endowed with Consciousness)

The conscious self can be identified with the psychical individual, as opposed to the above-discussed biological individual. I proposed a cybernetic model of the psychical individual in my recent book (Korzeniewski, 2010). I will present a brief description of the model first and expand it in more detail later on. In my opinion, the subjective psychic sphere is an emergent phenomenon, a derivative of the functioning of the neural network in the human brain. Integrative structures (inborn to a large extent) and associative structures of lower and higher order (all of which are acquired during ontogenesis) form *an image, a representation of the external world*. Formation of associative structures is supervised by the motivation system: instincts (e.g. self-preservation instinct, sexual instinct, the instinct of appetite satiation, cognitive instinct) plus the reward and punishment mechanism. The system creates and strengthens these associative structures that are correlated (in temporal or circumstantial terms) with satisfaction of instinctual needs and therefore stimulate the reward/punishment "center" in a positive way, while weakening and eliminating the structures that are associated with lack of satisfaction of instinctual needs and stimulate the mentioned (rather functional than structural) center in a negative way. As a result, the structure of the neural network is of *intentional* character. Neurons in the neural network signify by the functional context, by referring reciprocally to each other. The "sense" of a neuron is determined by other neurons (or else receptors or effectors) it is connected to and by

the manner of its connection to other neurons. Thus, the operative sense of particular neurons and their groups is of relative, relational character and it is determined according to the principle of *connotation*.

Let us take a closer look at this idea. The neural network responsible for the integration of sensory stimuli originated in receptors, for extracting more and more general features from the stimuli (e.g. lines and contours of various inclinations, colours, movement, complex shapes in the case of visual stimuli), and finally more complex "sensory images" is based on something I call integrative structures (Korzeniewski, 2010). Simpler among them (primary i.s.) are inborn (the basic organization and integration of stimuli, e.g. into spatial, temporal and causal relationships), while more complex among them (secondary i.s.) are acquired during ontogenesis (e.g. integrative structures related to identification of particular pathological changes in x-ray images). In turn, integrative structures serve as the base for the establishment of the so-called associative structures (of lower and higher order) that constitute a neural representation of objects, sets of objects, various dependencies appearing in the external world and relations between various actions and their effects (Korzeniewski, 2010). All of them are acquired and shaped on the basis of experience accumulated during ontogenesis. Associative structures may correspond to certain behavioral patterns (e.g. a choice of a plant or insect to eat, a decision to follow this hunting strategy and no other) or a certain category of objects and regularities that are present in the external world (e.g. recognition of particular objects, knowledge of the laws and dependencies, anticipation of future events). They also combine stimuli and sensory images from different senses (sight, hearing, smell, etc.) into one integral whole. Integrative structures process signals originating from receptors and extract certain features and aspects from the set of these signals. Complexity of extracted features/aspects grows at the successive stages of integration. Spatial and temporal coincidence of certain sets of features (a.s. of lower order), as well as identification of repetitive patterns in these sets by autonomous neurological processes in the brain (broadly understood "thinking") (a.s. of higher order) create associative structures corresponding to various objects, dependencies, rules and behaviors. The psychical correlate of the neural network is found in something I call a conceptual network (Korzeniewski, 2010). At the level of the conceptual network, concepts (primary and secondary) correspond to associative structures. For instance, as a result of accumulation of experience, there emerges the associative structure/concept of a "lion" (or a more vague idea of a "big terrestrial predator"), the directive demanding "do not eat plants with big round leaves with red dots and a certain smell, or else you will get poisoned", or an action plan stating that "it is easiest to hunt down an antelope in rain season by lurking in bushes covered with thick leafage". At the neural level, this process proceeds through the establishment and enhancement of neural connections (by lowering the sensitivity thresholds of synapses) between "routes" within the network of neurons in the brain that represent relevant features/aspects extracted from sets of receptor-generated signals and that are responsible for the generation of certain behaviors (or suppression of certain behaviors). Anyhow, it is of equal importance for the brain to remove and weaken (by raising the sensitivity threshold of synapses) of inappropriate connections that lead to incorrect identification of objects or to inadequate behavior (from the point of view of fitness). An associative structure constitutes a certain "circuit", a neural "object" in the brain, where nerve impulses can flow easily and are readily transmitted, which allows the entire functional structure to be activated by a relatively weak stimulation. For instance, spotting of small fragments of a cat running through high grass easily activates the entire associative structure/concept of a "cat". Establishment and removal of associative structures proceeds under the supervision of the system: instincts (drives), e.g. self-preservation instinct, the instinct of appetite satiation, sexual instinct, the instinct of avoiding illnesses and injuries, cognitive instinct, plus the reward and punishment system (Korzeniewski, 2010). If a given behavior leads to satisfying some instinctive need/drive, for instance to satiation of hunger, the associative structure at the base of such behavior will get strengthened/consolidated. The reward/punishment system (based, among others, on the neurotransmitter called dopamine) will send appropriate signals to appropriate neural circuits/associative structures. The same will happen if some blurred outline recognized as a leopard actually turns out to be a leopard. On the other hand, food poisoning after eating some insect with characteristic color pattern, a failure in a hunt after selecting a given hunting strategy for a recognized type of prey, or incorrect prey identification will result in weakening the associative structures at the base of these behaviors.

