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A GENERAL CLASSIFICATION OF INFORMATION AND SYSTEMS

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Nowadays the different forms of information are used beginning with deterministic information and finishing with fuzzy information. This paper presents a four-level hierarchical classification of information. The first level of hierarchy is deterministic information, the second one – probabilistic information, the third one – uncertain-deterministic and uncertain-probabilistic information, and the fourth level is fuzzy-deterministic and fuzzy-probabilistic information. Each following level has to be considered more general than the previous one. The scheme is very simple, but its applications will be immeasurable. An analogical scheme is described for classifying systems and different objects and phenomena.

Introduction

During its history the humanity has attempted to describe the universe deterministically (concretely and precisely). Scientists have found a lot of deterministic laws, objects and models. Nowadays the overwhelming majority of humanity's knowledge is a deterministic knowledge. However, besides the deterministic phenomena and objects, there are different non-deterministic phenomena and objects. The majority of phenomena and objects in the complex systems are non-deterministic. Also the information may be deterministic or non-deterministic in many ways.

The first step in studying the non-deterministic phenomena was made in the eighteenth century when the probability theory was presented. Nowadays the probability theory and mathematical statistics are powerful tools used for describing and modelling stochastic (random) events, variables, functions, processes and systems. The probabilistic models are used in physics, economics, energetics and in the other areas [1–4]. However, the probabilistic models are not suitable for modelling every non-deterministic phenomenon.

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The next step was taken with the use of uncertain information. Uncertain information means the information about an object in the shape of crisp sets (intervals). At first, uncertain models were applied to the game theory [5, 6]. After that the probabilistic and uncertain information was used in various areas [7–11].

In 1965 Lotfi Askar Zadeh published the principles of fuzzy sets [12]. With that he formed the basis for new kind of information, named fuzzy information. This is information presented by fuzzy sets. Nowadays the usage of fuzzy information is extending very rapidly [13–16].

The interest in non-deterministic factors began to increase explosively about 50 years ago. Several new scientific directions have been arisen, such as stochastic programming, decision analysis, stochastic control, robust control, fuzzy logic, fuzzy system, fuzzy control etc. At present there are thousands works where various types of non-deterministic information are used. This research area is developing very quickly. But unfortunately this development has not been sufficiently systematic. Different authors use the same notions in different meanings. For example, notion “uncertainty“ is used generally as non-deterministic information and a special kind of information; the fuzzy information is sometimes confused with the subjective probabilistic information etc. The fuzziness is named as an aspect of uncertainty. Many other notions are also used, such as “random uncertainty”, “vagueness”, “chaos”, “incomplete information”, “fragmentary information” etc. Besides the plurality of notions, many different approaches in applying the forms of information have also been created. More precise information about plurality of notions and approaches can be found in papers and books [14–16].

In principle it is possible to create a new part of theory for every kind of information or for every kind of object without considering how it will be connected with previous theories. However, generally it is useful to develop new parts of theories in a manner that they would form certain connections with more concrete and more general theories. In order to improve the systematization of science development it is necessary to classify the kind of information and objects.

The author has been working in the area of power system cybernetics (optimal control, operation and planning) for over 40 years. At that we have used the deterministic, probabilistic and fuzzy information and models. The classifications presented in this paper are also formed in that way. This scheme of classification for information was first published in 1983 [17].

Classification of information

In this classification the historically formed names for the main types of information are used – deterministic, probabilistic, uncertain and fuzzy information. But we do not use these names in their traditional general sense.

The main types of information will be looked at so that they will form a hierarchical entirety. Uncertain-deterministic and uncertain-probabilistic information are added to the uncertainty level, and fuzzy-deterministic and fuzzy-probabilistic information – to the fuzzy level.

On the basis of theoretical disquisitions and long-time practical experiences the following scheme for classification of information may be recommended:

1. Deterministic information
2. Probabilistic information
3. Uncertain information:
    - 3.1. Uncertain-deterministic information
    - 3.2. Uncertain-probabilistic information
4. Fuzzy information:
    - 4.1. Fuzzy-deterministic information
    - 4.2. Fuzzy-probabilistic information.

This is a four-level hierarchical scheme of classification, in which the deterministic information is absolutely concrete, the probabilistic information is more general than the deterministic information, and each higher level is more general than the lower one. The most general type of information is the fuzzy information.

In Fig. 1 the scheme of classification is presented as a hierarchical system.

