MEASUREMENT IN SOFT SYSTEMS

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Abstract-The paper reviews the problem of widely defined measurement in soft systems. It defines soft systems as those incorporating human activity, or describable by fuzzy logic. It considers examples from measurements in psychology, economics and psychology. A framework for considering measurement in soft systems is offered for discussion.

Keywords measurement theory, measurement philosophy, soft systems,

1. INTRODUCTION

Measurement is the essential tool for describing and understanding nature and a reliable basis of knowledge. The basic paradigm for measurement is derived from its application in natural science. However, its power as a tool of description and reasoning has lead to the extension of its application to the investigation of the human mind and of the behaviour of human societies. The logical basis of measurement in psychological and social applications has been satisfactorily developed. However, problems of measurement, in what might be called measurement in soft systems, remain. This presentation examines some of the major issues involved.

2. DEVELOPMENT OF THE THEORY OF MEASUREMENT

The theory of measurement is the analysis of the logical basis on which representation of objects and events of the real world by numbers rests. It is proposed to outline briefly its historical development. A somewhat more extensive outline is given in [1].

The practice of measurement emerged in the earliest stages of human development from uses in trade, crafts and surveying. It was based on intuitive understanding of the processes involved. There was much discussion of the concept in philosophy, from the Greeks to the Middle Ages, without deeper epistemological analysis. Application of mathematics to the description of nature, from Gallileo, through Newton, Lagrange, Maxwell and others achieved outstanding successes without investigating the epistemological and logical foundations of mathematical description of the world.

The foundations of the logic and epistemology of measurement were laid by Helmholtz in 1887 [2] and extended by Hoelder [3] shortly thereafter. They were presented by Campbell in 1920 [4] in a treatise devoted to the elements of physics. These works lead to a narrowly conceived theory of measurement, which basically viewed measurement theory purely from the point of view of physical measurement, as then understood.

This position was challenged by the needs of the sciences of psychology, economics, sociology and management and decision, which all strove to use the power of measurement. The validity of measurement in these domains was strongly disputed from the physical science perspective [5]. The need to extend the theory of measurement was driven by the philosophical trends of logical positivism and operationalism, which essentially defined meaningfulness of propositions in terms of operations of empirical observation [6,7]. The tools for formulating a more comprehensive theory of measurement were provided by the developing study of the foundations of mathematics and particularly the model theory of Tarski from 1936 on. [8, 9].

A conference in the United States [10], published in 1959, presented a review of the classical approaches to measurement as extended to needs of the social and behavioural sciences.

In the social sciences there had been concerns with the logical basis of mathematical representation, from the classical works of Bentham and Pareto to the seminal contribution of von Neuman and Morgenstern on the theory of games and economic behaviour in 1944 [11]. In psychology Stevens pioneered the advancement of understanding of psychological measurement [12, 13,14].

Modern theory of measurement, which embraces all measurement, in physical science and in other domains is based on model theory. This theory of measurement considers measurement, informally speaking, as the establishment of a correspondence between a set of manifestations of a property of objects and events of the real world and the relations between them, and a set of numbers and the relations between them.

An early clear exposition of the theory was presented in 1963 by Suppes and Zinnes. Suppes had been one of the pioneers of the theory [15]. This formal theory of measurement was then developed and well documented in a group of important books published between 1971 and 1990. Pfanzagl published

in 1968 the first monographic work devoted to the theory of measurement with a model theory approach [16] Krantz, Suppes, Luce and Tversky published between 1971 and 1990 a very detailed and thorough account of the foundations of measurement, in three volumes [17]. Other thorough accounts are those of Narens dealing with abstract theory [18], and of Roberts [19] considering in particular applications in social and management sciences.

This theory is the foundation on which measurement in the psychological and social sciences is based. It provides an epistemological and logical justification for concept formation, scaling and data analysis in those domains, and is generally accepted as such in the literature.

It basically embraces the theory of measurement in the domain of the physical sciences, as developed from Helmholtz to Campbell although it does not fully reflect the practice in those domains and is hence not widely reflected in the relevant literature.

The present author has brought the theory to the attention of the measurement and instrumentation science and technology community. [20, 21, 22, 23, 24, 25, 26, 1]. He, in particular, extended the concept of measurement to the more general representation by symbols, and introduced the concept of strongly and weakly defined measurement. The theory has been discussed and constructively criticised in the community in particular by Mari; whose most recently published contribution has much relevance to the present topic [27].