It must be stressed that there is no sharp distinction between integrative structures and associative structures, and between associative structures of lower and higher order.

The entire system of establishing/strengthening and removing/weakening of associative structures is obviously a set of negative feedbacks (more generally: regulatory cybernetic mechanisms) aimed at optimizing behavioral and cognitive processes. Here, the set "parameter value"—leading to maximizing of the chances of survival and reproductive success—consists in the recognition of objects and discovery of the rules of the external world that correspond to the actual state of things as much as possible, as well as establishment of a pattern of behaving and reacting to various aspects of the environment that are variable in time and space ("disturbances"). In this sense, the entire extremely complex set of behavioral and cognitive function in higher animals realized by the receptors-brain-effectors system is nothing more than a sub-system of an even more complex system of negative feedbacks (cybernetic mechanisms), which constitutes the regulatory aspect of the structure and functions of living individuals (discussed above). Nevertheless, the living individual and psychic living individual defined in cybernetic terms should be clearly separated, and negative feedbacks do not participate explicitly in creating the cybernetic model of the latter.

As mentioned before, I believe that the dynamic structure of neural connections in the human brain finds its psychic correlate in what I call a *conceptual network*. Concepts in this network, as nerve cells and their groups in the neural network, signify only by mutually referring to each other, i.e. by *connotation*. Ultimately, all concepts in a conceptual network condition ("define") all other concepts. Concepts constitute a more or less imperfect *representation* in the human brain of various objects, dependencies, aspects and laws *of the external world* (there also exist concepts that do not correspond to anything real or even sensible). The conceptual network constitutes the substance of our mind, everything we have direct access to. Such subjective objects/psychic processes as thoughts, impressions, emotions, dreams, hallucinations, recollections, ideas, etc.

—all of them are various types of excitation of the conceptual network.

In my theory, language is a system of a higher order, of a secondary character with respect to the conceptual network. Language names correspond to concepts that are best delineated and characterized by the highest "semantic intensity" (vague and underdetermined concepts remain nameless). The conceptual network constitutes a "significative lining" of language that allows its names and mutual connections to be understood. On the other hand, language together with its discrete names and grammatical rules facilitates greatly the use of the entire conceptual network. At the same time, however, language shapes and distorts the conceptual network to a significant extent.

Generally speaking, the feature the neural network and the conceptual network share due to their mutual interrelations consists in the fact that they represent the external world (including the organism's body) in the functional and cognitive sense and that they consist of elements that signify by connotation. The building substance, the evolutionary genesis and the resultant functional structure of the neural/conceptual network essentially shape and limit our cognitive abilities, as they condition and deform the image of the world formed in our brain/mind.

Let us return, however, to the core of the "psychic individual", i.e. to our "ego", our (self)consciousness[1]. In my opinion, not so much a degree, but a type of complexity and organization of the network of nerve cells of a conscious subject is crucial for the psychic level of reality to emerge from the neurophysiological functioning of the brain. I believe that it is the relation of self-orientation or self-application that constitutes this new quality, the specific mode of functional (operational) architecture of the neural network, which has led to the emergence of self-consciousness, and thus, of the psychic consciousness. As mentioned before, at the level of the conceptual network—which I consider as the mental equivalent (correlate) of the neural network in the brain—it involved the formation (within the network) of a subject capable of observing processes proceeding in this network, including himself, as well as the focusing of the cognitive apparatus—hitherto focused on receiving the world image shaped in the conceptual network—on itself, its own image within the network. This is the event that has led to the emergence of the third psychic level of reality (following the physical and biological levels), comprising the entire sphere of subjective sensations in our brain. It is this recurrence that develops ad infinitum, a kind of mutual reflection of two mirrors facing each other, that constitutes total dissimilarity of psychic phenomena (to the material world) and their uncommon character.

