Evolution of Cybernetic Systems: from Computer Systems with Strong Intelligence to Superintelligent Human-Machine Communities

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***Abstract*—The article considers the key features of cybernetic systems, their evolution and parameters that determine the level of their intelligence and self-organization. Hierarchical systems of parameters characterizing the current capabilities and speed of development of cybernetic systems, as well as factors contributing to the acceleration of their evolution are considered. Special attention is paid to semantically close concepts related to the level of intelligence of cybernetic systems and to the evolution processes of both individual and multi-agent cybernetic systems. The prospects of next-generation intelligent computer systems and the complex technology of their development and maintenance are considered. Finally, the impact of technological evolution on the development of human society is discussed, and the idea of the Global Human-Machine Community is proposed.**

***Keywords*—artificial intelligence, cybernetic system, evolution, multi-agent system, OSTIS, ecosystem, human-machine system**

I. Introduction

The current state of *artificial intelligence technology* can be characterized as follows:

- the illusion of well-being
- is very labor-intensive to develop and maintain <u>modern</u> *intelligent computer systems*
- is labor-intensive to combine modern *intelligent computer systems* into complex intelligent multi-agent computer systems.
- the inability of <u>modern</u> *computers* to implement *intelligent computer systems*, which leads to artificial complication of *intelligent computer systems* and to decrease of their performance.

The analysis of the above circumstances allows us to conclude that the problems of the current state of the theory and practice of *artificial intelligence*

- have <u>fundamental</u> methodological reasons and require rethinking of the fundamental foundations of the theory of *intelligent computer systems* and technologies of their development, maintenance and operation
- requires a transition to a <u>a fundamentally new generation of intelligent computer systems</u> and their corresponding technologies.

Challenges cited include:

1) The problem of convergence and integration of various aspects of new generation intelligent computer systems and the corresponding technology of complex support of their life cycle:
    - Convergence and integration of different models of information representation and processing in new generation intelligent computer systems:
    - Convergence and integration of different types of knowledge in knowledge bases of new generation intelligent computer systems;
    - Convergence and integration of different models of problem solving in new generation intelligent computer systems;
    - Convergence and integration of different types of interfaces of new generation intelligent computer systems;
    - Convergence and integration of different directions of artificial intelligence in order to build

a general formal theory of intelligent computer systems of new generation;
- Convergence and integration of design technologies of various components of new generation intelligent computer systems in order to build a comprehensive design technology of new generation intelligent computer systems;
- convergence and integration of technologies to support various stages of the life cycle of new generation intelligent computer systems in order to build a technology of complex support of all stages of the life cycle of new generation intelligent computer systems: design, reproduction, operation, monitoring, modernization;
- convergence and integration of various human activities in the field of artificial intelligence (research activities, development of technological complex, applied engineering, educational activities) to increase the level of coherence and coordination of these activities, as well as to increase the level of their complex automation with the help of semantically compatible intelligent computer systems of new generation;
- convergence and integration of the most diverse types and areas of human activity, as well as means of complex automation of this activity with the help of intelligent computer systems of the new generation.

2) The problem of ensuring the explainability of intelligent computer systems and increasing the level of trust in them.
3) Development of methods and means of decentralized situational management of agents' activity at different levels of hierarchical multi-agent systems.
4) The problem of creating self-developing and, in particular, self-learning intelligent computer systems.
5) The problem of ensuring interoperability of intelligent computer systems: semantic compatibility, mutual understanding and coordination of intelligent computer systems in the process of collective problem solving [1].

At present, the technological evolution of human society is transitioning to a fundamentally new technological mode, based on the development and expansion of applications of Artificial Intelligence technology in various fields and types of human activity. This requires a systematic approach to the creation of the next generation of applied *intelligent computer systems*, as well as a fundamental rethinking of the principles of organization of human activity with the help of such systems, which will turn from user-controlled tools performing complex tasks into sufficiently independent partners of joint activity. This systemic rethinking of the organization of human-machine activity should ensure the highest possible level of ***synergetic effect*** when integrating various types and areas of this activity and exclude the eclectic connection of a variety of specialized technologies, which is fraught with high overhead costs "at the junctions".

The modern differentiation and local (short-sighted) nature of the development of various directions of *artificial intelligence*, as well as the development of means of informatization of various spheres (branches) of human activity, the lack of complex, systemic approach in solving these problems have led to the fact that behind the "trees" the "forest" of informatization and intelligentization created by us became poorly visible and plunged into a thick "fog". The key approach to overcoming these difficulties is the *convergence* of various directions of artificial intelligence and various branches of human activity.

It is most logical to justify the necessity of such *convergence* on the basis of *General Theory of Evolution of Cybernetic Systems* and, in particular, *intelligent computer systems*. The ability to evolve, (i.e., to increase the level of self-organization and, in particular, to self-evolve) is a basic property of *cybernetic systems*. If a cybernetic system does not pay proper attention to it, the regression of this system is inevitable.

II. Cybernetic Systems

A. Cybernetic System Concept

cybernetic system
:= [open *dynamic system* that interacts with its environment on the basis of its *internal information model of the environment* (its subjective picture of the world).]
⇒ *explanation**:
[A fundamental distinguishing feature of ***cybernetic systems*** is that each of them has a ***processor-memory***, which stores and processes the ***internal information model of the environment*** of the corresponding *cybernetic system*. The specified information model with the help of **processor-memory** has a high enough level of **flexibility** and high speed of change, which allows ***cybernetic system*** to timely and adequately respond to changes in the ***external environment*** and manage its own ***activity***. Thus, the key factor in the efficiency (quality) of a cybernetic system is the structure and content of its *internal information model of the environment*. Accordingly, the key concept underlying the *cybernetic system* is the concept of ***information*** (*information construct*).]
⇒ *note**:

[The *environment of cybernetic system* includes all the objects it affects and, in particular, all the *cybernetic systems* with which it interacts.]
:= [*dynamic system*, actively, independently and purposefully interacting with its environment]
:= *explanation**:
[*dynamic system*, capable of maintaining its integrity, performing various *actions* and carrying out some *activities*, i.e. capable of being an active subject (agent) of some *actions* and some private (specialized) activities]
:= *explanation**:
[*dynamic system*, which is based on such properties as purposefulness, autonomy, homeostatic activity, self-organization, evolvability, learnability, intelligence, which determine the quality (level of development) of this *dynamic system*]
⇒ *note**:
[With respect to *cybernetic systems* we can speak of the following *dynamic systems*:

- *dynamic system*, which is investigated by the cybernetic system and is a part (fragment) of its *environment*.
- dynamics of the process of accumulating and refining information about the *dynamic system* under study — the history of *situations* and *events* occurring in this system.
- dynamics of the process of accumulation and refinement of *information* about a certain set (class) of systems similar to the system under study — the dynamics of evolution of *factual information* about the investigated *subject domain*.
- dynamics of the evolution of the *ontology* of the investigated *subject domain*, i.e. the evolution of knowledge about properties and regularities in this *subject domain*.
- dynamics of the problem-solving processes in this domain.
- dynamics of the evolution of methods, techniques and tools for solving problems in a given subject domain.

]
⇒ *note**:
[The environment surrounding a cybernetic system changes its state also under the influence of the cybernetic system itself. I.e. the mentioned medium, as well as the *cybernetic system* "living" in this medium, are *dynamic systems*. However, in the *memory* (in the information space) of each *cybernetic system*, the dynamics of its environment and the dynamics of its own behavior in this environment are described by static *information constructs*. In the simplest case — this is a "frame-by-frame" description of the sequence of states of the described *dynamic systems*.

Nevertheless, the dynamics of the very *information constructions* stored in the memory of *cybernetic systems* (located in its information space) also takes place. But the essence of this dynamics (the essence of *information processes* in the information space) is different — it is either *processes* of solving *cybernetic system* various *tasks*, or the processes that carry out imitation modeling (emulation) of real processes occurring in the external environment, or *processes* aimed at improving the quality of the current state of *information* stored in *memory* (information space), or processes of accumulating (collecting) and analyzing information about the environment (about situations, events and processes occurring in it).]

B. *Classification of cybernetic systems*

cybernetic system
⇒ *subdividing**:
{• *individual cybernetic system*
  ⊃ *biological organism*
• ***multi-agent cybernetic system***
  := [distributed cybernetic system]
  := [*cybernetic system*, in which its *memory*, *processor*, *interface* and the stored *internal information model of the environment* are distributed (to some extent virtual)]
  := [*cybernetic system*, which is a collection of *cybernetic systems* that are agents of a *multi-agent system*, interacting with each other through their interface facilities and possibly through a special communication environment]
  ⇒ *subdividing**:
  {• *two-level multi-agent cybernetic system*
    := [*multi-agent cybernetic system* all of whose *agents* are *individual cybernetic systems*]
  • *hierarchical multi-agent cybernetic system*
    := [*multi-agent cybernetic system*, wherein there is at least one *agent* that is a *multi-agent cybernetic system*]
  }
}
⇒ *subdividing**:
{• *natural cybernetic system*
  := [cybernetic system of natural (biological) origin]
  ⇒ *subdividing**:

{• *individual cybernetic system of natural origin*
• *multi-agent cybernetic system of natural origin*
}
• *computer system*
:= [artificial cybernetic system]
:= [cybernetic system implemented as a technical system]
:= [cybernetic machine]
⇒ *subdividing**:
{• *individual computer system*
• *multi-agent computer system*
}
• *natural-artificial cybernetic system*
:= [cybernetic system containing both natural and artificial components]
⇒ *subdividing**:
{• *individual natural-artificial cybernetic system*
• *multi-agent natural-artificial cybernetic system*
}
⊃ ***human-machine cybernetic system***
}

human-machine cybernetic system
⇒ *subdividing**:
{• *human-machine individual cybernetic system*
:= [system consisting of a mechanically (manually) operated *machine* (active tool) and a user operating the machine]
⇒ *note**:
[The controlled *machine* specified here is not a *cybernetic system.*]
• *human-machine multi-agent cybernetic system*
⇒ *subdividing**:
{• *human-machine dual-agent cybernetic system*
:= [bi-agent cybernetic system consisting of a *individual computer system* that may have different levels of *intelligence* and a human (user) interacting with the system]
• *human-machine multi-agent cybernetic system with more than two agents*
⇒ *note**:
[Such a multi-agent human-machine cybernetic system may include any number of interacting human and computer systems. The architecture of such systems may vary:
• individual computer system and many users;
• multi-agent computer system and one user;
• multi-agent computer system and many users;
]
}
}

multi-agent cybernetic system
⇒ *subdividing**:
{• *synergetic multi-agent cybernetic system*
:= [multi-agent cybernetic system that has achieved high efficiency in organizing the interaction of its agents]
• *nonsynergetic multi-agent cybernetic system*
:= [multiagent cybernetic system, contradictions and inconsistency between the actions of various agents of which significantly reduce the rate of evolution of the multiagent cybernetic system or lead to stagnation or even self-destruction]
:= [multi-agent cybernetic system on a dead-end evolutionary trajectory]
}
⇒ *subdividing**:
{• *population*
:= [multi-agent system, within which new agents are self-reproducing with the transfer of knowledge and experience accumulated by the population [2]]
• *multi-agent system that is not a population*
}
⇒ *note**:
[The general structural decomposition of cybernetic systems into memory, processor, sensor and effector complexes is also true for *multi-agent cybernetic systems.* Only in the case of *multiagent cybernetic system* the above components are distributed (distributed over the agents of the *multiagent cybernetic system*).]
⇒ *subdividing**:
{• *individual cybernetic systems team*
• *hierarchical multi-agent cybernetic system*
}
⇒ *subdividing**:
{• *multi-agent cybernetic system with a fixed number of agents*
• *multi-agent cybernetic system with a non-fixed number of agents*
⇒ *explanation**:
[Agents can disappear and reappear — like in a population]
⊃ *multi-agent cybernetic system with an expandable number of agents*
}

multi-agent system
⇒ *subdividing**:
{• *multi-agent cybernetic system*
⊂ *cybernetic system*
• *multi-agent embedded information processing subsystem*
⊂ *embedded information processing subsystem*
}
⇒ *note**:
[Multi-agent and customized can be not only a cybernetic system but also an embedded information processing subsystem.]

should be distinguished*
∋ {• *cybernetic system*
• *embedded information processing system*
}
∋ {• *multi-agent cybernetic system*
• *multi-agent embedded information processing system*
• *multi-agent system*
⇐ *union**:
{• *multi-agent cybernetic system*
• *multi-agent embedded information processing system*
}
}
∋ {• *multi-agent cybernetic system*
• *multi-agent processor-memory*
⊂ *multi-agent embedded information processing subsystem*
}

distributed internal information model of the environment of a multi-agent cybernetic system
:= [virtual unification (integration) of internal information models (subjective pictures of the world) stored in the memory of all agents of the corresponding multi-agent cybernetic system]
⇔ *analog**:
• *distributed memory of multi-agent cybernetic system*
• *distributed processor of multi-agent cybernetic system*
• *distributed sensor subsystem of multi-agent cybernetic system*
• *distributed effector subsystem of a multi-agent cybernetic system*

should be distinguished*
∋ {• *multi-agent cybernetic system*
• *agent-centric problem solver for individual cybernetic system*
:= [individual cybernetic system problem solver representing a hierarchy of virtual multi-agent information processing systems, each level of which is a multi-agent system whose activity is interpreted by a multi-agent system at a lower level of the hierarchy and/or is a multi-agent system that interprets the activity of a multi-agent system at a higher level of the hierarchy]
• *agent-oriented processor of individual cybernetic system*
:= [processor, which is a collection of agents that can function in parallel (simultaneously) and each of which reacts (is initiated) to its corresponding situation or event in the memory of an individual cybernetic system]
}

C. ***General structure of cybernetic systems***

cybernetic system
⇒ *generalized part**:
• *physical shell of the cybernetic system*
• *internal environmental information model*

sensor
:= [receptor]
:= [means of generating the value of the parameter (sign) corresponding to this sensor and determining the current state of the observed fragment of the external environment]
:= [mean of information perception]

effector
:= [environmental influencer]

environment
⇒ *generalized decomposition**:
{• *external environment*
• *I*
⇒ *generalized decomposition**:
{• *physical shell of the cybernetic system*
⇒ *generalized decomposition**:
{• *complex of sensors and effectors of a cybernetic system*
• *cybernetic system memory*
• *cybernetic system processor*
• *cybernetic system enclosure*
}
• *internal environmental information model*
}
⇒ *note**:

[All these components of a cybernetic system can be either localized (local) or distributed (virtual) depending on the structural type of the cybernetic system]

}

:= [external environment of a cybernetic system, and this cybernetic system itself, including all its components, including the internal information model of the environment]

⇒ *note**:

