

New Approach to The Concept of Information

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Abstract

This paper suggests a new approach to the concept of information, based on the assumption of its objectivity. It is suggested that information is a phenomenon that is only observed in complex material systems (technical, bio-chemical, biological, and social), and that it is closely related to a system memory. A memory of a complex systems represents a part of system environment in its interactions with a system, or system adaptive functioning environment (SAFE). Information is suggested to be interactions between elements of memory and elements of SAFE. Because any interactions imply mutual changes of interacting parts (memory and its environment), a regulation and representation are two aspects of the same process: an information and a program. Models which can be obtained with this approach represent a generalization of traditional communication models (as used by theory of information) and regulation models (as used by cybernetics); they therefore can be called information/cybernetic. Aspects of system dynamics and formal matrix model of information/cybernetic systems are considered. A proposed concept of information appears to be a promising way for re-consideration of information/cybernetic models of complex systems, such as biological and social systems.

1. Information systems

1.1 Material nature of information

The discussions on information continue ever since this concept has been intuitively proposed in the renowned work of Claude Shannon [Shannon, 1948]. Up till now they most likely led to a statement that information is basically indefinable, much like a ‘system’ or other semi-philosophical category (although some hundreds of definitions to the term have been suggested [Capurro, 1992]). One of the best known definitions says that information ‘is neither energy nor matter’ [Wiener, 1948]. The strict acceptance of this thesis may, however, lead to a mystical understanding of information as some ideal (immaterial) substance, or a ‘third substance’¹. To the contrary, we may argue that no objective means of observation and verification may exist for ideal objects thus allowing no basis for scientific theory.

Three major approaches to a concept of information may exist in general: (a) information is a material essence or phenomenon, (b) it is an ideal essence (or phenomenon), (c) or it is neither particular phenomenon nor some essence, but a fiction. Each of these approaches is mutually exclusive and may serve as a basis for further studies [Sokolov, 1990]. In order to study a phenomenon of information on the scientific basis, a position that information is objective (material) should be chosen; this follows a rationalistic tradition in information approach [Winograd, Flores, 1986].

Thus, it is natural to assume that information is strictly a material phenomenon, realized through a matter or/and a field of different type. If a principle of information materiality is abandoned, then, as an ideal object, information submits to some ‘ideal’ laws which cannot be verified, proven or disproved by a scientific experiment or life practice. In this sense, scientific value of paradigm of information immateriality seems minimal, although undoubtedly this point of view has a right to exist.

Materiality of information does not contradict to it being a very particular phenomenon which cannot be understood within a mechanistic physicalist approach. For some types of systems with information, it is not possible to use research methods of natural sciences adequately; in their current form, these methods are mostly applicable to technical and basic biological systems –

¹ One such theory is David Bohm’s Active Information [Peat, 1999]

and it is a big question mark whether they can be developed to study more sophisticated objects. Dynamic complexity of certain studied objects is very high, and it inevitably brings researchers to a higher level of abstraction². This kind of objects dominates biological, social and humanity sciences³. Abstraction from analysis of specific physical and chemical interactions is mostly a methodological convenience even for those systems where consideration of these aspects is feasible (e.g. it is frequent in design of computers and technical communication means).

However, one accepting a material nature of information can run into another methodological problem. If all information phenomena can be identified as various transformations of matter and energy (and nothing else beyond that), then it is possible to claim that information is but a 'fiction', a scientific convenience. Yet, any systems considered by natural sciences are just the same fictions! – e.g., for quantum mechanics, reality is full of 'wave packets of probabilities' and 'metric tensors'. These are but convenient models of a reality 'thing in itself'. Information systems are just as objective as any other objects of natural sciences.

To accept information as an objective material phenomenon emerging in complex systems is a step towards an objective theory of information. Opportunity for such theory has been discussed by Brier [Brier, 1992] and others. It is not our purpose to deduce information to the realm of physical and chemical systems, but rather to induce it from the latter.

1.2 Information system types

Not every material dynamic system should be considered as informational, primarily since use of information models is well-founded only when a high complexity of processes is achieved. On the other hand, a class of information systems can only broadly be defined because a concept of information is intuitively understood in very different manner by different researchers. Accordingly, it is necessary to describe various types of information processes, thereby specifying our own idea of information.

First of all, it is possible to outline range of objects traditionally considered by classical theory of information and cybernetics. Information is thought to exist in following real systems (our breakdown, based on various sources e.g. [Pylyshyn, 1983], [Roszak, 1986]):

(1) *Artificial technical systems*, including robotic and computer devices, and technical communication networks with 'technical' information⁴;

(2) *Natural biological systems*:

(2a) Self-reproducing biological systems: living organisms of various complexity (ranging from viruses to higher animals) with genetic memory. In such systems one can observe an innate biologic information (genetic code, genome and genotype of organisms and species), stored and transmitted through reactions of complex chemical compounds;

(2b) Biological organisms with central nervous system (CNS): complex biological systems which can use individually gained experience in their behavior. In such systems one can observe biological information which is not genetically inherited but is developed through learning and adaptation of specific living organisms of a given species, stored in neural nets of CNS and cerebrum;

² It is inability to describe these extremely complex processes in terms of natural sciences (e.g. physics and chemistry) that gives birth to various metaphysical interpretations of information as ideal (e.g. [Titov, 1996]). Absurdity of such approach is obvious for technical information systems, or bio-chemical systems, in which materiality of information processes is beyond any doubt.

³ Probably struck by an obvious complexity of a majority of systems with information (and their distance from 'elementary' systems with information such as computers), many researchers tend to associate information only with living systems. The counterexample showing that realms of non-living and living are not that separated, is a successful use of mechanical devices to replace body parts.

⁴ Although information is not considered to exist in simpler technical devices such as automatic governors and servo-mechanisms, it is possible to show (as it is attempted onwards) that they can also be treated as basic information systems

(2c) Populations of higher animals of herd, flock, pack or family organization: complex biological systems with developed outer communication, which can implement socially gained experience in their behavior. In such systems one can observe a biological information acquired by organisms in process of learning through imitation (imitations of passivity/activity samples) from other individuals of same species. This information is stored in neural nets of CNS and cerebrum of population specimen, as well as in reproduced chains of ‘demonstration-observation-demonstration’ (or chains of social relays, as suggested in [Rozov, 1997]);

(3) Social systems (socio-economic, socio-cultural and their sub-systems):

(3a) Systems with innate genetic memory (individually concentrated and mass distributed) of a given species (Homo Sapiens, various species of social insects, e.g. ants, bees etc., and any other species with quasi-social organization);

(3b) Systems that produce, store, use and reproduce individual experience gained through learning and interactions with environment. This category also includes most kinds of psychological phenomena (emerging socially, as it has been shown e.g. by Vygotsky [Vygotsky, 1978]);

(3c) Systems that accumulate, store and use socially gained experience. Phenomena of this category include languages, knowledge, beliefs, technologies, traditions and norms, cultural samples (e.g. objects of art) are all kinds of information possessed by individuals which only has meaning at a social level;

(3d) At a certain level of society development there may appear artificial technical systems of a society which contain technical information as well as information of socio-economic and socio-cultural systems. Such systems served as objects of study for classical theory of information (mathematical theory of communication): signals and messages in technical means of communication: telegraph, telephone, radio devices etc.

All the above-mentioned types of objects and phenomena have a great diversity in terms of their physical/chemical properties, as well as in terms of their organization and operation. Nevertheless, all of them have some universal structure and certain processes that allow to specify them as informational (out of a great variety of material systems). Accordingly, there should exist some universal *invariant* property, which is common to 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 universities⁵.

1.3 Invariant property

As we suppose, property that is universal to all of the enlisted types of systems is *a possession of memory*⁶. The first group of information systems (technical) has artificial built-in modifiable memory or quasi-memory⁷. The second group (biological systems) has genetic inherited memory and individually acquired memory. The third group (social systems), besides genetic and individual memory, also has a social memory ([Toffler, 1980], [Luksha, 2002]), localized in ‘super-organisms’ or in societies⁸.

⁵ This commonality, besides all else, is an oblique evidence that processes occurring in all of these extremely different systems have a similar material nature, and that, when modeling complex social and psychological systems, there is no need to introduce metaphysical (ideal) factors.

⁶ Memory as a universal property of organized matter has been first suggested in 1870 by the German physiologist and philosopher Ewald Haering. This idea has not become popular by then, probably to its scientific immaturity (before emergence of System Sciences)

⁷ For instance, in classical Shannon’s model, in which a source and receiver should not necessarily possess some ‘memory’, both coding (before transmission) and decoding (after transmission) require functionally separable memory devices which contain a code itself [Gallager, 1968]. In general case, in any technical system there exists some kind of memory, although it may not be differentiated (or lifetime of its stored representations is minimal).

⁸ See also [Kolevatov, 1984], [Platonov, 1975]. A similar, although slightly different, concept is considered in

Human beings, or observers (claimed to be ‘systems with information’ by second-order cybernetics and biosemiotics [Brier, 2001]), 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.

A correspondence of complex information system types and memory types is represented below (Table 1).

Table 1. Correspondence between information system types and memory types

No.	Type of information system	Types of memory
1	technical	<ul style="list-style-type: none"> • permanent and operative memory devices (memory and quasi-memory of technical systems)
2	biological	<ul style="list-style-type: none"> • genetic innate memory ▪ individual memory in central nervous system
3	social	<ul style="list-style-type: none"> • genetic memory of social behavior • individual memory • social memory in individual memories and technical devices

Intuitively, this observation can be phenomenologically generalized: there is no complex system which has information and in which information processes occur, and which at the same time does not possess memory. The opposite should also hold: there is no such complex system with memory in which no information is observed (since memory, at least, is one locus of information in a system)⁹.

Still, it is clear that a class of systems with memory is broader than the list of information systems given above. As one example, a ‘memory of metal’ phenomenon can be suggested: some alloys, e.g. NiTiInol, can ‘memorize’ and then ‘reproduce’ certain forms to which they were shaped in different temperature conditions [Callister, 1994]. Obviously, a study of information phenomena can then be extended beyond the traditional sphere of research¹⁰.

To develop our logic in a more accurate manner, it is necessary to specify our idea of ‘memory’, and to consider its implications.