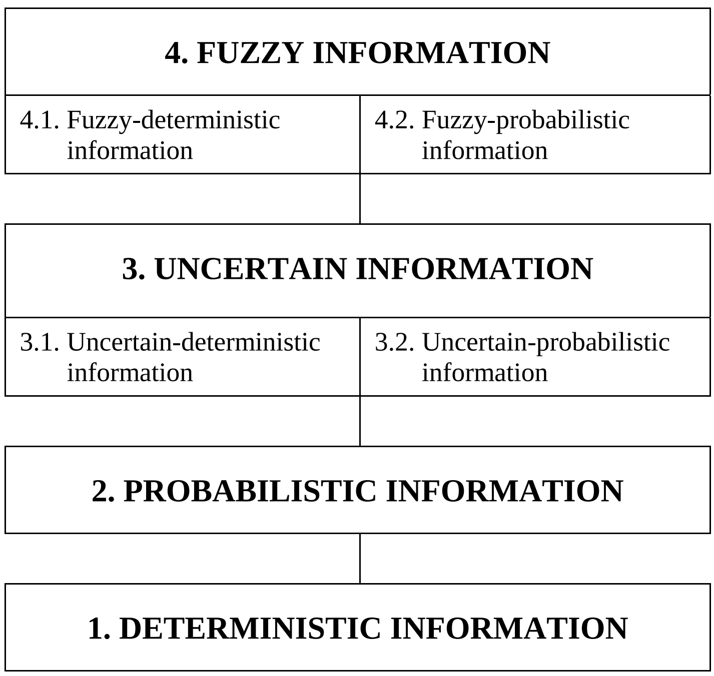

Fig. 1. General classification of information.

Deterministic information (DI)

The deterministic information determines uniquely the concrete event, concrete values of variables, concrete values of the processes, concrete relations and functions between variables and other objects. This is the most concrete form of information.

The deterministic information may be exact or inexact. If the deterministic information is absolutely exact, we can claim that we have complete information about the object. Otherwise the information is called incomplete. The deterministic information may be presented in many different forms.

Examples of the deterministic information:

1. DI about a variable: $X = 110$.
2. DI about a process: $V(t) = V_m \sin \omega t$, where V_m and ω are given parameters.
3. DI about a function: $i = \frac{u}{r}$.

If we do not have any exact deterministic information about the object, it is recommended to obtain probabilistic or uncertain information about it.

Probabilistic information (PI)

The probabilistic information determines uniquely the probabilistic characteristics of random events, variables, processes, relations and other objects. Mostly the probabilities, distribution functions, density functions, expectations, variances, standard deviations and different moments of a random variable and covariance are used. The probabilistic theory and mathematical statistics provide many possibilities. Probabilistic information has been developed for describing random or stochastic phenomena, events, variables, processes, functions and other objects mainly in priori. In the case of probabilistic information, a crisp set of events or values is given and the probabilistic measure in that is set. This type of information also enables to consider the errors of deterministic information.

The probabilistic information is more general than the deterministic form of information: $DI \subset PI$.

All types of deterministic information can be presented in the probabilistic form. It is not possible to do the contrary.

Examples of the probabilistic information:

1. PI about the random event: $P(\tilde{A}) = 0.5$, where $P(\tilde{A})$ is a probability of event $\tilde{A}$.
2. PI about a random variable in the shape of distribution function: $F(x) = P(\tilde{X} < x)$, where $F(x)$ is a distribution function of variable $\tilde{X}$.
3. PI about a random variable in the shape of expected value: $\bar{X} = E\tilde{X} = 110$, where E is a operator of expectation.
4. PI about a random variable in the shape of standard deviation: $\sigma = 6.5$, where σ – standard deviation, $\sigma = \sqrt{D(\tilde{X})} = \sqrt{E(\tilde{X} - \bar{X})^2}$.

If the probabilistic information is not enough exact or perfect, we must try to get the uncertain information about the object.

Uncertain information (UI)

The uncertain information may be:
1) uncertain-deterministic information
2) uncertain-probabilistic information.

Uncertain-deterministic information (UDI)

The uncertain-deterministic information determines only the intervals of deterministic information, but the actual value of the object is uncertain. This form of information enables to describe the uncertainties in the given interval objects and to take into account uncertain errors of deterministic information. The uncertain-deterministic information may be looked at as a deficiency of probabilistic information, which lacks the probabilistic characteristics. Now only the set of eventual values is given.

The uncertain-deterministic information is more general than the deterministic information. All types of the deterministic information may be presented in the uncertain-deterministic form. It is not possible to do the contrary.

If the intervals of uncertainty are not given exactly, we must try to get the fuzzy information about the object.