[The internal information model of the environment describes the model itself, including a description of its dynamics]

⇒ *note**:

[The environment of a cybernetic system includes everything that is not the combined information stored in the memory of the corresponding cybernetic system. Therefore, the environment of a cybernetic system includes its entire physical shell]

processor-memory of cybernetic system

⇒ *explanation**:

[This is, conventionally speaking, the internal (embedded) analog of a cybernetic system that:

- with the help of external sensors of the cybernetic system, as well as internal sensors and processor-memory effects forms its own internal subjective environment, which is a reflection (information model) of the external environment of the cybernetic system;
- permanently improves this internal information model of the external environment of the cybernetic system;
- controls external effectors and sensors of the cybernetic system, performing purposeful control of the impact on the external environment of the cybernetic system and its physical shell, as well as purposeful monitoring of the state of this external environment and its own physical shell;

]

cybernetic system processor

:= [knowledge base processing machine]

:= [set of functional means of the corresponding cybernetic system, which has sufficient completeness (integrity) for functional support of the activity of the said cybernetic system (for interpretation of information stored in the memory of the cybernetic system)]

:= [internal pseudo-cybernetic system of information processing, the environment of which is the memory of the corresponding cybernetic system]

:= [pseudo-cyber system embedded in the corresponding cybernetic system and processing information stored in the memory of the said cybernetic system with the help of the processor of this system (with the help of means of analyzing the stored information constructs and means of their transformation)]

should be distinguished*

∋ {• *cybernetic system processor*

• *cybernetic system problem solver*

:= [hierarchical system of interpretation of various methods (programs) of processing situations and events occurring in the memory of a cybernetic system stored in the memory]

⇒ *note**:

[The lower level of activity of the problem solver of a cybernetic system is the direct activity of the processor of that cybernetic system]

}

should be distinguished*

∋ {• *memory*

:= [cybernetic system memory]

• *unified aggregate information stored in the memory of a cybernetic system*

:= [dynamic information model of the environment of the corresponding cybernetic system, describing (reflecting) this environment with the required degree of detail]

:= [all the information stored in the memory of a cybernetic system]

⊃ *knowledge base*

:= [structured aggregation of information stored in the memory of a cybernetic system]

}

internal environmental information model

:= [part of the cybernetic system state, which is used by *processor* and *sensory-effector complex* to organize *activity* (behavior, functioning) of the *cybernetic system* in the process of its interaction with its *external environment*, with its *physical shell* and with its internal information environment (i.e. *internal information model of the environment*)]

:= [internal information model of the environment surrounding the relevant cybernetic system]

:= [subjective worldview of a cybernetic system]

⊃ *knowledge base*

⇒ *note**:

[The term is used to name subjective worldviews in cybernetic systems with a sufficiently high level of development (self-organization)]
:= [semantically structured internal information model of the environment of an intelligent cybernetic system]
:= [integrated information construct stored in the memory of a cybernetic system]
⇒ *note**:
[The presence of an internal information model of the environment in a cybernetic system means that the cybernetic system "lives" simultaneously in two worlds — in the external real world and in the internal world of its information model (reflection) of this external real world.]

cybernetic system environment
:= [world viewed through the "eyes" of the corresponding concrete *cybernetic system* and including one's own ***self*** (one's own *physical shell* and *internal information model of the environment*, i.e. one's own subjective picture of the world), as well as the environment external to oneself (the part of the *environment* that is outside one's own *physical shell*).]

embedded information processing subsystem
⇒ *explanation**:
[embedded information processing subsystem is not strictly speaking a *cybernetic system*. Nevertheless, it can be regarded as an analog of a cybernetic system, namely, as a cybernetic system whose external environment is the *memory* of the corresponding *individual cybernetic system* and the information stored in this memory]
⊃ *processor-memory of individual cybernetic system*
:= [maximum embedded information processing system]
:= [embedded information processing system that is not a subsystem to another embedded information processing system]

physical shell of a cybernetic system
:= [material shell of cybernetic system]
:= [body of a cybernetic system]
:= [internal (material) physical environment of a cybernetic system]
⇒ *generalized decomposition**:
{• *cybernetic system memory*
• *cybernetic system processor*
• *complex of sensors and effectors of a cybernetic system*
• *other material subsystems, providing the exchange of substances and energy with the external environment of the cybernetic system*
}
⇒ *note**:
[The physical envelope of a cybernetic system is subject to the constant destructive effects of the external environment — this must be counteracted]

cybernetic system interface
:= *frequently used term**:
[*interface*]
⇒ *generalized part**:
sensory-effector complex of a cybernetic system
⇒ *generalized decomposition**:
{• *sensory subsystem of a cybernetic system*
⇒ *generalized part**:
sensor
• *effector subsystem of cybernetic system*
⇒ *generalized part**:
effector
}

should be distinguished*
∋ {• *cybernetic system*
:= [solver of external tasks of purposeful interaction with the external environment and its own physical shell of the cybernetic system by means of its sensors and effectors]
• *processor-memory of cybernetic system*
:= [solver of information tasks of the cybernetic system and, among others, tasks of controlling sensors and effectors of the cybernetic system, providing the necessary detail of solving external tasks of the cybernetic system]
• *embedded information processing subsystem*
⇒ *note**:
[The result of the integration of all the information processing subsystems embedded in a *cybernetic system* is the *processor-memory* of that cybernetic system]
}

cybernetic system memory
:= [environment within which the sensors of a cybernetic system and its processor create and update an internal information model of the environment of said cybernetic system, which said cybernetic system uses to organize its activities]
:= [memory environment of a cybernetic system — the environment for storing and processing information (stored information constructs)]

D. ***Relationships and operations defined on the set of cybernetic systems***

cybernetic system

⇒ *defined relationship**:
{• *environment**
:= [be the environment from the point of view of (for) a given cybernetic system]
⇒ *explanation**:
[The environment of each cybernetic system and, accordingly, the description (model) of this environment includes:

- of this cybernetic system itself (itself, its own self, internal environment),
- external environment (environment outside of the self)

]
⇒ *explanation**:
[Accordingly, the information model (description) of the environment formed by each cybernetic system is the construction of a picture of the world common to all cybernetic systems, but with the obligatory description of what I am and how I am related to this world.]
⇒ *second domain**:
environment
• *external environment**
⇒ *second domain**:
external environment
• *self**
⇒ *second domain**:
I
• *physical shell of cybernetic system**
⇒ *second domain**:
physical shell of cybernetic system
⇒ *generalized decomposition**:
{• *sensor complex*
• *effector complex*
• *processor-memory of cybernetic system*
}
⇒ *note**:
[Information messages between cybernetic systems are also exchanged through the sensor and effector complexes of the said cybernetic systems]
• *sensor and effector complex**
:= [complex of means providing direct physical interaction with its external environment and physical shell*]
⇒ *second domain**:
sensor and effector complex
• *sensor complex**
:= [complex of tools for analyzing the physical state of one's external environment and physical shell*]
:= [system of sensors (receptors) of a cybernetic system, providing input (perception) of information about the state (situations) and processes (events) in the environment*]
:= [sensory subsystem of a cybernetic system*]
⇒ *second domain**:
sensor complex
⇒ *generalized part**:
sensor
• *sensor**
:= [receptor*]
⇒ *second domain**:
sensor
:= [receptor]
• *effector complex**
:= [complex means of impact on its external environment and physical shell*]
:= [system of effectors (including motor, mechanical), which are instruments of direct (physical) impact of a cybernetic system on the environment*]
:= [effector subsystem of a cybernetic system]
⇒ *second domain**:
effector complex
⇒ *generalized part**:
effector
• *effector**
⇒ *second domain**:
effector
• *cybernetic system memory**
⇒ *second domain**:
cybernetic system memory
• *internal environmental information model**
⇒ *second domain**:
internal environmental information model
• *cybernetic system processor**
:= [complex of means providing analysis of the state and changes in the state of the internal information model of the environment*]
⇒ *second domain**:
cybernetic system processor
• *processor-memory of cybernetic system**
⇒ *second domain**:
processor-memory of cybernetic system
⇒ *generalized decomposition**:
{• *cybernetic system processor*
• *cybernetic system memory*
}
⇒ *note**:
[This decomposition is not always possible. Not all cybernetic systems can be clearly divided into processor and memory]
⇒ *generalized part**:

embedded information processing system
:= [deep seamless integration of the processor and memory of an individual cybernetic system when the processor is distributed over memory and memory elements become processor elements at the same time]
- *cybernetic system enclosure**
  ⇒ *second domain**:
  cybernetic system enclosure
- *memory**
  := [physical environment in which the information model of the surrounding (external) environment of a given cybernetic system is stored and processed*]
  ⇒ *second domain**:
  memory
- *cybernetic system interface**
  ⇒ *second domain**:
  cybernetic system interface

}

external environment
:= [environment of the cybernetic system]
:= [world surrounding a cybernetic system, viewed through the prism of its interaction with this world and including its own external environment, its own physical shell and its own picture of this world, i.e. its own (subjective) internal information model of the environment]
⇒ *note**:
[The environment of a cybernetic system also includes the self internal information model (description) of this environment. In other words, the internal information model of the environment includes not only the description of its own external and internal environment, but also the description of this internal information model of the environment itself. It is nothing but metainformation about this internal information model.]

I
:= [Pointer to the sign of self]
:= [Singleton, the only element of which is the sign of the cybernetic system in whose memory the sign is located]
:= [Pointer to the sign of the cybernetic system that it is]
⇒ *note**:
[As part of the internal information model of the environment, a cybernetic system can store a description of a sufficiently large number of cybernetic systems with which it interacts (in particular, a description of its users). But out of the whole set of described cybernetic systems, each cybernetic system must select a description of itself, which is necessary, at least, for realizing (comprehending) itself and its activity in the environment.]

cybernetic systems
⇒ *set operation**:
- *convergence of cybernetic systems*
  ⊃ *convergence of internal information models of the environment of cybernetic systems**
  := [convergence of cybernetic systems' subjective pictures of the world*]
  ⊃ *semantic compatibility enforcement*
- *confluence of individual cybernetic systems**
- *division of individual cybernetic system**
- *collaboration of cybernetic systems into a collective**

E. *Key features of cybernetic systems*

cybernetic system
⇒ *principle underlying**:
- *presence of an internal information model of the environment (subjective picture of the world)*
  ⇒ *note**:
  [The flexibility of this model creates the conditions for self-evolution.]
  ⇒ *note**:
  [The basis for the functioning (behavior) of cybernetic systems is the use of an internal picture of the world (i.e., information processing).

  The main leitmotif (strategic goal) of a cybernetic system, regardless of the awareness of this goal setting, is the evolution of the cybernetic system, i.e. increasing the level of its self-organization.]
- *evolvability (unconscious, externally implemented)*
  ⇒ *principle-prerequisite**:
  - *flexibility*
  - *stratification*
- *self-evolving*
  ⇒ *principle-prerequisite**:
  - *reflectivity*
  - *expanding the diversity (specialization) of different components while increasing their synergy*
- [Intelligent system lives in several worlds at the same time:
  - In the real external world (in the simplest case, the external world is its users — end users and developers of different status)

- In the internal world (the world of situations and events occurring in its memory, which stores the internal information model of some fragment of the external world and is processed by agents)

In this case, both external and internal worlds can be decomposed into dynamic subject domains (into several private worlds). In each of these worlds the system simultaneously lives in the present (current), past and future time.]

evolutionary level of cybernetic system^
:= [***intelligence^***]
:= [intelligence level^]
:= [ability to maintain and increase one's level of self-organization^]

The key property of cybernetic systems is their ability to evolve (improve), including the ability to evolve independently (i.e. self-evolution). This ability is conditioned by the cybernetic system's internal information model of its environment (internal subjective picture of the world around it). The fundamental advantage of this information model is that its transformation (carried out with the help of the cybernetic system processor) has a much lower labor intensity compared to the labor intensity of transformation of the environment described by this information model.

The high speed of evolution of cybernetic systems is ensured by the flexibility of the internal information model of the environment and, as a consequence, by the simplicity of modification (transformation) of this model.

The environment itself can also be transformed, but it is much simpler and faster to transform its information model:

- to forecast the dynamics (changes) of this environment, which is not caused by own activities;
- to plan its transformation by its effectors;
- to model (foresee) the consequences of their actions in the external environment.

Since a cybernetic system is based on an internal information model of its environment, it is important how this information model is organized, what language it is represented in (what is the syntax and denotational semantics of this language), how the search for demanded information constructs (fragments of the information model) is carried out, and how these constructs are transformed [3].

should be distinguished*
∋ {• *information construct that is a fragment of the internal information model of the environment*
• *information construct, which is a message transmitted between cybernetic systems*
}

III. System of parameters determining the general level of intelligence (level of self-organization) of a cybernetic system

intelligence
:= [intellect]
∈ *complex parameter*
:= [complex parameter characterizing the general level of development of *cybernetic systems^*]
:= [complex parameter characterizing the general level of *self-organization of a cybernetic system* and defined by:

- by the achieved current state of self-organization (achieved capabilities of the cybernetic system to preserve itself, its integrity, neutralizing destructive effects of the external environment, as well as capabilities to influence the environment);
- by the achieved rates of its evolution (rates of increase in the level of self-organization of the *cybernetic system*);
- acquired and evolved abilities of the *cybernetic system* to maintain and increase the rate of its evolution.