2. Information/program relations and interactions

2.1 Functions of memory in information system

Memory can be broadly defined as a phenomenon in which structure and organization of one system are reflected, and further are ‘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, as we believe, generalizes various concepts of memory, which is in general a phenomenon of reflection [Grishkin, 1973]. In accordance with this definition, one may identify memory in various systems such as 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

mimetics [Dawkins, 1989].

⁹ It is obvious that this statement can be refuted by just one contradictory example. This, however, will not completely undervalue the consequent modeling, but will reduce it to a class of information systems with memory.

¹⁰ Other examples of systems which traditionally were not considered informational but can be treated as such include: automatic governors (e.g. Watt’s governor, see App. 1), hetero-catalytic reaction system (e.g. a Brusselator or Belousov-Zhabotinsky reaction [Kauffman, 1993])

(reflecting computer structure in its interactions with internal components and input-output devices), and in many other objects¹¹.

Memory can be localized in a given system as its component. Then, it can be defined as a *unit* (or a physical object) which reflects interactions of a given system with its environment¹². In order to represent another object, a memory must interact with it¹³. It can be observed as a process (a process of ‘memorizing’, usage and possible ‘elimination’ of its content) and as a result (a storage of representations which can be further somehow used in a given system). Thus, a content of memory is ‘representation of reality’ on one hand; on the other hand, memory contains ‘instructions’ that regulate system interactions with its environment. This vision is traditionally shared by artificial intelligence researchers, genetic biologists, scholars of social memory and others. For instance, DNA is a storage of genetic information about given organism, and it also contains instructions that code certain functions in this organism [Yockey, 1992]. For living systems with neural networks, as von Foerster argued, memory can be described as ‘cognitive eigen values’ which are cognitive reflections of environment and prescriptions for activities at the same time [von Foerster, 1984]. Similarly, social memory is a representation of a given society, and it prescribes social activities in this society [Zaslavskaja, Ryvkina, 1991].

In system’s environment, it is possible to identify objects and links with which system memory regularly interacts. Then, these objects and links are included into a operation cycle of a given system. A structure and organization of system memory can unambiguously be put into one-one correspondence with a set of these objects and links. In basic case, a memory can contain nothing but representations of objects with which a system regularly interacts¹⁴.

The relationship of memory and environment distinguishes some specific set of objects and links in the latter. This set of objects and links represented in system memory can be named a system adaptive functioning environment (SAFE).

Concepts similar to SAFE are found e.g. in environmental biology (a unity of organism and its environmental niche, as the ‘Umwelt’ of von Uexküll [von Uexküll, 1982]) or in psychology (a ‘field’ theory of Kurth Lewin [Lewin, 1950], or environmental psychology which assumes a unity of perceiving individual and perceived environment, e.g. [Lettvine et al., 1959]). They have been further formalized in work of Newell and Simon as the ‘task environment’ [Newell, Simon, 1963] or the limited variety of choices for a complex (problem-solving) system. A term similar to SAFE has been suggested by Agre and Horswill: their Lifeworld is ‘*the patterned ways in which a physical environment is functionally meaningful within some activity.*’ [Agre, Horswill, 1997]. Our notion is still more comfortable to use here, as it reflects the specific relation between a system’s memory and its environment.

2.2 Information and regulation

Accordingly, we propose to consider, as informational, only those processes in which content of system memory is explicitly revealed through interactions (representation or transformation) with its environment (more precisely, SAFE). In a discrete case, each interaction involves specific functionally monolithic object of SAFE (which can be called an element of SAFE), and

¹¹ That memory is the essence of mind, is one of the key ideas in Henry Bergson’s “Matter and memory” [Bergson, 2002]

¹² We do not specifically consider here a more complex phenomena: a memory about memory (reflections on reflections), as suggested by Heinz von Foerster [von Foerster, 1974], which, as it can be shown, is a type of two-level (or n-level, in a more general case) memory.

¹³ Representation without interaction is only possible in abstraction. Even in visual perception, interaction occurs through beams of photons from perceived object to observer (and backwards)

¹⁴ In more complex cases, however, it is not necessarily so – e.g. in inherited memory, some memory elements may stand for objects and links which existed when this memory emerged but later ceased to exist

a functionally/structurally monolithic block of memory. An elementary unit of information therefore would be an interaction between an element of memory and an element of SAFE¹⁵.

An idea that a complex system and environment exist and co-develop is one of the basic in the theory of autopoiesis. Maturana claims that interaction between an autopoietic system and its environment is essentially a communication [Maturana, 1988]; and the content of communication (in the tradition of information theory¹⁶) is information.

‘An element’ here means ‘any copy of a given object’. It is evident that, no difference which copy of SAFE element interacts with which copy of memory element, their interaction will have the same content and will occur in the same way. Multiple examples can be given to that. For instance, in DNA replication, a given copy of a memory element (nucleotide in DNA chain) cannot ‘distinguish’ which specific SAFE element (a specific molecule) interacts with it; what is distinguished is complementarity/ non-complementarity between interacting compounds. In famous Tinbergen’s experiments, silver gull nestlings could not distinguish between their mother’s beak and a ‘dummy object’; for them, it was only important that there is something ‘red’ and ‘long’ with stripes (i.e. a key irritant) [Tinbergen, 1965]. In social interactions social roles and universal social models (samples and norms) are most important, e.g. a driver and a road policeman have the same behavior patterns no matter what are personal qualities of each of them.

It is therefore possible to distinguish between unique information interactions (which occur if interacting elements are qualitatively different), and copies of same information (which are interactions between copies of same elements of memory and of SAFE). Production of multiple copies of the same information does not produce a *totally new* information in a system¹⁷ (e.g., increased replication of books and computer software in itself does not mean ‘a boost of information’ in a society¹⁸).

Considered in its dynamic aspect, an interaction between memory and SAFE is an elementary cycle of system operation. Each such interaction is a mutual change of interacting parts: a memory and SAFE¹⁹. Change in environment through its interaction with memory is a process of *regulation*, while changes in memory through interaction with environment is an identification, or a *representation*.

Not every physical interaction that leads to mutual change should be considered regulative (or cybernetic), even if one system impacts another. A stone in a mountain spring that changes water flow is hardly a cybernetic system, neither is a stone that falls to the ground because of gravity²⁰. However, if a system exhibits diverse (and repeated) types of operation, and especially when feedback loops can be identified in a system, then it is possible to identify a system memory and

¹⁵ In a continuous case such elements are impossible to define, because there exists no objective border that separates one element from another (e.g. a color scale); however it is possible to sample any continuous range of objects (by defining a sample and a variance), thereby adjusting it to discrete model.

¹⁶ The alternative approach suggested by Luhmann hints that information is opposite to communication, since ‘the former closes choices to a system while communication opens them’ (in [Hofkirchner, 1999]). Abstracting from philosophical and emotional implications of this statement, it is evident that interaction between memory and environment (the essence of communication and information in our concept) is opens and closes choices at the same time, as many interactions are potentially possible but only a single one occur (this is referred to also in Chapters 2.4 and 2.5).

¹⁷ It only increases reliability of a copied information (e.g. lowers a chance that a specific type of information is lost).

¹⁸ Unless it leads to new understanding and new ideas; as it will be further discussed, books and computer codes are not information but copies of SAFE elements, which, through interaction with various memory elements, may give an emergence of new information.

¹⁹ In the process of interaction, memory and SAFE must co-evolve together by impacting each other, e.g. autopoietic systems as one kind of complex information systems [Maturana, 1983].

²⁰ Although some renowned cyberneticians (e.g. [von Glasersfeld, 1996]) could say it is so, by claiming that here a principle of limited action (as introduced by Ashby, a situation when quantity of available operation types of a system is less than number of freedom degrees). We believe that application of cybernetic concepts to such elementary physical interactions is still less efficient.

its SAFE, and thereby to represent it as information/cybernetic model²¹. For example, natural homeostatic systems (such as a cascade waterfall pool or a geyser) can easily be described as cybernetic.

Regulation as a dynamic process of environment transformation always has a 'goal': a final state towards which both system and its environment evolve. This 'goal' may not necessary be a 'conscious' model of a final state, but it is somehow always is represented in system memory. For instance, operations of an automatic governor are also 'directed' (at least, quasi-directed) in a sense that dynamic changes of a system bring it towards an equilibrium. In molecular kinetics, sequences of chemical reactions may bring a system to some quasi-stationary state, and outcome of these reactions is in a sense pre-defined. Also in more complex systems, animal behavior (e.g. reproduction), or various types of human social behavior, frequently have identifiable initial and final states, which are not necessarily reflected in conscious representations.

Thus, interaction between memory and SAFE always has two aspects: it is an information and a program at the same time. We, therefore, propose to call them information/programs. Models which can be obtained with this approach represent a generalization of traditional communication models (as used by theory of information) and regulation models (as used by cybernetics); we therefore propose to call them information/cybernetic models (or information/cybernetic systems, ICS)²². We believe that there can never be (ideal and abstract systems apart) any real systems which are informational and not cybernetic (i.e. have regulations but not communications), and vice versa.

2.3 Actuality and potentiality of information processes

In system dynamics, it is necessary to distinguish between actual and potential form of information/program existence. Any actual information/programs represent actual interactions (current, or accomplished within some period of time) between elements of SAFE and elements of memory. Potential information/programs are such interaction which are possible in principle but are not currently observed (i.e. all potentially possible interactions between memory and SAFE elements). Process of actualization occurs when interaction between memory and SAFE commences; process of potentialization occurs when this interaction ceases²³.

Any information/program exists in a cycle of repeated potential and actual states – i.e. corresponding interactions between elements of memory and of SAFE should be observed. This situation resembles a changes in kinetic and potential energy for a swinging pendulum when it passes states of maximal potential (minimal kinetic) and maximal kinetic (minimal potential) energy²⁴.

