# DECISION MAKING IN MAN-MACHINE SYSTEMS: FUZZY CATEGORIES AND THE FUNCTIONAL ASYMETRY OF THE BRAIN

## Part I

D.I. Shapiro and V.S. Rotenberg

Institute of Automated Control Systems, Moscow, USSR

First Medical Institute, Moscow, USSR

## 1. The Problem of Decision Making in a Fuzzy Environment

The problem of decision making in a man-machine system that operates in an uncertain and counteracting environment is described as [1];[2]

$$\langle S_t, \tilde{X}, \hat{X}, \check{X}, F_o, F_i, \Gamma_i, Q_o, Q_i, L_o, L_i, U, V_i, \{q^j\}\rangle$$

where $S_t = \{\varrho, \tilde{x}, \hat{x}, \check{x}\}$ is the set of situational data; $\varrho$ denotes identifiers; $\tilde{x}$ is the condition of the environment, $\tilde{x} \in \tilde{X}$; $\hat{x}$ is the state of the system, $\hat{x} \in X$; $\check{x}$ is the subject's (or decision maker's) state, $\check{x} \in \check{X}$; $\tilde{X}, \hat{X}, \check{X} \in X$; $F_o$ and $F_i$ are the DM and the system's active elements, respectively; $Q_o$ and $Q_i$ are the criteria defined by the objectives of $F_o$ and $F_i$, respectively; $L_o$ and $L_i$ are the constraints of $F_o$ and $F_i$ as determined by their resources, time limits, and ethical standards; $\Gamma_i$ is the set of relations between $F_o$ and $F_i$ (specifically, binary relations); U is the set of strategies for $F_o$, $u \in U$; $V_i$ is the set of strategies for $F_i$, $v_i \in V_i$; and $q^j$ is the set of evaluations.

The state of the environment, system, or DM can be defined in quantitative ($\underline{X}$) and/or qualitative form ($\underset{\sim}{X}$).

The criteria and constraints may take the form of texts in

a natural language or they may depend on the qualitative parameters $\underset{\sim}{X}$. The evaluation procedure relies on the quality scales $q^j$ that are essentially either a membership function ($\mu(x)$) that describes the extent of the deviation of an attribute or a set of fuzzy points.

The effort to solve a particular application problem brought about by human-computer interaction can take advantage of several general principles. Thus, we can describe relevant data by both quantitative and qualitative parameters. We can incorporate into the system's operation man-specific qualitative assessments and selection procedures. We should also draw on the experience of an expert (DM, designer, or user) when developing and operating the system.

The designer (researcher) should identify such uncertainties and formalize them. Using a computer program, the DM (user) will select a final solution. Decision making in a fuzzy environment relies on a membership surface

$$R_\ell, \mu[R_\ell] = \pi[y^1, \ldots, y^m]$$

where $R_\ell$ is the decision ($R \in U$); $y^j$ is the evaluation with respect to the scale $q^j$ of the parameter $x^j$ ($y \in Y$).

Decision making in the context of fuzziness and counteraction relies on fuzzy integral games: $\Gamma_{fL} = \{\Gamma_{fi}[X, Y, U, V_i], Q, L\}$

$$-L_o \lesssim \tilde{U} \lesssim L_{oi}, \; -L_i \lesssim V_i \lesssim L_i, \; Q_o = -\prod_{i=o}^{n} Q_i$$

The decision is determined by the conditions:

$$\mu_{Q_o}(w_i, u(w_i)) = \mu_{Q_o}(w, u^*(w_\ell))$$

where $w_\ell = \max w_i$ provides the best compliance with the criterion $Q_0$.

A major problem in developing a system that generates rational advice is to identify, make a formal description of and apply fuzzy categories inherent in the definition of a problem and in evaluation and selection procedures. Each of the above steps must include the effects of the "unique expert's" (DM's) particular features.

## 2. Incorporating the 'Unique' Expert's Specific Features

Expert procedures make it possible to establish an isomorphism or homomorphism that maps a set of real-world objects with particular properties (or specifically related to one another) onto/into a formal system. Knowledge acquisition comprises several step-by-step phases: planning, implementation, and analysis. Planning consists of determining the experts' specific features and designing required experiments. This may involve two problems:

- a study of the object's properties (the room is 'small/ /large');
- a study of the environment conditions (the room is 'stuffy/ /cool').