]
⇒ *note**:
[It is important to emphasize that the overall level of *intelligence* (level of self-organization) of a cybernetic system is determined not only and not so much by what capabilities it has at the current moment, but by how fast and thanks to what it evolves. In other words, the main property of a cybernetic system is the level of its ***ability to evolve^***, modernizing, transforming itself (sometimes with the help of other subjects — teachers, developers) in various directions and preferably as fast as possible.]
⇒ *note**:
[*cybernetic system* is characterized not only by an overall comprehensive assessment of its current state, but also by an assessment of speed (rate) of increase (improvement) of the qualitative level of this state, as well as by an assessment of the available potential (opportunities, abilities) of the system accelerate the increase of the qualitative level of its state.]
⇒ *note**:
[Specification of the concept of ***intelligence^*** by listing all the ***parameters-factors**** whose values determine the value (level) of the ***intelligence^*** of a cybernetic system. That is, the enu-

meration of ***parameter-factors**** corresponding to the parameter ***intelligence^*** is nothing but a systematized indication of the requirements for *intelligent cybernetic systems*]

⇒ *parameter-factor**:

- ***current level of cybernetic system capability^***
  := [power, variety, quality, utility (for the cybernetic system) and integrity of the current activities that the cybernetic system is able to perform at the current moment^]
  := [current cyber system capability level^]
  := [current level of self-organization of cybernetic system^]
  := [overall current level of capability of a cybernetic system as it interacts with its *environment*, which includes not only its *external environment*, but also its *physical shell*, and its *internal information model of the environment^*]
  := [current skill level of*cybernetic system^*]
  := [volume and variety of tasks for which the cybernetic system has the necessary information resources and has mastered methods and techniques for managing its own *effectors* and *external tools*]
  := [multiple *technologies* mastered by the *cybernetic system^*]
  := [current level of intelligent potential (intelligent form) of the cybernetic system^]
  := [achieved value of the cybernetic system's action potential (power and efficiency of this potential)^]
  := [current level of knowledge, skills and understanding^]
  ⇒ *note**:
  [The activity of a cybernetic system should not stop, first of all, because the destructive impact of the external environment on a cybernetic system never stops and must be counteracted. The activity (life) of a cybernetic system is like riding a bicycle — you cannot stop, you will lose balance.]
  ⇒ *epigraph**:
  [Your life is 10% dependent on what happens to you and 90% dependent on how you react to those events.]
  ⇒ *author**:
  John Maxwell
  ⇒ *epigraph**:
  [I'm not a product of my circumstances, I'm a product of my decisions]
  ⇒ *author**:
  Steven Covey
- ***speed of evolution of cybernetic system^***
  := [current value of the rate of increase of the level of self-organization of the cybernetic system^]
  := [current value of cybernetic system evolution rate^]
  := [rate of increase in the current level of self-organization — the level of power, quality, utility and integrity of cybernetic system activity^]
  := [level of ability (adaptability) of a cybernetic system to evolve both with the help of external actors (teachers, developers) and independently^]
  := [evolutionary]
  := [evolutionary potential of a cybernetic system — the ability to increase the level of action potential (level of capability) of a cybernetic system^]
  := [rate of increase of the current level of cybernetic system capability^]
  := [ability of a cybernetic system to evolve unconsciously, to evolve blindly]
  := [ability of a cybernetic system to evolve (including learning)^]
  := [level (quality, rate) of evolutionary activity of a cybernetic system — the activity in anticipation, which brings benefit not at the present moment, but later (and it is not known exactly when and in what exactly this benefit will consist)^]
  := [speed of evolution of knowledge, skills and understanding^]
- ***accelerating evolution of cybernetic system^***
  := [level of development of acquired and evolvable abilities of a cybernetic system that support and enhance its own evolutionary rate]
  := [ability (adaptability) to evolve itself (possibly with the help of other entities — teachers, developers)^]
  := [level of knowledge of the laws of evolution and the resulting level of awareness, activity and autonomy to carry out the evolutionary process^]
  := [ability of a cybernetic system to control its own evolution, to independently and purposefully organize its evolution on the basis of knowledge of the laws of evolution^]
  := [meta-capability of cybernetic system to increase the level of its activity potential^]
  := [ability of a cybernetic system to develop (to raise the level of) its ability to raise the level of its activity potential^]

:= [metaevolutionary potential of the cybernetic system^]
:= [ability of a cybernetic system to increase its evolutionary potential]
:= [ability of a cybernetic system to increase its rate of evolution]
:= [ability of a cybernetic system to create (improve) conditions to increase its evolutionary rate^]
:= [ability of a cybernetic system to evolve its ability to evolve^]
:= [ability of a cybernetic system to conscious, sense, purposeful self-evolution^]
:= [ability of a cybernetic system to learn how to evolve better and better]
⇒ *note**:
[Cognition of the laws of evolution (knowledge of beneficial, harmful, and dead-end evolutionary paths) and their proper application greatly accelerates the evolutionary process]
⇒ *note**:
[A cybernetic system must not only be able to evolve (including learning), but also be able to learn how to evolve (including learning) better — that is, the highest form of evolutionary ability of a cybernetic system is to move to the meta-level of the evolutionary process]
:= [level (quality) of meta-evolutionary activity of a cybernetic system, aimed at making the evolutionary process not "blindly", but to bring the maximum possible benefit and as soon as possible^]
:= [rate of evolution of the very evolutionary activity of developing knowledge, skills and understanding^]

should be distinguished*
∋ {• *current level of cybernetic system capability^*
:= [current level of cybernetic system intelligence capability^]
• *evolution of cybernetic system*
⊂ *process*
:= [evolutionary process]
:= [process of increasing the level of self-organization]
• *cybernetic system evolution rate^*
:= [evolutionary potential^]
:= [evolutionary]
:= [ability of a cybernetic system to evolve^]
:= [ability of a cybernetic system to carry out its own evolution or to facilitate its evolution if it is carried out by other entities^]
• *acceleration of cybernetic system evolution^*
}

IV. Hierarchical system of parameters defining the current level of cybernetic system capabilities

current cybernetic system capability level^
⇒ *parameter-factor**:
- *cybernetic system memory capacity^*
- *functional capacity of the processor-memory of the cybernetic system^*
  := [diversity of *actions* and the integrity of the whole set of *classes of actions* performed by the *processor-memory of a cybernetic system* while processing the *internal information model of the environment* stored in its memory]
- *cybernetic system processor performance^*
- ***quality of internal information model of the environment^***
- *variety of possible influences of cybernetic system effectors on the external environment and on the cybernetic system's own physical shell^*
- *total number and variety of types of sensors of a cybernetic system^*
- *diversity and efficiency of utilization of the technologies possessed by the cybernetic system^*
  ⇒ *note**:
  [The concept of *technology* used by a cybernetic system should be understood broadly enough — as a set of *methods*, information *resources*, and *tools*, which allow a cybernetic system to carry out *activities* corresponding to this technology in the presence of necessary *source data* (both informational and material). In relation to the *cybernetic system* (as an executor) the *technologies* used by it can be:
  - internal (purely informational), requiring the use of only its own processor as a tool and not requiring the use of receptors and effectors of the cybernetic system;
  - external, not requiring the use of external tools;
  - external, requiring the use of external tools

  ]
  ⇒ *note**:
  [*technological evolution of cybernetic systems*, that is, the expansion of their capabilities and the improvement of the

technologies they use, is an important but not the only direction of the *evolution of cybernetic systems*]
- *self-sufficiency in the use of technology that the cybernetic system possesses^*
  := [level of autonomy in performing various activities within a multi-agent cybernetic system^]
- *interoperability^*
  := [ability of a cybernetic system, which is an agent or potential agent of at least one multi-agent cybernetic system, to effectively (useful) interact with other agents of the specified multi-agent cybernetic systems^]
  := [ability of a cybernetic system to engage in "social" behavior^]
  := [level of socialization of the cybernetic system^]
  := [agent socialization parameter^]
  := [quality of cybernetic system as an agent of multi-agent cybernetic systems^]
  := [social characteristic (socialization level) of the cybernetic system^]
  := [quality of performing the role of an agent in multi-agent cybernetic systems^]
  := [quality of social behavior]
  ⇒ *parameter-factor**:
  - *capability of understanding*
    := [ability to build rapport with partners]
    ⇒ *parameter-factor**:
    *ability to ensure semantic compatibility with partners^*
  - *consent*
    ⇒ *epigraph**:
    [People are lonely because they build walls instead of bridges.]
    ⇒ *author**:
    Stanislaw Jerzy Lec
    ⇒ *epigraph**:
    [Of the two quarreling, the one who is smarter is to blame]
  - *ability to coordinate one's own actions with the actions of partners^*
  - *ability to participate in the formation (creation) of new multi-agent systems^*
  - *ability of a cybernetic system to effectively participate in increasing the level of synergy of the multi-agent cybernetic system of which it is an agent^*
  - *ability of a cybernetic system to effectively participate in the training of a multi-agent cybernetic system of which it is an agent*
  - *ability of a cybernetic system to participate in decentralized organization of collectively performed activities of a multi-agent cybernetic system of which it is an agent^*
  - *ability to be an agent of multiple multi-agent cybernetic systems^*
  - *responsibility^*
    := [responsibility to partners (agents)^]
    := [ability of a cybernetic system to understand (realize) what it should (must) do, what it is obliged not to do, and what are the consequences of violating these rules of behavior^]
    ⇒ *parameter-factor**:
    - *ethical responsibility^*
      := [ethical responsibility^]
      := [moral responsibility^]
    - *legal responsibility^*
      := [legally compliant responsibility^]
    - *willingness to take responsibility^*
  - *controllability^*
    := [ability to <u>subordinate</u> where needed^]
  - *ability to recognize that you are being used (manipulated, parasitized, ignored)^*
  - *ability to resist manipulation by other agents^*
  - *absence of manipulative tendencies*
  - *decisiveness level*
  - *self-esteem adequacy*

  ⇒ *note**:
  [The parameter *interoperability* corresponds not only to *individual cybernetic systems*, but also to *multiagent cybernetic systems*, because multi-agent cybernetic systems can also be agents of multi-agent cybernetic systems (hierarchical multi-agent systems), and several of them at the same time.]
- *synergy level*
  := [quality of organization of useful interaction between components of a cybernetic system^]
  := [efficiency of the organization of "collective" problem solving in a multi-component cybernetic system^]
  ⇒ *narrowing the parameter over the domain of definition**:
  - *level of synergy of individual cybernetic*

*system^*
:= [level of hybridization of individual cybernetic system^]

- *level of synergy of multi-agent cybernetic system^*
⇒ *parameter-factor**:
  - *minimum level of interoperability of cybernetic system agents^*
  - *achieved level of mutual understanding between agents^*
  - *achieved level of contractual capacity^*
  - *achieved level of distribution of responsibility (duties) between agents for solving regular (regularly occurring) tasks^*
  ⇒ *explanation**:
  [This implies a priori decomposition of staff tasks into subtasks, distribution of these subtasks among agents, each of which should not only individually perform its subtask, but also clearly (first of all, informationally) interact with other agents, knowing a priori with whom and how. The process of collective solution of a staff task — this is what is called a business process.]
  - *accomplished level of ability to collectively solve abnormal problems*
  ⇒ *note**:
  [Decentralized organization of agent interaction is necessary for quick and most competent (for a given multi-agent cybernetic system) response to abnormal (unanticipated) situations and events.]
  - *achieved level of ability of agents of a multi-agent cybernetic system to coordinate their actions to keep collectively performed actions (processes) within certain limits according to predetermined parameters*
  - *diagram of the distribution of the level of interoperability across all agents of a multi-agent cybernetic system*
  - *diagram of semantic compatibility level distribution over all pairs of agents of a multi-agent cybernetic system*
  := [diagram of the distribution of the level of coincidence of subjective worldviews across all pairs of agents of a multi-agent cybernetic system]
- *level of independence of the cybernetic system in the process of realization of "vital" activities important for it^*
⇒ *parameter-factor**:
  - *level of autonomy of the cyber system in the process of ensuring its security^*
  := [level of self-preservation capability of a cybernetic system^]
  := [level of cybernetic system's ability to independently maintain its integrity in interaction with the external environment and in preventing (neutralizing) destructive (including malicious) and not always predictable impact on the physical shell of the cybernetic system, as well as on the internal information model of the cybernetic system's environment]
  ⇒ *note**:
  [This refers to both physical and information security]
  - *level of independence of the cybernetic system in the process of its material support^*
  ⇒ *note**:
  [It refers to the logistical and energetic provision of a cybernetic system with the necessary conditions of existence ("life") — the conditions that maintain the necessary capability of the system]
  := [level of a cybernetic system's ability to take care of itself]
  - *level of independence of the cybernetic system in the process of implementation of frequently performed activities corresponding to its specialization^*
  - *level of independence of the cybernetic system in solving a priori unintended tasks^*
  := [level of independence of the cybernetic system in solving abnormal tasks^]
  - ***the capacity for appropriate and purposeful behavior^***

quality of the internal information model of the environment^

⇒ *parameter-factor**:

- *volume of internal environmental information model^*
- *multiplicity of knowledge included in the internal information model of the environment^*
  - ⇒ *note**:
    [The most important type of knowledge stored in the *memory of a cybernetic system* is various kinds of methods (programs) for solving problems, the implementation (interpretation) of which is carried out by means of a program-controlled hierarchical reduction (detailing) of the problems to elementary subtasks, which are directly executed by the processor or *effectors of the cybernetic system.*]
- *consistency and syntactic error-free internal information model of the environment^*
- *semantic correctness of the internal information model of the environment^*
  - := [adequacy of the internal information model of the environment^]
  - := [match between the described fragment of the environment and the fragment of the information model of this environment^]
- *semantic completeness of the internal information model of the environment^*
  - := [sufficiency of information contained in the internal information model of the environment for the cybernetic system to solve its actual tasks, including tasks corresponding to its purpose^]
  - ⇒ *note**:
    [the level of *semantic completeness of the internal information model of the environment* is determined by the number of *information holes* present in it, as well as by the size of these holes]
- *information purity^*
  - := [amount of information trash^]
- *completeness of self-description*
  - ⇒ *note**:
    [This parameter characterizes the necessary condition for a cybernetic system to acquire the ability of reflexivity]
  - ⇒ *parameter-factor**:
    - *existence, sufficiency and variety of means of explicit designation and specification of actions performed by the cybernetic system, as well as plans, processes (protocols) and methods of their execution^*
      - ⇒ *note**:
        [The presence of means to describe the actions performed by a cybernetic system means that the cybernetic system performs these actions consciously, sensely, with understanding. In other words, it means that the cybernetic system knows what it is doing]
      - ⇒ *note**:
        [The set of actions performed by a cybernetic system is categorized into two classes:
        - informational actions performed in memory and transforming the internal information model of the environment
        - external actions performed to transform the external environment or one's own physical shell

        ]
- *syntactic and semantic compatibility of knowledge included in the internal information model of the environment^*
  - ⇒ *note**:
    [This is about the "depth" and "seamlessness" of the integration of the knowledge included in the *internal information model of the environment.* This requires a common *universal language* to represent all kinds of knowledge]
  - ⇒ *parameter-factor**:
    - *coherence of denotational semantics of all signs (first of all, concepts) included in the internal information model of the environment, as well as coherence of all terms (names) corresponding to these signs^*
    - *closeness of the representation of the internal information model of the environment to the semantic representation^*
      - ⇒ *note**:
        [*semantic representation* of the internal information model of the environment greatly simplifies problem solving:
        - of convergence and integration of different knowledge
        - of establishing semantic compatibility between agents
        - of searching for points of intersection of interests between agents

]

- *level of structuring and systematization of the internal information model of the environment with the help of various types of metainformation^*
  ⇒ *note**:
  [We are talking about description tools whose object is the internal information model of the environment itself]
- *level of development of language tools used in the internal information model of the environment to describe the structure and principles of functioning of its own physical shell*
- *ability of a cybernetic system to minimize the number of entities under consideration required to perform its actions*
  := [ability to minimize the number (set) of entities under consideration necessary to solve a task (to achieve a goal, to perform an action), as well as to implement the entire complex of activities of a cybernetic system]
  := [ability of a cybernetic system to adhere to Occam's Razor]
  ⇒ *epigraph**:
  Occam's Razor Principle
  =
  [It is foolish to exert more effort than is necessary to achieve a goal...Do not add more essence than necessary]
  ⇒ *author**:
  William of Occam

ability to behave in an expedient and purposeful manner
⇒ *parameter-factor**:

