Memory as producer of subjective time and space in complex systems

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Abstract: A concept of memory as a key property of complex information / cybernetic systems has been introduced by the author (presentations and papers at: FIS 2003; INTAS research project 2003/4; Delphi04). Memory is understood as not solely a psychic phenomenon, but as a general phenomenon of reflection (as different forms of memory exist in complex material systems: e.g. DNA, neural networks, computer RAM/ROM, cultural memory etc.). This approach has allowed to reconsider phenomena of information and regulation as interaction between system and its subjective environment. Memory, thus, not only represents (or stores images of) the system's environment (a function of passive reflection), but also regulates and transforms the environment (a function of active reflection). Operational cycle of a complex information system can be envisaged as a dynamic sequence of interaction between system memory and a specific part of its environment represented in memory (or, subjective environment; similar notions include von Uexküll's Umwelt and Lifeworld by Agre and Horswill).

Accordingly, internal (or subjective) time (as well as subjective space) of a complex system is determined by the content of its memory, and is revealed in its operational cycle. They are produced by information processes occurring in a complex systems (similar concept has been proposed by Bergson as 'human time', and by Vernadsky as 'living matter time'). It is possible to distinguish between actual, potential and potentially achievable time and space of a complex system. Classification of seven different types of potential time (based on a character of system's dynamic attractor) can be yielded, to distinguish between time of automates, self-reproducing automates and living systems. A typology of time for living systems is produced, that synthesizes existing approaches (Aksyenov, Vernandky, Fraser).

As memory is not only an agent, but also a object of changes, subjective time and space of a complex system can be altered by changing its memory content (which can occur purposefully, as in social memory modifications, or randomly, as in genetic memory mutations). For evolving systems, subjective time and space is defined, but not restricted, by their memory, as long as their evolution is open-ended.

Keywords: memory; information as interaction; time and space in complex systems

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1. Universal properties of information phenomenon[1]

1.1. Approach to informational phenomena

The debates on nature of information and properties of informational phenomena continue ever since this concept has been intuitively proposed in the renowned work of C. Shannon [35]. Up till now they led to a statement that information is basically indefinable concept of semi-philosophical character (although some hundreds of definitions to the term have been suggested [9]).

However, although information is not directly reducible to the categories of classical physics, it is neither a radically different category of another nature than mass and energy [10]. Thus, information can, and should, obtain a definition that is placed within the frame of existing scientific paradigm. In order to grapple this, it has to be defined as a material phenomenon [49], that is realized in a matter or/and a field of some type, and is occurred primarily in complex systems. If such a position is accepted, a possibility for an objective theory of information emerges (possibilities to construct such a theory are discussed by S. Brier [7], W. Hofkirchner [17] and others).

In order to specify more clearly what information is, one has to describe a variety of informational systems considered by conventional information theory and cybernetics. The following classification, based on various sources (e.g. [32, 33]) can be suggested:

(1) artificial technical systems: robotic and computer devices, technical means of communication and communication networks with 'technical information';

(2) natural biological systems:

(2a) self-reproducing biological systems: living organisms of various complexity (ranging from viruses to higher animals) with genetic memory;

(2b) biological organisms with endocrine regulation and nervous system (central and peripheral);

(2c) animal populations (of herd, flock, pack or family organization): information is stored in neural nets of CNS and cerebrum of individual specimen, as well as in reproduced 'demonstration-observation' behavioral chains (or chains of 'social relays' [34])

(3) natural / artificial social systems (socio-economic, socio-cultural, and subsystems thereof):

(3a) systems containing genetically inherited social memory of individuals of the given species (arising through 'group selection' [36], most explicit in social insect behavior);

(3b) individual social experience - systems which form, store, use and reproduce individual experience gained through learning and interactions with social environment (this category could also include most kinds of psychological phenomena, emerging through social interactions, as suggested by L. Vygotsky [47]);

(3c) systems that accumulate, store and use socially acquired experience (phenomena of this category [languages, knowledge, beliefs, technologies, traditions and norms, cultural samples (e.g. objects of art) etc.] represent information that is distributed individually but which is meaningful only socially);

(3d) artificial technical systems of a society which contain and use technical information, as well as information of socio-economic and socio-cultural systems (i.e. category (1) considered as a society sub-system[2]).