If some information/program exists only in a potential form (i.e. its actualization is extremely improbable), it is possible to say that there is no such information/program at all. This statement allows us to avoid a certain methodological trap. If there were information/programs that could exist in a potential state only, one could think of a potential interaction of any element of

²¹ It is important that a system has at least two different states [Heylighen, Joslyn, 2001]

²² It has been revealed through practical applications of information theory and cybernetics that any control system is a kind of communication system; on the other hand, systems traditionally analyzed by information theory can be represented as regulation systems. Amazingly, spheres of practical application for both disciplines practically coincide. [Finnemann, 1999]

²³ Certainly, models of real information/cybernetic systems depend on a mode of system observation (evidently, it is possible to model only *observed* processes in a system). To model properly, it is critical to have appropriate *length* of observation (observation duration spans should be at least comparable with system lifetime or exceed it) and *completeness* of observation (measurement of system operation should be accomplished in all possible ways that, whenever possible, do not impact system integrity and do not disturb its natural operation properties (although this is not totally possible, as observer is always a part of system observed)).

²⁴ This is only a distant analogy. In case of discrete models, there exist only two discrete states of every information/program: an actual state of information/program interaction, and a potential state of information/program relation. In case of continuous models, however, a gradual actualization may occur.

memory with any element of SAFE – which would increase a quantity of information/programs in a system to infinity. But then one should assume existence of finite systems in which there exist infinitely various, never observed and never realized potential information/programs.

A proposed distinction between potential and actual information/programs allows a deeper understanding of loci and modes of information existence. Thus, any element of memory and any element of SAFE contain information/programs in their potential form. On the other hand, information/program cannot exist in actual form other than interaction between memory and SAFE elements.

It is traditionally thought that information exists in communication channel as a signal – which, in terms of our concept, means that information exists either in actual form as an interaction between memory unit of a sender/ receiver (during generation of signal or during its receiving), or in potential form (as a signal in a channel between a sender and a receiver).

It is also traditionally assumed that information is contained in a memory of a system. Indeed, it is located there in a potential form. For instance, computer read storage cells are not necessarily involved in its operation; however, information they store can be actualized when it is required. Similarly, DNA chains potentially contain information about various types of proteins; however, this information is only actualized during DNA interaction with complex cell micro-bodies in cytoplasm such as ribosomes and tRNAs.

It is also suggested that information can be stored in some external mediums (in terms of the presented concept, elements of SAFE). Road signs, memorials, works of art, drawings, books are just few examples of objects that store information in potential form; this information can be actualized when an object interacts with proper system with a memory. One curious case is represented by so called external mediums in computer (hard and flexible disks), which are in fact elements of SAFE (in respect to computer's internal memory), but which are frequently called storage memory devices.

Our approach to programs as memory and SAFE interactions may appear paradoxical (as it contradicts a 'common sense'). A program is never traditionally considered as interaction; it is always a content of memory, a set of instructions to be executed. In our opinion, this is true, but only partially: information in its potential form (as a potential interaction) is contained in a system memory, but in its active form it may only be implemented through interactions with SAFE elements. Program stored and executed are two different, closely related, states of any program.

An idea that information/programs are contained in SAFE elements might look even more paradoxical. Since SAFE is only defined relative to memory, every element of SAFE contains information/programs in latent form, as a 'mode of usage'. An axe 'contains' a program of chopping (at least its handle is suited for handling [Winston, Binford, Katz, & Lowry, 1983]), or a 'social thing' in Lewin's field theory provokes specific social acts [Lewin, 1950]. Some stimuli may invoke unconditional reaction, or chemical compounds may provoke enzymes to act. SAFE is also a storage of potential modes of information/cybernetic system operation in its interactions with its environment.

A similar idea has been proposed in works of Maturana, who notes that states of system activity (primarily living systems) represent interactions between an organism and its environment, and cannot be considered outside of this interaction [Maturana, 1983]. Similarly, 'affordances' in Gibson's perception theory are objects which can only be considered in terms of interaction between a biological system and its living environment [Gibson, 1986]. Also, this idea presents in social sciences paradigm (social perception, dispositions and expositions, stereotypes of perception and reaction). All these are examples of SAFE elements in actual information/program interaction.

2.4 Relativity of information

Within the bounds of our approach it is possible to elucidate and specify an issue of information ‘omnipresence’, as suggested e.g. by Louis Brillouin [Brillouin, 1956]. Brillouin’s approach, following (and extending) the Shannon’s notion of information, was radically physicalist, but it posed an important question whether information is found in all physical events or just in particular ones.

There can never exist information *in general*. Any specific information/program exists only as a part of operation cycle of some specific finite information system. Any element of SAFE can only be considered as some part of environment relative to specific information system (and can only be considered in a ‘context’ of this system). Therefore, information can be ‘omnipresent’ in a sense that any object in Universe can potentially interact with some information system that may have a potential memory about it (e.g. an observer of this object). On the other hand, information is ‘specific’ in a sense that any actual regular interaction occurs between a very specific part of some specific object in environment and a specific element of memory. Set of potential information/program interactions is not infinitely manifold. Only if an object in environment is represented in memory device, there exists (and can be realized) a proper information/program²⁵.

This shall necessary imply informational closure of a complex systems. Multiple objects of environment represent a potential ‘flow of information into a system’; yet, only those reflected in a system memory may actualize corresponding information/programs. A variety of information/programs is limited by the volume of system memory (formally, this will be considered further on).

A universal principle of *relativity of information/program existence* can be brought forward. If there is no corresponding element of system memory representing some object of environment, then, relative to this system, even in case of regular interactions with this object, there is no information/program²⁶. At the same time, relative to other system which possesses a proper element of memory, there exists a corresponding information/program. It is worth noting that even regular interactions of system and object of environment do not imply that this object is a SAFE element and that interactions with it are information/programs. Part of regularly reproduced interactions may in fact be e.g. an incidental, occasional factor in system operation, not being informational in respect to the set of memory elements of the given system. It is necessary to identify a correspondence between a given interaction and a proper memory element (e.g. through structural analysis of memory, that can easily be accomplished in case of artificial information systems and basic biological systems, e.g. genome decoding, and can be achieved with more difficulty for multi-cellular organisms and societies).

It should also be noted that a following paradox situation exists: if there is no *a priori* empirical data about a set of memory elements, it is not possible to distinguish between those interactions which are information/programs and those which are not (since memory represents environment objects in their regular interactions with a given system). Consequently, based only on observation data, one has to assume that all regular interactions between a system with memory and its environment are information/programs.

²⁵ Evidently, human senses are limited and are only adapted to some range of disturbances in environment (visible part of light spectrum, audible range of sound etc) which represent human SAFE. It is potentially possible to limit a cognitive ability of a human with her wide (and increasing) but still finite SAFE.

²⁶ For instance, radiation cannot be sensed, and so humans could not have any information about level of radiation until measurement devices have been invented that serve as perceptible mediums within SAFE (sound or light indicator) for non-perceptible objects outside of SAFE (radiation itself)

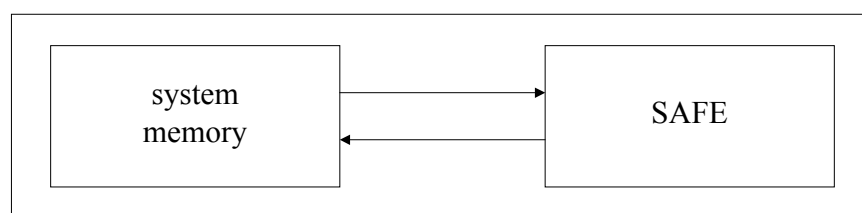
3. Flowcharts of information processes

3.1 Elementary information system

A basic scheme of information interaction can be considered. In elementary case (Figure 1), interacting SAFE and memory represent the simplest communication/regulation system. They consequently act as a source of signal (or a regulator) and a recipient of signal (or a subject of regulation). In order to interact, these two systems must have a unique basis for physical interaction, some kind of physical ‘similarity’ (just like a key ‘fits’ the lock, or a light ‘fits’ the eye).

A basic mechanic metaphor of elementary information system is two clutched cogs: two mutually dependent subsystems (cog-wheels), each can act as a signal / a regulator (a source of activity and movement) for the other.

Figure 1. Basic model of information/program interaction



Memory and SAFE in elementary information systems are isomorphic to each other. They represent two groups of physical objects and links (two physical systems), with a number of relations/interactions between these groups (set of information/programs). If there is no ‘reference system’, in respect to which properties of these two systems can be differentiated, then description of a basic information/ cybernetic system allows a certain voluntarism in a sense that decision about ‘roles’ of its components is solely to researcher’s convenience²⁷. For such a system, there may exist two equally rightful representations of what part is memory and what part is SAFE.

It is appropriate to describe this system as a model of elementary automate (or, elementary communicator), in a sense that it is a basic system where functions of regulation and communication are implemented. Objects and links that correspond to memory and SAFE in this system act as two physical poly-structural poly-functional pre-automata, which can only exist in regular interaction with each other. Since most information/cybernetic systems traditionally considered have a more complex structure and organization, then it is possible to call an elementary model of information/program interaction a pre-ICS (such systems may exist on basic levels of material organization, e.g. in complex chemical reactions where each of two interacting compounds may be represented as either SAFE or memory).

3.2 Information/cybernetic systems

In a more complicated case, elementary information/cybernetic system (pre-ICS) interacts “as a whole” with its external environment. Its structure and organization then can be functionally differentiated to

- a component that interacts (communicates/ regulates) with external environment, and
- a component that interacts (communicates/ regulates) with internal components, but not with external environment.

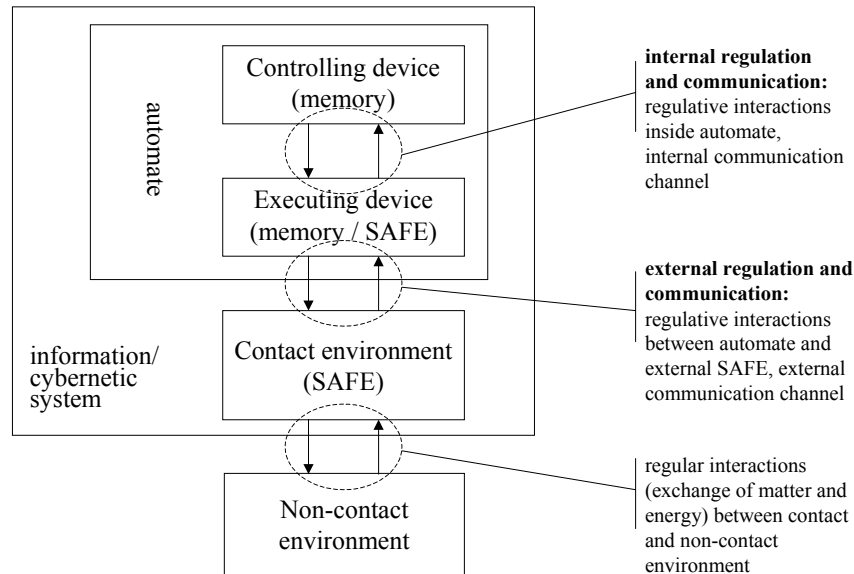
Since internal and external interactions are reproduced regularly, internal and external information/program interactions in this system would reflect each other.

