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Time in Physics and the Human Mind: A System-Theoretical Approach

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ABSTRACT

The authors elaborate on the subject of time perception raised by R. Gruber, R. Block and C. Montemayor. Time is probably the most enigmatic and multi-faceted notion, both in physics and psychology. It does not have one, clear or concise definition. Formulating such a definition seems to be hardly probable, for each definition may include only a few selected aspects of a definiendum. In this paper, the authors present physical and psychological perspectives of time. The former includes the mathematically describable concepts of time proposed by I. Newton and A. Einstein. The latter introduces a systemic outlook on motor operation construction in humans. Its 'backbone' is the modalities' ladder, derived from N. Bernstein's theory and the fact that movement is the only manifestation of all human mental activity. Each of the particular modalities of information processing – proprioceptive, contactceptive, teleceptive, verbal and symbolic – includes its specific, respective perception of time. The authors also discuss the concept of the IGUS system created by J. Hartle, the aim of which is bridging the gap between physics and psychology. However, in the presented paper an attempt is made to invent a general view on the structure of time perception in psychology and anthropokinetics, on the basis of System-Theoretical Approach (STA).

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Introduction

Ronald Gruber, Richard Block and Carlos Montemayor described physical and psychological aspects of time [1]. In this paper, an attempt is made to present these issues in a different, system-theoretical approach (STA).

Time is, no doubt, one of the most enigmatic and mysterious phenomena in our world. Since antiquity, it has intrigued poets, philosophers and scientists. For Aristotle, it was merely an 'envelope' for events for Isaac Newton – a stiff 'frame' for occurrences, which absolutely have to adjust to it and for Albert Einstein – a plastic setting for things, phenomena and processes, which have to deform along with it [2- 4].

Already in 1905, Albert Einstein said to his friend Michele Besso: "Time cannot be absolutely defined, and there is an inseparable relation between time and signal velocity". Even until now, scientists were not able to formulate a short, concise and complete definition of time. We do not even know what, namely, may be termed as the very essence of time. However, one may discern two main functions of time. The first is a measure of sheer duration. The other has been wittily described by Albert Einstein with the words: "The only reason there is time is so that everything doesn't happen at once". Accordingly, time brings order to a sequence of events. Paradoxically enough, it was Einstein that had extremely complicated the idea of what he termed "at once" [5].

Time in Physics

Albert Einstein stated: "What we call physics comprises that group of natural sciences which base their concepts on measurements; and whose concepts and propositions lend themselves to mathematical formulation" [6]. Therefore, it is the measurability and mathematisability that make up the fundamental aspects of physics.

In the 17th century, Isaac Barrow – Isaac Newton's mentor – stated: "Time implies motion to be measurable; without motion we could not perceive the passage of Time" [7]. However, Newton remarked that "'True' time is not directly accessible – only indirectly, through calculation" [2]. In this context, the following statement by Roger Penrose sounds highly illustrative:

There are two other words I do not understand – awareness and intelligence. Well, why am I talking about things when I do not know what they mean? It is probably because I am a mathematician and mathematicians do not mind so much about that sort of thing. They do not need precise definitions of the things they are talking about, provided they can say something about the connections between them [8].

Accordingly, it seems justified to search for time (t) essence in its relations with other physical quantities: space (distance, d); and movement (velocity, v). One might state that:

- Time and movement define space: $d = t * v$;
- Time and distance define movement: $v = d/t$;
- Movement and distance define time: $t = d/v$.

These relations actually do not unveil the very 'soul' of time; however, they show its functioning in relation to space and movement. Following this line of reasoning, detaching the respective concepts from sensory experiences and introducing them into purely mathematical sphere of reasoning resulted in the creation of specific theory of relativity and famous statement by Hermann Minkowski, who 'dressed' the Einstein's theory in a 'mathematical robe": "Henceforth space by itself, and time by itself, are doomed to fade away into mere shadows, and only a kind of union of the two will preserve an independent reality" [9].