During evolution, the brain developed a certain (rather functional than strictly localized and structurally defined) cognitive and decision-making "center", a complex "neural circuit" which compares data received from receptors with the memory records, co-ordinates various functions of the central nervous system and makes decisions concerning the stimulation of effectors. The center confronts the signals from the environment with the already-existing conceptual network and the world view shaped within the network. At the same time, it uses appropriately integrated sensory data to develop and extend the network. At the level of the neural network, its operation consists in the activation, creation and modification of associative structures of the lower and the higher order. Fundamental role in its functioning is played by the autonomous activity of the brain cortex, i.e. thought processes. If it is arbitrarily separated as a relatively well isolated system, its inputs will comprise receptors and the parts of the neural network (the sensory cortex) which process the data provided by receptors, as well as the existing memory records. The emergence of the (self-)consciousness would consist in orienting a part of the inputs of the system on the system itself, i.e. in self-recognition of the processes occurring in the above-mentioned center. The processes would also "process" themselves, as they formerly processed the data obtained from receptors. Apart from the image of the external world, the center established within itself an image of itself as well. In other words, the center projects (maps) itself on itself and creates a model of itself within itself. It refers recurrently to itself. This is essentially a relation of self-application, analogous to a great extent to the relation found in the liar's paradox, Russell's antinomy and Gödel's proof[2]. The psychic correlate of this state of affairs consisted in the emergence of the concept of the "ego", the "self" within the conceptual network, which resulted in an apparent delamination of the entire network into the "subjective" sphere focused both on itself and on the image of the external world, and the "objective" sphere, which establishes the image of the external world. This self-orientation corresponds to subjective psychic sensations. In my theory, the psychic consciousness is closely linked to self-consciousness as the former is conditioned by the latter.

My idea of a recurrent, incessant projection of the cognitive center onto itself without end, isomorphic with the quoted logical paradoxes, is aimed at explaining the dramatic qualitative dissimilarity (to the external world), specific and exceptional, or even uncanny character of the subjective sphere of psychic phenomena, as well as of the essence of (self-)consciousness and the sense of *ego*. This is precisely the dissimilarity and specific character that call for explanation. Explanation of their genesis is what is precisely what I do not find in proposals presented by other authors, who also deal with the nature of the brain, psyche and consciousness, and with the relation of these phenomena to brain functioning (see e.g., Crick, 1995; Dennet, 1997; Damasio, 1999; Macphail, 1998; Cainrs-Smith, 1996; Greenfield, 1998; Penrose, 2002; Koch, 2004; Llinas, 2002 for example). I cannot discern the genesis of the categorical difference of (self-)consciousness in such explanations as the total size of the network of nerve cells, correlated in time firing of neurons at the frequency of 40 Hz (or other), fixed action patterns, quantum effects in microtubules, competition between brain activity patterns, conditioning of the presence of consciousness by the activity of the medulla oblongata, etc. I believe that the special character of the subjective mind calls for special explanations, and I find such special explanation in the logically paradoxical (recurrent in its essence)

[1]I believe that "psychic" consciousness—as opposed to "instrumental" consciousness, i.e. to purely "mechanical" representation of an object within a subject—cannot exist without self-consciousness. Such purely instrumental representation is present in the case of, for instance, picture recording by a video camera, sensing the presence of lactose in the environment by a bacterium (operon model) or forming a picture of a passing fly on the retina of a frog.

[2]The liar's paradox is expressed in the statement: "I always lie". In Russell's antinomy, one arrives at a contradiction by giving either the positive or the negative answer to the question: "Is the class of all classes that are not elements of themselves an element of itself?". The structure of Gödel's proof may be summarized in the following statement: "It is hereby proven that this entire sentence cannot be proven".

relation of self-application, of focusing of the "cognitive center" on itself.