- *ability to set goals and plan actions^*
  := [ability to generate objectives (goals) and plans for their fulfillment (achievement) — that is, to generate a hierarchical system of reducing the original task to lower-level subtasks]
  := [ability of a cybernetic system to qualitatively generate and initiate goals (tasks)^]
  := [ability of a cybernetic system to make quality decisions^]
  := [ability of a cybernetic system to qualitatively plan its actions and forecast their results and possible consequences (including negative ones)^]
  := [ability to build a clear and consistent system of its goals, including strategic goals of the highest level and a hierarchical system of tactical goals^]
- *ability to adequately assess one's capabilities*
  := [ability of a cybernetic system to adequately (corresponding to reality) self-evaluate — to realize what tasks and how well the system can solve^]
- *ability of a cybernetic system to realize (highlight) the tasks (actions) that must be performed^*
  ⇒ *note**:
  [A mandatory task is either a self-preservation task or a task that corresponds to the purpose (duties) of the cybernetic system.]
- *ability of a cybernetic system to intelligently combine its mandatory actions and its optional actions for the current moment*
  ⇒ *note**:
  [The actions (intentions, desires) of a cybernetic system that are optional for the current moment include, in particular, actions aimed at its evolution.]
- *ability of a cybernetic system to make sufficiently high-quality forecasts of significant and, above all, dangerous for the system situations and events in the environment^*
  := [ability of a cybernetic system, in the course of its activity, to form and take into account its predictions — hopes and fears (fears)^]
- *ability to recognize their main (strategic) goals (attitudes, motives, constraints, principles) and, accordingly, to distinguish their beneficial effects on the environment from possible harmful effects^*
  := [ability to understand right and wrong]
- *appropriateness and correctness of goal-setting^*
  := [ability to plan one's behavior in exact accordance with the main goals (attitudes, motives)^]
- *appropriateness and purposefulness of direct behavior*
  := [ability to carry out behavior in accordance with one's goals and plans]
- *purposefulness^*
  ⇒ *epigraph**:
  [It's not enough to wish: you have to do]
  ⇒ *author**:
  Johann Wolfgang Goethe
  ⇒ *epigraph**:
  [Whatever your dream is — start working on it! And then the real miracles will begin to happen in your life.]
  ⇒ *author**:
  Johann Wolfgang Goethe

:= [ability of a cybernetic system to achieve the set goals (to solve the set tasks) both if the methods of solving these tasks are known and if these methods are currently unknown]
:= [targeting]
:= [matching goal, plan, and action^]
:= [activity to perform an action, to achieve a goal^]

ability to understand^
:= [level of cybernetic system's ability to understand^]
:= [ability to understand (evaluate) new information^]
⇒ *parameter-factor**:
- *ability to understand messages from other cybernetic systems*
  ⇒ *parameter-factor**:
  - *ability to understand commands or requests received from other cybernetic systems of varying levels of complexity, and in particular to assess the feasibility, timeliness, and quality of their execution*
- *ability to assess the importance and relevance of the information being acquired^*
- *ability to understand sensory information (in particular to detect and recognize important objects, situations, events, processes)^*

V. Hierarchical system of parameters determining the rate of evolution of a cybernetic system

cybernetic system evolution rate^
⇒ *note**:
[Parameters-factors of this parameter are parameters specifying (detailing) the rate of evolution of the cybernetic system by all parameters (attributes), which specify the *current level of capabilities of the cybernetic system* by increasing the values of these parameters. Thus, there is a correspondence between the parameters defining the current level of capabilities of the cybernetic system and the parameters defining the Speed of evolution of the cybernetic system.]
:= [level of development of acquired and improved abilities of a cybernetic system that support and enhance its own evolutionary rate]
:= [ability to improve oneself, to develop]
⇒ *parameter-factor**:
- *overall adaptability of a cybernetic system to its evolution by external subject-teachers^*
  :=
  [ability to be a receptive, flexible object of the evolutionary process "in the hands" of other subjects^]
  ⇒ *note**:
  [When we talk about the evolution of a cybernetic system with the help of teachers, we mean the creation of a temporary multi-agent cybernetic system, one of the agents of which is the evolving cybernetic system and the other agents are — its teachers, tutors, trainers, psychologists, developers]
  ⇒ *note**:
  [The evolution of a cybernetic system is not only its learning (improvement of knowledge and skills), but also the improvement (modernization) of its physical shell (its body)]
  ⇒ *parameter-factor**:
  - *ability of a cybernetic system to be trained by external actors^*
    := [cybernetic system's ability to be a good student]
  - *ability of a cybernetic system to modernize (transform) its physical shell, carried out by external entities^*
- *overall ability of a cybernetic system to self-evolve*
  := [ability of a cybernetic system to be both the object and subject of evolution^]
  := [ability of a cybernetic system to self-evolve^]
  := [self-evolving]
  ⇒ *parameter-factor**:
  - *self-learning^*
    := [ability of a cybernetic system to learn itself^]
  - *ability of a cybernetic system to independently modernize (transform) its physical shell^*
- *learnability^*
  := [cybernetic system's ability to learn^]
  := [ability of a cybernetic system to evolve its *internal information model of the environment^*]
    ⇒ *note**:
    [The internal information model of the environment includes not only a description of the environment itself, but also includes a description of oneself (one's own self) and a description of how to interact with the environment itself and with the internal information model of the environment]
  := [ability of a cybernetic system to expand and improve the quality of its *internal*

*information model of the environment^*]
:= [progressiveness^]
:= [developmental]
:= [improvement^]
:= [ability to reshape one's own worldview]
⇒ *epigraph**:
[The most important thing — not knowledge, skills and abilities, but the ability to use them effectively in their activities, as well as the ability to improve them and quickly acquire new knowledge and skills]
⇒ *epigraph**:
[The mind, once expanded, will never return to its former boundaries]
⇒ *author**:
Albert Einstein
⇒ *note**:
[Learnability as an increase in the quality (accuracy) of solving problems of the same class (method improvement) should be distinguished from the expansion of the <u>number</u> of methods]
⇒ *note**:
[If an intelligent system can only solve learning tasks, unlimitedly expand and systematize knowledge, skills and abilities, then it is potentially universal in the sense that it can learn anything, including solving any task.]
⇒ *parameter-factor**:
- *ability of a cybernetic system to be trained by external actors^*
  := [ability to be a good student]
  ⇒ *explanation**:
  [Teacher (trainer, tutor, developer) — is a subject (cybernetic system), which transfers the knowledge and skills known to it into the memory of the learner. Here the teaching methodology and qualitative management of the learning process are important.]
- *self-learning^*
  := [ability of a cybernetic system to act as both student and teacher^]
  := [ability of a cybernetic system to independently perform its own learning^]
  := [level of independence of cybernetic system in the process of its training^]
  ⇒ *parameter-factor**:
  - *ability of a cybernetic system to learn from its own experiences and mistakes^*
  - *ability of a cybernetic system to learn independently from the experience of other cybernetic systems^*
    ⇒ *parameter-factor**:
    - *ability of a cybernetic system to learn independently from the experience of other cybernetic systems by imitating and analyzing the activities of those systems^*
    - *ability of a cybernetic system to learn independently from the experience of other cybernetic systems by utilizing the knowledge and skills accumulated by these cybernetic systems^*
      ⇒ *note**:
      [Such training requires that the cybernetic system to be trained be an agent of a multi-agent cybernetic system in which the experience of all its agents is captured in the shared public memory of that multi-agent system, which may be either a distributed memory (distributed across agents) or the memory of a corporate agent (corporate system) that is part of said multi-agent system]
  - *ability to navigate modern information sources^*
  - *ability to understand modern information sources^*
  - *ability to analyze and improve one's cognitive activity^*
- *ability to detect and eliminate contradictions and syntax errors in the internal information model of the environment^*
- *ability to detect and fix information holes in the internal information model*

*of the environment^*

- *ability to detect and remove information garbage from the internal information model of the environment^*
  ⇒ *explanation**:
  [Information garbage — is unnecessary (redundant) or easily recoverable information]
  := [ability to detect and forget unnecessary information^]
- *flexibility of the internal environmental information model^*
  := [labor intensity of modification (editing, reconfiguration, restructuring) of the internal information model of the environment^]
- *stratification of the internal information model of the environment^*
  := *explanation**:
  [quality of structuring the internal information model of the environment designed to minimize the size of the activatable area of this internal information model, sufficient to solve each initiated task^]
- *ability of a cybernetic system to understand^*
  := [ability to converge the different knowledge included in the internal information model of the environment, or to converge externally acquired knowledge and "immerse" it in the internal information model of the environment]
  := [ability to realize (comprehend) the new acquired information and to immerse (bind, link) the new information more deeply into the context of the current state of the entire internal information model of the environment]
- *cognitive motivation and activity of cybernetic system^*
  := [cognitive activity^]
  ⇒ *epigraph**:
  [One day you stop learning, and you start dying.]
  ⇒ *author**:
  Albert Einstein
  ⇒ *note**:
  [Cognitive activity can occur in two ways:
  - in width — expansion of the studied part of the environment (expansion of the number of subject domains, expansion of the number of known facts within a subject domain).
  - in depth — improving the system of acquired knowledge

  ]
- *reflexivity of the cybernetic system^*
  := *explanation**:
  [the ability of a cybernetic system to analyze its own and, first of all, insufficiently effective behavior (its own experience in solving various tasks) and especially to analyze its own mistakes^]
  := [ability to be aware of one's actions, to make sense of and focus one's behavior^]
  := [ability of a cybernetic system to realize what it is doing, as well as how and why^]
  ⇒ *parameter-factor**:
  - *ability to distinguish between qualitative understanding and illusionary understanding*
    := [ability to distinguish sufficiently deep (valid) understanding from insufficiently complete (superficial) understanding, which does not ensure its qualitative (reliable) use in the organization of cybernetic system activity^]

  ⇒ *epigraph**:
  [A smart man is not the one who knows a lot, but the one who knows himself]
  ⇒ *author**:
  Johann Wolfgang Goethe
  ⇒ *epigraph**:
  [Awareness of your imperfection brings you closer to perfection]
  ⇒ *author**:
  Johann Wolfgang Goethe
  ⇒ *epigraph**:
  [True greatness begins with understanding your own nothingness]
  ⇒ *author**:
  Johann Wolfgang Goethe
  ⇒ *epigraph**:
  [You can act and you know why you act, but you don't know why you know that you know how to act.]
  ⇐ *quote**:
  Rose name

⇒ *author**:
Umberto Eco

- *motivation to progress^*
  := [purposeful (conscious) developmental attitude^]
  := [hunger, desire for progress]
- *capability to progress*
  := [ability to progress^]
  := [capacity]
- *determination for progress*
  := [activity^]
  := [cognitive activity^]
  := [cognitive]
- *courage*
  := [absence of fear of the unknown, contradictions, cognitive dissonance^]
- *supergroupsign*
  ⇒ *note**:
  [In order to simplify morphisms between similar information constructs (desire for isomorphism of analogies, permanent restructuring of the world picture).]
- *ability to adjust the system of concepts used^*
  ⇒ *note**:
  [In order to minimize the number of concepts used (following Occam's Razor Principle).]
- *ability to restructure the internal information model of the environment^*
  ⇒ *explanation**:
  [The increase in the level of intelligence is not limited by the number of facts (and knowledge), but is determined by the way these facts and knowledge are interpreted (explained, conceptualized) within the framework of expanding personal experience (individual subjective picture of the world). Each new information acquired or generated by the cybernetic system forces to rethink the whole picture of the world. The evolution of the world picture is not just an accumulation of knowledge, but also the ability of the cybernetic system to restructure its own world picture.]
- *ability to minimize contradictions^*
  := [cognitive dissonance coping]
- *ability to minimize explicit information holes^*
- *ability to detect and eliminate synonymy of signs^*
- *ability to detect patterns, generate hypotheses^*
- *hypothesis-supporting ability*
- *ability to improve one's learning ability*
  := [ability to continually improve one's ability to learn]
- *multiplicity of types of knowledge and skills evolving during cybernetic system training^*
  := [multiple directions in which cybernetic system training is most active^]
- *ability of a cybernetic system to converge and deeply (seamlessly) integrate the knowledge it acquires^*
  := [ability of a cybernetic system to move from the eclectic accumulation of the knowledge it acquires to their harmonization and systematization with the help of appropriate meta-language tools^]

- *ability of a cybernetic system to modernize (transform) its physical shell^*
  ⇒ *parameter-factor**:
  - *ability of a cybernetic system to modernize (transform) its physical shell, carried out by external entities^*
    := [ability to modernize the physical shell using external entities^]
  - *ability of a cybernetic system to independently modernize (transform) its physical shell^*
  - *flexibility of the physical shell of a cybernetic system^*
    := [modifiability (modernizability, reconfigurability, transformability) of the physical shell (body) of a cybernetic system^]
- *ability of a cybernetic system to increase its level of autonomy^*
  := [ability to increase one's independence, self-sufficiency, self-reliance]
- *ability of a cybernetic system to increase its level of interoperability^*
- *ability of a cybernetic system to increase its level of synergy*
  ⇒ *note**:
  [It is about improving the quality (efficiency) of the organization of interaction between the components of a cybernetic system (components of an individual cybernetic system or agents of a multi-agent cybernetic system)]
  ⇒ *parameter-factor**:
  - *ability of a cybernetic system to*

*increase its level of hybridization^*
⇒ *explanation**:
[Hybridization of a cybernetic system implies convergence and subsequent deep (diffuse, seamless) integration of components of a cybernetic system — different kinds of knowledge (including programs), different kinds of problem-solving models, different components of a multimodal interface, different agents of a multi-agent system.]
⇒ *parameter-factor**:
- *ability to converge between components of a cybernetic system^*
  ⇒ *note**:
  [It refers to the convergence (convergence, compatibility) of the components of an individual cybernetic system as well as the agents of a multi-agent cybernetic system]
- *ability to perform deep integration of cybernetic system components^*

:= [evolutionary]
:= [ability to evolve (to increase self-organization)^]
:= [speed of evolution (quality improvement) of cybernetic system^]
:= [speed (first derivative) of the process of evolution (quality level increase) of a cybernetic system^]
:= [labor intensity of cyber system quality improvement^]
⇒ *decreasing a parameter by its domain of definition**:
- *evolution of a class of cybernetic systems^*
- *evolvability of a particular cybernetic system^*

⇒ *parameter-factor**:
- *evolvability by external actors (teachers, developers)^*
- *self-evolving^*
- *flexibility^*
  := [modifiability^]
  - *plasticity^*
  - *reconfigurability^*
  - *rearrangeability^*
  - *transformability^*
- *stratifiability^*
- *reflexivity of external actors carrying out evolution (teachers, developers)^*
- *ability to self-reflect (to analyze one's own activity for its effectiveness)^*

VI. Accelerating the evolution of cybernetic systems

accelerating cybernetic systems evolution
:= [ability to grasp the theory of evolution and use it for your own evolution]
⇒ *parameter-factor**:
- *ability of a cybernetic system to optimize the distribution of priorities of evolution rates by different parameters (directions) in each period of time in order to maximize the complex effect^*
- *ability of a cybernetic system to determine the strategy of the evolutionary process^*
  ⇒ *note**:
  [A cybernetic system must be able to intelligently plan its evolution, clearly aligning strategic and tactical objectives with its motivation and abilities]
- *ability to formalize methods of evolution of cybernetic systems and permanent improvement of these methods, as well as the evolution of the theory of evolution itself*

The laws of evolution of individual cybernetic systems and collective cybernetic systems have many similarities, but also significant differences. The unity and struggle of individual cybernetic systems with the external environment should change into unity and struggle with the external environment of multi-agent cybernetic systems, but not between its agents.