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[1] Chapters 1-2 are largely based upon my earlier publication [27], which presents these views in more detailed and argued manner. Initially presented at FIS'03 meeting , also at INTAS 03 meeting, and Dephi'04 conference.

[2] Artificial technical systems have been included as a separate category solely to celebrate the contribution made by many famous students of such systems: C. Shannon, N. Wiener, A. Turing, A. Kolmogorov, J. von Neumann and

The enlisted types of objects and phenomena a greatly distinct in their physicochemical properties, as well as in their organization and functioning. Despite that, all of them also have some universal structure and certain processes that allow to specify these systems as informational. Accordingly, some *invariant* property of these systems should exist, due to which a silicon computer chip, a series of chemical reactions in DNA replication, an unconditional reflex in mammal behavior, and a process of higher education in universities can all be considered as similar systems with information.

1.2 The key invariant property: memory

It can be suggested that the property that is universal to all enlisted system types is that they all possess memory[3]. The first group (technical information systems) has artificially created mechanism that acts as a memory or quasi-memory of some kind. The second group (biological systems) has the genetically inherited memory and the individually acquired memory (usually localized in neural system). The third group (social systems), apart from genetic and individual memory, also has social memory [26, 39], localized in 'super-organisms' or in societies (and bearers of this type of memory are individual specimen or member of the society)[4].

Human beings, or observers (claimed to be 'systems with information' by second-order cybernetics and biosemeotics [6]), are but one kind of complex systems with memory. For an observation, existence of some kind of memory is obligatory (in order to store new observations, or compare them with previous ones, and with innate samples of perception). Yet, a system with memory must not necessarily be an observer – as in the case of technical devices and biochemical systems when no 'consciousness' or 'observer' exists. Therefore, we suggest that phenomena of second-order cybernetics are enclosed into the presented theory.

Correspondence between major types of information systems and types of memory is presented in Table 1.

Table 1: Correspondence between types of information systems and types of memory

No	*Type of systems*	*Types of memory*
1	technical	• permanent and operative memory devices (RAM/ ROM) and quasi-memory of technical devices[5]
2	biological	• innate genetic memory • system of endocrine control • neural system (central and peripheral)
3	social	• innate properties of organism • individually acquired memory • social memory in individual memories and technical devices

Intuitively, the following generalization could be proposed: there can be no complex system which is said to 'have information' or in which 'information processes occur', and which yet does not possess memory. The opposite statement also holds: there can be no complex system with memory in which information and information processes are not observed (since memory, at least, is a locus of information in the system). At the same time, it is clear that class of systems with memory includes other members than given above (e.g., a phenomenon of 'memory of the

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others.

[3] The statement that 'memory is a universal property of organized matter' has first been suggested in 1870 by the German physiologist and philosopher E. Haering.

[4] See also publications by V. Kolevatov [19] and K. Platonov [30]. Similar concept is considered in memetics [12], although memetic representation of social memory must be criticized [28].

[5] The notion of 'quasi-memory' refers to features of technical system design, that allow for variety of states of the information system (e.g. several positions of a switch).

metal' [8]), and thus studies of information phenomena can be naturally extended beyond their traditional sphere.

2. Conception of information / cybernetic systems (ICS)

2.1 Formal description of memory functions in ICS

Being a material entity, any complex informational system is involved in continuous interacting with its environment. These interactions are by definition manifold, and they regularly repeated (see analysis of cybernetic systems by Ashby [3]).

Memory can generally be defined as a phenomenon in which structure and organization of a system are reflected, and are further 'stored' for some time, in other system, and are used in interactions between these systems. In the former aspect, a memory's function is *representation*, and in the latter it is *regulation*. Such definition is believed to synthesize the existing concepts of nature of memory, which is seen as a phenomenon of reflection [16]. Following this definition, it is possible to identify memory in mirrors (reflective amalgam surface as a 'shortest-term' memory device), chromosomes (reflecting structure and functions of specific cells and of organism as a whole), nervous networks (reflecting accumulated experiences of organism interactions with its environment), in computer memory units (reflecting computer structure in its interactions with internal components and input-output devices), and in many other objects[6].