Living (Biological) Individual vs. Psychical Individual

Now I would like to discuss parallels between the essence and genesis of life (the biological individual) and self-consciousness (the psychical individual) as defined in cybernetic terms. The analogy between the network of regulatory mechanisms at the base of the biological individual and the neural (and conceptual) network at the base of the psychical individual is rather strong. Firstly, as mentioned before, both networks constitute a certain *functionally purposeful* (*intentional*) *representation*, an operational mapping of various aspects *of the external* (*and internal*) *world*, important for the survival of an individual. It is worth pointing out that the neural/conceptual network is in fact (in formal and cybernetic terms) a part of the network of negative feedbacks, responsible for behavioral and cognitive functions. Secondly, the significance of particular elements of a network—negative feedbacks/cybernetic mechanisms in a living individual, on one hand, and neurons and associative structures/concepts in a psychic individual, on the other hand—is established by *connotation*, i.e. an element makes sense only with reference to other elements and ultimately in the context of the entire network. Finally, both networks are recurrently *focused on themselves* (the relation of *self-application*). The ultimate task of the network of negative feedbacks constituting the cybernetic identity of the living individual consists in survival and replication of itself in as many copies as possible. The neural network at the base of the psychic individual, in turn, is focused on itself in the cognitive sense. Thus, it constitutes both the subject and the object of its own cognition.

To put it briefly, although with a considerable degree of simplification, a living individual is a homeostatic replicator. Without a network of negative feedbacks, the self-replicating system would be simply a replicator of the type one can easily find in simple autocatalytic chemical systems. And that was probably how life came into being at the dawn of biological evolution. First there formed replicators (positive feedback), consisting probably (at least in my opinion) of hypercycles (Eigen, 1979) of proteins and nucleic acids, enclosed in objects similar to coacervates (simple vesicles that replicate spontaneously by growth and fission as a result of elementary physical processes). Only then, they were "dressed" in a network of negative feedbacks that supported their existence and proliferation and made it possible for their complexity to grow (in the process of evolution). In the case of evolutionary formation of (self)consciousness, the sequence of events was reversed. First, the neural/conceptual network was formed. Only then, the network got focused on itself (during the evolution of man and possibly of certain animals). So, I believe that this sequence of evolutionary events differentiates the processes of formation of life and consciousness. I do not claim, however, that both phenomena are identical in every respect. I only claim that life and (self) consciousness show considerable formal similarities.

To a certain extent, the analogy between living, purposeful systems and self-conscious systems, underlies the teleological fallacy, i.e. our tendency to attribute conscious purpose to any system that exhibits purposeful or goal-directed behavior.

In conclusion, according to my conception, a "higher" level of reality (biological or psychic) emerges from the "lower" level (physical or biological, respectively) by self-orientation of a network of elements (negative feedbacks or associative structures/concepts, respectively) signifying by connotation, which is an evolutionarily purposeful, intentional representation of certain aspects of the external (and internal, within body limits) world. In this formulation, the emergence of psychic consciousness (self-consciousness) from a network of neural connections in the brain devoid of consciousness would constitute, in a sense, a "repetition" at a higher level of the act of emergence of the phenomenon of life from inanimate matter.

Therefore, I do not believe that a separate being—in a philosophical sense, a vital force in the case of life, or a spirit in the case of the psyche—is necessary for the higher level of reality to emerge from the lower level. I am not a primitive reductionist, however, as I do not claim that everything that in fact exists is atoms and neurons, respectively. I am convinced that the crucial aspect is the degree and, above all, the type of (objectively existing) complexity, functional organization of these elements. In fact, only the SYSTEM counts.

Discussion

Obviously, the entire discussion and conclusions presented in this article depend on the presented cybernetic definition of a living (biological) individual and the cybernetic model of a psychical individual (self-conscious subject). A definition cannot be true or false, but only adequate, heuristically fruitful and useful, or not. Apart from the above-presented arguments, one can formulate the following additional arguments to show that the cybernetic definition of a living individual is useful and adequate:

1) It is formulated in terms of cybernetics and information theory. It shows clearly—and does so in terms understandable e.g. for physicists—what is the essence of life that cannot be reduced to (and expressed in terms of) the physical level of reality. If the phenomenon of life could not be distinguished and characterized in strictly formal terms, there would be no good justification for saying that life is something more than a complicated physicochemical system.