However, it seems that, even at a contemporary level of science development, scientists are not able to precisely describe the 'very soul' of time. Arturo Hotz's following statement seems to sound very instructive:

Time is a human invention. It has been developed because of the need for orientation in events. Nature itself only produces various rhythms: the sun and moon periodically rises and sets, the heart beats – all these phenomena enable us to recognise and experience the flow of time [10].

Accordingly, the physical standard of the notion of second bases on a peculiar number of oscillations – a specific rhythm – of the caesium atom in the time period termed 'second'.

Physical bodies do not dispose of an intrinsic purposefulness; physics has no teleological 'face' [11]. They passively obey the laws of physics, extrinsic to them. The physical phenomena consist of simple relation stimulus-reactions, without any intermediate elements between them. Therefore, the basic and effective language of physics is 'relation-oriented' mathematics. However, what results from Penrose's declaration, is not an unveiling of the essence regarding items under consideration. In physics, such an essence does not influence the behaviour of physical bodies, hence, it may be 'transparent' to the language of description. This is why mathematics is an eligible language for physics. Nevertheless, Israel Gelfand remarked:

Eugene Wigner wrote a famous essay on the unreasonable effectiveness of mathematics in natural sciences. He meant physics, of course. There is only one thing that is more unreasonable than the unreasonable effectiveness of mathematics in physics, and this is the unreasonable ineffectiveness of mathematics in biology [12].

Mark Latash (educated physicist) termed this the 'Wigner-Gelfand principle' [13]. Along with Mindy Levin, John Scholz and Gregor Schöner wrote:

Progress in motor control over recent years has been slowed down by the lack of a broadly accepted and exactly defined set of notions that would be specific to typical problems of motor control, an adequate language for this area of research [14].

Accordingly, mathematics is obviously not an adequate language for biology, psychology and motor control (anthropokinetics).

Time in Biology, Psychology and Anthropokinetics

No matter, at what level of abstractness at which any idea is created, its only manifestation is a specific movement. The ingenious achievement of Albert Einstein would never function in science if he had not performed the following movements: grabbing a sheet of paper, taking out a fountain pen from his breast pocket and writing something down, with specific movements: $E = mc^2$. Any movement is inseparably associated with time, thus, its mental representation – in planning, realisation and memorisation – has to be processed in the mind along with spatial aspects of a movement.

Incidentally: paraphrasing Immanuel Kant, one might state that because of the inseparable connection between movement and the mind in humans, 'anthropokinetics without psychology would be irrational; but psychology without anthropokinetics would be blind.'

Mathematics efficiently deals with items having no specific 'identities'. Consequently, it cannot contribute to the analysis of such identities; they are invisible to mathematical analyses. However, the fundamental difference between physical body and living structure (and, all the more, organism) is that the latter disposes of intrinsic purposefulness, which results from its identity.

Physics strives to possibly build objective and mathematically describable patterns of thinking about the nature. Nonetheless, the biological and psychological occurrences are, to a great extent, driven by subjective processes, unique to a given structure and circumstances, which build peculiar, elusive purposefulness. Even a cellular membrane somehow 'knows', what substance – at the moment – it may let into the cell, and what has to be pumped out, sometimes against the gradient of concentration or electrical potential. Probably this is why Mark Latash termed it "one of the greatest achievements of evolution" [15]. Consequently, the behaviour of living organisms is extensively shaped by mechanisms, which do not lend themselves to mathematical description. Here, a scientist has to deal with not a simple stimulus-reaction pattern, but with the stimulus-information processing-motor response. No longer a sheer reaction!

In information processing in living organisms, a very important element is time. Arturo Hotz remarked:

To learn, how to move properly in the environment, and finally, to be able to give the reason, form and shape to sheer getting around – merely enabling mastering a situation – there are necessary, subjectively, the knowledge and patience, and objectively – time, measurable and liable to be experienced. Movement needs and moulds space. Inner space, i.e. freedom from and to something, and outer space that poses a challenge. Independently treating movement, spontaneous or forced, might be expressed in terms of play between time and space. While looking at movements' playing spaces from the outside – they become observable; from the inside – they become a shapable reality, liable to being experienced thanks to its realisation. Describing the observable behaviour and following the experienced shaping, possibly to explain and to understand it, comprise an important goal for human psychology [10].

