

## A NOTE ON HYBRID INTELLIGENCE

Alexander Ryjov

alexander.ryjov@gmail.com

RANEPa School of IT Management, Moscow, Russia  
Lomonosov Moscow State University, Moscow, Russia

### ABSTRACT

*The focus of this note is Hybrid Intelligence - symbiosis and cooperative interaction between Human Intelligence and Artificial Intelligence in process of solving a wide range of practical tasks. This understanding of intelligence systems is very close to the ideas of founders of cybernetics and could help with solving current problems with Artificial Intelligence, especially with its business applications. Basic problems of such systems as well proposed solutions and application's scenarios have been formulated and discussed in the article.*

**Keywords**— Artificial Intelligence, Hybrid Intelligence, evaluation and monitoring of complex processes, personalization.

### 1. INTRODUCTION

Many people see the expectations over Artificial Intelligence (AI) are becoming too inflated. Last decades give us exciting results in AI (championships in Chess, Go, Poker, etc.), but real business applications are still limited by photo tuning, low quality chats, danger self-driving cars, and similar things. The question “What is AI?” is becoming actual and discussible once again like in 1960, 1980, 2010...

Autonomous and self-sufficient AI in real business is still a dream. AI will indeed change everything, but not any time soon. Artificial Intelligence applications in real tasks still depends on Humans.

Reverting to 1960-th, we can see that AI fathers-founders discussed AI in different terms: AI as an “amplifier” of human’s “Intellectual power” (William Ross Ashby), AI as “Man-computer symbiosis” (Joseph Carl Robnett Licklider), AI as “augmenting human intellect” (Douglas Carl Engelbart), etc., - they thought about hybrid intelligence, not about independent one; about partnership manner, not about opposition.

Thinking in this paradigm, we can present all spectrum of intelligent technologies using two poles: pure Human Intelligence and autonomous Artificial Intelligence (Figure1). We use Human Intelligence tool everywhere and every time over thousands of years; we are doing the first steps only in using Artificial Intelligence in everyday life. Moving from Human Intelligence to Artificial Intelligence is one of the recognizable trend for society

(see, for example, Automation of Knowledge Work as disruptive technology № 2 in [14]). This paradigm drives us to re-think main problems of intelligence systems.

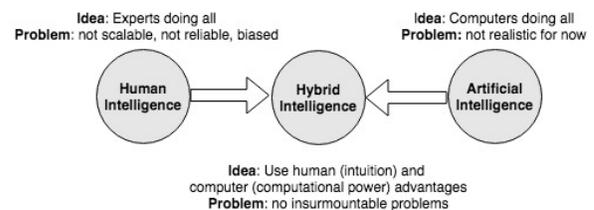


FIGURE 1: SPECTRUM OF INTELLIGENT TECHNOLOGIES.

The goal of this note is to discuss basic problems of Hybrid Intelligence and possible models of usage this approach for everyday life.

The rest of the paper is organized into four sections: the first will summarize related work; the second will formulate and discuss basic problems for Hybrid Intelligence systems; the third will present two scenarios for using this approach; finally, will tackle the debate and outline the future lines of research.

### 2. BACKGROUND

We can name the last decade as the time of Artificial Intelligence. AI and management, AI and leadership, AI and finance, AI and logistics, AI and creativity, AI and many other areas are the focus of a number of conferences, books, blogs, posts. AI has a wide spectrum of definitions; they cast themselves as a number of technologies that span across a lot of different things and can be described in different ways. This is not good situation for science and engineering. A formal criterion like Turing test has been successfully passed [34], unformal criteria like playing chess or Go have been passed, too. So, we do not understand what AI is; as a result, we can see points like “Artificial intelligence has accrued some very bad reputation over the years” [5] or “Some industry experts believe that the term artificial intelligence is too closely linked to popular culture, causing the general public to have unrealistic fears about artificial intelligence and improbable expectations about how it will change the workplace and life in general” [17], etc. We would not like

to participate in such discussions, without a common criterion like Turing test it is matter of taste. We believe in AI. We see autonomous adaptive self-learning and self-sufficient intelligent systems as a future (the question is how far this future?), but more realistic way to solve intelligent tasks for now is symbiosis of human and computer intelligence.