²⁷ This situation resembles an attempt to define ‘top’ and ‘bottom’ in imponderability: if there is no some third object (e.g. a planet with its gravity field), ‘top’ and ‘bottom’ are defined in respect to observer’s own position.

Part of a system that directly interacts with external SAFE, participates (simultaneously or consequently) in two sets of information interactions; and thus its states are reflected both in internal and external relations of a system. This part of system acts as a ‘*external*’ memory for external SAFE, and at the same time as *internal SAFE*. A part that does not interact with external SAFE is an *internal memory* of a system.

In terms of cybernetic / automata theory, such system is a combination of automate (an aggregate of internal memory and internal SAFE), and its contact environment (specifically, its part which is an external SAFE). ‘Internal memory’ component acts as an internal control unit, and ‘internal SAFE / external memory’ component acts as an executing unit²⁸.

Figure 2. Cybernetic interpretation of basic information/ cybernetic system



A simple flowchart of information/cybernetic system of this kind is presented above (Figure 2). In this flowchart, a control unit and execution unit linked by direct connection and feedback (differentiated or monolithic) are unified into an automate. This automate interacts with a contact environment (its part which acts as an external SAFE). Contact environment is in its turn a part of environment (in fact, the rest of Universe outside/inside of automate). Contact environment is in regular (permanent) interactions with non-contact environment²⁹.

Information/cybernetic system of this type is an universal case of elementary two-level ICS. Its main features are (1) a distinguished controlling device (an internal memory of a system), and (2) an executing device linking controlling device to external environment. A fundamental (and the only material) difference of elementary ICS model from traditional cybernetic models (which can be generally described by this flowchart) is that external environment is a necessary component of a system³⁰.

²⁸ The emergence of two-level cybernetic systems as evolution of control is discussed in Turchin’s meta-system transition theory ([Turchin, 1977] [Turchin, Joslyn, 1989]) which may be a helpful tool in analyzing complex information/cybernetic systems.

²⁹ As an example of non-contact environment (that is not directly reflected in system memory), even an internal environment of a system may act. For instance, a human cerebrum does not possess internal tactile-kinesthetic receptors (and this allows neurosurgery under local anesthetic) In this sense, internal environment of a cerebrum is non-contact in terms of its information/ cybernetic model – although indirectly state of this internal environment may impact a system operation (e.g. presence of tumors and mechanical failures).

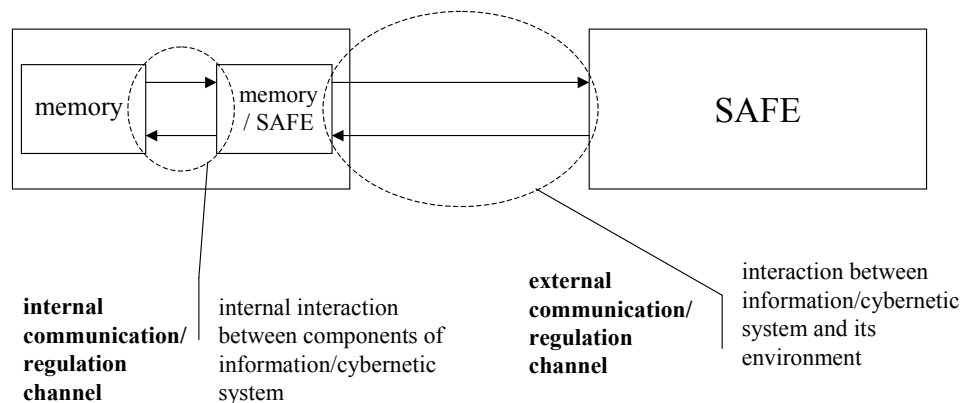
³⁰ Although, as it has been already mentioned, complex models of biological systems consider ecosystems of different layers in biosphere hierarchy, where population of some species and its econiche present a united, indissoluble whole.

3.3 Information/cybernetic systems: communication aspect

It can be shown that a basic information/cybernetic system is identical to basic model in Shannon's communication theory (Figure 3). This theory assumes there exist two objects separated in space: a source of signal (an object that generates a signal) and a recipient of signal (an object that receives a signal). A source and a recipient are connected through a medium (a communication channel). When a signal is translated: (1) it is coded (by a coder) from a source 'internal language' into a form suitable for its transportation in communication channel, (2) it is translated (transferred or stored) in a communication channel until it interacts with a receiver, (3) when it is received it is decoded into 'internal language' of a recipient.

In such system, a unit of information is determined through a typical (regular) interaction between a source and a recipient (i.e. through a typical signal interaction between an element of SAFE and a corresponding element of memory). We therefore suggest that information is not a 'thing' that is sent or received; it only exists (in actual form) as an interaction between what is being/ has been sent, and a sender/receiver.

Figure 3. Information system with differentiated components



An element of SAFE is a signal, which initially is naturally emerged or artificially created and further exists in an environment of information/cybernetic system. In terms of traditional theory of communication it can be typified as

- (1) a signal generated by a source at the 'entrance' to communication channel (in the process of coding/translation),
- (2) a signal after coding and translation, i.e. a signal inside communication channel, or
- (3) a signal at the 'exit' from communication channel (in the process of receipt/decoding).

Such description allows to distinguish two types of SAFE elements. First, there are natural objects that exist independently from the given information system (a physical reality in potential relations/ interactions with a system). Second, there are various natural/artificial objects that exist in form of 'delayed' (or, postponed) interactions, as signals translated by other information system that either are transferred or are stored in a communication channel (sometimes a 'delay' can be minimal, as in 'demonstration-imitations' social rituals). Books in libraries, web-pages, architectural monuments and other cultural samples are just few examples of signals inside a communication channel. In all real systems it is possible to precisely distinguish between these two types of SAFE elements, although there is always some space get deluded³¹.

An element of memory can be described as a corresponding 'interpretation', a result of signal transformation for structure and content of internal memory. Then, element of memory can be represented as a 'signal' outside of communication channel (after receipt and decoding). In ideal

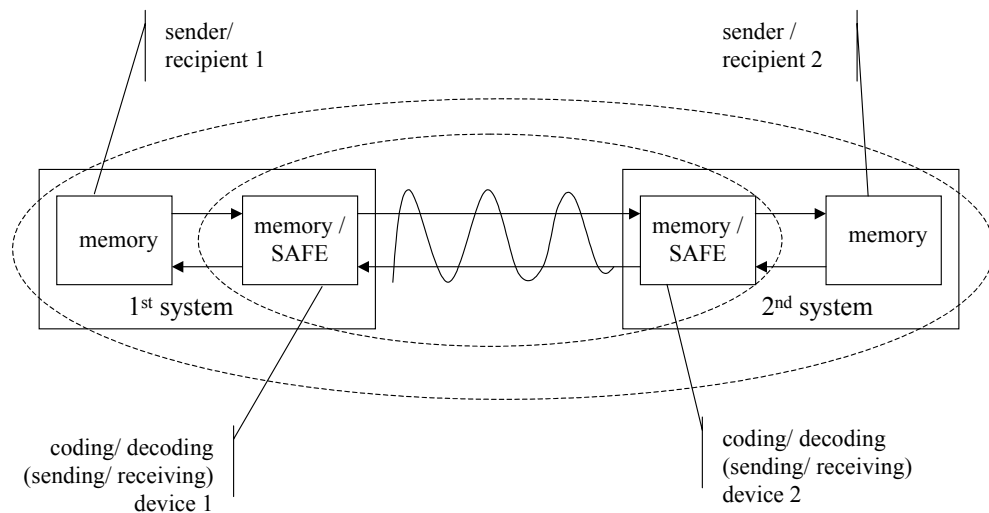
³¹ For example, Sumerian cuneiform has been identified by some archeologists as traces of insects or worms, and by some as a production activities spin-off, like a scratched anvil

case (communication without errors) element of memory is an isomorphic representation of a corresponding element of SAFE.

3.4 Communication of two information/cybernetic systems

By assuming that external SAFE of an information/cybernetic system may contain another information/cybernetic system, it is possible to describe a contact communication model. Each system acts as a (part of) SAFE for other system.

Figure 4. Information/program interaction of two ICSs



In such information/program interactions, each of two systems interacts with its own SAFE – and, therefore, in such system there is evidently more than one information interaction (internal interaction inside 1st system, external interaction between 1st and 2nd system, and internal interaction in 2nd system). This situation can be easily imagined if one considers e.g. communication between a human and a computer: each of these systems has its own information related to properties and content of its own memory (in computer, an information interaction corresponds to changes in chip circuit states; in human, it corresponds to excitation of brain cells; between human and computer, it corresponds to transformations of environment like light and sound waves)³². Human to human social communications are similar: if organization of brain is different for each person (and there are no two man alike), then same physical objects or social acts may have totally different interpretation for each of them, i.e. completely different information/programs are actualized³³.

4. Dynamic aspect of information/ cybernetic systems

4.1 Cycles of information/ cybernetic systems operation

Information/ cybernetic system is a dynamic system that passes through a certain set of states (information/program interactions between memory and SAFE). These states are regularly reproduced³⁴ in some (certain pre-determined) sequence forming a cycle of ICS operation³⁵. In

³² Similar ideas also discussed in [von Foerster, 1986]

³³ In this sense, a famous hermeneutic principle ‘what is said is not what is heard’ has a certain universality. In a case of interaction between two information systems with different organization and content of memory, information in these systems will be different.

³⁴ In accordance with a requirement of regular actualization of every information/ program in set of potential information/programs, as introduced above (Chapter 2.4).

³⁵ A macro-cycle is therefore as a dynamic attractor. If macro-cycle only directs to a final state (as in some mechanical devices) then this final state can be described as ‘a focus point’, if a sequence of information/program, repeated in the same loop, is executed, then it is a case of limit cycle. If variations in dynamics occur, then it shows

terms of system dynamics, all information/programs should be studied respective to full cycle of system operation (macro-cycle).