It seems that it would be very difficult to formulate equally apt and concise characteristics concerning the physical and psychological perception of space and time.

Facing the ineligibility of mathematics, in anthropokinetics – it is necessary to search for another 'adequate language'. One promising mental methodology seems to be STA. This method of reasoning may be traced – for example – to the works by William Carpenter, John Hughlins Jackson, Henri Ey, Jan Mazurkiewicz, Stanisław Gerstmann, Paul MacLean or Jürgen Konczak [16-22]. Antonio Damasio also argued:

Of necessity, conscious states of mind handle knowledge based on different sensory material – bodily, visual, auditory, and so forth – and manifest varied qualitative properties for the different sensory streams. Conscious states of mind are felt [23].

One of the inseparable elements regarding such a 'sensory stream' is, no doubt, the perception of time, specific to a given 'sensory material.' Moreover, in humans, these 'different sensory streams' make up a single, coherent system. Nikolai Bernstein termed the combined information chunks from different streams the 'sensory syntheses'.

Bernstein – who was strongly inspired by the works of Hughlings Jackson – invented the possible most advanced and holistic systemic theory on human motor behaviour. As a neurophysiologist, he followed in the footsteps of evolution and analysed the development of sense organs, central nervous system and motor control abilities in the course of evolution [24-26]. It was not until 2021 that his masterpiece, "On the Construction of Movements", was translated in full into English [27]. In a comment to this book, John Rothwell wrote:

Like me, I expect that many people's understandings of Bernstein's ideas about motor control is limited to the notions of synergies and levels of movement construction. But this classic volume demonstrates that Bernstein's interests ranged far wider than that [28].

The words by Rothwell are probably an 'overstatement'. The concept of freedom degree reduction was, indeed, popular among the English-speaking scientific community, but the same cannot be said about Bernstein's five-level movement construction system. Mihai Nadin argued:

Recognition is good, but influence, in the sense of affecting the progress of science, is better. On this account, NAB's (Nikolai Alexandrovich Bernstein's – WP, RS, MS) impact is rather under- and not over-, whelming [29].

Nevertheless, Gerrit Jan van Ingen Schenau and Arthur van Soest claimed:

It has often been stated that the ideas of Bernstein, relevant to many disciplines that constitute the human movement sciences, placed him ahead of his time by 20-50 years [30].

Unfortunately, Bernstein spoke eight languages, but he wrote mainly in Russian. Therefore, his achievements became fully accessible to English-speaking scientists only in 1996, when "On Dexterity and Its Development" was published, and in 2021, when the English version of his masterpiece, "On the Construction of Movements", appeared. Both text have been translated by Mark Latash, who uniquely joins the knowledge of Russian, English, neurophysiology and motor control.

Bernstein followed the development of the central nervous system within the context of motor abilities. The particular, more and more advanced levels of the system, developed as a response to growing requirements of the environment. The whole structure was termed 'the brain skyscraper' by Bernstein [25, 26]. Its simplified version, 'the modalities' ladder', is used to emphasise functional aspects concerning particular levels of the 'brain skyscraper', leaving evolutionary and neurophysiological aspects aside [31, 32]. Both models, 'the brain skyscraper' and 'the modalities' ladder', have been discussed in [33].

Symptomatically enough, Tatyana Glezerman and Victoria Balkoski wrote: "In Bernstein's terms, each function level operates in the frame of its own 'synthetic space' and 'synthetic time'" [34].

The mental processing of elusive time is very 'expensive' in terms of mental effort. However, in many motor operations, there is no need to process it in its full intellectual richness. The lower the rung of the modalities' ladder, the simpler the depiction and processing of time representation (shape of time axis). Therefore, let us analyse time perception and processing at particular rungs of the modalities' ladder.