The implementation phase is associated directly with an action dictated by the program or with a response to the questions presented. The experts' opinions are examined via a dedicated computer program, which helps formulate, generalize, and formalize the opinions. State-of-the-art computer applications tend to employ both shared computers with private terminals and PCs to implement particular man-machine procedures. The procedures allow the DM's experience, his peculiar features and interests to

be utilized most effectively. To this end, the software employed should incorporate the experience the DM has gained operating in normal or particular off-normal conditions. Thus, the area of possible approaches to knowledge acquisition becomes somewhat restricted. The presence of a 'unique' expert is an important factor in the above class of man-machine decision making systems (MMDMS) that operate under uncertainty and counteraction.

The statement of a decision-making problem contains a situation description, criteria, and constraints written as a text in a natural (formal natural) language [1]. Linguistic terms serve as elements of the scales used to evaluate objects or their individual attributes. They are an 'objective' source of the uncertain and a formal representation of the qualitative uncertainties involved makes it possible to employ them in an MMDMS. However, analysis and formal description of such uncertainties in human (the DM's) evaluation and selection ('subjective' sources) are even more important for this kind of MMDMS. Account should also be taken of problem-related, professional, and situational aspects of fuzzy categories.

A unique DM as a component of a man-machine system, in effect, calls for special arrangements to exploit his capabilities. The concept of integrating the DM's specific features into an MMDMS intended for an uncertain and counteracting environment implies two major goals. The first is that we should, on the one hand, investigate the effects of the DM's psychophysiological characteristics on his actions (these may include will, needs, emotions, way of thinking, and functioning of physiological systems) and, on the other, make use of the DM as an expert to formalize both objective and subjective fuzzy categories, a feature essential

for our class of problems. The former categories comprise qualitative situational data, criteria, and constraints written as a text in a natural language. The latter stems from the mental processes involved in the formal description of fuzzy categories and in evaluation and selection procedures. In fact, an 'objective' fuzzy category is not fuzzy per se but only in a human perspective. Thus, we can only consider a factor to be subjective when it has nothing to do with the semantics of the situation description. The second goal is to examine and utilize the neurophysical processes that reflect the DM's state.

Our class of problems takes advantage of changes in the sympathetic nervous system (SNS) to account for the DM's state [2].

## 3. The Effect of Hemispheric Asymmetry on Decision Making Processes

It is generally recognized that the consideration of distinctions between the cerebral hemispheres in perceiving and processing any kind of information offers the greatest potential when discussing the effect of hemispheric asymmetry on a particular psychic function.

The authors have advanced the hypothesis [3; 4] that the left and the right hemisphere arrange the contextual relations between the images of objects or phenomena and their respective symbols in different ways. Verbal logical thinking characteristic of the left hemisphere (LH) examines the entire range of such actual and possible relations to select those individual and most pronounced relations that help link the cause and the effect, present the external world as an ordered entity and reduce it to an

unambiguous model. The LH thought process fully complies with the rules of formal logic and is controlled by well-defined algorithms.

By contrast, the thought process supported by the right hemisphere can instantly grasp all such rich relations, comprehending also relations mutually exclusive in formal logic, and arrange a polysemantic context that represents the entire complex and contradictory external world. We can designate it as 'image' thinking as polysemantic relations appear to be most appropriate to form an integral image and connect it to other images of this kind. We should emphasize that the main determining relations cannot be selected just by grasping a large number of relations. The selection process involves a preliminary analysis and matching to a previously constructed model and modeling is a LH function. However, we cannot rule out the possibility that the right hemisphere (RH) has ready references for the above selection procedure and they are the result of an earlier analysis by the LH.

It is apparent that the declared differences are largely similar to those between the iconic (pattern) and the symbolic (texts) system of representation. The only distinction is that we emphasize the arrangement of contextual relations rather than the consecutiveness, or simultaneity of the synthesis [4].

Research provides increasingly abundant evidence that the ability to arrange a polysemantic context is a specific immanent function of the right human hemisphere and need not be further amplified by the brain stem reticular formation. In healthy subjects tested under normal conditions the left hemisphere is always more active than the right as revealed by the frequency and the amplitude of the alpha rhythm or the alpha index .