As it has been discussed above, regulation implicitly implies that there exists some ‘goal’ (or final state) for it. Then, a concept of information/ cybernetic system should include a direction of regulation in a macro-cycle, or final ‘target’ state (which is a certain state of both automate and of SAFE)³⁶. For natural complex systems, this final state is also an initial state, as they can only exist in self-reproduction and self-maintenance cycle; accordingly, natural information/cybernetic systems (as emerged through a process of evolution of matter) are inevitably complex self-reproductive and self-maintaining (or, autopoietic) systems³⁷.

For a ‘chaotic’ macro-cycle, sequences of information/programs are arbitrary; thus, any state can be initial and any state can be final. In chaotic operation reproduction of any state is a random event that is not determined by previous states of a system; it is therefore impossible to say that a system directs to some final state. If ICS operation is directed a certain final state, then realization of absolutely chaotic macro-cycle may not occur.

It is evident that macro-cycle is not a completely arbitrary set of information/programs in arbitrary sequence; it is a quasi-targeted process related to a teleological aspect of ICS operation³⁸. It is a ‘target’ that determines necessity and adequacy of set of information/ programs in a macro-cycle: a certain sequence of operations (interactions between memory and SAFE) *must* be accomplished to achieve this final state. Moreover, these operations must be accomplished in a certain sequence. Most explicitly, necessity of certain order of information/programs realization can be seen in cases when results of transformation of one information/program enter as SAFE element into another information/program: e.g. a consequent processing of some product by an industrial robot, or a ritualized behavior of social animals, including human (when, in order to achieve a final state, all information/programs must be implemented, and only in a specific sequence).

If system macro-cycle has a target state, it naturally incorporates nonrandom ordered sequences of information/programs. A limit case is one single ordered sequence: a linear determined macro-cycle. Potential emergence of such sequences is driven by two main factors:

- (1) each next information/program may involve a result of previous transformation as an element of SAFE (e.g. in technological cycles), or
- (2) in SAFE, there may exist naturally reproduced sequences of SAFE elements (e.g. due to contact and non-contact environment interaction: day/night, summer/winter cycles etc).

In most cases, a macro-cycle of ICS can be separated to a number of sub-cycles, or meso-cycles. Each of these sub-cycles is indivisible in respect to a certain type of (targeted) operation. Every sub-cycle can be in its turn 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). Accordingly, it is possible to identify meso-cycles of certain type of operation (e.g. reproduction sub-cycle of mammals), and then to decompose it by lower level sub-cycles (e.g. reproduction may include elements of breeding ritual and breed care). Meso-cycle of maximal length is equivalent to

a dynamics of a strange attractor. As it is shown by Prigogine and Stengers [Prigogine, Stengers, 1986], this is the most typical case in complex system dynamics.

³⁶ A final state of ICS corresponds to a ‘target state’ of functional systems (which assumes some result ‘acceptor’ in internal memory) in functional system theory of Russian physiologist P. Anokhin [Anokhin, 1978]. A concept of macro-cycle is a direct analogy of ‘behavior continuum’ in functional system theory. However, this interesting attempt to build up a general information/cybernetic theory suffered from overlooking many interesting implications that arose with it.

³⁷ Yet, the opposite must not necessarily hold, as artificially designed information/cybernetic systems are not all autopoietic

³⁸ This goal directedness, as Heylighen and Joslyn point out in their review, can be understood as “suppression of deviations from an invariant goal state” [Heylighen, Joslyn, 2001].

macro-cycle. A minimal (and further indivisible) meso-cycle is an elementary cycle of operation operation (or micro-cycle)³⁹.

A micro-cycle, or a minimal unit of ICS macrocycle, can be considered as a functionally *monolithic* mode of operation, in a sense that (1) it realizes a single function of memory and SAFE transformation, and (2) it is further indivisible within the bounds of information/cybernetic model of a given level of abstraction. In terms of information/program content, it is an interaction between one type elements of SAFE and one type of elements of memory (that is, it corresponds to a single information/program). As a dynamic manifestation of information/program, a micro-cycle is always localized in pre-automata interaction (with properties of memory and SAFE) – either inside an automate (internal memory and internal SAFE), or between an automate and external SAFE.

Cycle typology in information/cybernetic systems is presented below (Table 2).

Table 2. Typology of cycles in respect to information/program levels of organization

<i>Cycle type</i>	<i>Information/program organization</i>	<i>Properties</i>
elementary cycle of operation (micro-cycle)	actualization of a single information/program	cannot be decomposed to lower level (lower complexity) cycles on a given level of abstraction
sub-cycle (meso-cycle)	combination of several information/programs (in certain sequence)	can be decomposed to meso-cycles of lower level and microcycles; has a determined goal
ICS operation cycle (macro-cycle)	(repeated) cycle with a final major goal state and a full variety of information/ programs	can be decomposed to meso-/ micro-cycles; repeated cycle in self-maintaining and self-reproducing systems

4.2 Sources of activity in information/cybernetic systems

It is important to discuss a source of activity in (a direction of) information/program interactions in ICS. In basic communication system, information interaction is initiated by a SAFE element (a signal) which appears (or emerges) in a SAFE. In elementary regulation system, a regulative function is controlled by a program contained in a system memory. Accordingly, regulatory interactions have an opposite direction (and a different source of activity) than communicative interactions. An information/program interactions which unifies these two types of interactions, is equivalent to both regulatory and communicative interactions. It may look like a paradox, but there is none.

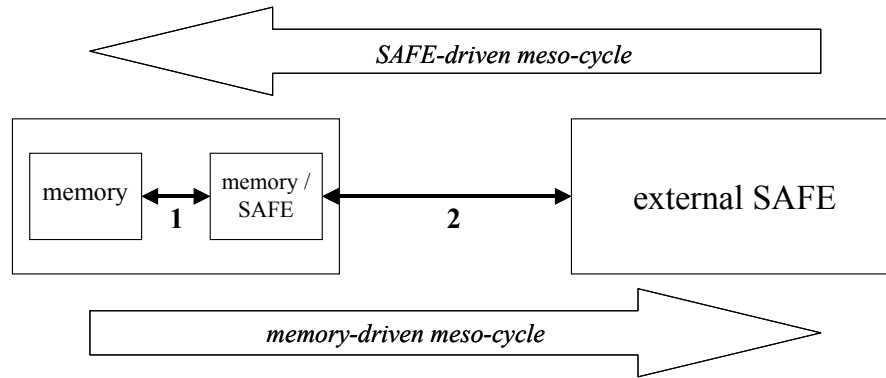
Any actualized information/program relation is an interaction, and interaction *always* involves two parties. In elementary physical or chemical processes it is rarely possible to which of two interacting objects is a process initiator. Even more so, it is impossible to identify ‘initiators’ in complex material interactions. Moreover, actualization of an information/program is conditioned by a simultaneous presence of SAFE and memory elements in the given space and time of information/cybernetic system. It is why information is contained in both SAFE and memory.

A source of activity in ICS can either be internal memory, or external SAFE. It is therefore possible, even for elementary information/cybernetic system, to distinguish between two types of meso-cycles, or sub-cycles of a macro-cycle (Figure 5).

If first an internal interaction is actualized (interaction 1 in the Figure), and then through poly-functional execution unit an external interaction (interaction 2 in the Figure) is actualized, then a meso-cycle is memory-driven. If first an external interaction (2) is realized, and then internal interaction (1) is realized, then a meso-cycle is SAFE-driven.

³⁹ Decomposition of system activities is considered by Sussman [Sussman, 1975], as ‘goal/sub-goal interactions’. Similar approach can be found in [Turchin, 1977]

Figure 5. Two types of meso-cycles in information/cybernetic system



Accordingly, SAFE-driven operation can be defined as a type of system operation in which sequence of information/program interaction is determined by presence (or appearance) of specific elements in external SAFE. On the opposite, memory-driven operation can be defined as a consequent actualization of information/programs from internal memory.

In general, memory-driven system operation can be characterized by following features. First, in this type of meso-cycle, an information/program (or a rigidly fixed sequence of information/programs) from internal memory is actualized. Second, a system ‘expects’ all elements of SAFE to present in actual external SAFE, all at once or in a rigid sequence that corresponds to information/program sequence (although in reality some elements may not be there, forcing a meso-cycle to halt). Third, as a rule, information/programs of memory-driven meso-cycle are actualized after a SAFE-driven information/program (or a meso-cycle) which could roughly be called a ‘touch-string’. The only exception is for macro-cycles that completely exclude SAFE-driven meso-cycles (e.g. a linear determined macro-cycle).

A memory-driven type of operation can be realized in several variations. In a basic case, memory-driven meso-cycle is actualized when all necessary elements present in SAFE. This type of sub-cycle can also be observed when SAFE element for every next interaction is a result of previous interaction, or several interactions (a case of sequent transformation of SAFE elements, e.g. in production technologies like a conveyor assembly, or in a multi-cellular organism digestion system).

It is also possible that necessary elements do not present in external SAFE, but a rigidly fixed sequence of information/programs requires a system to implement a given type of operation. Such behavior can be observed for animals extracted from their standard biotope (e.g. wrong reflexes and ineffective instincts [Dewsbury, 1978]). Another example of memory-driven meso-cycle in absence of actual SAFE elements can be identified in magical and religious rites (which, as it have been shown, represent replicated sets of actions without a proper substrate [Levi-Strauss, 1962]). A memory-driven type of operation is sometimes a case of ‘busy wait’ for interactions with SAFE (e.g. idle operation of industrial robots and other technical devices).

SAFE-driven behavior represents information/programs (kind of ‘touch string’) in a field of corresponding elements of external SAFE. Accordingly, information/program or a sequence of information/programs actualization depends on what element of current SAFE will be most rapid or most intense to interact with memory. Consideration of SAFE-driven operation allows to explain a branch-like structure of macro-cycle for many real complex systems, a conditionality of complex ICS behavior (‘if-then’ switches, and switch of a operation mode depending on certain conditions)⁴⁰.