3. INFORMAL OUTLINE OF MEASUREMENT THEORY

A formal presentation of measurement theory, even in outline, is outside the scope of this presentation. Reference may be made to the full discussions of [17. 18, 19], or to the outlines presented in [1] and [26]. However an informal summary is given here in support of the arguments of this presentation.

Measurement can be defined in the wide sense as a process of empirical, objective assignment of symbols to attributes of objects and events of the real world, in such a way as to represent them, or to describe them.

Description or representation means, that when a symbol, or measure, is assigned by measurement to the property of an object or event, and other symbols are assigned by the same process to other manifestations of the property, then the relations between the symbols or measures, imply and are implied by empirical relations between the corresponding property manifestations.

The term objective process in the definition of measurement means that the symbols assigned to a property manifestation by measurement must, within the limits of uncertainty, be independent of the observer.

An empirical process in the definition of measurement presented above means, first that it must be the result of observation and not, for example, of a thought experiment. Further, the concept of the property measured must be based on empirically determinable relations and not, say, on convention.

The wide definition of measurement is often disputed by those who consider the paradigm of measurement in the physical sciences as normative, or, at least, require measurement to be a numerical representation in which reflects, at least, an order.

For this reason it is convenient to distinguish between strongly and weakly defined measurement.

Strongly defined measurement is defined as a class of widely defined measurement, which follows the paradigm of the physical sciences. In particular it has precisely defined empirical operations, representation by numbers and well-formed theories for broad domains of knowledge.

Measurement that constitutes representation by symbols of properties of entities of the real world, based on an objective empirical process, but which lacks some, or all, of the above distinctive characteristics of strong measurement, may be termed weakly defined.

Measurement owes its power, primarily, to the objectivity of its description, to its basis in empirical observation, and to the compatibility of the representative symbols for further processing.

The power of a measurement scale depends upon the richness of the empirical relational system that it represents. Formulae in terms of representative symbols that do not correspond to empirically determinable relations are not meaningful.

4. SOFT SYSTEMS

The term soft systems is proposed here to describe the main areas of measurement in psychological, social and economic domains. The term is derived from two uses: that of soft systems methodology and that of soft computing.

The term soft systems and the methodology of investigating them is due to Checkland [28, 29]. It describes systems involving human action, perception, feeling, decisions and the like. It can thus not be described by a system of invariant relations.

The term soft computing, which describes computing operating with symbolic relations, and using fuzzy logic, leads to a description of systems as soft if the elements and their relations are best representable by fuzzy logic.[30, 31, 32, 33].

Finally, we may have systems in which the relations between elements are simple and invariant, that is hard, but because of the size and complexity of the system, it may not be practicable to determine empirically relations between system elements.

We may thus generalise and describe as a soft system any system for which there is not an adequately complete, empirically validated theory.

This embraces much of the psychological, social and economic domains.

5. PHILOSOPHICAL CONSIDERATIONS

Measurement in systems involving human actors, is part of the application of the scientific method to their study and is based on the philosophical perspective of positivism, operationalism and their developments. The application of the scientific method in these domains is the dominant approach to their study and can claim considerable achievement. Those who use it, claim that social studies conform to the canons of scientific method and have the same status as natural science.

This approach however encounters philosophical criticism. It is argued that in social systems the observer and analyst are not objective, but operates on the basis of ideologically motivated theories. The objects of observations are humans. They have their beliefs, desires and methods of reasoning and may not be amenable to description by simple models. The understanding of their behaviour must be based on empathy and the experience of life.

There are thus philosophical challenges to the application of measurement to systems involving human actors.

A full discussion of the topic is outside the scope of this presentation. For an introduction to the subject reference may be made to [34, 35, 36].

6. EXPERIMENT AND OBSERVATION

Experimental processes are, in the theory of measurement, the basis of the formation of the concept of a quality, or of a scale of measurement. They rely on the observation of a single quality, or a limited number of related qualities. Such experiments are frequently not possible, or conceivable, in soft systems.

In many systems, such as economies or societies it is not possible to disturb the system for the purposes of an experiment.

It is generally not possible to disintegrate the system in order to perform observations, or experiments, on its individual components.

It is frequently not possible to ensure that repeated observations on a system are made under the same conditions.

Empirical knowledge of soft systems is thus commonly obtained by observation of the whole, functioning system without disturbing the system. This is commonly the case in economics, sociology and in some psychological empirical evidence, [37, 38, 39].

The testing of whole functioning systems presents problems. In general, only a limited set of variables is accessible to observation, other must be estimated from a model of the system. The models are based on theory, and for the purposes of measurement the variables and parameters of the model are required to correspond to quantities of theoretical interest. This basis in theory weakens the empirical nature of the measurements. It is generally difficult to establish model validity. It is also difficult to estimate internal variables and system parameters in systems of even moderate complexity.[40, 41, 42].