Laws of evolution of cybernetic systems:

- In the evolution of cybernetic systems, not only the increase in the values of parameters that determine the level of intelligence (level of self-organization) of a cybernetic system and indicate different directions of the evolutionary process, but also the balance (harmony) of evolution rates (velocities) in all these directions is important;
- This balance (distribution of importance) of cybernetic system evolution directions depends significantly on the stage of cybernetic system evolution — what was unimportant at previous stages may become key for the current stage.
- If a cybernetic system does not evolve, it degrades. Evolution must be permanent.
- The evolution of a multi-agent cybernetic system is determined by the diversity, intelligence and interoperability of agents, as well as by the improvement of the principles of organizing the interaction of agents (i.e. the evolution of their synergy) — the competition of intelligent agents is a brake on the evolution of a multi-agent cybernetic system
- Collectives of non-intelligent agents — dead-

end branches of the evolution of multi-agent cybernetic systems (example — swarm multi-agent systems).

- *multi-agent cybernetic system* ⊂ *multi-agent system*
- The cybernetic system's knowledge of the laws of evolution — a factor in the acceleration of evolution

The ability of a cybernetic system at each stage of its evolution to competently correct (refine) the distribution of importance of the directions of its further evolution is the main factor of evolution acceleration. If this ability is absent — there is a danger of "falling" into a dead-end branch of evolution.

General principles of evolution of cybernetic systems:

- to expand the scope and increase the semantic power of the *internal information model of the environment* (expansion and deepening of knowledge)
- extension *multiplicity* of components for different types of components
  - of knowledge base fragments
  - of problem-solving models
  - of agents of multi-agent systems
- *convergence* of different components (from eclectic diversity to *synergy*)
  - of knowledge base fragments
  - of problem-solving models
  - of agents of multi-agent systems
- *stratification* and fractality.
  - multilevel, hierarchy
  - to increase synergies within each level and between levels
- *universalization* of problem-solving methods, models and agents

The current evolutionary level (current stage of evolution) of a cybernetic system determines:

- principles underlying the self-organization of this system;
- of directions (tactics and strategy) of further evolution of the mentioned system.

deadlocked branch of cybernetic system evolution

:= [cybernetic system on a dead-end branch of its evolution]

:= [cybernetic system with limited evolutionary possibilities]

⇒ *note**:

[The main reasons for the inhibition of the evolutionary process and even more so for the emergence of fundamentally insurmountable limitations for further increase in the intelligent level of cybernetic systems are:

- imbalance of different evolutionary directions
- insufficient attention to the convergence of components of cybernetic systems and, as a consequence, the lack of synergy effect
- insufficiently high level of intelligence of cybernetic systems that are combined into multi-agent cybernetic systems
- insufficiently high level of interoperability (socialization) among agents of multi-agent cybernetic systems

]

deadlocked branch of the evolution of individual cybernetic systems

⊂ *deadlocked branch of cybernetic system evolution*

⊃ *an individual cybernetic system that does not allow for convergence, deep integration and synergy of all the different kinds of components — all the different kinds of knowledge used, problem-solving models, all the different kinds of interfaces*

:= [individual cybernetic system that is not hybrid or that is hybrid but not capable of extending a diversity of knowledge types, problem-solving models, and interfaces]

Key evolutionary directions:

- Transition from eclectic diversity of components to their synergy (harmony)
  - from eclectic diversity of knowledge to its convergence and systematization
  - from eclectic diversity of problem-solving models to their convergence and seamless integration (to hybridization)
  - from the diversity of specialization of agents in multi-agent systems to their convergence (compatibility), interoperability and synergy
- Increase the number of hierarchy levels

Branches of the evolution of cybernetic systems:

- evolution of customized artificial cybernetic systems
- transition from individual to multi-agent artificial cybernetic systems (from collectives of weakly intelligent cybernetic systems to collectives of intelligent systems — from swarm intelligence to superintelligence).
- the individual evolution of human beings
- the evolution of human collectives
  - the instrumental evolution of humans
    - ∗ from passive tools to machines
    - ∗ to computer systems
    - ∗ to intelligent computer systems

∗ to a superintelligent human-machine community.

should be distinguished*
∋ {• *evolution of cybernetic system*
• *evolution of the internal information model of the cybernetic system environment*
• *evolution of a cybernetic system problem solver*
• *evolution of cybernetic system memory*
• *evolution of the cybernetic system processor*
• *evolution of the interface of a cybernetic system with the external environment and its own physical shell*
• *evolvability of cybernetic system*
:= [ability of a cybernetic system to evolve]
• *learning cybernetic system*
• *self-evolving cybernetic system*
• *self-learning cybernetic system*
}

VII. System of key concepts semantically similar to the parameters defining the level of intelligence of cybernetic systems

A. *Information constructs, languages and semantic representation of information, types of knowledge, knowledge bases*

information construction
:= [information]
⊃ *information construct stored in memory*
⊃ *sense representation of information*

language
⊃ *universal language*
⊃ *natural language*
⊃ *artificial language*
⊃ *language of semantic representation*
⊃ *specialized language*
⊃ *formal language*

sense representation of information
:= [sense representation of the information construct]
:= [sense construction]
:= [meaning]
:= [invariant of the diversity of forms of representation of an information construct]
:= [refined semantic network]
⇒ *principles underlying**:
{• [Each sign, which is a part of the semantic representation of an information construction, enters the information construction once, i.e. there is no synonymy of signs within each semantic construction]
•
[Each character included in a semantic information construction is an elementary fragment of this information construction, i.e. a fragment whose structure analysis is not required in the process of syntactic analysis, semantic analysis and understanding of the semantic information construction]
⇒ *note**:
[Thereby, letters, words, phrases are not used to represent signs in semantic constructions]
• [The semantic information construction includes only signs and, accordingly, does not include such fragments as delimiters, limiters]
• [The set of signs that make up semantic information constructions is divided into the following three classes:
  • class of binary oriented mappings, each of which denotes either some binary oriented relation between some signs included in the semantic construction, or some binary oriented relation between the described entities denoted by the corresponding signs. Such mappings will be called arcs;
  • class of binary non-oriented mappings, which we will call edges and which have a denotational semantics similar to binary oriented mappings;
  • The class of signs that are not binary bindings (such signs will be called nodes included in semantic constructions).

]
• [The direct relationship between the signs included in a semantic construction is syntactically specified by two binary oriented incident relations:
  • The ratio of the incidence of bindings with the corresponding bound signs, which can be signs of any kind;
  • The ratio of the incidence of the incoming arcs with the corresponding linked signs.

]
• [Alphabet of syntactically distinguished elements of semantic constructions is defined by additional partitioning of the class of arcs, class of edges and class of nodes into corresponding subclasses, each of which has a clear denotational semantics]
• [The operation of integration (unification) of semantic constructions is reduced to the theoretical-multiplicative unification of all elements of these constructions (all signs included in their composition) with identification (gluing) of synonymous signs, i.e. those signs from different unified constructions that

denote the same described entities]
}
⇒ *properties**:
{• [Sense information constructions are non-linear (graph) structures, because the signs of described entities, which are represented once in a sense construction, can have an unlimited number of connections with other signs]
• [Any information corresponds to its unambiguous semantic representation, i.e. all variants of semantic representation of any information are not only semantically equivalent, but also syntactically equivalent, connected by isomorphism, which pairs of correspondence connect synonymous signs]
}

should be distinguished*
∋ {• *sense**
:= [Relationship linking information constructs to their semantic representation]
• *sense*
:= [sense representation of information (information construct)]
:= [sense representation of information]
:= [naked representation of information, devoid of any details that are not directly related to the described situations, events, processes, structures (i.e., which are not signs of the components of the described objects)]
⇒ *note**:
[The meaning of the information is not in the signs of the entities in question, but in the configuration of the relationships between them]
⊃ *semantic representation of the internal information model of the environment*
:= [semantic representation of the subjective picture of the world]
• *language of semantic representation*
⇒ *subdividing**:
{• *specialized semantic representation language*
• *universal semantic representation language*
∋ *SC-code*
}
⇒ *subdividing**:
{• *graphic language of semantic representation*
• *language of internal semantic representation in the memory of a cybernetic system*
∋ *SC-code*
}
• *sense memory*
⊂ *associative memory*
}

should be distinguished*
∋ {• *sense representation of information*
• *language of semantic representation*
∋ *SC-code*
• *alphabet of the language of the meaning space*
• *sense**
• *semantic space*
• *semantic distance between characters*
⇒ *note**:
[in the semantic space]
• *semantic proximity of semantic constructions*
⇒ *note**:
[in the semantic space]
• *morphism of semantic constructions*
}

convergence of information constructs
:= [reducing information constructions to syntactically equivalent form (to the same syntax and to maximum possible use of synonymous signs by transforming the original information constructions into semantically equivalent ones)]

{• *semantic compatibility of cybernetic systems^*
:= [level of semantic compatibility of cybernetic systems^]
∈ *parameter*
• *learning cybernetic system^*
:= [learning level of cybernetic system^]
∈ *parameter*
}
⇒ *note**:
[Semantic compatibility of cybernetic systems is the most important factor in significantly increasing the level of their learnability, because in the presence of semantic compatibility of a cybernetic system with other cybernetic systems, a cybernetic system becomes a social subject capable of quickly acquiring new knowledge not only independently (in the process of individual interaction with the environment), but also in a "ready-made" form from other subjects.]

semantic cyber interoperability^
:= [degree of semantic compatibility between two cybernetic systems^]
∈ *parameter*
⇒ *quote**:
[The meeting of two people is– the meeting of two

chemical elements. The reaction may not happen, but if it does — both are changed.]
⇒ *author**:
Karl Gustav Jung
⇒ *area of definition**:
pair of cybernetic systems
⇐ *parameter-factor**:
understanding of cybernetic systems
:= [level of understanding between two cybernetic systems]
⇒ *note**:
[Semantic compatibility is a necessary but not sufficient condition (factor) for mutual understanding.]

should be distinguished*
∋ {• *semantic compatibility of cybernetic systems^*
∈ *parameter*
⇒ *area of definition**:
a pair of cybernetic systems
• *ability to ensure semantic compatibility with partners^*
∈ *parameter*
⇒ *area of definition**:
cybernetic system
}

knowledge
⊃ *task*
⊃ *question*
⊃ *definition*
⊃ *method*
⊃ *information processing program*
⊃ *program of external goal-directed behavior*
⊃ *protocol*
:= [description of the action performed]
⊃ *ontology*
⊃ *subject domain*

B. ***actions, tasks, task classes, methods, task types, intelligent tasks***

task
⊃ *explicitly initiated (formulated) task*
⊃ *task situation that is not an explicitly stated initiated task*
⇒ *note**:
[Often, these non-explicit tasks are various problem situations in the knowledge base, such as:
- contradictions or errors in the internal information model of the environment (contradictory situation, cognitive dissonance)
- information garbage
- information hole
- a dangerous (harmful) situation (event) in the environment (a situation in which something must be done)

]
⇒ *note**:
[All problems and classes of problems could be formulated]
⇒ *subdividing**:
{• *procedural formulation of the problem*
• *declarative problem statement*
}

should be distinguished*
∋ {• *level of ability to perform a given action (a given task) or a given activity*
:= [level of skill and ability to perform a given action (given task) or given activity]
:= [how capable (trained, skilled) a cybernetic system is to perform a given job]
• *level of willingness of a given cybernetic system to perform a given action*
:= [willingness (motivation) to solve a given task or perform an activity of a given type in a given area]
:= [how much and what the cybernetic system wants to do]
• *level of activity (performance, energy) of a cybernetic system in performing a given job*
:= [how much time, effort, resources a cybernetic system spends on work]
• *level of responsibility (seriousness of attitude) of the cybernetic system to the result of this work (doer/simulator)*
}

should be distinguished*
∋ {• *quality goal-setting ability^*
⇒ *area of definition**:
cybernetic system
• *quality of goal-setting^*
∈ *parameter*
⇒ *area of definition**:
action
⇒ *parameter-factor**:
• *relevance and timeliness of goal setting^*
• *quality of generated goals and plans^*
⇒ *parameter-factor**:
• *end should not justify the means*
• *goal must not contradict higher-level goals^*
• *strategic goal should not be sacrificed for tactical goals^*

}

C. ***understanding, explanation, ability to understand, ability to explain***

understanding^
⇒ *questions**:
- if we understand this kind of understanding
- whether we can distinguish between qualitative (deep) understanding and less qualitative
- whether we can test understanding (in humans and in intelligent computer systems)
- if we have a high enough level of understanding

⇒ *problems**:
- not a high enough level of understanding
  - individual understanding
  - of understanding between people
  - of understanding between intelligent computer systems and users
  - mutual understanding between intelligent computer systems
- the basis of understanding is the presence of a sufficiently powerful and qualitative subjective picture of the world (context)
- modern education teaches knowledge, skills, but not the ability to understand
- needs understanding tests
- mutual understanding — it is a coincidence of world pictures (semantic compatibility, unification)

⇒ *testing**:
- the level of understanding of some entity is determined by the power, quality, originality of the semantic neighborhood of the sign of this entity in one's subjective picture of the world (including comparisons, analogies ...)
- level of information understanding — it is the quality of the semantic neighborhood of the sign of this information construct, as well as the quality of the semantic neighborhoods of all signs included in this information construct
- understanding often requires moving to a higher-level view of the system — and to a meta-language

⇒ *note**:
[The basis for improving understanding is the semantic structuring of the internal information model of the environment (world picture, knowledge base).