Memory can be physically localized in a system, if a certain part of this system performs memory function. In this case, memory can be described as a *unit* (or a physical object) which reflects, in its structure and organization, a certain part of system environment in its interactions with the system (since any material objects have to interact before they can contain representations of each other).

Memory, in its reflection function, can be considered as a process (a process of remembering: 'memorizing', usage and possible 'elimination' of its content) and as a result (a storage of memories that can be further used by the system). Thus, memory contains 'representations of reality'; but at the same time, these representations are but 'instructions' that regulate system interactions with its environment. This vision is intuitively shared by many artificial intelligence researchers, geneticists, sociologists and others. For instance, DNA is a storage of genetic information about organism (structure of its organs etc), but this information is stored in the form of 'instructions' that 'code' various functions of this organism (performed by these organs) [52]. In neural networks of living systems, memory can be described as 'cognitive eigen values' which are cognitive reflections of environment and prescriptions for activities at the same time [45]. Similarly, social memory holds a description of a society, but this description can only exist embedded in social agencies [53]. Memory is, therefore, always an internal system component: an outside object, e.g. a book or a photograph, is not a 'memory' itself, but only an item that forces memory to work (this is argued at large in the earlier paper [27], where notions of potential and actual informational interactions is introduced).

2.2 Conception of SAFE

Objects that provoke memory to work can be generalized under the notion of 'system adaptive functioning environment'.

In the system environment, it is possible to identify objects with which system regularly interacts. These objects are thus included into functioning cycle of the system with memory. Then, structure and organization of system memory can unambiguously be put into one-one correspondence with a set of objects that system regularly interacts with.

[6] That memory is the essence of mind, is one of the key ideas in "Matter and memory" by H. Bergson [4]. Although Bergsonian concept was one of the inspirations, the concept outlined refers to different phenomena, human mind being only one of them.

This set of objects, that system *regularly* interacts with, and which is represented in system memory, can be called system adaptive functioning environment (or SAFE). SAFE and memory are reciprocally defined through each other, and they can only exist as a unity (corresponding to each other as 'key' and 'lock', which can only act together). There cannot be a memory without its SAFE (e.g. an organism cannot live without its environmental niche). There also cannot be SAFE without its memory (e.g. part of a physical world turns into an environmental niche only when inhabited by organisms[7]).

Similar concepts exists in ecology and environmental biology (organism environment described as 'Umwelt' in works of J. von Uexküll [41, 42]) or in psychology ('field' theory of K. Lewin [25]), or in animal psychology [22]. A notion similar to SAFE has been coined by P. Agre and I. Horswill [1]: their Lifeworld is "the patterned ways in which a physical environment is functionally meaningful within some activity".

Accordingly, every element of SAFE has some use for the given system in its operational cycle, and thus it is not only has its place in the outside world, but also contains a prescription of its usage. E.g. an axe contains a 'program' of chopping (its handle allows to take it in a certain way and to accomplish only a limited assortment of movements [51]). Certain stimuli provoke an unconditional reflex, and certain molecules provoke action of enzymes. In the perception theory of Gibson [14], objects of the outside world are represented in perception as 'affordances', or interactions between a biological system and its environment.

2.3 Informational processes and information / cybernetic systems

It is proposed to consider, as informational, processes in which system memory content can be observed in interactions (representation or transformation) with its environment (more precisely, SAFE). In case of discrete systems (robotic / computer devices and digitized representation of natural living/social systems), each interaction involves a certain structurally/ functionally monolithic object of SAFE (which can be called an element of SAFE), and a certain structurally/ functionally monolithic block of memory. An elementary unit of information is then *an interaction between an element of memory and an element of SAFE*[8].

In dynamic aspect, interaction between memory and SAFE represents an elementary cycle of system functioning. Every such interaction implies reciprocal change of interacting parts: memory and SAFE. Change in environment in the course of its interaction with memory is the process of *regulation*, while change in memory through interaction with environment is the process of *identification*, or of *representation*.

In order to underline the dual nature of information, it is proposed to call systems with information as information/cybernetic systems (ICS). ICS (or complex informational systems) can only exist as unity of memory and SAFE, and frequently only as a 'superposition' of several components acting as memory or SAFE (or poly-functionally playing both roles). For instance, genetic information exists only in 'DNA-RNA-enzyme' complexes (and not in DNA exclusively); information in neural system exists as interaction between neurons of peripheral and central neural system, and not only in neurons; social information exists as interaction of social memory, human agencies and internal environment of social artifacts [26, 28].