The idea of intelligent systems as a tool for augmenting human intelligence was first proposed in the 1950-s and 1960-s by cybernetics and early computer pioneers. The term Amplifying intelligence was introduced by William Ross Ashby in his classical work ([2], p. 271). At the end of his fantastic book he wrote: "Intellectual power, like physical power, can be amplified. Let no one say that it cannot be done, for the gene-patterns do it every time they form a brain that grows up to be something better than the gene-pattern could have specified in detail. What is new is that we can now do it synthetically, consciously, deliberately." ([2], p. 272). The idea of symbiosis of human and computer was formulated by psychologist and computer scientist Joseph Carl Robnett Licklider: "Man-computer symbiosis is an expected development in cooperative interaction between men and electronic computers. It will involve very close coupling between the human and the electronic members of the partnership. The main aims are 1) to let computers facilitate formulative thinking as they now facilitate the solution of formulated problems, and 2) to enable men and computers to cooperate in making decisions and controlling complex situations without inflexible dependence on predetermined programs. In the anticipated symbiotic partnership, men will set the goals, formulate the hypotheses, determine the criteria, and perform the evaluations. Computing machines will do the routinizable work that must be done to prepare the way for insights and decisions in technical and scientific thinking. Preliminary analyses indicate that the symbiotic partnership will perform intellectual operations much more effectively than man alone can perform them." ([11], p. 4). This idea was specified and studied by Douglas Carl Engelbart: "By "augmenting human intellect" we mean increasing the capability of a man to approach a complex problem situation, to gain comprehension to suit his particular needs, and to derive solutions to problems. Increased capability in this respect is taken to mean a mixture of the following: more-rapid comprehension, better comprehension, the possibility of gaining a useful degree of comprehension in a situation that previously was too complex, speedier solutions, better solutions, and the possibility of finding solutions to problems that before seemed insoluble. And by "complex situations" we include the professional problems of diplomats, executives, social scientists, life scientists, physical scientists, attorneys, designers—whether the problem situation exists for twenty minutes or twenty years. We do not speak of isolated clever tricks that help in particular situations. We refer to a way of life in an integrated domain where hunches, cut-and-try, intangibles, and the

human "feel for a situation" usefully co-exist with powerful concepts, streamlined terminology and notation, sophisticated methods, and high-powered electronic aids." [6].

After this romantic period, we had some tens of years stagnation for human-computer systems. One of the basic problem from our point of view was a huge difference between ways of perception, manipulation of information, reasoning, etc. for a human being and for a computer. Boolean 0/1 logic is natural for computers but very artificial for the people; work with uncertain information is natural for the people, but very complex for computers. How we can organize symbiosis of such two completely different subsystems?

Mathematical tool that is capable to be an interface between human being and computer - fuzzy logic - was introduced by Lotfi Zadeh in [37]. In ([38], p. 200) he wrote "The main applications of the linguistic approach lie in the realm of humanistic systems-especially in the fields of artificial intelligence, linguistics, human decision processes, pattern recognition, psychology, law, medical diagnosis, information retrieval, economics and related areas". His definition of the humanistic systems is "By a humanistic system we mean a system whose behavior is strongly influenced by human judgement, perception or emotions. Examples of humanistic systems are: economic systems, political systems, legal systems, educational systems, etc. A single individual and his thought processes may also be viewed as a humanistic system" ([38], p. 200). Fuzzy logic allows us to use perception-based descriptions of objects and manipulate them in a human-like reasoning manner in computer models. It is a base for cognitive computing and for Augmented Intelligence as defined by IBM [9] "At IBM, we are guided by the term "augmented intelligence" rather than "artificial intelligence". It is the critical difference between systems that enhance and scale human expertise rather than those that attempt to replicate all of human intelligence. We focus on building practical AI applications that assist people with well-defined tasks, and in the process, expose a range of generalized AI services on a platform to support a wide range of new applications". This understanding of human-computer symbiosis is the most similar to ours. The aim of our systems for evaluation and monitoring is "assist people with well-defined tasks" in management of complex processes.

From business perspective these systems are close to "Automation of knowledge work" set of technologies in McKinsey Global Institute terms ([14], p. 41) "These capabilities not only extend computing into new realms ..., but also create new relationships between knowledge workers and machines. It is increasingly possible to interact with a machine the way one would with a coworker". McKinsey estimate potential economic impact across sized applications in 2025 from \$5.2 trillion to \$6.7 trillion per year ([14], p. 44).

### 3. BASIC PROBLEMS OF HYBRID INTELLIGENCE SYSTEMS

From scientific point of view Hybrid Intelligence means a new problem definition: how we can organize and optimize the synergy of human and computer intelligence components?

Following the concepts “Intellectual power amplifier” (William Ross Ashby) “Man-computer symbiosis” (Joseph Carl Robnett Licklider), “Augmenting human intellect” (Douglas Carl Engelbart), “Humanistic system” (Lotfi Zadeh) described above, we can present a principle scheme of Hybrid Intelligence like in Figure 2.