7. MODELS

One of the principal applications of measurement is to the building and validation of models of systems. The nature of soft systems means that their models are generally incomplete and have other inadequacies.

Models of hard systems are generally constituted by variables and parameters measurable on a ratio scale and related by mathematical equations. In soft systems models are commonly constituted by variables measurable only scales of lower level, such as nominal or ordinal scales. The relations between them are commonly only expressible in the language of logic, or fuzzy logic. Nevertheless the objectivity and empirical base of measurement gives the models considerable validity. The power of symbolic and soft computing makes the models increasingly tractable.

Models have three principal functions: descriptive, explanatory and predictive.

The descriptive function of models is to represent a state of the real world in symbolic form. Models of soft systems based on measurement have, generally, considerable descriptive power. This is despite the low level of the measurement scale and the possible fuzziness of the relations in the system. Econometric and sociological models are generally descriptive.

The explanatory function of models is to link the description of the system to a more general theory of the relevant domain. In soft systems such theories are not generally available, or at least are not adequately empirically validated. Nevertheless measurements represent a test of relevant theories.

The predictive function of models is to represent the behaviour of systems under conditions in which they have not been observed. Models of soft systems have, generally limited predictive validity.

8. CONCEPT AND SCALE FORMATION

The representational theory of measurement provides a framework for the logical formation of concepts and scales of measurement, based entirely upon objective empirical operations. It leads to solidly founded knowledge from a positivist, operationalist perspective. If the appropriate empirical operations can be established, sound concepts and scales of measurement can be established for any system [1, 17, 18, 19].

However, it has been argued that, while the framework of the representational theory is applicable to the strongly defined measurement in the physical sciences, it does not constitute the perspective on

which measurement in these domains is based [1]. In such domains a mathematical theory of a domain is accepted as a basis, and concepts of quantities and scales are derived from the theory. The theories in hard measurement are of course originally arrived at objectively and empirically by the type of processes that are the basis of the representational theory viewpoint [23].

In fuzzy systems adequate and complete theories are not available. Logically and philosophically the formation of the concepts of measurands and of scales of measurement is based on the kind of approach used in the representational theory of measurement, viewing the problem from a positivist and operationalist perspective. However such methods are frequently not conceived. In general practice, theories for a domain are formulated in natural language and empirical operations are devised to assign numbers to observations of the system, in such a way that the numbers and the relations between them correspond to the theory. The problem with this approach is that the theories may be based on subjective views and have limited empirical validation. The problem will be illustrated by some examples.

Consider firstly the notion of intelligence. It is a very important concept in much educational, social, and political discourse. However, no satisfactory definition of the concept exists. A survey of the different views of the concept is given in [43], which discusses the problem and cites more detailed literature. The definition varies with the theoretical position and often the ideology of the definer. Tests have been devised, which assign numerical scores to the subjects tested. In the sense that they assign numbers to qualities of an observed object in the real world, by an objective empirical operation, they are measurement in the wide sense.[44].

However, they raise significant problems. The first is whether the intelligence scores correspond to the concept of intelligence of the definer. The minimum requirement is that the same test, when replicated, should lead to the same result for an individual, with an acceptable degree of dispersion of results. The next is that the order of scores should correspond to the order in which the theory places the individuals. Given that there may be no other basis of the order of individuals than the test under examination, this is of doubtful validity. The scales of the intelligence tests are ordinal only, though the numbers may give the appearance that they are on a ratio scale. There is no basis of stating that an individual with a score of 120 in an intelligence test is 20% more intelligent than an individual with a score of 100. The most significant question for any concept of intelligence, and any test based on it, is how it is related to any other concepts of a theory of a wider domain, or is a test score merely related to a tendency to score similarly in similar tests. Finally the question arises how different intelligence tests based on different concepts of intelligence are correlated. Essentially a recursive process should

arise. Inadequate theories lead to inadequate measurand concepts and scales. The inadequacies of measurands should lead to a refinement of underlying theory and hence to a refinement of concepts and measurement processes, driving the domain forward in a spiral of improvement.

Discussion of measurement in psychology must mention the measurement of sensations evoked in individuals by physical stimuli. Measurement of this kind was, historically, the basis of much work in the theory and philosophy of measurement. A general survey of such psychophysical measurement is given in [45] and an analysis of the logical and philosophical basis in [46]. Measurement is performed by administering to the observed individual a physical stimulus, measurable by the usual physical means, and recording the subjective judgement of the sensation by the tested individual, such as the equality of response to two stimuli, or placing two stimuli in order of sensation. Problems arise in the consistency of judgement by an individual and the resultant uncertainty. The main questions, however, issue from the building of models of sensory response.