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[7] Although biologists distinguish between actually inhabited, or Eltonian, and potentially inhabited, or Grinellian, niches [15]

[8] In this context, an 'element of SAFE' implies 'any copy of multitude of SAFE elements of the given type'. Evidently, in every specific informational interaction participate a specific element of memory and a specific copy of SAFE element (specific molecule, specific production instrument etc.). However, for any given information relation / interaction there is no qualitative difference between specific copies of SAFE and memory elements of the same type.

2.4 Dynamics of information / cybernetic systems

Information/ cybernetic system can be described as a dynamic system that functions within a certain range of states (or, interactions between memory and SAFE). These states are regularly reproduced in certain (as a rule, in non-arbitrary) sequences that form a cycle of ICS functioning (or, macro-cycle).

Regulation (as an aspect of ICS functioning) implicitly implies the existence of a regulation 'goal'. Then, it is necessary to introduce a criterion of 'target state' or orientation of ICS functioning in its macro-cycle: a certain final state of the system (incl. 'active' memory element) and a certain target state of its SAFE. For natural systems (biological and social) the final state of macro-cycle is, at the same time, the starting state of a new macro-cycle, since they can only exist in a continuous cycle of self-maintenance and self-reproduction.

ICS macro-cycle is, therefore, a set of informational interactions that is not an arbitrary, but quasi-targeted. It is possible to suggest that, certain necessary sequences of informational interactions always have to be realized in macro-cycle. The most explicitly such sequences exist, when an output of one informational interaction enters another interaction, e.g. in sequential processing of some product by industrial robot, or in ritualized behavior of social animals (including human). Such sequences can be formed due to the following factors: (1) every next informational interaction can use, as an element of SAFE, an output of the previous interaction (e.g. in technological cycles), and (2) stable sequences of emergence of SAFE elements exist in the environment (e.g. natural cycles: day/night, winter/summer etc.). A limit case is one single ordered sequence, a linear determined macro-cycle.

In most cases, a macro-cycle of ICS can be separated into a number of sub-cycles (or meso-cycles). Each of these sub-cycles is indivisible (or monolithic) in respect to a certain type of (targeted) operation. Every sub-cycle can also be decomposed as a combination of sub-cycles of a lower level (as every complex type of operation is a combination of some simpler types of operation)[9]. Meso-cycle of maximal length is equivalent to macro-cycle; meso-cycle of the minimal length is an elementary operation cycle (or micro-cycle) – it is a single interaction between an element of SAFE and an element of memory (non-decomposable further on a given level of modeling).

Typology of ICS functioning cycles is presented in Table 2.

Table 2: Typology of ICS functioning cycles

Type of cycle	*Organization*	*Properties*
elementary operation cycle (micro-cycle)	single interaction between memory and SAFE	cannot be decomposed further on given level of modeling
sub-cycle (meso-cycle)	certain sequence of interactions	has a target state; can be decomposed into meso-/micro-cycles
ICS functioning cycle (macro-cycle)	(repeated) cycle with a target final state and a full variety of informational interactions	can be decomposed into meso-/micro-cycles; repeated cycle in self-maintaining and self-reproducing systems

3. Spatial and temporal properties of information / cybernetic systems

3.1 Formal dynamic model of ICS

State *S* of information/ cybernetic system can be described as

$$S = (M, E) \qquad (1)$$

[9] Decomposition of system activities is considered by G. Sussman [37], as 'goal/sub-goal interactions'. Similar approach can be found in the work of V. Turchin [40]

where M is a set of variables describing 'internal' state of system, and E is a set of variables describing a state of system environment (SAFE).

It is implied that

$$E \subset \mathtt{E} \tag{1.2}$$

$$M \subset \mathtt{M} \tag{1.3}$$

where $\mathtt{E}$ is region of feasible states of SAFE, $\mathtt{M}$ region of feasible states of memory. Based on the considerations outlined above, it is possible to write that

$$\mathtt{E} = \mathrm{U}(\mathtt{M}) \tag{2}$$

i.e. $\mathtt{M}$ defines, in a 'universal set' of environment objects U, a subset of 'feasible' (identifiable and transformable) objects of SAFE $\mathtt{E}$.