2) It is based on primary and fundamental properties that cannot be derived from any other, more primary/primitive properties. It involves only two primary notions: negative feedback and positive feedback. Other properties of a living individual—including the fact that it is a dissipative structure (or, more generally, a system significantly displaced from thermodynamic equilibrium); it evolves and it is characterized by structural and functional complexity, which can increase during evolution; it is capable of flexible adaptation; and it separates the (genetic) record of identity from the executive machinery—can be derived from this definition and from the properties of the real physical world (Korzeniewski, 2005). A definition that is based on properties that can be derived from other properties is not a definition, but a result of some logical operations. A true definition should be based on axioms that are irreducible to anything else. In my opinion, the cybernetic definition is as minimalistic as possible, while it is at the same time sufficient.

3) It clearly distinguishes a living individual from different systems that are not living individuals (Korzeniewski, 2005), namely: a) inanimate systems, b) psychological and social systems, c) biological systems that are not individuals (units of

evolution), like a cell, liver or ecosystem. The concept of a living individual is absolutely central for the phenomenon of life. One can, for instance, fertilize some distant planet with a single bacterium and thus give rise to a whole biosphere, but one cannot have life without at least one living individual.

4) It clearly determines the subject of evolution (unit of selection). Evolution is an inseparable property of real life. However, life as a whole certainly is not the subject of biological evolution. Therefore, a good definition of life should clearly determine what in fact constitutes this subject.

5) It offers a measure of the purposeful—i.e. valuable in the context of a living individual—biological information (as opposed to statistical, thermodynamic information that is meaningless in the biological sense) (Korzeniewski, 2001, 2005). The main functional difference between inanimate matter and living beings is that the latter are purposefully, intentionally directed at the realization of some task, namely survival and self-replication. This purposefulness must be related to some specific, biologically relevant information that is different from the thermodynamic information of purely physicochemical systems. Therefore, to define the essence of life, one has to define the essence of the biologically relevant information.

The cybernetic definition of a living individual, due to its minimalism, seems to be very economical. Yet, neither the process of origination of life on the Earth about 3.8 billion years ago, nor the current form of life can obviously be reduced exclusively to the cybernetic aspect. The genetic, structural, thermodynamic and energetic aspects are no less important. I am convinced, however, that all aspects emerge—automatically in a way—when the abstract cybernetic definition of a living individual is confronted with the external physical world (Korzeniewski, 2005).

As opposed to a definition, a model may be correct (when it corresponds to reality) or defective. Obviously, this also applies to the cybernetic model of a psychic individual. If it is to be possible to assess something as true or false, it must be testable (verifiable/falsifiable). It should therefore be stressed that my concept of the essence and genesis of (self-)consciousness meets all the conditions required to be met by a sound scientific hypothesis, namely it allows one to formulate predictions that can be experimentally tested. Here are some of them. Firstly, it follows from the conception that there are closed neural loops in the brain of an adult human being that lead from the dispersed "cognitive center" in the prefrontal cortex and back to this center. Secondly, a temporary blocking of these circuits due to an external intervention leads to temporary switching off of self-consciousness. Thirdly, such closed neural circuits are not found in the brains of infants. Fourthly, they are not present in the brains of the majority of animals considered to be devoid of consciousness. Fifthly, the transmission of signals in the closed loops ceases during sleep, at least during the deep sleep phase. Sixthly, lots of evidence indicate that there exists a minimum "atomic" moment of consciousness that lasts for about 0.5 second (compare, for instance, Liebet's experiment (Liebet et al., 1979)). It could coincide with the period of a single "cycle" of signals running in the postulated closed neural loops.

According to my conception, mind/psyche (together with the phenomena it consists of) is not a categorically different phenomenon (in the philosophical sense). It is an emergent property of brain functioning, of the dynamic architecture of neural connections, but it has no feedback-type influence on the brain. It cannot cause any actions in the external material world, for it is the brain (the neural network underlying the mind) that can. This general approach is referred to as connectionism or functionalism. It refers to the so-called soft problem of self-consciousness, i.e. the conditions to be met in the physical world for self-consciousness to come into being. On the other hand, the hard problem—i.e. the question of the essence of self-consciousness—is on principle irresolvable (just like the hard problem of the physical reality or anything else). My objective is to find out what sort of functional complexity of a network of neurons (or other analogical information-processing elements) leads to the emergence of the subjective sphere of mental phenomena. I find the solution in the recurrent relation of the focusing (orienting) of the cognitive center on itself.