⁴⁰ If a system operates in ‘reactivity paradigm’ (as assumed in behaviorism), i.e. it only reacts to stimuli from its environment, then it executes a SAFE-driven meso-cycle. If a system operates in ‘activity paradigm’, i.e. it executes some functions directed towards a final state, then it operates as a system with memory-driven meso-cycle.

This logic is applicable both to interactions between automata and its external SAFE as in ICS (Figure 3), and to interactions between two communicating automata (Figure 4).

4.3 Adequacy/inadequacy and efficiency/inefficiency of information/programs

It is possible to find many confirmations to the fact that there exist non-isomorphic (and not only one-one) interactions between elements of memory and SAFE. In DNA reduplication a one-one interaction is so-called complimentary junction of nucleotides (pairs: adenine-guanine, thymine-cytosine), but periodically also non-complimentary junctions occur. Another case of non-isomorphic interactions are wrong reflexes and inefficiency of instinct movements in zoo-psychology, e.g. in a case described by Lorenz, a fox follows an inherited behavior program and tries to conceal a piece of meat in a concrete floor of a cage [Lorenz, 1965]. Finally, distortions in technical means of communication is another typical case, a problem that led to emergence of information theory itself.

Although memory and SAFE are defined as two isomorphic sets of objects, it is not implied that one-one relations of memory and SAFE describe a variety of potential interactions between them. In principle, every element of SAFE can be related to a number of memory elements (i.e. to participate in several qualitatively different information/program interactions). Similarly, every element of memory can poly-functionally participate in a number of different memory-SAFE interactions. A one-one interactions are only most frequent, and there is some reason why.

Information/programs are qualitatively different in respect to a macro-cycle and its sub-cycles. All information/programs can be distinguished on the degree of adequacy/efficiency. It is possible to define adequacy/efficiency roughly as following: if actualization of some set of information/programs ensures a macro-cycle (or its sub-cycle) which is optimal according to some criterion, then this set of information/program is adequate/efficient. All other sets of information/programs would be inefficient. The issue is a criterion of optimality.

Two such criteria can be suggested (other criteria can also be thought of)⁴¹:

(1) *evolutionary* criterion, or *survival* criterion, can be described as following: actualization of a given set of information/programs assures a maximal reiteration (realization of a maximal number of copies) of a given macro-cycle / meso-cycle.

(2) *functional* criterion can be described as following: actualization of a given set of information/programs allows to achieve a maximal efficiency ratio (or maximal production of net energy, in terms of thermodynamics) in a given macro-cycle / meso-cycle.

These two criteria appear to be a summary of traditional criteria of adequate/efficient operation of complex technical and biological systems. These criteria are

- adequate identification (or exact recognition of signals, when a predator is recognized as a predator, or a symbol as a symbol);
- efficient transformation, when a required result is achieved with maximal accuracy and minimal 'cost' (time and energy).

By considering what 'adequate identification' specifically is, one may discover that an adequate system has a greatest chance of maximal survival. A nestling that learns to tell auk from hawk (or 'identify adequately') will hide in case of danger and will ensure a greater lifetime for itself. An automatic system of image recognition (e.g. printed text or sound patterns) that adequately recognizes objects will have a maximum 'lifetime' without being ousted by better technical systems (much like any other technical device in co-evolution with social system). The less recourses a system takes to recognize critical signals, the more it saves for other activities; thus, a functional criterion is also fulfilled.

⁴¹ These criteria refer primarily to natural complex systems; however, they also partially fit for artificially designed information systems.

Similarly, an ‘efficient transformation’ corresponds to both evolutionary and functional criteria. Achievement of some ‘required result’ with maximal efficiency assumes that there exists a final state of transformation that has to be achieved with maximal speed and minimal energy – i.e. an efficient transformation implicitly assumes realization of functional optimality criterion. In its turn, a ‘required result’ also assumes a reason why this result is required. In any real (not abstract) information/cybernetic system, requirement is determined by a survival, a maximal lengthy reiteration of system macro-cycle – or, an evolutionary criterion.

A system capable to adaptation tends to eliminate inadequate/inefficient information/programs, thereby increasing overall adequacy/efficiency of its macro-cycle⁴². Thereby, frequency of adequate/efficient information/programs is higher than frequency of those inadequate/inefficient. It is this property that allows to model most regularly occurring interactions between elements of memory and SAFE as ‘adequate/efficient’⁴³.

5. Quantity of information

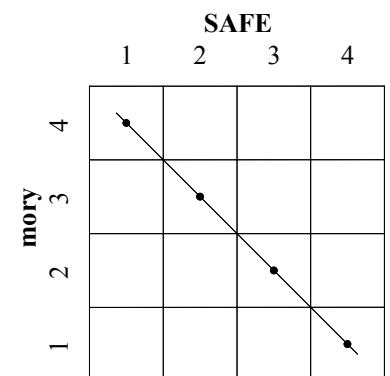
5.1 Matrix model of information process

Although memory and SAFE are defined as two isomorphic sets of objects, it is not implied that one-one relations of memory and SAFE describe a variety of potential interactions between them. In principle, every element of SAFE can be related to a number of memory elements (i.e. to participate in several qualitatively different information/program interactions). Similarly, every element of memory can poly-functionally participate in a number of different memory-SAFE interactions.

A full potential information content of every memory element is a set of all potential information/programs associated with it. Similarly, there also exists a full information/program content for every element of SAFE. A set of all information/program interactions possible within the bounds of a given information/cybernetic system, will define its information/program variety⁴⁴.

This situation can graphically be described by a matrix (similar to a combination matrix such as a Pannet square used in genetics) that combines memory elements on vertical side and corresponding SAFE elements horizontal side. Relations and interactions between memory and SAFE will correspond to combinative cells of this matrix. Theoretically, a relation between any element of memory and any element of SAFE is possible; yet, in practice some cells will be ‘deleted’: corresponding potential interactions will never actualize.

The main diagonal of a matrix represent adequate/efficient interactions (interactions between memory and SAFE elements that isomorphically correspond to each other)⁴⁵. All other cells represent inadequate/inefficient interactions. The basic matrix corresponds to elementary information system of interactions between memory and SAFE introduced in Chapter 3.1 (Figure 1).



⁴² A mechanism of pleasure is one example of natural stimulation of evolutionary preferable activities (satiation, reproduction etc). In social systems, however, it leads to various social deviations (alcoholism, narcotism, criminality etc.) that work against the criteria of adequacy/efficiency, and still cannot be totally excluded from the system (this is a more complex case of conflict between layers of social organization, which involve social and biological layers with different criteria for adequacy/efficiency).

⁴³ However, if a new element of memory emerges, with some corresponding SAFE element, it is not possible to realize whether it is adequate/efficient or not, before several repetitions of a macro-cycle.

⁴⁴ A concept of variety as a quantitative measure of distinct states of a system has been introduced to cybernetics by Ashby [Ashby, 1964].

⁴⁵ Since we have assumed that there is at least a one-one relation between each element of memory and SAFE (there cannot be an memory element without a corresponding SAFE element, and vice versa), then a matrix is necessarily

Such matrix per se is a case of classic theory of information, when a signal from the transmitter is not necessarily equivalent to a signal received by a receiver. There may be errors and distortions emerging in actual information interaction (e.g. noises in a communication channel that may corrupt an original signal). There are two opportunities for the outcome:

- (1) various elements of memory and SAFE are qualitatively completely different from each other (as in a discrete case, e.g. '0' and '1'), and then any distortions in a signal lead to a 'completely inadequate' identification, or
- (2) neighboring elements have certain qualitative similarity (as in continuous case, e.g. grades of light), and signal distortion leads to 'not completely adequate' identification⁴⁶.

A flowchart of information/cybernetic system introduced in Chapter 3.2 (Figure 2) can be similarly represented as a matrix model. It may be represented by a junction of two matrices that correspond to an internal and an external information/program interaction. These matrices may be joined by a poly-functional component, that corresponds to an execution device in automatic regulation system, or to coding/decoding device in communication network of internal memory and external SAFE.

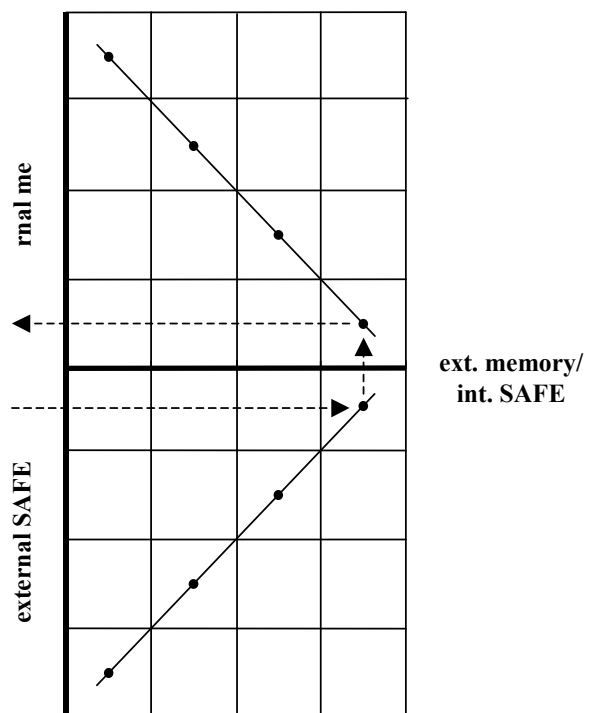
Initial interaction with external SAFE (e.g. appearance of some new objects near the system, that initiates an information/program in external communication / regulation channel) is adequately reflected in internal communication / regulation channel. If there are no distortions in interaction (i.e. only isomorphic interactions are actualized), then such sequence of interactions corresponds to a homogenous transitive reflection of external SAFE element into internal memory element.

If an interaction occur with distortions (is non-isomorphic), then a distortion can be observed either in external channel, or in internal channel, or in both. In this case, there is no correspondence between an external SAFE element and an internal memory element. There is the same element that participates in internal and external interaction: a poly-functional element of external memory / internal SAFE.

Poly-functionality of external memory / internal SAFE is one possible mechanism that stands behind a 'structural coupling' in autopoietic theory [Maturana, 1988]; yet the latter refers only to autopoietic systems, while the former to all systems with memory.

Same logic is applicable to the reverse situation, when internal information/ program interaction is equivalently reflected in external interaction. In case of no distortion, an element of internal memory is homogenous transitively reflected in external SAFE.

