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MEASUREMENT AS A COGNITIVE PROCESS

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Abstract – Two principles for arranging existing and possible theories of measurement into a system are proposed. The second (functional) principle seems to be more useful for engineering education.

Keywords: theory of measurement, engineering education

1. INTRODUCTION

This paper is a result of observations and investigations made by the author during half-a-century studying and working at the Department of Electrical Measuring Instruments (now the Department of Measurement Information Technologies) of Leningrad Polytechnic Institute (now SPb. State Polytechnic University).

Since the pre-war time the thinking part of the staff of the Department was occupied by the search for scientific basis of their educational and engineering activities.

First of all *energy transfer* in the electric circuit of an instrument was considered to be the main object of theory. Later, in early fifties, attention was drawn to the concept of *measuring converter* as a functional and physical element of an instrument. Some other ideas were associated with the concept of measuring converter, namely:

structural presentation of measuring instruments;

application of *signal theory* to the description and analysis of measuring circuits;

use of *similitude theory* for the analysis of reversible transducers;

treatment of *physical effects* used in instruments as the most important objects of teaching.

Then, also in fifties, the ideas of *statistical communication theory*, *cybernetics* and Shannon's *information theory* became popular and attempts to adapt them to the problems of measurement were made. All these ideas displaced (in our minds only) the engineering specialty "Electrical Measuring Instruments" from the domain of Electrical Engineering to the domain of Information Technologies. In middle sixties the name of the specialty (and the curricula) were changed correspondingly.

In early seventies the author, being the lecturer in Digital Measurements, made an attempt to create a kind of physical theory of analog-to-digital conversion. The main notion of the proposed theory was a *material coded scale* – i.e. the set of switched current sources, the train of pulses used as time marks, the coded disc etc.

The concept of coded scales proved to be in concordance with the general concept of *scales of measurement* proclaimed in 1946 by S.Stevens and later evolved into so called *representation theory* (RT). Some specialists regarded RT as the long sought theoretical basis of the specialty, but this theory obviously did not cover the whole field of problems connected with measurement

The steady growth of the set of loosely interconnected "theories of measurement" compelled us to search for an organizing principle – a kind of a framework, which could transform this set into a system – having in mind the cognitive nature of measurement.

2. STAGES AND LEVELS OF MEASUREMENT

One possible organizing principle was the concept of *stages of measurement* developed in our country by T. Siraya and her colleagues. But it proved rather difficult to connect each stage with some corresponding theory. Another possible principle, *level decomposition of measurement,* proposed by the author, appeared to be more useful in this respect.

It is interesting to mention that the stages and levels of measurement proved to be interconnected within the *U-shaped model* of measuring process [1]. The proposed system of levels (Fig. 1) consisted of the lowest – *physical* level, then *signal* level, *sign* level, *primary data* level, *message* (or *protocol*) level, *user model* level, and finally *knowledge* level.

Stages of measurement (somewhat modified) went in that system from the highest – knowledge level – down to the physical level and then from the physical level back to the knowledge level. The overall result was the transition from the *a priori* knowledge to the *a posteriori* knowledge.

The U-shaped model with its 7 levels and additional horizontal links between corresponding levels became strikingly similar (by the form only!) to the well-known model of open systems interaction (OSI), though the similarity certainly was not planned beforehand.