For us, of course, it is a very important difference between life and psyche that we experience the latter from within, from the depths of our self-consciousness. In a sense, the subjective sphere of the mind can be identified with a (special kind of) objectively existing complexity that is seen "from inside". This does not subvert the fact that, from the "external" point of view, a psychic individual is to a large extent isomorphic with a biological individual.

Finally, one could ask, what life and self-consciousness emerged for. Or, in other words, what is the sense and purpose of biological and psychical evolution. The answer to these questions is simple: "for nothing". The mentioned processes have no purpose or sense. They simply occur in material circumstances, where certain above-formulated conditions are met. Similarly, bodies that have mass fall in gravitational field and crystals grow in a saturated solution of salt. I am referring here, strictly speaking, to the "external" point of view. As I argued above, both biological systems and systems endowed with psyche have a certain type of "internal" purposefulness (intentionality), originating from specific cybernetic mechanisms they are equipped with. It is not for nothing that negative feedbacks are called purpose-oriented mechanisms, aimed at the realization of a specific task (in the case of living individuals, the ultimate task consists in survival and reproduction). Similarly, neurophysiological mechanisms at the base of self consciousness may play a role in the functioning of language or social relations. The focusing of the cognitive center—the "see" of the processes of thinking and planning—on itself would lead to the emergence of a clear-cut "ego" and, as a consequence, to a clear-cut distinction between "me" and "him" ("them"). Undoubtedly, we have a subjective, psychic sense of purposefulness and intentionality of our mind. This, however, does not change the fact that the phenomena of life and self-consciousness—when viewed from the outside—are equally "senseless" as purely physical processes. At best, we can speak of an "internal function" of networks of negative feedbacks and neural networks, the operation of which allows these phenomena to emerge.

What are heuristic benefits of the found analogies between the biological individual and psychical individual as defined in cybernetic terms? First of all, at least for me, they are very interesting in themselves. It is exciting and perhaps surprising to see that the most general functional architectures of apparently so different and so important phenomena as life and self-consciousness are based on essentially the same relations. Next, the extracted formal similarities between life and self-consciousness cause that understanding the essence of one of these phenomena helps much to understand the essence of the other. At the same time, these similarities suggest that in both cases a

"higher" level of reality emerges from the "lower" level in a strictly analogous way. They can also suggest that the definition of a living individual and the model of a psychical individual are examples of something that can be regarded as a universal formal definition/model of an individual formulated in cybernetic terms. Such a universal definition/model could help to decide whether various possible systems constructed in the future by humans or found on some distant planets in the Universe are alive and/or self-conscious or not.

Of course, the common traits of the biological individual and psychical cybernetic individual result partly from the fact that the latter constitutes, in a sense, a part of the former. The neural network underlying our subjective psyche is, whatever else it could be, a fragment of the network of negative feedbacks (regulatory mechanisms/signal transducing pathways) forming the cybernetic base of the living individual. It participates e.g., in negative feedbacks involved in cognitive, behavioral and motor functions. Therefore, it is not surprising that the neural network "inherits" numerous properties of the regulatory network. No doubt, a prominent one is intentionality, first directed exclusively on survival and reproduction. However, once the psychical intentionality originated, it gradually become oriented on other than only biological goals, namely on self-realization, self-manifestation. The "civilization buffer" weakens significantly the pressure of natural selection. No wonder therefore that in conscious subjects, especially those living in developed societies, the axes fitness-lack of fitness and pleasure-displeasure diverge to a large extent (Korzeniewski, 2010). The deviation from purely biological motivations can adopt the form of overeating leading to obesity, sex not leading to reproduction or alcohol or narcotics addiction on the one hand, and of science, art, religion, philosophy and ethics on the other hand. Therefore, the repetition on a higher level, during origination of the psychic individual, of the same process (forming a self-oriented intentional network of elements meaning by connotation containing a representation of the world) that took place during origination of the biological individual on a lower level can explain why the goals of the former can be, at least to some extent, different than the goals of the latter.