Examples about the uncertain-deterministic information:
1. UDI about a uncertain variable: $90 \le \tilde{X} \le 130$.
2. UDI about a function $\tilde{G}(X)$: $G^-(X) \le \tilde{G}(X) \le G^+(X)$, where $G^-(X)$ and $G^+(X)$ are given border functions.

Uncertain-probabilistic information (UPI)

The uncertain-probabilistic information determines the zones (intervals) of uncertainty for the probabilistic information. These zones are given exactly in the shape of crisp sets, but the actual values of probabilistic information in the given zones remain uncertain. That enables to describe objects with inexact probabilistic characteristics.

The uncertain-probabilistic information is a more general form of information than the probabilistic information. All types of the probabilistic information may be presented in the uncertain probabilistic form. It is not possible to do the contrary.

The uncertain level of information as a whole is more general than the deterministic and probabilistic information: $DI \subset PI \subset UI$.

Examples about the uncertain-probabilistic information:
1. UPI about a probability of random event: $0.3 \le P(\tilde{A}) \le 0.6$.
2. UPI about a distribution function: $F^-(X) \le F(X) \le F^+(X)$, where $F^-(X)$ and $F^+(X)$ are the border functions.
3. UPI about a expected value of $\overline{X}$: $90 \le \overline{X} \le 130$.
4. UPI about a standard deviation: $8 \le \sigma \le 10$.

Fuzzy information (FI)

The fuzzy information may be:

1) fuzzy-deterministic information
2) fuzzy-probabilistic information.

The information is fuzzy when the zones of uncertainty are given as fuzzy zones (sets). A fuzzy set $\tilde{A}$ is defined in the crisp set U as a set of ordered pairs $\tilde{A} = \langle (w, \mu_A(w)) | w \in U \rangle$, where $\mu_A(w)$ is the membership function, which indicates the degree that w belongs to $\tilde{A}$ [12–15]. The membership function takes values in the interval [0, 1] and is defined so that $\mu_A(w) = 1$ if w is a member of $\tilde{A}$ and 0 otherwise. At that, if $0 < \mu(w) < 1$, the w may be the member of $\tilde{A}$. In the last case, the situation is fuzziness.

Fuzzy-deterministic information (FDI)

The fuzzy-deterministic information determines the zones of the uncertain-deterministic information in the shape of fuzzy sets. That enables to describe objects with inexact zones or inexact borders of uncertainty zones. Usually only the borders of uncertainty zones are fuzzy.

The fuzzy-deterministic information is more general than the uncertain-deterministic information. All types of the uncertain-deterministic information may be presented in the fuzzy-deterministic form. It is not possible to do the contrary.

Examples about the fuzzy-deterministic information:

1. FDI about a variable *w* in the shape of fuzzy interval. The membership function $\mu(w)$ is following (Fig. 2):
   1) $\mu = 1$ if $w_2 \le w \le w_3$
   2) $\mu = \dfrac{w - w_1}{w_2 - w_1}$ if $w_1 \le w \le w_2$
   3) $\mu = \dfrac{w - w_3}{w_4 - w_3}$ if $w_3 \le w \le w_4$
   4) $\mu = 0$ if $w \le w_1$ or $w \ge w_4$.
2. FDI about a function in the shape of fuzzy zones. The fuzzy function and its membership function are shown in Fig. 3.

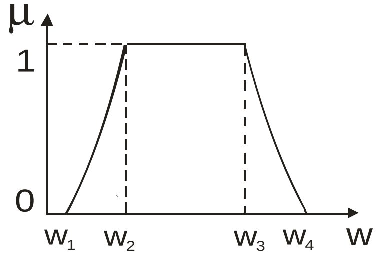

Fig. 2. Membership function $\mu(w)$.

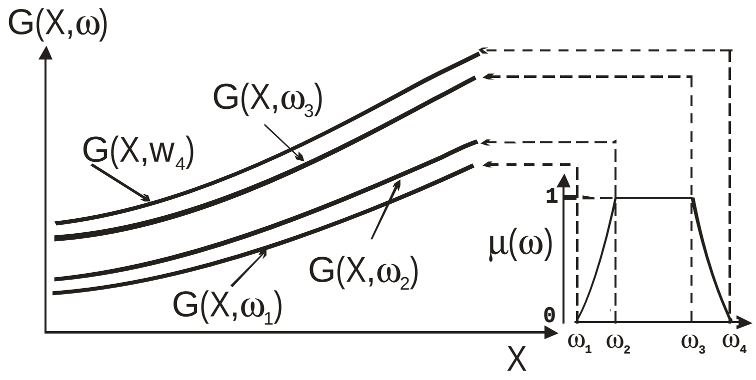

Fig. 3. Fuzzy function $G(X,\omega)$ and its membership function $\mu(\omega)$.