The intensity and uniqueness of day-dream images show a positive correlation with the alpha index. Vivid mental visualisation or an intensely emotional experience does not decrease EEG synchronization for persons who have well-developed image thinking [4]. In meditation, which corresponds to the RH pattern of thinking, alpha waves have a high amplitude and become generalized. When a person with a high creative potential succeeds in solving a problem that calls for imaginative and creative handling, his alpha rhythm is very distinct, especially in the right hemisphere. Today, the primary role of RH image thinking in creative work is indisputable. The more unconventional the problem solving process, the higher the role of the right hemisphere. When the LH pattern of data processing dominates a subject who goes through a Raven matrix test, we observe a higher articulation activity that tends to enhance the activity of the left hemisphere and we also register clear vegetative and somatic signs of a mental stress. This is commonly the case with persons whose speech processor fails to be lateralized completely and whose non-verbal capabilities are reduced because the responsibilities for various functions are not localized to a particular hemisphere. If, on the other hand, the RH pattern is used to cope with an intellectual problem, no signs of a mental strain or additional verbal activity are observed.

We believe that the LH data processing pattern requires higher cerebral activity just because it attempts to arrange the information available and bring out the few relevant links in a multitude of irrelevant relations. The RH pattern gives the human mind a great deal more leeway in handling information and

thus involves smaller energy costs. This fact in no way implies that RH thinking is merely a passive contemplation of the external world. The mind is active in whatever it does, although its activity may take different forms. Our culture assumes that an activity should always have a purpose, a known goal to be accomplished. However, some oriental societies also allow for activity unfettered by the limitations of prediction and goals. Such activity characteristic of natural 'here and now' behavior is believed to be the most creative. This cerebral activity involves no statistical prediction and sets no cause-and-effect relations; it requires no extra stimulation by the stem reticular formation. The right hemisphere is responsible for prediction that extends beyond the actual statistics and thus comes close to an experience brought about by insight or clairvoyance. Its mechanism is yet to be identified. RH prediction may be kaleidoscopic in nature: many versions of the future are simultaneously presented but their probabilities are very close. As a result, an event unlikely from the perspective of past experience has the same weight as a product of reasoning.

We will now look at the DM's impact on the formalization of fuzzy categories and at selection procedures, based on the understanding of the processes related to hemispheric asymmetry.

Needs can control behavior if they are associated with conscious and unconscious images of desired objects and the actions required to satisfy them. The unconscious images are handled by the right hemisphere and are such because of their complexity and ambiguity prohibitively high for straightforward thought or because of their antagonism to the conscious.

The left hemisphere provides the rationale for man's motivations and actions. The LH tends to order information by making it simpler and ignoring relations that are not indispensable for the main task. Analysis and the awareness of purpose imply prediction of the results, which is the responsibility of the LH.

The DM's mind seeks to apprehend the situation and make a proper decision. The process of thinking can be partitioned into five phases.

The first one is related to delays of spontaneous impulse responces (LH) to make an appraisal of the task at hand which may rely on either one-by-one elimination (LH) or general apprehension (RH) followed by distinguishing and correlating the essential components.

The second phase seeks to arrive at a general mental policy that comprises the choice of an appropriate course of action (LH) and the formation of a general pattern of thinking. The latter can be either integral intuitive insight (RH) or detailed analysis (LH).

The third phase deals with the selection of means and operations and is implemented in the left hemisphere.

The execution of the fourth phase (decision making or response generation) may heavily rely on RH processes if the problem calls for an imaginative approach.

The fifth phase, i.e. comparison of the results and the source data, goes on in the left hemisphere.

Decision making involves such mental functions as:

1. Problem data generalization, which is a conscious LH process as it includes data reduction. Actually, any generalization,

i.e. an effort to derive more universal and abstract ideas, is a function of the left hemisphere. However, it is the right that appraises as a whole the results of LH generalization.

2. Perception, which depends on various sensory channels (auditory, visual, etc.) and data carriers (printed or audio texts, pictures, color shades, impulses, etc.). The RH is responsible for perception of any entity that is at least partially continuous but the LH, too, makes its contribution by classifying individual elements and breaking down the sensation into its components.

3. Understanding the data perceived (printed and audio texts, specifically, color shades and voice pitch). If understanding is conscious awareness or at least sets cause-and-effect relations then it belongs to the left hemisphere. However, picture coloration, as a whole, cannot be brought to the front of the mind as it is inherently continuous in some aspects. The right hemisphere identifies the saturation, lightness, and hue of color and the left verbalizes the resulting color evaluation (especially for intermediate colors).

4. Formation of a text or conscious action is an LH responsibility; a spontaneous response to a critical situation is generated in the RH.

5. The right hemisphere also supports an intuitive decision to make a choice among equiprobable alternatives when the decision contains an unconscious element.