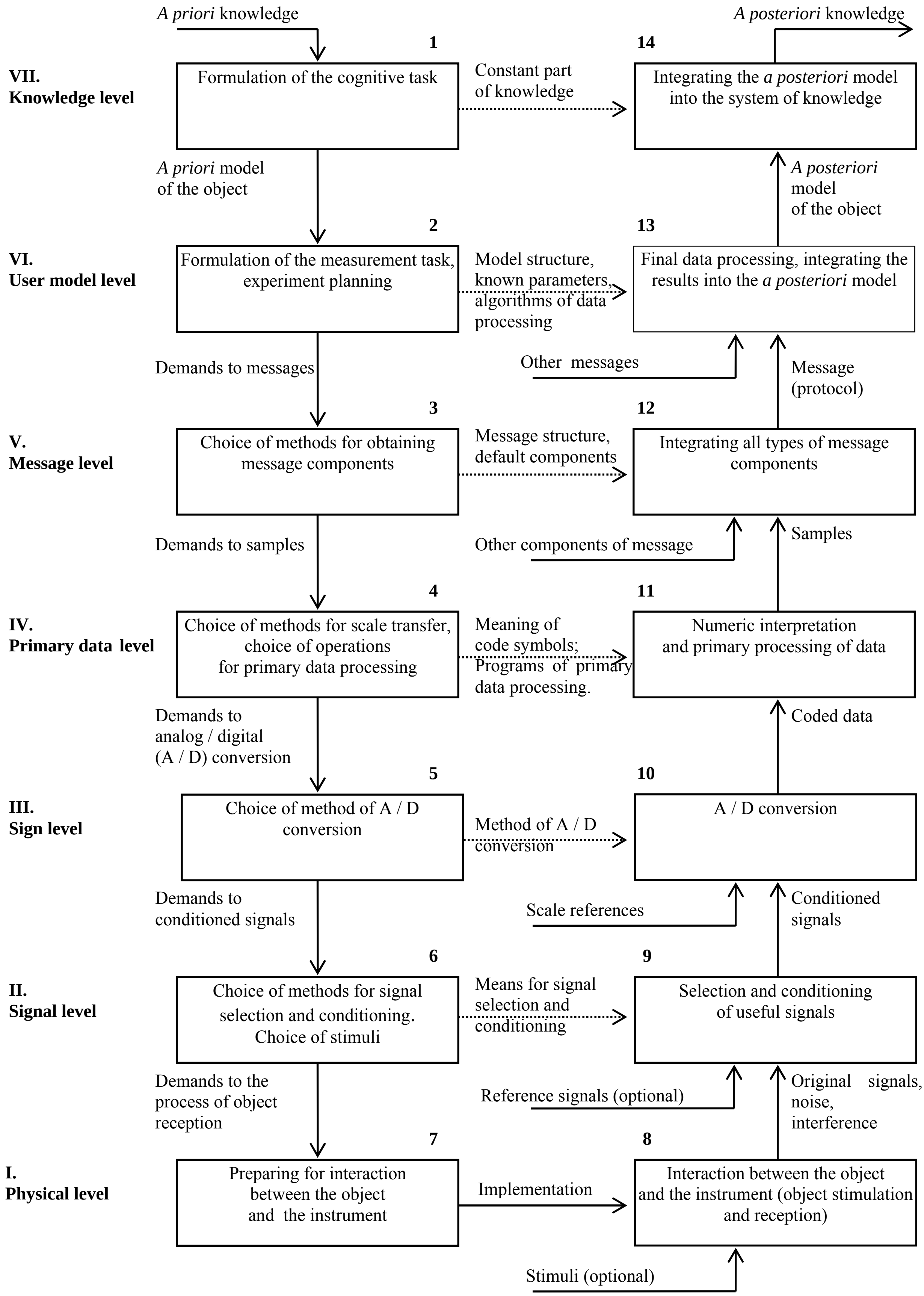

Fig.1. U-shaped structure of measurement process

One distinction between them consists in the additional inputs to the blocks of the upward branch in the model of measurement that do not exist in the OSI model.

The means for description and analysis of measurement process depend on the level regarded and vary from one level to another. This fact can be easily understood by regarding the upward branch of the U-shaped model (blocks 8 – 14).

On the *physical* level both the object and the instruments used are described as complex physical (or chemical, biological etc.) systems.

On the *signal* level, when a certain physical process, common for the object and the instrument, has been selected as *the signal*, only one (as a rule) parameter of this process is considered to be the *informative parameter*. So one can adequately describe the process on the signal level by means of an algebraic expression or graph depicting the informative parameter vs. time. Such descriptions (employed both for useful signal and for noise) can be called the *signal functions.*

On the *sign* level measurement usually appears to be the *comparison* of the signal at a given instant with some *material coded scale*, the result being a sequence of code symbols or signs.

On the *primary data* level the code sequences are decoded first as *numerals* and then as *numbers*. On the same level the numbers can be interpreted as the values of some *quantity* (or quantities if the measurand should be somehow calculated) and processed, e.g. corrected if necessary.

On the *message* (or *protocol*) level sets of samples obtained on the previous level are combined with other necessary data (e.g. time marks, instrumentation data etc.). Now the details of physical interaction between the object and the instrument, as well as the operations of signal conditioning and A/D conversion can be ignored – the message or protocol, if properly created, must be self-sufficient.