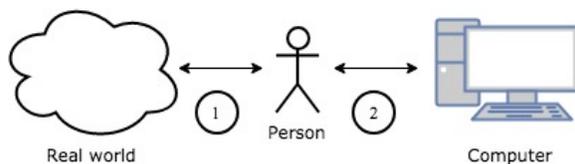


FIGURE 2: A PRINCIPLE SCHEME OF HYBRID INTELLIGENCE.

Note, that for natural sciences (physics, chemistry, etc.) and engineering we will have a classical modelling system if we replace “Person” on “Measuring device” on Figure 2. Principal point is that for a number of processes in social sciences, politics, etc. we do not have such measuring devices, and we can measure the parameters of the processes using evaluations made by experts only.

For this scheme we can formulate the following two basic problems:

- **Problem 1** (Perception modelling): How we describe objects from the real world? Can we describe the objects by the most reliable and the most effective for further computing way?
- **Problem 2** (Perception-based computing): How we can manipulate with perception-based information (for example, search or generalize)? Can we optimize these calculations?

These problems were studied and solved. Below is a summary of the results.

#### 3.1. Perception modelling

Let’s reformulate the Problem 1 as follows:

Is it possible, taking into account certain features of the man’s perception of objects of the real world and their description, to formulate a rule for selection of the optimum set of values of characteristics on the basis of which these objects may be described? Two optimality criteria are possible:

**Criterion 1.** We regard as optimum those sets of values through whose use man experiences the minimum uncertainty in describing objects.

**Criterion 2.** If the object is described by a certain number of experts, then we regard as optimum those sets of values which provide the minimum degree of divergence of the descriptions.

It is shown [19] that we can formulate a method of selecting the optimum set of values of qualitative indications (collection of granules).

Moreover, it is shown [22] that such a method is robust, i.e. the natural small errors that may occur in constructing the membership functions do not have a significant influence on the selection of the optimum set of values. The sets which are optimal according to criteria 1 and 2 coincide.

Following this method, we may describe objects with *minimum possible uncertainty*, i.e. *guarantee optimum operation of the hybrid intelligence systems* from this point of view.

#### 3.2. Perception-based computing

Hybrid intelligence systems assume, at least, the storage of linguistic evaluations of the objects/ processes indicators in the system database. In this connection the following interpretation of problem 2 arises.

Is it possible to define the indices of quality of information retrieval in fuzzy (linguistic) databases and to formulate a rule for the selection of such a set of linguistic values, use of which would provide the maximum indices of quality of information retrieval?

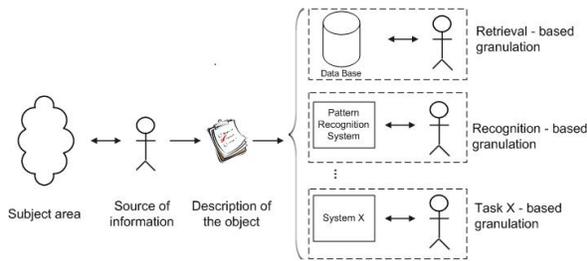
It is shown [23] that it is possible to introduce indices of the quality of information retrieval in fuzzy (linguistic) databases and to formalize them.

It is shown [25] that it is possible to formulate a method of selecting the optimum set of values of qualitative indications (collection of granules) which provides the maximum quality indices of information retrieval.

Moreover, it is shown [23] that such a method is robust, i.e. the natural small errors in the construction of the membership functions do not have a significant effect on the selection of the optimum set of values.

It allows to approve that the offered methods can be used in practical tasks and *to guarantee optimum work* of hybrid intelligence systems.

Based on the results above, we can provide recommendations how we can use similar approach for different type of tasks (information retrieval, pattern recognition, data mining [30] etc. – see Figure 3).



**FIGURE 3: TASK-DRIVEN INFORMATION GRANULATION.**

In general terms, these recommendations are:

1. Formalize of the quality of the task's solution.
2. Try to find dependence of the quality functional and granulation or use computational techniques for approximation the quality functional.
3. Choose granulation which provide maximum of the quality functional.

These results have theoretical level. Where and how we can use this in practical tasks? Two possible frameworks are presented below.

#### 4. SCENARIOS OF USAGE THE HYBRID INTELLIGENCE APPROACH

For now, we have tested two scenarios of using Hybrid Intelligence: in evaluation and monitoring of complex processes and in personalization of collaboration people with digital world.