Fuzzy-probabilistic information (FPI)

The fuzzy-probabilistic information determines the intervals of the probabilistic information in the shape of fuzzy sets or intervals. This form of information is created for the cases when the intervals of uncertainty for the probabilistic information are not given exactly. The fuzzy-probabilistic information enables to consider the fuzziness of borders of the uncertain-probabilistic information.

The fuzzy-probabilistic information is more general than the uncertain-probabilistic information. All types of the uncertain-probabilistic information may be presented in the fuzzy-probabilistic form. It is not possible to do the contrary.

Therefore the main types of information are defined in the manner of the following connections: $DI \subset PI \subset UI \subset FI$.

Examples of the fuzzy-probabilistic information:

1. FPI about a distribution function is given by four border functions $F(X,\omega_1)$, $F(X,\omega_2)$, $F(X,\omega_3)$, $F(X,\omega_4)$ and membership function $\mu(\omega)$ (Fig. 4).
2. The expected value of variable X is given by fuzzy intervals. The membership function $\mu(\bar{X})$ is following (Fig. 5):
   1) $\mu = 1$ if $90 \le EX \le 110$
   2) $\mu = \dfrac{EX - 70}{90 - 70}$ if $70 \le EX \le 90$
   3) $\mu = \dfrac{EX - 110}{120 - 110}$ if $110 \le EX \le 120$
   4) $\mu = 0$ if $EX \le 70$ or $EX \ge 120$

Analogical schemes of classification may be composed for whatever objects that are bound with notion information. For the following we will present the general classification of systems.

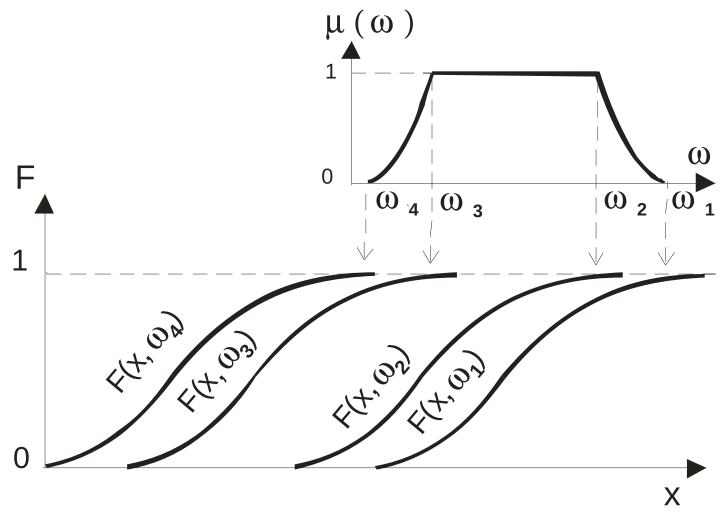

Fig. 4. Fuzzy distribution function.

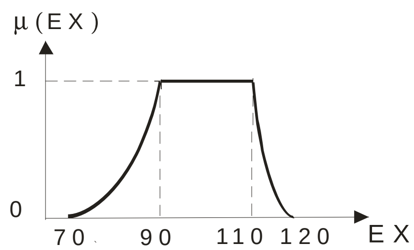

Fig. 5. Membership function of expectation EX.

General classification of systems

The systems can be defined in different ways. A system is an object that consists of elements and relations or connections between the elements and the environment.

The general classification of systems from the information side also consists of four main levels:

1. Deterministic systems
2. Probabilistic systems
3. Uncertain systems:
    - 3.1. Uncertain-deterministic systems
    - 3.2. Uncertain-probabilistic systems
4. Fuzzy systems:
    - 4.1. Fuzzy-deterministic systems
    - 4.2. Fuzzy-probabilistic systems

In Fig. 6 the scheme of classification is presented as a hierarchical system.