For instance, in a discrete model, state of SAFE can be described as vector E_n of dimension n, where $e_i \in N$ is i-th vector member, corresponding to the quantity of SAFE elements of i-th type. State of memory can be described as a scalar $M \in 1 \ldots n$ that corresponds to one of n states. Then, set $\mathtt{E}$ is described as N^n, and $\mathtt{M}$ as a set of numbers (1, 2, …n). A version of expression (2) would be, e.g., that a set of numbers $\mathtt{M}$ determines in the space of infinite-dimensional natural vectors U=N^∞ a sub-space of n-dimensional natural vectors $\mathtt{E}=N^n$.

Dynamics of information / cybernetic system can be described as a transformation

$$T\colon S \rightarrow S \tag{3}$$

Transformation (3) can have continuous or discrete character, and it can be either deterministic or probabilistic.

Accordingly, transformation

$$\mathtt{T}\colon \mathtt{M}\times\mathtt{E} \rightarrow \mathtt{M}\times\mathtt{E} \tag{4}$$

describes a set of possible trajectories for a given set of memory elements $\mathtt{M}$ and a set of SAFE elements $\mathtt{E}$.

A particular case of described formal model of ICS is Turing automate and its derivatives (e.g. von Neumann's self-reproducing automate [46]) – in this case, transformation has a deterministic discrete character. Models of non-linear dynamics can be another particular case, when transformation has a deterministic continuous character.

Since ICS dynamics implies repetition of states, then, in deterministic case, a set of trajectories $\mathtt{T}$ will has an attractor of one of the following types:

(1) focal point (transformations stopped in a certain 'absorbing' state),

(2) cycle (exact repetition of a specific sequence of transformations and corresponding resulting states),

(3) 'strange attractor' (dynamics has a chaotic character within the acceptable range).

Initial ICS state S_0 determines, in the set of potential system trajectories $\mathtt{T}$, an 'actual' subset of trajectories (or, in deterministic case, a single trajectory) $\mathtt{T}_{S0}$. This trajectory (or set of trajectories) $\mathtt{T}_{S0}$ determines in the set of SAFE states $\mathtt{E}$ an 'actual' subset $\mathtt{E}_{S0}$, which will be observed when going over the trajectory.

3.2 Spatial properties of ICS

Space of a complex informational system is not the same as its physical space, since this system only exists in the space that it is capable to 'perceive' (identify) and 'change' (transform). Accordingly, the space of ICS is its system adaptive functioning environment.

The following typology of SAFE-spaces of information/ cybernetic system can be drawn. *Actual space* of ICS is a current SAFE state E, that exists (partially) as an outcome of the previous interaction and generates the subsequent interaction of memory and SAFE. This space exists as a particular manifestation of a *potential space* of ICS – its potential SAFE E. However, it appears more relevant to use a notion of *potentially accessible space* – SAFE E_{S0} that is potentially accessible in the state S_0, i.e. a range of SAFE states relevant to the set of dynamic trajectories given current state of a system.

A simple example of three concepts can be proposed. For instance, an observer is in the room: he is surrounded by some pieces of furniture, appliances etc.; he sees part of a street in the window; inside his body, certain processes occur – all these are variables characterizing his actual adaptive functioning environment *E*. In this moment, spaces beyond *E* as though do not exist (i.e. they only exist potentially). As a specimen of *Homo sapiens*, a species with rather wide environmental niche, this observer could have been anywhere where man could reach, almost any place on Earth and in its near space – this is a potential SAFE E (e.g. other stars and planets are still not included in E, because there is yet no way to reach them). However, because this observer can have limitations in his health, available cash etc., his potentially accessible space E_{S0} would be a smaller sub-set of his potential SAFE: most likely, he will not be able to climb Everest, fly to the near space, dive into Mariana trench etc.

It is evident that subjective space of complex systems is not equivalent to their 'absolute' physical space. Physical space continues and exceeds the bounds of complex systems , while subjective space of ICS 'fuzzily discontinues' where SAFE of ICS discontinues.