##### 4.1. Evaluation and monitoring of complex processes

A big part of “tasks that rely on complex analysis, subtle judgments, and creative problem solving” ([14], p. 41) is evaluation the status and monitoring the progress of processes in business, economy, society, etc. Modeling and control for these processes is very different from physical and technical ones. These processes are unique in the physical sense – a series of independent experiments is not possible; we cannot measure parameters like in physics – “measuring device” is a human being; we do not have adequate models like heat transfer equation – processes are described in natural language or in the form of parametric dependencies, etc. As a result, we can conclude that classical mathematics is not suitable for describing and modeling of socio-economic processes due to huge complexity, uncertainty, vagueness. Only the right mixes of computer intelligence and human intelligence can solve these problems.

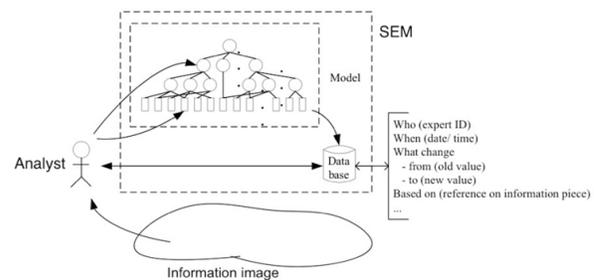
From the systems point of view, systems for evaluation and monitoring (SEM) relate to a class of hierarchical fuzzy discrete dynamic systems. The theoretical base for this class of systems is provided by the fuzzy sets theory, discrete mathematics, methods of the analysis of hierarchies, which was developed in works of L.A. Zadeh

[37], [38], M.D. Mesarovich et al. [12], T.L. Saaty [31], and others. The analytic hierarchy process (AHP) was developed in the 1980s by Saaty [31]. It is a systematic decision-making method which includes both qualitative and quantitative techniques. It has been widely used in many fields for a long time. J.J. Buckley [4] incorporated the fuzziness into the AHP, called the FAHP. Hierarchical fuzzy systems have attracted considerable attentions in recent years. V. Torra [33] summarized the related recent research work in this domain. Detailed FAHP literature review is also presented in [16].

SEM allow to uniformly process diverse, multi-level, fragmentary, unreliable, and varying in time information about some process. Based on this type of information SEM can perform monitoring of the process' status evolution and work out strategic plans of process development. These capabilities open a broad area of applications in business (for example, [10], [24]), socio-political problems [28], control of bilateral and multilateral agreements [20], healthcare [1], etc.

Theoretical foundations and basic principles development SEM presented in [27].

SEM workflow is presented in Figure 4:



**FIGURE 4: SEM WORKFLOW.**

SEM allow having the model of the process developing in time. It is supported by the references to all information materials, chosen by the analysts, with general and separate evaluations of the status of the process. Using the time as one of the parameters of the system allows to conduct the retrospective analysis and to build the forecasts of development of the process.

Having set up a SEM, we can solve two types of problems: direct and inverse.

The direct problem is to find all "critical ways" of the process. It means to reveal those elements of the process, the small change of which status may qualitatively change the status of the process as a whole. For big class of aggregation operators, we can calculate degree of criticality for any element of the model; for all aggregation operators we can use universal algorithms (like backtracking algorithms) for calculation of the degree of criticality for any element of the model. That means that we can understand and measure strengths and weaknesses of any element of the current process. This

understanding is a base for developing a strategic plan for control of the process in the optimal way.

The inverse problem is to find elements of the model which must be changed for reaching some given status of the target element of the model. For example, we can understand how we can reach maximal effect for given budget or reach given effect for minimal budget.

Examples of such tasks could be evaluation and increasing of capitalization for startups, increasing an investment's attractiveness for companies and/or regions, increasing sustainability of a business, etc.

We can solve these tasks if and only if we have the model (structure and tuned aggregation functions), actual status of the nodes, i.e. working system for evaluation and monitoring of the process. Comparison analysis of these capabilities with other analytical tools is presented on Figure 5.

#### 4.2. Personalization

Personalization is one of the most visible trend of applications of modern ITC from fashion industry till smart learning [3], [7], [8], [13], [15], [18], [35], [36].

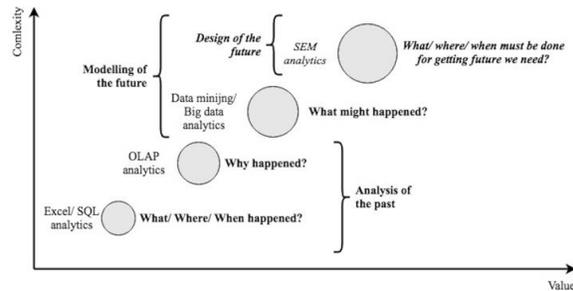


FIGURE 5: SEM ANALYTICAL CAPABILITIES.