If the measurement is not fully automated a message has usually the form of a table on the paper, which is delivered to the person responsible for the final data processing. In contemporary "data acquisition systems" a message may take the form of a frame or a sequence of frames transmitted from a controller or even from an intellectual transducer to the higher level computer.

On the *user model* level the values of quantities are processed (usually by statistical methods) and the results with their estimated uncertainties are treated as the parameters of the model accepted for the object. A routine measurement may end at this point.

The process of research measurement includes one more level, namely *knowledge* level. At this stage the model of the object with its *a posteriori* parameters is treated as the element of some *system of models*.

The system of levels is to some extent interconnected with the set of theories existing in the domain of measurement.

The *physical effects* and the principles of their systematisation, the theory of *reversible transducers*, *similitude theory* etc. – all these ideas definitely belong to the physical level.

Various aspects of *signal theory* and *structural presentation* of measuring instruments refer to the signal level.

Algorithmic theories of A/D conversion obviously correspond to the sign level.

The theories of statistical processing of numerical data seem to belong to the user model level.

Nevertheless some theories exist that span several levels, i.e. RT deals both with relations between physical objects and with their counterparts in numeric domain.

3. FUCTIONS OF MEASUREMENT

Another model of measurement, also proposed by the author, has been called *functional model*. The term *function* was intended to mean a certain aspect of measuring process, preferably associated with its own theory or group of theories.

This meaning of the term "function" combines the linguistic usage of the word ("communicative function" and "modelling function" of language) with the meaning leveraged off the description of the Hewlett Packard Interface Bus (a part of the system responsible for definite operations). Maybe such combination has lead to certain non-uniformity in the treatment of functions.

Twelve functions were chosen rather heuristically, namely: *object modelling* function, *scale building* function, *scale transfer* function, *object reception* function, *object stimulation and conditioning* function, *localization* function, *communicative* function, *comparison* function, *store* (or *memory*) function, *selection* (or *information refining*) function, *estimation* function, *presentation* function.

They are certainly not independent and differ in many aspects: some of them are mandatory and others optional; some are supported by well-defined theories and others are not; some are rather simple and others complex etc.

The twelve functions may be for convenience grouped, as shown in Fig.2.

It is interesting to list some existing theoretical disciplines related to each function of measurement and point out the non-existing but necessary theories.

The *object modelling* function may use the similitude theory, the theory of dynamic analogies, parts of the theory of system identification and the design of experiments, but these are only fragments. General theory of modelling has not been created yet, though some authors (e.g. Victor Rosenberg in USSR) proclaimed the wish to create it.

The *scale building* function has its own theory, i.e. RT, and the *scale transfer* function lies (or rather should lie) completely within metrology, for this function is connected with the notion of traceability.