Two-matrices model explicitly demonstrates a realization of cause-effect relations in automate-environment interactions through a poly-functional execution unit. Accordingly, if a cause of system activity is in external SAFE (first external and then internal interaction occur), it is a SAFE-driven meso-cycle. If a cause of activity is in internal memory (first internal and then external interaction occur), it is a memory-driven meso-cycle.



square.

⁴⁶ In photography, utilization of filters that distort initial light conditions but leave a whole image recognizable is a very popular artistic technique.

This differentiation allows to understand why a poly-functional external memory/ internal SAFE component in ICS is an execution unit⁴⁷. This part of an information/ cybernetic system is not, and typically cannot be, an immediate initiator of information/program interactions: it transfers / codes either external environment states into internal information/programs (similarly to receptor function), or internal memory states into external information/programs (similarly to effector function)⁴⁸. An execution unit serves as an (interacting) intermediate between internal memory and external SAFE (and each of these interactions may be a source of distortions).

One key topic in second-order cybernetics was a discussion of referential and self-referential systems [von Foerster, 1974]. A matrix model brings this evident: a system of n-th degree of reference (or representation) is possible in a n-layer memory (representations of representations of representations...); therefore, a process of reference cannot be infinite, there will be as many references as there are memory layers (a virtually 'infinite' self-reference is possible in closed circle loops where each memory is poly-functionally a SAFE to some other memory: a 'stupid infinity', like two mirrors reflecting each other). Such models can easily be constructed within matrix model, and they would be just one example of complex information/cybernetic system with several layers of information and control.

An example of matrix model of an elementary information/cybernetic system (a Watt's governor) is presented in Appendix 1.

5.2 Measures of quantity of information/programs

Based on the matrix model, formal measures of information/program quantity can be suggested. The measures suggested here may indicate a potential path of mathematization for concepts introduced.

Definition of information/program matrix

Let $M=\{m_1, \dots m_k\}$ be a set of k memory elements, $E=\{e_1, \dots e_l\}$ be a set of l corresponding SAFE elements. Since it is required that one-one relation exists for each element, then $k=l$.

Let $(m_i e_j)$ be information/program interaction between i-th element of memory and j-th element of SAFE; a set of interactions $M \times E$ defines information/program content of the given system⁴⁹. Then, elements where $i=j$ are adequate/efficient information/programs, while those where $i \neq j$ are inadequate/inefficient.

Measures of information/program variety

It is possible to associate each interaction $(m_i e_j)$ with its relative frequency, or probability, P_{ij} (values form a probability matrix $\|P\|$)⁵⁰. Then, matrix of actualization $\|A\|$ is formed as

$$A_{ij} = \begin{cases} 1 & \text{if } P_{ij} > 0 \\ 0 & \text{otherwise} \end{cases} \quad (1.1)$$

which means that all *possible* interactions are marked as 1s, and those impossible as 0s.

Then, a measure of quantity of full information/program variety is

$$V_F = \sum_j \sum_i A_{ij} \quad (1.2)$$

and quantity of adequate/inadequate variety is

$$V_A = \sum_j \sum_i A_{ij} \quad \text{for } i=j \quad (1.3)$$

⁴⁷ Few examples of such a component of ICS are input-output devices in robot-computer technique and is of receptor-effector system in multicellular organisms

⁴⁸ There may be an exception: malfunctioning receptor/effector may both ineffectively percept/transform external environment and interact with internal memory (e.g. a broken robot manipulator, or a damaged limb). In some cases, it is also possible that receptor/effector devices emit 'phantom signals', e.g. well-known phantom pains [Sherman et al. 1996].

⁴⁹ Another way to treat system-environment on activity basis is considered in [Agre, Horswill, 1997]

⁵⁰ This assumption is used as a starting point in Shannon's theory of information.

Quantity of inadequate/inefficient variety is

$$V_N = \sum_j \sum_i A_{ij} \quad \text{for } i \neq j \quad (1.4.1)$$

or

$$V_N = V_F - V_A \quad (1.4.2)$$

since

$$V_F = V_A + V_N \quad (1.4.3)$$

Evidently, a number of possible potential interactions is between a number of one-one interactions of memory and SAFE (that is, quantity of diagonal elements), and a number of all possible combinations of memory and SAFE (that is, a number of all elements in the matrix):

$$k \leq V_F \leq k^2 \quad (1.5)$$

A number of adequate/efficient interaction is always equal to number of memory (or SAFE) elements (one-one interactions *always* occur in a system⁵¹):

$$V_A = k \quad (1.6)$$

Then, a quantity of inadequate/inefficient information/program variety is

$$0 \leq V_N \leq k^2 - k \quad (1.7)$$

The rate of efficiency in information program variety is given by the ratio

$$\xi_V = V_A / V_F \quad (1.8)$$

which is maximal when $V_F = V_A = k$. If a system is capable to eliminate inefficiencies, then ξ_V may increase over time⁵².

The law of requisite variety, as introduced by W. Ashby [Ashby, 1964], can be re-considered and re-stated (based on (1.5)-(1.8))⁵³:

- A quantity of information/program variety must be greater to variety of controlled objects or events (various elements of SAFE). If there is no memory element for the given object or event in environment, then there is no information/program that can control it.
- On the other hand, an upper bound of system variety can be pointed out: it is the square of controlled environment disturbances (SAFE elements). In efficiently operating information/cybernetic system, a variety of controlling information/programs tends to a number of SAFE elements.

Consideration of information/program repetitions

A matrix of probabilities for real information/cybernetic systems is derived from interaction observations. Each interaction ($m_i e_j$) has number of observations Q_{ij} (forming a matrix of observations $\|Q\|$), a total number of observations $T = \sum_j \sum_i Q_{ij}$. An estimation of matrix of probabilities is derived from the matrix of observation as

$$\|\hat{P}\| = \frac{1}{T} \cdot \|Q\| \quad (2.1)$$

Evidently, this estimation tends to $\|P\|$ when $T \rightarrow \infty$.

Then, let R be number of reiterations of macro-cycle during the period of observation. An estimation of matrix of information/program frequency in a macro-cycle can be obtained as

⁵¹ Unless this system is specifically designed artificially to realize only inadequate/inefficient information/programs

⁵² This idea fits in well with Complex Adaptive Systems theory, whereas specific mechanisms of adaptation may vary significantly [Waldrop, 1992]

⁵³ It is well-known that this law in its stronger form 'the variety of the control system must be equal to or larger than the variety of perturbations in order to achieve control' does not hold in general [Heylighen, 1992]. Yet, all counterexamples fit well into a suggested refined form of the requisite variety law.

$$\|\hat{F}\| = \frac{1}{R} \cdot \|Q\| \quad (2.2)$$

which tends to some 'true' frequency matrix $\|F\|$ when $T \rightarrow \infty$.

An average length L of a macro-cycle is then determined as

$$\hat{L} = \frac{T}{R} \quad (2.3)$$

$$L = \lim_{T \rightarrow \infty} \frac{T}{R}$$

then a relation between $\|P\|$ and $\|F\|$ is

$$\|F\| = L \|P\| \quad (2.4)$$

A matrix $\|F\|$ allows to introduce following measures, similar to (1.2)-(1.4):

a. full quantity of information/programs with reiterations:

$$I_F = \sum_j \sum_i F_{ij} \quad (2.5)$$

b. quantity of adequate/efficient information/programs with reiterations:

$$I_A = \sum_j \sum_i F_{ij} \quad \text{for } i=j \quad (2.6)$$

c. quantity of inadequate/inefficient information/programs with reiterations:

$$I_N = I_F - I_A = \sum_j \sum_i F_{ij} \quad \text{for } i \neq j \quad (2.7)$$

From (2.1), (2.4), and (2.5),

$$I_F = L \quad (2.8.1)$$

and

$$I_A \leq L \quad (2.8.2)$$

$$I_N \leq L - I_A \quad (2.8.3)$$

If it is assumed that every information/program must be actualised in a macro-cycle at least once, and if it is assumed that all adequate/efficient information/programs must be actualised (following the principles introduced above), then

$$V_A \leq I_A \quad (2.8.4)$$

$$V_F \leq I_F \quad (2.8.4)$$

The rate of efficiency in macro-cycle is given by the ratio

$$\xi_I = I_A / I_F \quad (2.9)$$

If $\xi_V = 1$, then $\xi_I = 1$.

Dynamic aspect

All the measures discussed above, consider a quantitative but not dynamical aspect of information/cybernetic system. As it has been suggested, a sequence of meso-cycles is directed towards some 'goal' state, which implies that not every combination of information/programs is possible, and even not every combination of adequate information/programs is adequate. Such aspects of information/cybernetic system dynamics are well elaborated in abstract automata theory (e.g. [Arbib, 1969]); it is not profitable to go into details here.

However, it is worth noting that measures of information/program quantity with repetitions (2.5)-(2.7) are only indications of information/program capacity. That is, they do not indicate what is a specific order of information/programs in a macro-cycle, and whether this order is

unique (or – how many alternative macro-cycles allow to achieve the same goal state)⁵⁴. The same, however, applies to more traditional measures of quantity: e.g., it has been suggested that Shannon’s measure of information quantity represents an information ‘package’ capacity [Korogodin, Korogodina, 2000]. This aspect of macro-cycle dynamic structure is to be developed further.

Traditional measures of information quantity

From all definitions of information quantity, the largest attention has been paid to a quantitative measure suggested by Shannon [Shannon, 1948] and that suggested by Kolmogorov [Kolmogorov, 1965]. Both of them can be obtained within the suggested matrix model.

A Shannon’s measure of “quantity of information” can be obtained based on matrix $\|P\|$:

$$I = \sum_i \sum_j \frac{P_{ij}}{P_i Z_j} \quad (3.1)$$

where

$$P_i = \sum_j P_{ij} \quad (3.2.1)$$

$$Z_j = \sum_i P_{ij} \quad (3.2.2)$$

This measure can be described as an integrated characteristics of a matrix $\|P\|$, showing a ‘concentration’ of information/programs. It reaches its maximum when all states (information/programs) are equally probable, and is reduced when a number of potential states reduces. The measure is therefore an indicator of ‘inner uncertainty’ in a basic information/cybernetic system as represented by elementary matrix model.