The A-rung activity (in humans – reflexes) is based on proprioceptive stimuli. The neural structure and muscles do not need to 'know' the past, while the neurophysiologist hits the knee of a patient with a hammer. The action – knee reflex, the A-rung movement – is 'anchored' in the present and directed towards the near future. Hence, it does not need to 'tow' any image of the past into the future. As a consequence, its intellectual processing is very 'inexpensive' in mental terms. It works so fast, that – while observed from the outside – it vividly resembles a physical reaction.

The B-level operations (in humans – automatisms) are stimulated by haptic stimuli and do not require visual control. In this context, the following words by Charles Darwin sound highly instructive:

If worms are able to judge, either before drawing or after having drawn an object close to the mouths of their burrows, how best to drag it in, they must acquire some notion of its general shape. This they probably acquire by touching it in many places with the anterior extremity of their bodies, which serves as a tactile organ [35].

The worms are B-rung, 'haptic', organisms. Consequently, to perform such an action, they have to dispose of some feeling of the close past – present – near future, despite the fact that they do not own visual sensory organs. Nevertheless, such time perception is quite 'cheap' in terms of mental effort, hence the B-rung motor operations – automatisms – are nearly as quick as A-rung reflexes in humans.

Formation of C-level (and its equivalent on the modalities' ladder, the C-rung) made a real breakdown in the process of extending cognitive and motor abilities in living creatures. At that level, the main sense organ in humans is sight. It enables observation of movement and assessment of its velocity. Together, they enable both the perception and evaluation of the passage of time in psychological terms. Accordingly, at that level, the time perception gains a peculiar scale, subjective and specific to a given individual and situation. In a sense, the subjective psychological assessability is equivalent to the objective physical measurability. As a result, the mental processing of time representation at the C-rung becomes quite 'expensive' and motor operations carried out at that rung – motor habits – are much slower than reflexes and automatisms, but can usually be processed 'in real time,' i.e., at the pace of events in reality. For example, driving a car, which requires rather complex spatial-temporal assessments, can only be performed using the visual information processing modality.

Another milestone was the creation of the D-level (and D-rung). The verbal information processing contributed to extending the time axis far into the past and future, beyond the limits of direct sensory experiences. The A-rung may be associated with the proprioceptive; the B-rung – with haptic; and the C-rung – with remote (in humans mainly visual) information processing. Living creatures have no other sensory organs. However, it is only the verbal modality that enables the creation of motor operation patterns – the motor programmes – reaching far into future, beyond the temporal limits of direct sensory feelings (qualia). This is probably why Jack Cohen and Ian Stewart stated that "language is a kind of sense – it, too, involves processing incoming data and extracting meaning – and it is the most self-referential of our sense organs" [36].

Intellectual processing concerning the D-rung representation of time is very 'expensive' in mental terms. Therefore, it is rather sluggish and usually far slower than the course of events in reality.

The E-rung (symbolic modality) may be perceived as a product of inevitable development of the D-rung verbal modality by going beyond the D-rung's 'stiff' geometrical constraints and endowing space and time images with specific ('topological') plasticity. Intellectual processing at that rung is extremely 'expensive' and slow. To invent the special theory of relativity, Einstein needed five or six weeks [5], but to work out the general theory of relativity – about eight years [37]. Evidently, mental processes of such duration cannot control any real motor activity.

The conceptual arrangement of simple and more and more complex time representations at different rungs of the modalities' ladder is shown in Table 1.

The time perception characteristics presented in Table 1 unveil the specific and very important abilities regarding a system of human motor operation construction. The crucial rule invented by Bernstein is the principle of lower level development as the consequence of a higher one's formation. Accordingly, the motor operation pattern worked out at a higher level may be performed at a lower one. Hence, its realisation may be as effective as if it were performed at a higher rung and, at the same time, as swift and 'cheap' in mental terms as that 'belonging' to a lower rung. For example, while pushing the brake pedal (A-rung), a driver does not need to analyse the temporal aspects of such a motor operation within the context of the whole trip (D-rung). Nevertheless, a creature disposing of A-rung, but not of D-rung, is not able to execute this simple activity effectively in the context of a car-driver-way relation.