One should teach not only knowledge and skills — but also systematization of the knowledge base (teach the rules of semantic structuring of the knowledge base).]

should be distinguished*
∋ {• *understanding ability*
  ∈ *parameter*
• *understanding*
  ⊂ *process*
  ⊃ *understanding the information stored as part of the internal information model of the environment*
  ⊃ *understanding of the object of study*
  ⊃ *understanding sensory information*
  ⊃ *understanding by a computer system of a message received from another computer system*
  ⊃ *user's understanding of the message received from the computer system*
  ⊃ *understanding by the computer system of the user's message*
}

should be distinguished*
∋ {• *ability to understand*
  := [ability to understand the meaning (essence) of the value, significance, quality of acquired or independently produced (deduced) information]
  ⇒ *explanation**:
  [Understanding new information is not only about using it in the current moment (as a reaction to the current situation), but also about saving it for use in any unpredictable circumstances when needed. Therefore, any information should be immersed in the context of the current state of the subjective picture of the world, i.e. placed in such a place in the structure of this picture of the world, where it can be easily found.

  This is the essence of the difference between training artificial neural networks and training intelligent computer systems (from the evolution of the all knowledge base)]
• *understanding*
  := [understanding the meaning]
  := [understanding the essense]
  ⇒ *note**:
  [To understand some information — is to determine how important it is to the goals that a cybernetic system is pursuing, and to determine how and when (under what circumstances) that information is to be used]
  ⇒ *questions**:
  {• [What is meaning]
  • [What is the process and result of un-

derstanding:

- Translation into semantic language (language of semantic representation of information)
- Establishing links (immersion) of the semantic representation of the understood information into the current state of the internal information model of the environment

]

}

}

should be distinguished*

∋ {• *understanding*

- *depth of understanding^*
- *ability to understand^*
- *mutual understanding*
- *level of understanding between the agents of a multi-agent cybernetic system^*
  ⇐ *parameter-factor**:
  *intelligence of multi-agent cybernetic system^*

}

understanding

⊃ *understanding the information perceived by your own sensors*

⊃ *understanding messages from other cybernetic systems (from other agents in the same multi-agent system)*

⊃ *understanding the real entities of the external environment*

  ⊃ *understanding the external objects that the cybernetic system acts on*

  ⊃ *understanding of external actors (their behavior)*

  ⊃ *understanding of external situations, events, processes*

  ⊃ *understanding your own physical shell*

  ⊃ *understanding your own goals and behavior*

⊃ *understanding the abstract entities of the internal information model of the environment*

  ⊃ *understanding of the concepts used*

  ⊃ *understanding the fragments of the internal information model*

  ⊃ *understanding your own information processes*

⇒ *epigraph**:

[Heard a bell ringing, don't know where it is]

⇒ *epigraph**:

[I don't get upset if people don't understand me, — I get upset if I don't understand people.]

  ⇒ *author**:
  Confucius

⇒ *explanation**:

[To understand — is to consider the object of study not only at the level of its internal structure, but also at the meta level — to establish what it is a part of, what classes it is an element of, what analogs it has and how it differs from its analogs. So, for example, to understand Euclidean geometry, it is necessary not only to know axioms, theorems, basic concepts, proofs, methods of solving geometric problems, but also what geometries are still known, what is the field of application of Euclidean geometry, and so on.]

⇒ *note**:

[It should be emphasized that knowing and knowing are not the same as understanding. It is possible to have some knowledge and even to be able to use this knowledge in the process of solving various problems, but to understand it all very superficially. Note, however, that the methodology for testing knowledge and skills is quite clear, whereas the methodology for testing understanding requires considerable development.]

⇒ *note**:

[The need for cybernetic systems that are aware of what they are doing and, in particular, of the consequences of their actions, that understand what they are doing and why they are doing it, will increase. Otherwise, there will be no further technological progress.]

⇒ *epigraph**:

[The bee collects honey and knows how to do it. Only the beekeeper realizes that she is collecting honey for him.]

the ability to understand^

⇒ *parameter-factor**:

- *ability to understand the state and dynamics of the external environment^*
  := [ability to understand the causes and predict the consequences of current situations, events, processes]
- *ability to understand the behavior (including goals) of external actors^*
- *ability to increase the level (quality, reliability) of understanding^*

⇒ *epigraph**:

[If you can't explain it to your grandmother, you don't understand it.]

  ⇒ *author**:
  Albert Einstein

  ⇐ *epigraph**:
  *ability to explain^*

⇒ *epigraph**:

[Everyone hears only what he understands.]

  ⇒ *author**:
  Johann Wolfgang Goethe

should be distinguished*

∋ {• *learning^*

:= [ability to learn, to acquire and assimilate new knowledge and skills^]

• *ability to understand*

:= [ability to understand acquired knowledge and skills^]

}

⇒ *note**:

[These are fundamentally different levels of ability. Knowing and understanding are not the same thing.]

should be distinguished*

∋ {• *understanding*

∈ *activity*

:= [immersing new information into one's internal information model of the environment]

• *quality of understanding^*

:= [degree of understanding]

:= [level of understanding^]

• *explanation*

:= [transmitting information (message) that allows something to be better (more adequately) understood]

⇒ *explanation**:

[The process of *understanding* can be interpreted as an explanatory (explaining) dialog with oneself, that is, as a process of *explaining* to oneself the relevant entity to be explained]

• *quality of explanation^*

:= [explanation clarity]

:= *explanation**:

[indicator of how easy it is to understand the essence of an explained entity — a concept, a material object, a connection, a pattern, a problem, a proof, an information construct (text, message) of any kind]

• *ability to understand*

• *explanation ability*

• *learning*

• *understanding test*

:= [test requiring meta-level — metaknowledge and metacognition]

• *explanation*

}

should be distinguished*

∋ {• *understanding*

∈ *process*

:= [process of solving the problem of understanding]

• *result of understanding*

:= [sufficiently complete but compact specification (description) of the entity to be understood, containing all basic information about the entity (its relations with entities at the same level of the entity hierarchy, and its place within entities at a higher level of the hierarchy)]

:= [result of solving the problem of understanding]

• *understanding task*

:= [statement of the task of understanding the specified entity]

}

should be distinguished*

∋ {• *understanding*

⊂ *information process*

⊂ *action*

• *depth of understanding^*

:= [quality of execution of the understanding process^]

:= [level of understanding^]

:= [degree of understanding^]

• *object of understanding*

:= [understood entity]

⇒ *note**:

[The object of understanding can be any entity — an event, situation, process, action, activity (behavior of some cybernetic system), any external or internal information construct, etc.]

• *ability to understand*

:= [level of ability of a cybernetic system to grasp the essence (including causes and consequences) of an event, phenomenon, subject, and so on]

}

depth of understanding^

⇒ *explanation**:

[*depth of understanding* is determined by the number of essential connections of the understood entity (*object of understanding*) with the current state of the internal information model of the environment (subjective picture of the world), which is considered as the context of the understood (investigated) entity. In other words, the depth of understanding is determined by informative of the semantic neighborhood of the sign of the understood (investigated) entity in the subjective picture of the world. Consequently, the depth of understanding is determined by the quality (informativeness, semantic power) of the subjective picture of the world itself.]

explanation

:= [explanation of behavior]
⇒ *note**:
{

should be distinguished*
∋ {• *simulation of a person explaining the solution to a particular problem*
⇒ *explanation**:
[By approximating similar explanations on a large number of such explanations — on a large statistical sample (dataset).]
• *logical-semantic explanation of how a generative artificial neural network constructed this imitation of a human explanation*
. ⇒ *note**:
[In addition to the explanation of how the problem was solved, there must be evidence (justification) that the solution process is correct and the result can be trusted.]
}
}

should be distinguished*
∋ {• *process of problem solving*
• *explanation of the problem-solving process*
• *explanation of the problem-solving process*
:= [this explanation of how the problem was solved by decomposing the solution process into interrelated subprocesses, in which for each specified subprocess its operational semantics (its meaning) is further explained]
}

It is intuitively clear that the ability (ability) to understand is a necessary property (ability) of intelligent cybernetic systems. It is also obvious that the level of understanding in people and intelligent computer systems requires a significant increase in connection with the transition to a new technological mode. In addition, the level of mutual understanding needs to be significantly increased.

The problem of ***high level of understanding***, or rather the problem of providing ***high level of understanding*** — the key problem of the current stage of development of Artificial Intelligence technologies and the development of Mankind. Both intelligent computer systems and Humanity must adequately understand what they are doing.

Understanding involves structuring the knowledge base and associativity of search procedures. Knowledge base structuring should have universal subject-independent principles — all new (acquired) knowledge should be immersed (placed) in the knowledge base so that it can be easily found in situations,

1) that are inherently unpredictable.
2) in which it is not known a priori what knowledge stored in memory can be useful

D. ***Learning, self-learning, and learnability***

should be distinguished*
∋ {• *current state of the internal environmental information model^*
:= [current level of development of subjective picture of the world (knowledge and skills of the cybernetic system)^]
⇐ *parameter-factor**:
*current level of cybernetic system development^*
• *learning*
⊂ *process*
:= [process of expanding and improving the quality of the internal information model of the environment (subjective picture of the world)]
⇐ *generalized part**:
evolution of a cybernetic system
• *study tempo^*
⇐ *parameter-factor**:
*evolutionary rate^*
• *learning^*
:= [learning ability]
⇐ *parameter-factor**:
*evolutionary potential^*
:= [evolutionary]
}

should be distinguished*
∋ {• *learning*
:= [improvement and/or expansion of knowledge and, in particular, skills]
⊃ *learning with a teacher*
⊃ *self-learning*
• *learnability^*
:= [learning ability^]
:= [training labor intensity^]
• *factors that ensure learning*
:= [properties that enable learning]
}

learning
⇒ *explanation**:
[The most important type of tasks solved by a cybernetic system are learning tasks aimed at expanding the knowledge and skills used by the cybernetic system, which in turn leads to an

expansion in the number and variety of tasks solved by the cybernetic system]
:= [process of solving a meta-problem aimed at increasing the number of problems to be solved and improving the quality of their solution]

learnability^
:= [learning ability]
⇒ *note**:
[A high level of *understanding* is a necessary factor in *understanding* is a high level of *understanding*. Indeed, a deep *understanding* of situations and events occurring in the *environment* and, in particular, a *deep* understanding of the acquired *information* is the foundation of the *learning* process of a cybernetic system.]

should be distinguished*
∋ {• *educatedness^*
:= [volume and quality of acquired knowledge, skills and abilities]
⇒ *parameter-factor**:
- *volume of internal information model of cybernetic system environment^*
- *quality of the internal information model of the cybernetic system environment^*

• *highly educated cybernetic system*
:= [cybernetic system capable of solving intelligent problems]
⇒ *note**:
[In order to be able to solve intelligent problems, one must have a high level (amount and quality) of knowledge, skills, and abilities]
}

E. ***Convergence, interoperability, synergy in individual cybernetic systems, hybrid cybernetic systems, synergy in multi-agent cybernetic systems, interoperability***

should be distinguished*
∋ {• *compatibility^*
• *semantic compatibility of cybernetic systems*
• *information construct compatibility*
• *convergence*
• *synergy*
}
∋ {• *compatibility^*
:= [closeness^]
:= [convergence^]
⇒ *area of definition**:
family of cybernetic systems or their components
⇒ *parameter-factor**:
- *couple compatibility^*
- *semantic compatibility^*
:= [level of understanding^]

• *convergence*
:= [compatibility upgrade process]
• *ability to increase mutual understanding (semantic compatibility) — to converge one's worldview and that of one's partners^*
}
∋ {• *hybridity level^*
:= [multiplicity and compatibility of components^]
. ⇒ *note**:
[The basis of a customized cybernetic system with a high level of hybridity is a common platform]
• *synergy level*
:= [component interaction efficiency^]
⇒ *note**:
[For a multi-agent cybernetic system with a high level of hybridity — this is the unification of the messaging language (language of communication) and the basis for combating the Babylonian pandemonium syndrome and the information crisis.]
}
[The greatest friendship exists between extreme opposites. The opposite nourishes the opposite, while the similar receives nothing from the similar.]
⇒ *author**:
Plato

should be distinguished*
∋ {• *synergy level*
:= [efficiency of interaction of cybernetic system components^]
:= [synergy]
:= [quality (efficiency) of interaction of components of a complex dynamic system^]
• *synergy level increase*
∈ *process*
:= [transition of a cybernetic system from chaos to order, to efficient interaction of its components]
⊃ *increased synergy of individual cybernetic system components*
⊃ *increasing the level of synergy of agents in a multi-agent cybernetic system*
• *capability to increase synergy*
⇒ *decomposition by domain of definition**:
{• *ability of an individual cybernetic system to increase its level of synergy^*
• *ability of a multi-agent cybernetic system to increase its level of synergy^*
}

}

synergy
:= [effective communication^]
⇒ *necessary condition**:
convergence of diverse components
:= [resonance of interacting components^]
⊃ *synergy of the components of the world picture*
:= [deep (seamless) integration]
⊃ *synergy of information processes and different problem-solving models^*
⊃ *agent synergy of multi-agent cybernetic system^*
⇒ *condition**:
*interoperability^*
⇒ *factor**:
- *interoperability of all agents*
- *efficiency of interaction organization*
⇒ *component**:
  - *standard mode of interaction (regulated with clear distribution of roles and responsibilities)*
  - *emergency regulated mode*
  - *emergency unregulated treatment under unforeseen circumstances*
- *evolution*

:= [component synergy level^]
⊃ *synergy of fragments of the internal information model of the environment^*
⊃ *synergy of methods*
⊃ *synergy of problem-solving models^*
⇒ *explanation**:
[*synergy* is a kind of "creative" resonance of activity of all components of a cybernetic system (resonance can also be destructive — self-destructive).]

cybernetic system component synergy^
:= [degree of depth of interpenetration and seamless integration of cybernetic system components^]
:= [level of efficiency of interaction of cybernetic system components^]
⇒ *explanation**:
[This parameter characterizes the most important direction in the evolution of cybernetic systems, which consists in the transition from the eclectic connection of various (including heterogeneous) components of cybernetic systems (e.g., using the "black boxes" methodology, which does not take into account the internal structure of the connected components) to a more effective interaction of components, which involves taking into account the internal structure of the connected (integrated) components.]
⇒ *note**:
[In the course of evolution of cybernetic systems, synergies are manifested at different structural levels of these systems:
- at the level of integration of different components of the internal information model of the environment (different types of acquired knowledge)
- at the level of integration of various components of the cybernetic system problem solver (including various problem solving models)
- at the level of integration of various components of the multimodal interface of a cybernetic system
- at the level of organization of interaction between different agents of a multi-agent cybernetic system (including agents with different specializations)