A measure of Shannon, also interpreted as a measure of ‘uncertainty reduction’, is relevant when a function of ‘expectation’ is implemented in the signal receiver. Then, the higher probability of a signal, the lower “quantity of information” obtained by a receiver. But then, ‘expectation’ function can only be implemented as a memory that produces ‘expectations’. It is why Shannon’s model must necessarily be at least a two-level system: an internal interaction that ‘produces expectations’, and the external interaction that ‘receives signals’, as in Figure 3. In our approach, the expression (3.1) does not measure ‘information quantity’; it is one possible indicator of a uncertainty degree of external information/program interaction for internal information/program interaction.

A Kolmogorov-Chaitin measure is formally defined as following (from [Li, Vitanyi, 1997]). Algorithmic complexity of an object x (a string, or any constructive object) can be described as the *minimal* length of a program p such that execution of program p by universal Turing automate U produces x :

$$K(x) = \min |p|: U(p)=x \quad (3.3)$$

A conditional measure of complexity is defined as

$$K(x|y) = \min |p|: U(p, y)=x \quad (3.4)$$

that is, minimal length of a program to produce object x given object y .

Then, information in object y about object x is

$$I(y:x) = K(x) - K(x|y) \quad (3.5)$$

The paradoxical thing about Kolmogorov’s definition is that it defines information through information. A universal Turing automate is still *an automate*, with a set of instructions (or information) that determine its operation. Constructive measure is defined in respect to this automate, but it does not explain what information actually is.

⁵⁴ For sake of simplicity, we may assume that macro-cycle is linear and unique; however, this is frequently not the case.

If Turing automate is represented as a matrix of interactions between internal states (states of memory) and tape states (states of SAFE) in the evolution to a target state x (which can be represented as the final state of a macro-cycle), then, length of this evolution will make up at least p information/programs (that is, a length of optimal macrocycle, or L when $I_F=I_A$), as in (3.3). If a system is provided with element y in its actual environment, then its macro-cycle is reduced to $L_2 \leq L$, as in (3.4). Then, a “quantity of information” in y is a number of information/programs to produce y from initial state (or achieve a state when y is in actual SAFE), that is, a number of information/programs that refer to y , as in (3.5).

Note that Turing’s automate is also represented by at least two matrices: one represents external interactions between system (automate) states and environment (tape) states, while the other is internal interactions between internal memory and execution unit that define rules of automate operations.

6. Conclusion

It has been discussed widely that re-consideration of information concept is necessary for successful utilization of information approach in biological, social and human sciences. All these spheres seek for new, and possibly unifying, paradigm. Autopoiesis and cybersemiotics are good moves forward. Yet their definition of information as the property in living ‘autopoetic’ systems is somewhat self-referencing: living systems are informational, and informational systems are living. We believe there is information *outside* of the living systems, as long as they are systems with *memory*.

By considering memory in its interactions with environment, it becomes evident that both systems undergo a mutual change: a change in memory may be called ‘representation’ (‘identification’, ‘perception’), and the content of this interaction is and information, and change in environment can be called ‘transformation’ (‘regulation’, ‘control’), and the content of this interaction is a program. An information and cybernetic systems are in fact representations of the same: a complex information/cybernetic systems with macro-cycles of information/programs.

A concept of information suggested in this article appears to be a promising way to re-consider information/cybernetic models of complex systems, such as biological and social systems. An application has been found e.g. in our recent models of self-reproducing societies [Luksha, 2002], as well as in modeling of biological self-reproductive systems [Luksha, 2003]. We believe it may be fruitful to share these ideas on re-consideration of information theory, by suggesting that studies of systems with memory may become a new efficient focus for the Foundation of Information Science.

It may well be that a language of this paper is found cumbersome by some of the readers. Our major purpose, however, is to introduce some original concepts that do not yet have appropriate names in contemporary scientific dictionary. If these concepts are found valuable, we welcome our colleagues to innovate and to suggest improvements in terminology.

Appendix 1: Modeling Watt's governor

Much like a telegraph has been used for traditional model of information theory, a Watt's automatic governor has become a first model object of cybernetics, a first homeostat. It is extremely simple in operation, and yet it is ideal to study control and feedback principles [Rosnay, 1978].

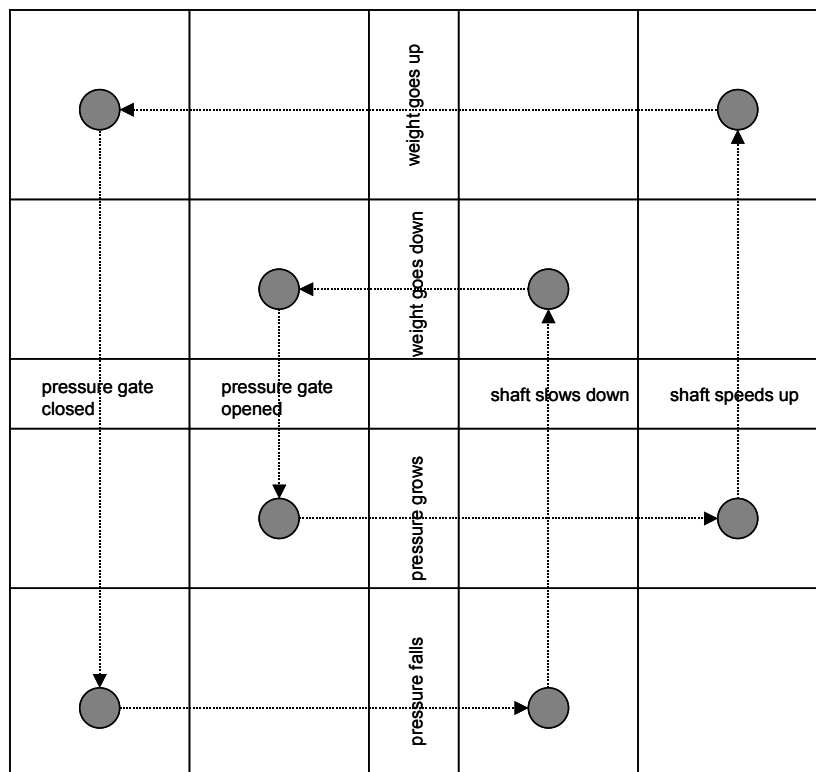
A Watt's regulator is a part of boiler regulation mechanism. Steam generated in a boiler moves a piston, transforming heat energy into mechanical energy. Part of this working energy is taken aside onto a regulating weights, which have different position depending on working effort. If this working effect is too strong, then weights will lift up and release a lever connected to the pressure gate. A lever opens a pressure gate to let extra steam out. Pressure falls, working effort also falls, and weights go down closing a pressure gate through a lever. In this way, a system can control its own state.

Let us consider Watt's governor as a basic information/cybernetic system. Appropriateness of such analysis is seen as following: it is possible to direct and feedback interactions in a governor; these interactions can be then considered as communication channels. Some part of the system may act as a control unit (internal memory), another as an execution unit, third as an external SAFE.

Modes of operation of a suggested information / cybernetic system can be identified. A cycle begins with growth of pressure in the boiler (source of activity in SAFE-driven meso-cycle). High pressure changes weight position (high or low). Weight position impacts lever position. Lever opens/closes a pressure gate. Opened/closed gate lowers/increases pressure in the boiler.

An execution unit (pressure gate) exist in two discrete states: opened and closed. Accordingly, despite the continuity of parameters of other elements of construction (pressure, weight position, lever position) the whole system can be reduced to a combination four discrete pre-automata, each of them can exist in one of two mutually exclusive states. It allows us to represent a basic matrix model of a system, and to indicate corresponding regulating efforts (Figure 6).

Figure 6. Preliminary model of a Watt's governor

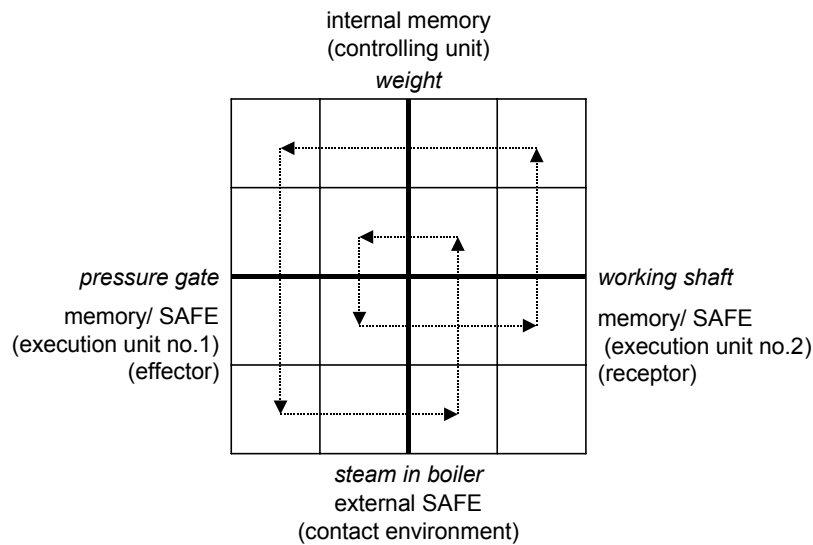


Let us consider a structural organization of Watt's regulator based on the introduced matrix (Figure 7). A control unit of this system is a regulator weight – since mode of system operation depends on weight position.

Execution device appears to be broken into two components. 'Perception' (or 'identification') is accomplished by a torsion shaft that transmits part of working effort (which is proportional to boiler steam pressure). 'Transformation' (or 'regulation') is accomplished by a lever with pressure gate that regulates steam pressure.

An external SAFE in this system is boiler itself; or, more precisely, high and low pressure are two elements of SAFE that change state of a system they interact with. Then, as it has been mentioned before, elements of SAFE are specific sides and aspects of a phenomenon with which regulating system interacts.

Figure 7. Structural matrix model of Watt's governor



This system is a complex information/cybernetic system of four coupled pre-automata. Each of them have two distinct types of information/program interaction. The macro-cycle of such system is linear determined, no inefficient/inadequate information/programs may occur, unless system is broken.

Then, for measures of information/program quantity introduced (as an example),

$$V_F = V_A = 8$$

and

$$I_F = L = I_A = 8$$

then

$$\xi_V = \xi_I = 1$$

We will not go in more details here.

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