Table 1: The conceptual arrangement of time function, representation and perception at various rungs of the modalities' ladder; a systemic structure of time perception in a human

Rung	Ordering function of time	Shape of time axis	Method of ordering motor operations
A	Now – not now; motor impulse – muscle contraction	Very short period, present-future, without a scale	'Feeling-in-hand' reflex
B	This muscle now – that muscle later, synergy	Short period, past-present-future, with some feeling, but without a scale	Technique; automatism
C	Coordination of movements in time; net of synergies, agility, dexterity	Quite short period past-present-future, with a scale (timing)	Tactics; habit
D	Movement representation on stiff (geometrical), four-dimensional space-time continuum, motor cleverness	Full axis of time with a stiff, 'geometrical' scale, truly representing temporal reality	Strategy: performance
E	Movement representation on 'rubber' (topological), four-dimensional space-time continuum, motor inventiveness and fantasy	Full axis of time with a 'rubber', 'topological' scale, enabling any temporal transformations	Politics: no specific motor operation: dreams, far-reaching plans

In this example, we come across another issue. From Aristotle, we know that "nature does nothing uselessly". The best sprinter may run for a very short moment at a speed of about 45 km/h [38]. Consequently, the human movements' construction system is not adjusted to higher velocities. However, while traveling by car, a driver moves far more quickly. To deal efficiently with such a speed, a human has two mechanisms to his/her disposal:
- Anticipation (D-rung);
- Executing the high-level operation with low-level swiftness (C-rung and lower ones).

Paradoxically, the D-rung anticipation, although resulting from slow information processing, enables the execution of necessary motor operations in practice far more efficiently than simply instantaneous reflexes, because it may be initiated before a 'trigger-stimulus' is being received.

Hence, the system shown in Table 1 makes up a specific 'gearshift box' enabling the choice of the cheapest, yet effective, information processing procedure for a given motor operation in a given situation. This may be perceived as a display of the very general rule of parsimony in nature.

IGUS Model

Ronald Gruber, Richard Block and Carlos Montemayor presented the physical IGUS model (Information Gathering and Utilisation System) as a tool aimed at solving psychological issues [1]. They wrote:

Hartle's IGUS view is widely accepted, amongst physicists at least, to bridge the gap between physics and psychology for issues relating to past/present/future and the 'now'. Hartle provides a means to reconcile the physical 'now' with the experiential 'now' [1].

This model has been invented by James Hartle, but it concerns information processing in robots and not in humans [39]. Therefore, it may be aimed at bridging the gap between psychology and technology, and not between psychology and physics. Physical bodies passively obey physical laws extrinsic to them, thus, they do not gather, or – all the more – utilise any information. Their behaviour is not purposeful; physics is not teleological [11]. The physical bodies do not dispose of intrinsic purposefulness, which makes up the main attribute of even simplest living structures and organisms.

To realise a purposeful behaviour, it is necessary to gather, select and utilise specific information, i.e., to apply a specific intelligence. Thus, some sort of it is necessary for any living structure [40]. It seems that in contemporary technology, it is solely intelligence (and, may be, to some extent – instinct) that may be somehow emulated as artificial intelligence – AI [41, 42]. In general, however, in the contemporary state of science, technical models seem to be hardly qualified for psychology, because intelligence is only one element of the intellect, moreover, the simplest.

In STA, two other, much more complex components, are intuition and instinct. It is not for nothing that Albert Einstein noted that a "really valuable factor is intuition".