It is likely that the reason of the origin and the primeval function of the psychical individual were to support the biological individual. This means that at the beginning mind and self-consciousness were directed exclusively on survival and reproductive success of their biological "carrier". However, the question arises what was the rationale of the emergence of self-consciousness, i.e. why a self-conscious brain was more effective in realizing this task than a brain devoid of self-consciousness. Perhaps the higher-level psychical intentionality enhanced the biological intentionality delivering an additional 'drive' or 'force' that supported and 'channeled' social interactions, cognitive activities, development of language, sexual relations and so on. However, as mentioned above, after some time this drive gained some autonomy that expressed itself in origin of culture, art, systems of beliefs and so on. The psychical individual ceased to be only (or predominantly) a servant of the biological individual, developed its own purposes and became to a large extent independent. Finally, it started to consider its own origin and nature.

The cybernetic definition/model of an individual can be applied to artificial and virtual life in order to decide if a considered object/system is a living individual (in cybernetic terms) or not. In particular, this definition/model was used to determine how (hypothetical) artificial living individuals based on metals, plastic, glass, silicon and so on, whose most basic structural and functional units appear at the supra-molecular level, would look like (Korzeniewski, 2011). It was shown that such artificial "supra-molecular" living individuals existing self-dependently in the environment of some distant planet would have to have the form of dispersed individuals, composed of several separate "sub-individuals" that would be integrated functionally but not structurally. These sub-individuals would be analogous to such "modules" of human technical civilization as machines, robots, steelworks, chemical plants, electronic factories, power stations, mines etc. Such dispersed individuals would resemble colonies of social insects and moles, which are also composed of separate sub-individuals (particular insects and moles) carrying out different specialized functions.

One could also speculate whether it is possible to repeat the formal process leading to emergence of the biological and psychological cybernetic individuals for the third time, on a yet higher level. What kind of level could come into consideration? Of course the first one that could come to our minds is the social level. In the material sense a society (or a state created by it, understood as organization of people and not in geographical terms) is a system of particular humans, but in the formal, cybernetic sense it is rather a system of interacting self-conscious minds of those humans. Does this system fulfill the definition/model of the cybernetic individual presented here? Let us look closer at it. The social roles, functions of society members are certainly determined in relation to other members. Workers in a factory produce goods for other people, teachers transfer knowledge to (children of) other people, physicians cure other people, engineers design and construct different devices for other people, and so on, and so forth. All society members condition the existence of all other members and, on the other hand, rely on the activity of other members. The sense of a given society member is determined by its relation to other society members. Therefore, we can undoubtedly say that society members and relations between them form a functional network, in which all members and relations mean by *connotation*. Certainly, the structure of the society constitutes to some extend a *representation of the external world*, including the biological and psychological nature of particular members. Farmers must know and apply the relevant physical and biological laws in order to gain high harvest, engineers—to construct devices, buildings and so on, physicians—to cure people. It is also not difficult to demonstrate that the network of social interactions represents some aspects of the external world. A special organization of people (taking into account their biological and psychological properties) is necessary to build a house or factory, to perform science that serves medicine and technology, to produce and deliver artificial fertilizers. (By the way, cybernetic relations between society members include among others negative feedbacks, for instance in economy, in the demand-supply balance.) Therefore, the society, the network of social relations underlying it constitutes an operational, functional representation of the real (physical, biological, psychological) world. In a sense, this statement is obvious or even trivial—to exist and function in the reality a society must take into account its features, cannot be autistically isolated from it. A society/state is also *intentionally oriented on itself*, its own survival, functioning and expansion. All above-mentioned cybernetic mechanisms based on co-conditioning serve this purpose. Additionally, police helps to keep internal homeostasis. Army