]
⇒ *note**:
[Increasing the level of synergy of the components of cybernetic systems implies ***convergence*** of these components and their subsequent integration as deep as possible (seamless). Let us emphasize that a very promising basis for this ***convergence*** and integration of cybernetic systems components is the ***semantic representation of information***, the key advantage of which is that this representation of information is a <u>invariant</u> variety of semantically equivalent forms of representation of the same information.]
⇒ *note**:
[A prerequisite for synergy between the components of a cybernetic system is their ***semantic compatibility*** (semantic compatibility between knowledge base components, problem solver components, different sensors and sensor configurations, and different agents of multi-agent systems). The key factor in ensuring semantic compatibility is the use of ***universal language of internal semantic representation of information*** in the memory of cybernetic systems. The main advantage of such language is the unambiguity of information representation, i.e. the absence of a variety of variants of representation of the same information.]
⇒ *note**:
[The increasing synergy of the components of cybernetic systems, being an important direction in the evolution of cybernetic systems, is to some extent opposed to the dialectical law of unity and struggle of opposites. In order for the self-organization of a cybernetic system to resist the destructive impact of the external environment, it <u>inside itself</u> must move from the unity and struggle of opposites to the unity and <u>synergy</u>

of opposites, which in multi-agent cybernetic systems means the need to move from conflict and competitive interaction, from the search for compromise solutions to the search for consensus, to improve the quality of self-organization. In intelligent multi-agent cybernetic systems, the competition of agents is not a stimulus but a brake on evolution]

.

should be distinguished*

∋ {• *hybridity level^*
  ∈ *parameter*
  := [level of compatibility of the diversity of components of a cybernetic system^]
• *hybridization*
  := [evolution of a cybernetic system by (in the direction of) increasing the level of hybridity]
  := [transition of a cybernetic system from an eclectic variety of components to a harmonious integrated system, to a systematized variety]
  := [systematization]
  ⊂ *direction of evolution*
  ⊂ *cybernetic system activity*
  ⊃ *hybridization of individual cybernetic system*
    := [convergence and deep integration of different kinds of knowledge and problem-solving models]
  ⊃ *hybridization of multi-agent cybernetic system*
    := [convergence of different specialized agents of a multi-agent cybernetic system]
}

interoperability^

:= ["socialization" (level of "socialization") within various a priori unknown communities (collectives) of cybernetic systems^]
:= [semantic and interoperability of cybernetic systems^]
:= [ability of a cybernetic system to effectively, purposefully interact with other cybernetic systems in the process of collective (distributed) and decentralized solution of complex tasks^]
:= [ability of a cybernetic system to be a useful member of various teams^]

should be distinguished*

∋ {• *homeostasis*
  := [self-preserving the constancy of one's inner state]
  := [homeostatic activity]
  ⊂ *activity*
• *level of homeostasis*
  ∈ *parameter*
  := [homeostasis quality]
}

∋ {• *adaptation*
  ⊂ *activity*
• *adaptability^*
  := [level of cybernetic system's ability to adapt^]
  := [ability of a cybernetic system to adapt to changes in the conditions of its existence (environment) in order to (1) at least maintain its viability and (2) at most increase its level of development^]
}

VIII. The Evolution of Individual Cybernetic Systems

A. *stimulus-responsive individual cybernetic system*

⇒ *explanation**:
[A ***stimulus-responsive individual cybernetic system*** is a converter (transformer) of sensory signals into signals that control effectors (subsystems that directly affect the external environment or their own physical shell). If the said transducer becomes flexible, capable of distinguishing its successful reactions from erroneous ones and capable of correcting its erroneous reactions (i.e. capable of learning from its mistakes), then such a transducer becomes the processor-memory of a stimulus-response cybernetic system.]

B. *individual cybernetic system with sign memory*

⇒ *explanation**:
[The transition from stimulus-responsive individual cybernetic systems to individual cybernetic systems with sign memory means the separation of the processor-memory of a cybernetic system into a memory that stores the sign information model of the environment and a processor that performs changes in the state of this stored sign information model. This separation does not necessarily have to be realized physically (as, for example, it happens in modern computers).]

⇒ *semantically close sign**:
• *sign*
  := *explanation**:
    [fragment of an information construct that is an image (representation) of the corresponding described entity]
• *atomic sign*

:= [sign that does not include other signs]
⊂ *sign*

- *non-atomic sign*
  := [sign-expression]
  := [sign consisting of several characters]
  ⊂ *sign*
- *sign construction*
  ⊂ *information construction*
    := [information]
- *internal sign construction*
  := [symbolic construct stored in the memory of the corresponding cybernetic system]
- *sense representation of information*
  := [sense sign construction]
- *external sign construction*
  := [symbolic construct that, for a given cybernetic system, is or is part of either a received or transmitted message]

C. ***task-oriented individual cybernetic system***

⇒ *explanation**:
[An individual cybernetic system that operates in its memory with the formulations of the tasks it has done, is doing, or expects to do, and is therefore to some degree "aware" of what it has done, is doing, or expects to do.]

⇒ *direction of evolution**:

- *expanding the variety of formulations of the problems to be solved*
  ⇒ *note**:
  [These are operational problem statements and declarative problem statements — goal statements]
- *expanding the sense variety of tasks to be solved*
- *expanding the total number of tasks to be solved*
- *expanding the number and variety of problem-solving methods and models used*
- *gaining the ability to generate new problem formulations*
  ⇒ *private evolutionary direction**:
  acquiring the ability for goal-setting
- *acquiring the ability to solve not only those problems whose solution methods are known, but also problems whose solution methods are not currently available*
- *acquiring the ability to solve problems in the face of non-factors (incompleteness, inaccuracy, unreliability,...)*
- *shifting from using only operational problem statements to using goal statements as well*
  ⇒ *explanation**:
  [The organization of information processing in cybernetic systems is dominated by semantic analysis of initiated goals and semantic analysis of information that is semantically close to these goals (such semantically close information is *goal context*). The context of a given goal determines the task situation corresponding to that goal, and therefore determines the way and path to achieve the specified goal.

Why cybernetic systems should be able to solve tasks that have a declarative formulation, i.e. formulation of the goal (result). Because most often in real practice tasks are formulated in a declarative way. At the same time, the solution of such tasks generally involves the analysis of the goal and context, construction of a solution plan, and search for appropriate methods (programs). Besides, each goal generally corresponds to a large number of ways to achieve it (variants of problem solution).

Thus, the most important type of knowledge stored in the memory of intelligent systems and underlying the organization of information processing in these systems are the descriptions of their pursued *objectives*, solved tasks. In this sense intelligent systems "realize" their tasks, goals, "know" what they are doing. Goals can be informational (such goals will be called questions) and external, aimed at changing the external environment. The main source of goals that are set for an intelligent system are its users. Nevertheless, in the process of achieving such goals, the intelligent system can generate (set for itself) new auxiliary goals aimed at achieving the original user goals. In addition, some general goals can be embedded in the system and at the stage of its design. Such goals can include:

- to ensure the safety of users
- to ensure your own safety
- to continuously improve their knowledge and skills to improve the efficiency of service to users
- and so on

Let us emphasize that the semantic diversity of goals that an intelligent system can achieve, and, in particular, the diversity of types of questions it can answer, largely determines the level of development of this system. An intelligent system should be able to answer not only those questions that can be handled by traditional information systems based on modern databases, but also questions like why, why, how, what it is, how the given objects are related to each other, what is the similarity or difference of the given objects, what analogs (antipodes) of the given object are known, whether the given statement is true, what properties the objects of the given class have, and so on.]

- *expansion of the variety of types of problems solved by a cybernetic system and corresponding expansion of the problem-solving models used*
  ⇒ *private evolutionary direction**:
  acquiring and expanding the ability to solve intelligent problems

intelligent task
⇒ *explanation**:
[*intelligent task* — a task for which the corresponding method of its solution stored in the memory of a cybernetic system is either not available (not known) at the current moment or fundamentally impossible due to the dependence of the process of solving this task on a large number of unpredictable circumstances and conditions. Intelligent tasks include proof tasks, hypothesis generation tasks, tasks of planning behavior in real conditions and, in particular, in real time, design tasks and many others.]
⇒ *note**:
[The absence of a *method* known to the cybernetic system and guaranteeing solutions to the *intelligent problem* is compensated for by the fact that the cybernetic system can store in its memory not *methods* for different types of intelligent problems, but ***strategies*** of their solution, which do not guarantee the solution, but describe how intelligent problems can be reduced to subtasks for which the corresponding methods are known. It should be emphasized that the library of these strategies (methods) describing the solution of various types of intelligent problems, as well as the library of methods, should be constantly expanded and improved in a cybernetic system.]

D. ***individual cybernetic system with a structured internal information model of the environment***
⇒ *epigraph**:
- [From data and databases to knowledge and knowledge bases]
- [From data science to knowledge science]

⇒ *direction of evolution**:
- *evolution of meta-language tools that provide a description not of the environment itself, but of the internal information model of this described environment*
  := [evolution of linguistic means of structuring and systematization of fragments of *internal information model of the environment*]
- *increasing the level of independence of evolution (improvement) of methods (programs) stored as part of the internal information model of the environment and evolution of information used and processed with the help of these methods (evolution of processed data)*
- *increasing the level of formalization of meaning — for the information being processed*
  ⇒ *note**:
  [It is about creating a common formal language to represent the data being processed, with a well-defined denotational semantics and completely independent of the programming languages used in the cybernetic system.]
- *increasing the semantic power of the internal information model of the environment*
- *increasing the power of associative access to information stored as part of the internal information model of the environment*
  ⇒ *explanation**:
  [Associativity of access is determined by the presence of subject-independent and simple enough metaprocedures for searching answers to questions of different semantic types. And the maximum completeness of such access means that at final set of the specified metaprocedures the search of answers to questions of any semantic type is provided.

  In other words, the completeness of associative access is the presence of universal and rather simple metaprocedures that allow either to find in the memory of an intelligent system an answer to any question posed to this system, or to establish the fact of absence of such an answer at the current moment. This is the essence of the full (ultimate) form of associative access to information stored in the memory of a computer system.]
- *increasing the level of general unification of representation of different types of knowledge included in the internal information model of the environment, and, in particular, blurring the boundaries between the representation of stored methods (stored programs) and the representation of information processed with the help of these methods (processed data)*

⇒ *note**:

[The concept of processed information (processed data) is relative, as some programs may be processed by other programs.]

- *acquiring the ability to analyze and improve the quality of its internal information model of the environment (its knowledge base)*

  ⇒ *note**:

  [It means analyzing the completeness (integrity, sufficiency) of the knowledge base, detecting and possibly eliminating information holes and inconsistencies.]

- *increase the level of activity of knowledge included in the knowledge base*

  ⇒ *note**:

  [Activity of knowledge means that the very fact of entering some knowledge into the knowledge base can initiate or put the corresponding information processes on hold. This is one of the factors of organizing situational decentralized management of information processes in a cybernetic system.]

E. ***hybrid individual cybernetic system***

:= [individual cybernetic system operating with a wide variety of types of knowledge, including types of methods (programs) stored in memory as part of its internal information model of the environment, as well as a wide variety of models of problem solving, i.e. skills of interpretation of methods of problem solving stored in memory]

⇒ *note**:

[The essence of a hybrid individual cybernetic system is the transition from the eclectic diversity of its components to a high level of compatibility and synergy, based on a universal language of semantic representation of the internal information model of the environment.]

:= [individual cybernetic system based on a deep convergence of different models of knowledge representation, different models of problem solving, different channels and means of interaction with the external environment.]

:= [individual cybernetic system having multimodal knowledge base, multimodal solver, multimodal interface]

⇐ *union**:

{• *individual cybernetic system with hybrid problem solver*

  := [individual cybernetic system with a wide variety and synergy of different problem-solving models]

- *individual cybernetic system with a hybrid internal information model of the environment*

  := [individual cybernetic system with a wide variety and synergy (compatibility) of different types of knowledge included in the internal information model of the environment]

- *individual cybernetic system with hybrid multimodal interface*

  := [individual cybernetic system with a wide variety and synergy of different kinds of sensors and effectors, i.e. different kinds of perceived primary information (including received messages in different languages) as well as different kinds of influences on the external environment]

  ⇒ *note**:

  [In particular, the level of synergy of the interface components of an individual cybernetic system is determined by the quality of sensorimotor coordination in performing complex types of actions]

}

F. ***learnable individual cybernetic system***

:= [individual cybernetic system with a high level of learnability and, consequently, a high level of flexibility, stratification and reflection]

⇒ *note**:

[Learnability of a cybernetic system is a key characteristic of a cybernetic system that determines its rate of evolution]

G. ***self-sufficient individual cybernetic system***

⇒ *note**:

[An independent individual cybernetic system must be aware of itself, i.e. have knowledge about itself (its own self) — about its capabilities, its destination, its obligations and responsibilities, its moral and ethical principles (rules). That is, an independent cybernetic system must have a high level of reflexion, must be able to take care of itself and maintain the necessary level of its capability, must be able to make decisions independently, and must consider itself to a certain extent an independent *subject* of the corresponding activity]

cybernetic system self-sufficiency

⇒ *parameter-factor**:

- *ability of free (independent) goal-setting*
- *ability to plan independently to achieve goals*
- *ability to achieve goals, realize one's plans — purposefulness*

H. ***individual cybernetic system with strong intelligence***

:= [strongly intelligent individual cybernetic system]

:= *explanation**:

[individual cybernetic system that has passed all conventionally allocated stages of evolution of individual cybernetic systems and has reached a high level of development in the corresponding directions of evolution:

- on the development of stimulus-response behavior; {item on the development of sign memory;
- on developing task-oriented behavior;
- on the development of an internal information model of the environment;
- to expand the diversity and synergy of different kinds of components of the individual cybernetic system;
- to enhance learning;
- to increase the level of autonomy in all its activities.

]

⇒ *note**:

[While emphasizing that an individual cybernetic system with strong intelligence must:

- to have a *reasoning ability*^ (to make inferences, to solve complex logical problems)
- to have the *ability to understand* and develop an internal information model of the environment.