Then, complex system space can be envisaged only as their adaptive functioning environment. One of the first proponents of this view was J. von Uexküll [42], for whom the space of complex systems (von Uexküll writes about living systems) is limited by their *Umwelt*, or 'own world'. In some sense, since *Umwelt* (or, more broadly, SAFE, because this concept also includes non-living and social systems) is not only 'perceived', but also 'transformed', or created, then ICS turns to be its own space creator.

Based on the concept outlined, ICS space is determined by its memory content and is revealed in ICS functioning cycle. If potential space is unambiguously determined by the memory content, then actual and potentially accessible spaces will also be defined by the 'current position', a combination of memory and SAFE.

3.3 Temporal properties of ICS

What will be the temporal properties of information / cybernetic systems? What types of subjective time can be described in such systems?

It is evident that two different moments of time in a system can be distinguished only if some change occurs in system state (i.e. a difference between states emerges). Change of ICS state *S* is a change of a set of variables *M* and a set of variables *E*, i.e. changes in a state of memory and a state of SAFE.

Transformations relevant to SAFE change can be described using the example of vector of object quantities E_n. If Δe_i denotes quantitative change in *i*-th component of vector E_n, then following types of transformation can be considered[10]:

(1) occurrence of a new object in SAFE (e.g. identification by a system): $\Delta e_i = +1$, $\Delta e_j = 0$ $(j = 1 \ldots n, j \neq i)$

(2) disappearance of an object from SAFE: $\Delta e_i = -1$, $\Delta e_j = 0$ $(j = 1 \ldots n, j \neq i)$

(3) transformation of object in SAFE: $\Delta e_i = +1$, $\Delta e_k = -1$, $\Delta e_j = 0$ $(j = 1 \ldots n, j \neq i, j \neq k)$ [can also be described as a simultaneous action of 'occurrence' and 'disappearance']

[10] Similar considerations can be used to describe motion (change of position) for objects in SAFE, as position of an object relative to an informational system can be one of the characters to distinguish between various objects

However, other situations are also possible, when no explicit change of SAFE occurs, but ICS state changes – e.g., in case of 'pure identification'. In this case, change of temporal moments can only be identified if changes in memory states ('internal states') occur.

Typology of ICS temporal properties can be accomplished similar to spatial property typology. Actual time of ICS is a transition, or a single change between states of information/ cybernetic system $S \to S$; it corresponds to actual space (actual SAFE) of a system and an actual state of its SAFE. Potential time of ICS is described by the variety of its potential trajectories $\mathtt{T}$; it corresponds to potential space $\mathtt{E}$ of ICS (all trajectories are implemented in 'potential space'). Potentially realizable time of system $\mathtt{T}_{S0}$ is determined by system current state S_0 and it is realized in potentially accessible space $\mathtt{E}_{S0}$ (it is evident that $\mathtt{T}_{S0}$ has less or equal variety compared to $\mathtt{T}$).

Continuing an example with 'observer in the room', subjective time of observer can be described. Actual time T is determined by biological and psychic rhythms of the observer (e.g. a human is not capable to identify changes if their period is lower than 50 milliseconds [43]). His potential time $\mathtt{T}$ encompasses all possible trajectories of his life from his birth (or even from embryo formation) to his death (and the moment of death is the stop and complete cessation of his subjective time). However, current state of the observer (e.g. his social status, his health etc.) constraint his potentially realizable time $\mathtt{T}_{S0}$ to what can be called a 'range of destinies' (the longer this individual exists, the more constrained is his realizable time, the less degrees of freedom he has).

Similar position has been first expressed by H. Bergson who wrote that time and space are produced by properties of human mind [5]; so time is a property of human beings, not of the physical nature. Later, the same kind of statement, generalized for the living matter (time as a property of life) can be found with V. Vernadsky [44]. In accordance with the approach outlined, human mind and living organisms belong to different classes of information / cybernetic systems (which may also include social systems and complex technical devices).

Correspondingly, properties and current state of memory SAFE turn to be factors that determine temporal (and spatial) characters of a complex system.

If system memory undergoes changes (computer reprogramming, genetic mutation, creation of new knowledge or new behavioral patterns), then spatial-temporal properties of the system change as well. For instance, time of 'traditional' societies (primitive tribes 'conserved' in favorable environment, e.g. Indian tribes in Amazon river basin) has properties of a cycle, and their space is closed to their habitat. European civilization, by choosing steady progress to be one of its values, has realized acyclic time; its continual territorial expansion means nonclosed and constantly enlargement of its subjective space. Similarly, genetic mutations may rise new micro- and macro-organisms, generating evolution and biological 'time arrow'. Thus, changes in memory are key to unfolding of time, its transformation from 'circle' into 'spiral' (in terms of subjective time typology presented below).