defends the system against external threats and can serve expansion of the society. Economical homeostasis, development and expansion play in a sense a similar role. A society/state cares about itself using various cybernetic mechanisms, purposefully tends to maintain its integrity and possibly to expand. On the other hand, while the biological and psychical individuals are "closed" systems, a society does not have well defined boundaries, is in a sense "fuzzy". For instance, its members can directly interact with the members of other societies and particular societies can even exchange members. Of course, this does not take place in the case of negative feedbacks or (sub-networks of) neurons belonging to different biological and psychical individuals, respectively (as a matter of fact, psychical individuals can exchange concept/ideas, although in an approximate and imperfect way; however, this occurs through linguistic communication and not through a direct exchange of neural sub-networks underlying them). Furthermore, while the elements of the biological individual and psychical individual (negative feedbacks and neurons/concepts, respectively) have generally fixed position and relations with other elements, the roles and social relations of society members can change quickly and significantly. Finally, the superior goal of the whole society (integrity, homeostasis, development and possible expansion) frequently contradicts the individual goals of its elements (particular people). Again, this does not take place within biological and psychical individuals, where negative feedbacks and (sub-networks of) neurons are subordinated to the whole entity—the individual (although one could argue that different contradictory psychical motivations within one mind are counter-examples for this rule). As we see, a society (or state) fulfills quite well, although not perfectly, the cybernetic definition/model of an individual, first applied to life and self-consciousness. This definition/model can be used to estimate the degree of "individualness" of a given system. The above analysis emphasizes heuristic fruitfulness of formal similarities between the biological individual and psychical individual that allow to formulate a universal model of a cybernetic individual.

The social quasi-individual (society/state) has its own intentionality (directed on maintaining integrity and homeostasis, development and expansion of itself) that frequently contradicts the intentionalities of particular psychical individuals it is composed of—humans (human psyches). Numerous human motivations and behaviors are egoistic and not altruistic, and the society must use different regulations and mechanisms to suppress/control them (e.g., law, justice, police). (This process is analogous to some extent to the suppression of uncontrolled proliferation of cells within a multi-cellular biological individual in order to avoid cancer; compare Korzeniewski, 2001, 2005) The discussed conflict of intentionalities resembles quite closely the conflict between the (intentionalities of the) psychological individual and biological individual—the above mentioned divergence of the pleasure-displeasure and fitness-lack of fitness axes. It should be clearly stated that these conflicts result directly from the fact of the existence of (cybernetic) (quasi-)individuals on different levels of hierarchy of system organization (biological, psychical, social).

A similar reasoning as for societies/states can be applied to industrial or other companies. I will not analyze them in detail, because their formal structure is quite similar to the structure of entire societies/states. Certainly, their elements (employees and their roles) mean by connotation, the network of their relations constitutes a representation of both the external (material goods, competition, customers' preferences) and internal (employees' skills, ambitions) world, and the whole company is intentionally directed on its own maintenance, development and expansion. Therefore, to some extent, they should also be counted among cybernetic individuals, although they meet similar limitations as societies/states. To be sure, both societies/states and companies resemble rather biological than psychical individuals, although they are significantly different from both (for instance, the expansion of a company consists in a quantitative growth of the company rather than in its reproduction, that is production of new companies with similar identities).

Another, much more speculative possibility of a cybernetic "super-individual" is a group of directly connected (by wires, laser impulses and so on) "artificial brains", having their own subjective minds, but forming intentionality and self-consciousness on a higher level. Another speculation concerns a network of computers resembling Internet. Also in this case the formal model/definition could help to decide if it is possible to create within/from it a sort of a cybernetic individual.

Generally, the formal cybernetic definition/model of an individual can be applied not only to the biological individual and psychical individual, but also to many various systems of different nature. In this sense, this model/definition is universal. We cannot be sure what kinds of object/systems can be found in the Universe or artificially created in the future by humans. The formal definition/model can help to decide whether we deal with a cybernetic individual in a given particular case or not.

Conclusion

If we accept the cybernetic definition of a living individual and the cybernetic model of the psychical individual, we conclude that there exist significant formal similarities between the essence of life and self-consciousness. Namely, an individual (biological or psychical) is constituted by: 1) a network of elements (negative feedbacks/regulatory mechanisms or neurons/concepts, respectively) signifying by connotation; 2) that is intentional (in the operational sense); 3) that constitutes a functional representation of (some aspects of) the world; 4) and that is recurrently directed on itself (its own reproduction or cognition, respectively). Thus, the biological level of reality emerges from the physical level in a way analogous to that in which the psychical level emerges from the biological level. A certain specific type of objectively existing functional complexity of the *system* is crucial for the emergence of life and self-consciousness. It is postulated that the cybernetic definition/model of an individual applied to the biological individual and psychical individual is a universal one and can be used to decide if societies/states, companies and different objects/systems existing in the Universe or constructed in the future by humans are individuals or not, and to what extent.

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