As a product of the human mind, a representation of reality – and time as well – may differ depending on its original intellectual source ('sensory material', as called by Damasio). Therefore, it is differently perceived in physics and psychology (as well as anthropokinetics). Physics resides in the Kingdom of Objectivity and strives to create a strict as possible description of phenomena and processes. Its natural language is mathematics. It deals with physical bodies, which passively obey the laws extrinsic to them. In other words, they do not actively shape (or co-shape) its behaviour. Their behaviour can therefore be quite easily described and accurately predicted by means of mathematical formalism – although in the sphere of special and general relativity such formalism must inevitably be very complex.

On the other hand, psychology lives in the Empire of Subjectivity. The events in this field of science are unique, enigmatic and elusive. Hence, there is no experimental repeatability similar to that in physics. As a result, the design and interpretation of psychological experimental research are, intellectually, extremely challenging. The psychological observations may be mathematically ordered, indeed, but mathematics cannot, 'by itself' contribute to unveiling the deep essence of psychological phenomena and processes; they are invisible to it.

To sum up, it seems hardly probable that psychologists will find solutions to their specific problems while using physical and mathematical tools. Therefore, while facing the charging grizzly bear in Alaska, it is better to be accompanied by an experienced trapper with a rifle, and not by ingenious Albert Einstein with his curved time-space continuum.

Conclusion

Let us conclude this paper with the following quotation from Albert Einstein.

On the other hand, it must be conceded that a theory has an important advantage if its basic concepts and fundamental hypotheses are 'close to experience', and greater confidence in such a theory is certainly justified. There is less danger of going completely astray, particularly since it takes so much less time and effort to disprove such theories by experience. Yet more and more, as the depth of our knowledge increases, we must give up this advantage in our quest for logical simplicity and uniformity in the foundations of physical theory. It has to be admitted that general relativity has gone further than previous physical theories in relinquishing 'closeness to experience' of fundamental concepts in order to attain logical simplicity [43].

The Reader may pose the question: 'If we contest the usefulness of mathematics in biology, psychology and anthropokinetics, then why do we conclude our paper with the reflections of an ingenious physicist?'. Because it is exactly this statement that is, no doubt, of philosophical rather than physical nature. Moreover, physics deals with much simpler matter than psychology (and anthropokinetics), hence, a certain very general rule may be more visible while seen with 'physical glasses', and not from biological or psychological perspectives.

To epitomise, the Einstein's reflection concerned evident, objective and mathematisable physics. Nevertheless, it may be a 'glimpse' into a much more general principle of nature. However, the matter of psychology (and anthropokinetics) is subjective – complex, unique, enigmatic and elusive – thus hardly mathematisable. Accordingly, it has to be far more abstract and inevitably, not so 'close to experience' as is physics. Its task is unveiling much more complex – and more deeply hidden – biological and psychological processes in the living organisms under research than directly observable physical phenomena. In this respect, a scientist has to follow the advice of Paul Gauguin: "I shut my eyes in order to see"; Albert Einstein termed such a technique of reasoning in science 'thought experiment'. It is more and more evident that biology, psychology and anthropokinetics need other research methods and other language for the description of phenomena and processes compared to those applied in physics or technology. Also, the mental representation of time, while seen from a psychological perspective, needs a different language of description than that used in physics.

Gruber, Block and Montemayor argued:

Thus, there are not two opposing times, one outside and one inside the cranium. There is just one fundamental physical time which the brain developed, now possesses and is itself sufficient for adaption but then enhances [1].

Unfortunately, even in physics there is no single, universal and irrefutable picture of time. Therefore, even if we assume that there is only one existing time that encompasses all phenomena and processes throughout the universe (and underlies causality – the absolutely fundamental basis of science), it is so multifaceted that its representations 'inside' and 'outside' the cranium must be different. However, from the system-theoretical perspective, there is little hope for any 'Grand Unified Theory' in this regard.

Author Contributions

WP, RS, MS and DS contributed to the conception and design of the study. WP organised the database and wrote the first draft of the manuscript. RS, MS and DS completed fragments and wrote corrections of the first version. All authors contributed to manuscript revision, reading, and approved the submitted version.

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