3.4 Typology of ICS subjective time

ICS subjective time $\mathtt{T}$ is revealed in ICS functioning cycle through interactions of memory and SAFE, and resulting changes of their states. Correspondingly, subjective time varies in character depending on a type of functioning cycle.

For instance, for Turing automate (that consists of a tape with digits and an active reading/writing header with motor), in each interval of subjective time, one of the following events can occur: (a) header reading digit, (b) header erasing digit, (c) header writing digit, (d) header moving relative to the tape. Since an observer has a full description of automate state, 'pure identification' (header reading) can be identified as a change of moments in automate subjective time. Time begins, when the automate commences interactions with the tape. When the final state is reached (some absorbing state) and operations are stopped, there is no further possibility to distinguish internal intervals of system time, i.e. system time ceases. Therefore, set of realizable dynamic trajectories T_{S0} (or, time flow) of the automate is fully determined by instructions on tape and rules of automate functioning , i.e. by the set $S_0 \subset M \times E$. This time flow is similar to a walk on a ladder with a limited number of steps: Turing automate thus has 'ladder'-time.

Similarly, in digital computers (designed by J. von Neumann inspired by the model of A. Turing), subjective time flows only when they perform computations. Although the physical time flow in computers as objects of the material world (related to objective and continual changes in lower layers of matter organization) is continuous and ceaseless, its subjective time is discrete and finite – subject to absence of infinite loops in computations.

A continuous analogue of the system of this kind would be an abstract (point-like, in order to abstract from internal changes) body movement beginning in one point and stopping in another (e.g. in the center of gravity field). After movement is ceased, states of this system are no longer distinguishable, and its subjective time stops (turns into what can be named the 'point'-time).

Self-reproducing (SR) automate of von Neumann[11] is a model of Turing automate in physical space, constructing its own copy based on instructions [46]. Final state of SAFE in SR-automate macro-cycle is its assembled copy; after cycle completion SR-automate immediately proceeds to a new assembly. Functioning of such automate has a discrete cyclic character (it can be called the 'drum'-time).

An exact analogue of such a system in continuous time would be an engine with zero entropy production (a perpetual motion machine). More broadly, any system with cyclic continuous dynamics and without internal component deterioration has this type of time (the 'circle'-time).

Finally, systems with chaotic dynamics (within a limited set or space of acceptable states) have properties of a cyclic system (since their characters very within a certain diapason – temperature or illumination fluctuations etc), but also an acyclic system, since previous states are never repeated. Such systems are called 'strange-attractors' (both discrete and continuous), and so they have what can be called the 'spiral'-time.

Typology of time for systems with deterministic dynamics is presented in Table 3.

Table 3: Typology of subjective system types

Topographic figure	*Type of attractor*	*Character of time*	
		continuous	*discrete*
'point'	absorbing state = initial state	time stop = single immutable state	
'segment'	absorbing state ≠ initial state	'body moving from point A to point B; (fragment of time in classical physics)	'ladder' (time of Turing automate or digital computer)
'ring'	cycle	'circle' (time of a perpetual motion machine, exact reproduction of the past without entropy production)	'drum' (time of von Neumann's self-reproducing automate or other automate with infinite loop)
'sprial'	'strange attractor'	continuous 'strange attractors', e.g. Lorenz attractor	discrete 'strange attractors', e.g. Henon attractor

Similar typology can be developed for probabilistic discrete / continuous dynamic systems (to which, apparently, all complex biological and social systems belong). In such systems,

[11] Or other similar: e.g. Laing's automates [21]

emergence of absorbing states or cycles has probabilistic character, so variety of time types can be described probabilistically. The most frequent type of time, apparently, has to be 'chaotic time', in which unfolding of actual time is described by Markov process.

Thus, within the bounds of presented approach it is possible to describe and typify subjective time of complex systems. The founding father of first-order cybernetics, N. Wiener, claimed, that a contemporary automate exists in the same Bergsonian time as a living organism [49]. Yet, his position needs to be rectified: subjective time of living organisms will be different from automate subjective time, due to a discrete (a la Turing automate) nature of the latter.