Overwhelming majority of such publications are focusing on more deep segmentation, customization of communications, etc. Here we use term “personalization” literally - make the digital world personal for every person.

For reaching this effect we need in interactions with the user for “calculating” his or her own semantic of used words and concepts. These concepts are formulated by the user in natural language, and modelled by fuzzy sets, defined on the universum of the significances of the attributes. After adjustment of user’s concepts based on search results, we have “personalized semantics” for all terms which particular person uses for communications with digital sources (for example, “young person” will be different for teenager and for old person; “good restaurant” will be different for people with different income, age, etc.).

General picture of such adaptive semantic layer in information processing is presented on Figure 6.

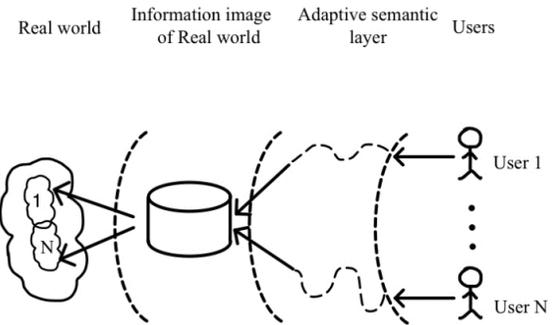


FIGURE 6: ADAPTIVE SEMANTIC LAYER.

General structure of the adaptive semantic layer is presented on Figure 7.

The most important thing here is modification of user’s concepts based on interactions with the system (for example with database for information retrieval task).

It is obvious enough that different users (classes of users) can have different formalization of the concepts (different membership functions). For example, concept “expensive” for student and for businessman can be different. How can we make our interface “personalized”? The idea of such modification is presented on Figure 8.

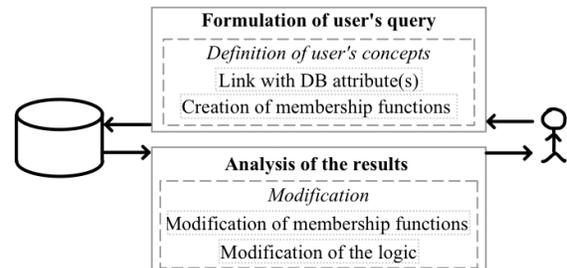


FIGURE 7: THE STRUCTURE OF AN ADAPTIVE SEMANTIC LAYER.

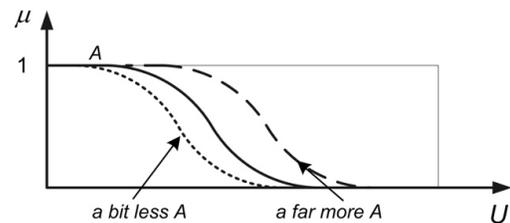


FIGURE 8: ADJUSTMENT OF THE SEMANTIC OF USER'S CONCEPT A.

Here *more*, *less* - directions of modification; *a bit*, *not so far*, *a far*, ... - volume (“power”) of the modificatory. This approach is described in [23].

Using a series of successive refinement like “a bit less expensive”, “a far cheaper”, etc. for concept “Cheap”, we can find the membership function which formalize this concept for particular user by the best way. For another user it could be different function. Some theoretical questions like convergence for this type of refinement are still open.

Such personalization of information retrieval and social networks described in [26] and [29] correspondingly.

## 5. CONCLUDING REMARKS

Self-sufficient autonomous Artificial Intelligence is still a piece of art (Chess, Go, etc.) with unclear business applications in observable future. Many authors say about inflated expectations, hysteria, etc., - actually about the AI's crisis. Hybrid Intelligence means a practical or pragmatic sense of the intelligence systems, and it is a reality.

The basic fundamental problems of Hybrid Intelligence solved. We can develop robust and optimal Hybrid Intelligence. Several local problems are still open, and we hope to see solutions in the nearest future.

Applications of Hybrid Intelligence for various types of organizations (international, federal, corporate levels) and various types of the problems (non-proliferation of nuclear weapons and materials, security, healthcare, microelectronics) were successfully developed and tested. Vision and understanding for new applications (natural and technological disasters management, smart city/ smart regions/ smart countries, smart learning for education, smart healthcare, personalization and optimization for social networks/ information retrieval/ other interactions of humans with digital world, etc.) are proposed and discussed. We will be happy to see new researchers and new applications in the nearest future.

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