]

IX. Evolution of multi-agent cybernetic systems

The level of *intelligence* (level of self-organization) of any cybernetic system is determined by the degree of development of *cybernetic system* components and the quality of organization of their interaction at all structural levels of the cybernetic system. All this is also true for multi-agent cybernetic systems, but with one very important clarification. The point is that multi-agent cybernetic systems (as well as embedded multi-agent information processing systems) have a very important feature — their agents have a high degree of self-activity and, as a consequence, unpredictability of behavior. Moreover, in the process of evolution of cybernetic systems, the degree of their independence increases. Correspondingly, the degree of unpredictability of their behavior also increases. Therefore, the main leitmotif of organizing the activity of a multi-agent cybernetic system and, in particular, the organization of its evolution (primarily, increasing the level of *synergy* of interaction between its agents) is to support high rates of agents' evolution (including increasing the level of their independence) and to prevent contradictions between the goals and activities of a multi-agent cybernetic system and the goals and activities of its agents. Improvement of methods and means of ensuring contractual capacity, i.e. the ability to coordinate positions (including goals), as well as ensuring the ability to coordinate (harmonize) the actions of the agents of a multi-agent cybernetic system in the course of performing these actions are the most important factors of its evolution.

In other words, without permanent immunity support against the Babylonian pandemonium and information crisis syndrome, as well as the Swan, Cancer and Pike syndrome, the progress of a multi-agent cybernetic system is impossible. Moreover, at a certain stage of evolution of a multi-agent cybernetic system, the competition of its agents ceases to be a stimulus for its evolution.

One of the important directions in the evolution of cybernetic systems is the transition from a set of independent cybernetic systems to their collectives — multi-agent cybernetic systems capable of collectively solving problems that each member (agent) of these collectives alone is either fundamentally unable to solve, or can, but for an unacceptably long period of time. Let us emphasize that this transition from a set of independent cybernetic systems to their collectives can generate *hierarchical multi-agent cybernetic systems* with an unlimited number of hierarchy levels — from sets of *individual cybernetic systems* to collectives of *individual cybernetic systems*, from sets of *collectives of individual cybernetic systems* to *collectives of collectives of collectives of individual cybernetic systems*. In addition, agents of some hierarchical multi-agent cybernetic systems can have different structures — can be individual cybernetic systems, collectives of individual cybernetic systems, collectives of collectives of collectives of individual cybernetic systems, and so on. Let us emphasize that only such an approach to the creation of a branched hierarchical network of cybernetic systems distributed over the space of their external environment will provide an unlimited increase in the level of development of this environment (the level of "expansion" of a cybernetic system).

X. New Generation Intelligent Computer Systems

new generation intelligent computer systems
⇒ *principles underlying**:

- *textual representation of knowledge* in memory *intelligent computer systems*
- the use of a *universal language of semantic knowledge representation* common to all intelligent computer systems in the form of *refined semantic networks*
- *structurally-reconfigurable (graphodynamic) memory organization* of intelligent computer

systems, in which knowledge processing is reduced not so much to changing the state of the stored *signs*, but to changing the configuration of links between these *signs*

- *semantically unrestricted associative access to information* stored in *intelligent computer systems* memory, in a given pattern of arbitrary size and arbitrary configuration
- situational decentralized control of information processes in the memory of intelligent computer systems, realized by means of *agent-oriented model of knowledge processing*, in which *initiation* of new *information processes* is carried out not by transferring the control to the corresponding a priori known procedures, but as a result of occurrence of corresponding *situations* or *events. in the memory of an intelligent computer system*, because «The main problem of computer systems is not the accumulation of knowledge, but the ability to activate the necessary knowledge in the process of problem solving» (D.A. Pospelov)
- the transition to semantic *problem-solving models*, which are based on taking into account not only syntactic (structural) aspects of the processed information, but also *semantic* (semantic) aspects of this information – «From data science to knowledge science»
- ***ontological stratification of knowledge bases*** of *intelligent computer systems* as hierarchical system of *subject domains* and their corresponding *ontologies*
- clear specification of *syntax* and ***semantics*** of the whole variety of *languages of interaction between users and intelligent computer systems*, including language tools for user interface management, introduction into the composition of the *intelligent computer system* of the corresponding help-subsystems, providing a significant reduction of the language barrier between users and *intelligent computer systems*, which will significantly increase the efficiency of *operation of intelligent computer systems*
- *minimizing the negative influence of the human factor* on the efficiency of *exploitation. intelligent computer systems* by realizing an interoperable (partnership) style of interaction not only between the *intelligent computer systems* themselves, but also between the *intelligent computer systems* and their users. Responsibility for the quality of the collaborative activity should be shared between all partners

⇒ *publications**:
- *[4]*
- *[5]*

XI. Complex technology for development and maintenance of new-generation intelligent computer systems

The proposed *technology of complex life cycle support of new-generation intelligent computer systems* is named ***OSTIS technology*** (Open Semantic Technology for Intelligent Systems) [4], [5]. Accordingly, the *new-generation intelligent computer systems* being developed using this technology are called ***ostis-systems***. The OSTIS technology itself is realized in the form of a special *textitostis-system*, which is called ***OSTIS Metasystem*** and whose *knowledge base* contains:

- The formal theory of *ostis-systems*;
- OSTIS Standard and OSTIS Technologies (***OSTIS Standard***);
- The core of the Reusable Component Library (***OSTIS Library***);
- *Methods and tools for life cycle support* of *ostis-systems* and their components.
- The current state of OSTIS Technology has been tested on a range of applications as well as at annual OSTIS conferences that have been specifically organized for this purpose since 2011

The current state of OSTIS Technology allows not only to continue the work on the development of this technology, but also to start the work on its complex use to transfer the current level of informatization of the Republic of Belarus to a fundamentally new level, based on the mass application of semantically compatible and effectively *self* interacting with each other intelligent computer systems of new generation. The main problem here lies not in the intelligent computer systems themselves, but in the necessity of *rethinking* informatization of various branches to ensure their semantic compatibility, stratification, convergence and, ultimately, to simplify the relevant information resources and information processes as much as possible – eclectic, myopic, uncoordinated implementation of information resources and processes artificially and significantly complicates the informatization of already very complex types and types of information.

XII. The Technological Evolution of Human Society

The following processes underlie the unrestricted *evolution of multi-agent cybernetic systems*:

- is the process of expanding the hierarchical structure of a multi-agent cybernetic system:

- adding new cybernetic systems as agents of a multi-agent cybernetic system
  - inclusion of already existing cybernetic systems as an agent in an existing multi-agent cybernetic system (a cybernetic system that is part of a hierarchical multi-agent cybernetic system can be an agent of several multi-agent cybernetic systems that are part of this hierarchical multi-agent cybernetic system at the same time).
- is the process of preliminary preparation of new cybernetic systems for their inclusion in a hierarchical multi-agent cybernetic system as agents:
  - formation of the necessary "qualifications" for these future agents, taking into account their specialization (roles within the corresponding multi-agent cybernetic systems).
  - intelligence formation for the specified potential agents at the level of *strong intelligence*
  - of developing a high level of *interoperability* in these potential agents.
  - formation of a high level of *synergy* in potential agents, if they are multi-agent cybernetic systems.
- permanent support of high level *synergy* of all multi-agent cybernetic systems included in the evolving *hierarchical multi-agent cybernetic system*.

We can talk about three vectors of evolution of cybernetic systems:

- evolution of individual cybernetic systems
- evolution of collective individual cybernetic systems.
- evolution of hierarchical multi-agent cybernetic systems

Dead-end branches of the evolution of multi-agent cybernetic systems are:

- Multi-agent cybernetic systems, in the course of their evolution, increasing the level of *interoperability* of their agents and increasing the overall level of *synergy* of multi-agent cybernetic systems are not the priority directions of their evolution. Examples are many modern human communities and organizations
- Multi-agent cybernetic systems whose agents do not possess strong intelligence or are fundamentally incapable of reaching the level of strong intelligence in the course of their evolution during their existence. Examples are swarms of bees, anthills, swarms of fish, birds, mammals, and other animals
- Multi-agent cybernetic systems that have no publicly available picture of the world for all agents and permanently improved by all agents, which accumulates and systematizes the experience acquired by all agents of a multi-agent cybernetic system in the course of its activity. At the same time, this publicly available picture of the world can be either concentrated in the memory of one of the agents, or completely distributed among the agents
- multi-agent cybernetic systems that have no current diversity of agent types or agent specialization (in particular, the distribution of agent responsibilities).
- multi-agent cybernetic systems whose agents have no possibility to flexibly change their current specialization (current qualification). We emphasize that the most important factor of intelligence of a multi-agent cybernetic system is a high level of diversity of agents transformed into their flexible convergence and synergy
- Multi-agent cybernetic systems, in the process of evolution of which the rate of evolution of technologies (methods and means) of training and retraining of their agents is delayed from the rate of evolution of the multi-agent cybernetic system itself in other directions. Let us note that agents of multi-agent cybernetic systems can be not only computer systems, but also people (we will call such multi-agent cybernetic systems human-machine communities)

From the point of view of the theory of *evolution of cybernetic systems*, the highest form of technological development of *human society* is ***superintelligent multi-agent cybernetic system***, the agents of which are people and intelligent computer systems possessing *strong intelligence* and a high level of *interoperability*. But in order to create this superintelligent multi-agent cybernetic system (*superintelligent human-machine community*) it is necessary to provide strong intelligence and high level of interoperability not only for all artificial agents of this community (for all intelligent computer systems), but also for all people. The latter is a serious challenge for the modern system of education, the main goals of which should be not only the formation of knowledge, skills and competences necessary for effective participation in professional activity in the corresponding specialties, but also the systematic formation of the general picture of the world and, in particular, the formation of understanding of the directions (tendencies) and stages of *evolution of the superintelligent human-machine community*. Besides, the most important goal of education should become not only the formation of a strong level of intelligence in people, but also the formation of a high level of *interoperability* (socialization), necessary for competent functioning as an agent of the *superintelligent human-machine community*.

Let us also emphasize that in order to create *superintelligent human-machine community* it is necessary to provide not only *strong intelligence* and high level of *interoperability* of all agents of this community (both artificial and natural), but also high level of *synergy* of their interaction. For this purpose it is necessary to permanently analyze and improve the principles of organization of this interaction, which is one of the most important directions of evolution of the *superintelligent human-machine community*.

agent of the superintelligent human-machine community
$\supset$ *user of superintelligent human-machine community*
  $\Rightarrow$ *note**:
    [Different users within the same community may have different responsibilities (different roles).]
  $\Rightarrow$ *note**:
    [The same person can be a user (member) of more than one community at the same time]
$\supset$ *personal user assistant of the superintelligent human-machine community*
  $\Rightarrow$ *note**:
    [The interaction of each user with all other agents of the superintelligent human-machine community is carried out only(!) through his personal assistant, which allows to provide a high level of automation of interaction of each user with all users of this community, as well as with all artificial agents of this community.]
  $\Rightarrow$ *note**:
    [If a person is a user of multiple superintelligent human-machine communities simultaneously, his personal assistants for all of these communities are integrated (merged) into a physically single integrated personal assistant, which provides comprehensive and coordinated automation of the user's activities across all communities of which he is an agent.]
$\supset$ *corporate system of superintelligent human-machine community*
  $\Rightarrow$ *explanation**:
    [This system ensures the coordination of the activities of all agents of the respective community, combining both centralized and decentralized management techniques in a reasonable manner]

Examples of specialized superintelligent human-machine communities are:

- superintelligent human-machine community for development and maintenance of new generation intelligent computer systems
- superintelligent human-machine community for the development of technologies for the development and maintenance of new-generation intelligent computer systems
- superintelligent human-machine community for research and development activities in the field of Artificial Intelligence
- superintelligent human-machine community for Artificial Intelligence educational activities
- superintelligent human-machine community to develop strategy and tactics for the development of activities in the field of Artificial Intelligence (integration of all previous ones)

The final stage of technological evolution of human society is the transition from a set of independent specialized superintelligent human-machine communities to their unification (integration) in the ***global superintelligent human-machine community***, which is a hierarchical system of interconnected and synergetically interacting specialized superintelligent human-machine communities of different purposes.

The development of a permanently evolving architecture of such a *Global Human-Machine Community* is the key practical task of the current stage of development of Cybernetics and, in particular, Artificial Intelligence. It is obvious that to solve this problem it is necessary to reduce interdepartmental and interdisciplinary barriers, to ensure interdisciplinary convergence, unification and standardization, as well as to increase the level of interoperability and synergy.

XIII. Conslusion

At present, many countries have adopted a strategy for the development of work in the field of *artificial intelligence* at the state level, which is necessary to harmonize and coordinate research and application activities.

At the current stage of work in the field of *artificial intelligence*, the following trends are relevant:

- transition from differentiation of approaches and directions to their convergence and deep integration;
- transition from compromise solutions to consensus-based solutions;
- transition from competition to complementary and mutually beneficial interaction;
- transition from highly specialized solutions to flexible, adaptive and potentially universal solutionsPospelov1986, Varshavsky1984;
- transition from syntactic compatibility to logical-semantic compatibility of intelligent computer systems on the basis of formalization of meaning and semantic representation of knowledge;
- transition to hierarchical multi-agent models for solving complex problems [6]–[8];

- transition from centralized to decentralized control of agent interaction in multi-agent systems [7], [8];
- situational management of the process of solving complex problems, taking into account changes in the context (conditions) of problem solving [6];
- Increasing the level of agent interoperability;
- orientation on *intelligent computer systems* of fundamentally new generation that meet modern requirements;
- search for approaches to effective hardware support of *intelligent computer systems* of the next generation in the form of universal computers of the new generation;
- Improving the quality of information resources and combating the information crisis.

The overwhelming majority of actual problems of the current stage of development of theory, technologies and application of *intelligent computer systems* require unification and coordination of efforts of all specialists working in the field of *artificial intelligence*. [9], [10].

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ЭВОЛЮЦИЯ КИБЕРНЕТИЧЕСКИХ СИСТЕМ: ОТ КОМПЬЮТЕРНЫХ СИСТЕМ С СИЛЬНЫМ ИНТЕЛЛЕКТОМ К СУПЕРИНТЕЛЛЕКТУАЛЬНЫМ ЧЕЛОВЕКО-МАШИННЫМ СООБЩЕСТВАМ

Белоцерковский А. М., Голенков В. В., Головко В. А., Гулякина Н. А., Краснопрошин В. В., Недзьведь А. М., Шункевич Д. В.

В статье рассматриваются ключевые особенности кибернетических систем, их эволюции и параметров, определяющих уровень их интеллекта и самоорганизации. Рассматриваются иерархические системы параметров, характеризующих текущие возможности и скорость развития кибернетических систем, а также факторы, способствующие ускорению их эволюции. Особое внимание уделено семантически близким понятиям, связанным с уровнем интеллекта кибенетических систем, и процессам эволюции как индивидуальных, так и многоагентных кибернетических систем. Рассматриваются перспективы интеллектуальных компьютерных систем нового поколения и комплексная технология их разработки и сопровождения. В завершение обсуждается влияние технологической эволюции на развитие человеческого общества, предлагается идея Глобального человеко-машинного сообщества.

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