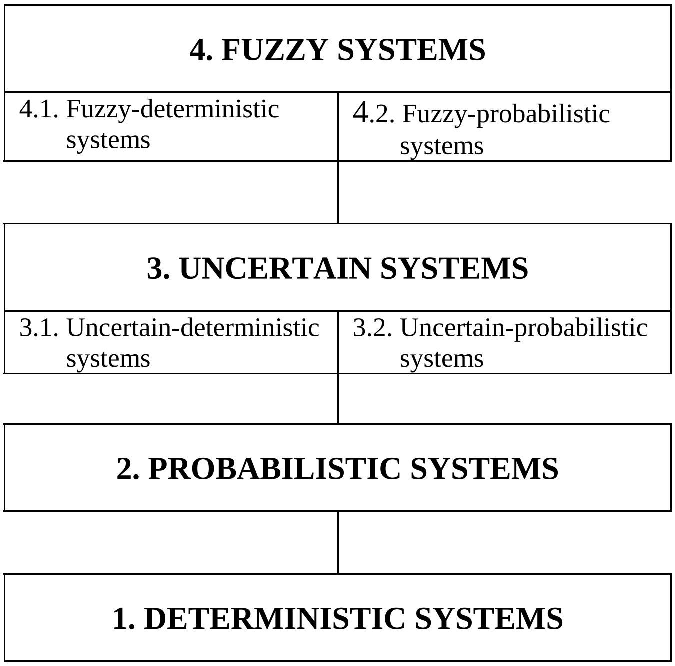

*Fig. 6***.** General classification of systems.

This is a four-level hierarchical scheme of classification, in which the deterministic systems are on the first level. The probabilistic information is more general than the deterministic information, and each higher level is more general than the lower one. The most general type of information is fuzzy information.

Deterministic systems (DS)

Deterministic systems are the systems that can be completely described by the deterministic information and deterministic models. In deterministic systems the inputs and initial conditions uniquely determine output processes.

The deterministic system with absolutely exact deterministic information is called the system with complete information.

The systems that are not deterministic ones are called non-deterministic, stochastic or random systems.

Examples of deterministic systems are computer, law of Ohm, classical physics, etc.

Probabilistic systems (PS)

The probabilistic system is defined as the system that consists of at least one probabilistic component and does not consist of any uncertain or fuzzy component. At that the probabilistic system may contain deterministic components.

A probabilistic system is more general than a deterministic system. Deterministic systems may be looked at as subsystems of a probabilistic system.

Examples of probabilistic systems are quantum physics, lotteries and complex systems that do not involve any uncertain and fuzzy components.

Uncertain-deterministic systems (UDS)

Uncertain-deterministic systems are the systems that consist of at least one uncertain deterministic component and do not involve any uncertain probabilistic and fuzzy component. At that the uncertain deterministic system may contain deterministic and probabilistic components.

The uncertain deterministic systems are more general than the deterministic and probabilistic systems.

For the examples of uncertain deterministic systems are the complex systems that consist of deterministic, probabilistic and uncertain deterministic components.

Uncertain-probabilistic systems (UPS)

Uncertain-probabilistic systems are defined as systems that consist of at least one uncertain-probabilistic component and do not involve any fuzzy component. At that the uncertain-probabilistic systems may contain deterministic, probabilistic or uncertain-deterministic components.

The uncertain-probabilistic systems are more general than the deterministic, probabilistic and uncertain-deterministic systems. The deterministic and probabilistic systems may be looked at as the subsystems of uncertain systems.

For the examples of uncertain-probabilistic systems are the complex systems that consist of deterministic, probabilistic, uncertain-deterministic and uncertain- probabilistic components.

Fuzzy-deterministic systems (FDS)

Fuzzy-deterministic systems are the systems that consist of at least one fuzzy- deterministic component and do not involve any fuzzy-probabilistic components. At that the fuzzy-deterministic systems may contain the deterministic, probabilistic and uncertain components.

The fuzzy-deterministic systems are more general than the deterministic, probabilistic and uncertain systems. The deterministic, probabilistic and uncertain systems may be looked at as the subsystems of fuzzy-deterministic systems.

For the examples of fuzzy-deterministic systems are the complex systems that consist of deterministic, probabilistic, uncertain-deterministic, uncertain-probabilistic and fuzzy-deterministic components.

Fuzzy-probabilistic systems (FPS)

Fuzzy-probabilistic systems are defined as the systems that consist of at least one fuzzy probabilistic component. Fuzzy probabilistic systems may contain deterministic, probabilistic, uncertain or fuzzy-deterministic components.

Fuzzy probabilistic systems are the most general type of systems. The following relations are valid: $DS \subset PS \subset US \subset FS$.

Therefore deterministic, probabilistic, uncertain and fuzzy-deterministic systems may be looked at as the subsystems of fuzzy probabilistic systems. If we do not have any kind of information, we will have to do with ignorance.

Complex systems with fuzzy-probabilistic components are good examples of fuzzy-probabilistic systems.

Conclusions

1. The hierarchy in the sense of concreteness and generality is a very important point of view that has not been sufficiently utilized. This enables to compose the classification of whatever objects, qualities, notions etc.
2. Also, the principle of hierarchy simplifies the generalization of scientific results to higher levels of information hierarchy and helps to concretize the scientific results of higher levels.
3. This direction of research looks promising.

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