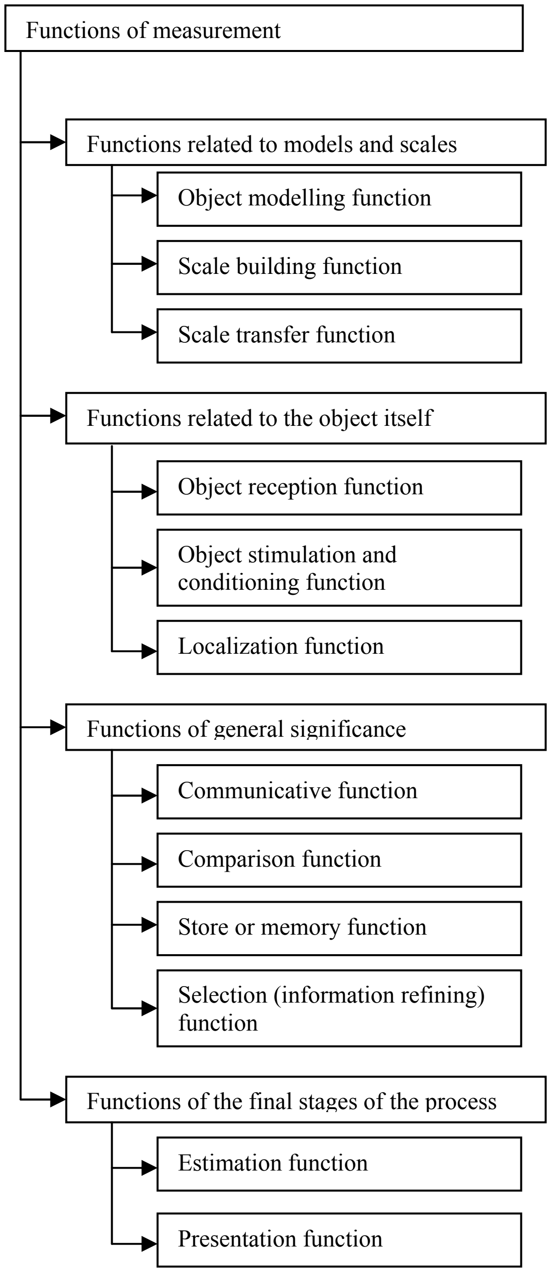

Fig.2. Groups of function

The *object reception* function, strange enough, has not yet been thoroughly investigated. Some efforts were only made towards the general theory of transducers or sensors but this "sensorics" could only be a part of the object reception theory. The author tried to outline the problems connected with reception in the short paper [2].

The *object stimulation and conditioning* function can be regarded as optional, though even passing the current through a resistor in the process of resistance measurement can be called stimulation. The existing theoretical fragments related to this function are: the part of the design of experiments concerning the choice of factors; theory of dynamic testing; theory of digital circuits testability etc.

The *localization* function becomes necessary when it is desirable to determine the region or the point in physical space/time or in the object structure to which the acquired information relates. This function is of special importance for procedures such as diagnostics and searching but is often needed for plain measurement. The so-called dating (aperture) error is a special case of the localization error.

The *communicative* function is listed among functions of general significance because it is relevant to all technical cognitive procedures. All the theories working on the signal level support this function.

The *comparison* function is also relevant to all cognitive procedures because transition from the real world to the "world of signs" can be implemented only by means of elementary or complex comparison. The first is mandatory for measurement and the second for pattern recognition. Foundations of the theory of elementary comparison were laid by H.Helmholtz [3] in XIX century, but it still needs development.

The *store* or *memory* function reflects an important feature of measurement: the recorded values of the quantities are the memories of the object properties. This function implies that the instruments should maintain stability of their own characteristics. The theory of their aging seems to be poorly developed. Some interesting considerations can be found in [4].

The s*election* or *information refining* function is probably the most complicated one. Its aim is to preserve the useful information in the process of measurement and reject all that is not useful. All levels of measurement (see Fig.1) can be involved in the implementation of this function. So nearly all the theories in the domain of information acquisition are somehow related to it, but general theory of selection still has to be constructed.

The *estimation* function can be referred both to the object (e.g. its quality) and to the result of measurement (whether it is satisfactory or not). The theory of decisions is useful in both cases.

Finally, the *presentation* function should provide clear and unequivocal perception of the measurement result by the consumer (human or electronic) with accordance to the rules accepted. If the knowledge level is included in the process, the principles of artificial intelligence may be involved.

The complexity of the proposed system of functions reflects the complex nature of measurement as a cognitive process.

4. EDUCATIONAL EXPERIENCE

The proposals described in the previous sections were practically tested only once, when the author delivered an experimental lecture course for third year students of the measurement specialty. The system of levels was mentioned in the lectures but the main part of the course was based on the system of functions. Such structure of the course permitted to touch upon all the theories connected not only with the process of measurement but also with some other cognitive processes.

The result was rather satisfactory [5], though it was clear that the system of functions needed additional testing in regard to its applicability in various spheres of measurements

5. CONCLUSION

The proposed systems of levels and functions can certainly be improved. Nevertheless at least two conclusions can be drawn even now.

The first conclusion follows from the fact that there is no *single* function that could cover all the problems associated with measurement. Why should we choose – *either* physics *or* information systems? The theory of measurement can easily look to *both*; one function (e.g. object reception) being nearer to physics and some other (e.g. information selection) to information systems. It is no use to proclaim: "Measurement is comparison" (Malikov) or "Measurement is transmission and conversion of information" (Novickij). Measurement is *both* conversion *and* comparison! The half-a-century search for a single remedy, witnessed by the author, as was mentioned in the beginning of the paper, confirmed it quite reliably.

The second conclusion (that seems more serious) comes from the fact that each function in itself has a *wider* scope than measurement [6]. The author does not wish to support the tendency of calling any procedure of "pinning numerals to objects" (as Stevens phrased it) measurement. But the scope of true measurement can be clearly defined only if we investigate the wider region of *information acquisition*, including various test procedures, data acquisition in social sciences and maybe even what is called data mining (Muravyov's idea).

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