3.5 Levels of subjective time

Initially, the idea about different levels of time flow has been proposed in publications of J.T. Fraser [13]. He has identified six levels of time, corresponding to six 'worlds' or layers of material organization: quantum, molecular, thermodynamic, biological, psychical and social. Fraser does not specify how temporal levels transit into each other, i.e. different types of time appear independent from each other [2, p.285].

Concept of time flow levels and relations between them can be specified within the proposed approach. One of the relevant objects for illustration is living systems, since an idea of multi-layer organization of living matter is traditional for biological sciences.

Several classifications of structural layers of biological organization can be enlisted, e.g. Chandler's [11]. According to classification by V. Kremyanski [20], four major layers of life organization are: (1) molecular-genetic (revealed on the level of individual cells), (2) ontogenetic (revealed on the level of individual organism), (3) population/ biocenose, and (4) biospherical .

Accordingly, for each of these layers can broadly be defined the actual time T, potential time $\mathtt{T}$ and potentially realizable time $\mathtt{T}_{S0}$ (see Table 4).

Table 4 Types and layers of time for living matter

Layer of living matter organization	*Actual time T*	*Potential time $\mathtt{T}$*	*Potentially realizable time $\mathtt{T}_{S0}$*
individual cell	interaction of macro-molecules [2]	cycle of cell growth and division	time to complete cycle of growth and division
body tissue or organism	cell division [44]	organism living cycle (ontogenesis)	time to complete ontogenetic cycle
population / biocenose	life of individual organism (ontogenesis)	population living cycle (phylogenesis)	time to complete phylogenetic cycle
biosphere	appearance / disappearance of phyla [13]	potential time of living matter existence	potential time of living matter existence since a certain time

It is evident from the table, that time of structural layers of living matter is linked by the same relation, as structural layers themselves. In the same manner as objects of the lower layer of organization act as elementary structural units for the higher layer, potential time $\mathtt{T}$ of the lower layer turns to be actual time T of the higher layer: e.g., cell division cycle is potential time on the molecular-genetic level and actual time on ontogenetic level.

System description level (and properties of its model) determine character of subjective time of this system. Therefore, in literature, various concepts can be found for biological time (e.g. G.T. Fraser [13], V. Vernadsky [44] and G. Aksyenov [2]), and much the same, for social time. However, since layers of structural organization represent certain objective properties of material systems, typology of subjective time for corresponding complex systems also has a certain objective basis. Similar concept (time for each level of material system organization is produced on the lower, system-forming level) is discussed in papers of A. Levich [23, 24].

4. Conclusion

Proposed approach allows to suggest the key properties of subjective space and time of complex systems. It is possible to introduce concepts of actual space, potential and potentially accessible space, which are not equivalent to physical space of the system (and form its sub-space). Similarly, it is possible to introduce notions of actual time, potential and potentially realizable time.

Time of complex informational systems always have some type of internal constraint, compared to ‘potentially unconstrained’ physical time (and also, certain cyclic properties, compared, to the ‘arrow’ of physical time [31]). Based upon the formal model of information/ cybernetic system, subjective time can be typified (for deterministic dynamic systems, seven types of subjective time have been identified). Besides, it is possible to speak of subjective time flow cessation in complex informational systems (or, about ‘point’-time), although physical time of these systems may never stop.

However, it is also possible to question whether it is relevant to think of physical space and time outside of the frame of complex system subjective time. Since an observer is also a complex informational system, his subjective time and space will have the properties described. Objects outside of observer’s subjective space, and dynamics of events outside of his subjective time are but his constructions. Reality is not abstract, observer-independent space and time (invented by classical physics), but only the observer’s space and time. Speaking of ‘abstract time’, G. Whitrow remarks that “instead of being a prior condition, our concept of time should be regarded as a consequence of our experience of the world” [48, p. 186]

Identification of relations between ‘abstract’ physical time and subjective time of human individuals allows not only to resolve contradictions between scientific and anti-scientific concepts of time [18, 38], but also to find correspondences between informational system dynamics (life dynamics, mind dynamics, etc.) and physical processes underlying them.

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