As an example of measurement in economics we may take the measurement of national income. A simple definition and account of its measurement is given in [47]. It is defined as the money value of goods and services becoming available to nation from economic activity. There are three approaches to its measurement: as a sum of the incomes from employment and profits; as a sum of expenditures on consumption and investment; and finally as a sum of the products of the industries of the nation. The definition is well founded on a reasonably complete theory of economics. A number of problems arise. There are problems in the processes of measurement. They depend on the reliability of national statistics. They exclude economic activities not included in national statistics, the so-called black economy, which may be more important in some economies than in others. They also exclude unpaid activity, which provides true economic goods and services, but does not enter a money economy. The unit of measurement is money, and this has inadequacies. Firstly the value of money changes over time. Monetary values must be adjusted for inflation or deflation, if comparisons of national income are to be made over time. This is done by way of price index number, in which a price of different goods is adjusted as a proportion of the total proportion of the good in the total bundle considered. The price index numbers used involve choices made by human decision and are thus a weakening of the objectivity of measurement [48, 49]. The national income is generally calculated in the currency of the economy under consideration. In comparison of different national incomes it is necessary to use exchange rates. The exchange rates may be determined by national policies, or interventions, and may not reflect economic realities such as the purchasing power of the currencies being

compared.[50, 51].

Another example of economic measurement is that of unemployment. Unemployment may be defined as the set of those persons who are in the process of movement between jobs, or are unable to find employment acceptable to them. The concept and its scale of measurement appear simple, but there are underlying problems. One is in the criteria and methods by which national statistics are compiled. They may have criteria of what constitutes unemployment, which change the count of unemployed. Another may be hidden unemployment, such as people who retire from the labour market not wholly voluntarily, because of difficulties of finding a job, or people who are employed, say on a family farm, not wholly economically. [52].

For an example of measurement in sociology, we may take the concept of class. It is one of the basic concepts of sociology. Various theories have a system of classification of persons by social class and of placing social classes in order. Once a framework of analysis is established it is possible to place individuals in classes, which are ordinally arranged, and to this extent this may seem a form of measurement. The lack of much empirical support for underlying theories to a substantial extent invalidates the measurement status of such classifications. However they are much used in such applications as marketing.[53].

Finally we may take the example of the concept of attitude. That may by be defined as a relatively fixed system of beliefs concerning an object and resulting in an evaluation of the object [54]. Scales of attitude may be established by administering to subjects a set of statements with which the tested person is asked to agree or disagree, including a judgement of degree, such as "strongly agree" to "strongly disagree". The statements are based on a theoretical framework, or the judgement of a panel of experts. The resulting data are statistically processed using scaling techniques. [55]. The process of observation is objective and empirical and yields numerical results, it thus has some of the properties of measurement. However, the theoretical basis has generally weak empirical validity and the tests may be based on the subjective judgements of experts, weakening its status as measurement.

9. SELF-AWARE SYSTEMS

Systems that include human actors present, as far as their observation is concerned, a problem of self-awareness. By this is meant that if the system is observed, and the fact of the observation and its results are known, the human actors tend to alter their behaviour. The measurement thus distorts the observation.

10. UTILITY

Utility, and its quantification, is an important philosophical notion [56, 57] and a key concept in decision making. Formal theories have been developed for the construction of scales of utility [19, 58, 59] and have considerable power. The resultant scales of utility have similarity to scales of measurement. However, utility, however strongly defined, is only a description of the subjective judgement of the decision-maker. It is not a measure of any objectively defined characteristic of the object evaluated and may not even express a stable attitude of the decision-maker. It thus does not appear to be measurement.

11. CONCLUSIONS

The modern theory of measurement, based on the model theory of mathematics and logic, and on a positivist and operationalist philosophical perspective provides a sound basis for the understanding of measurement in the wide sense. The dominant paradigm of measurement remains that of measurement in the physical sciences, that is of strongly defined measurement. However, widely defined measurement is extensively applied outside the physical sciences, in systems incorporating humans and those for which no complete hard theory exists. Psychology, economics and sociology study such systems. There are objective empirical processes of assignment of numbers to properties of such systems so as to describe them. They have considerable power. However, there are logical and philosophical problems underlying some of these processes. These problems have been presented in this paper. They are offered for discussion. It is proposed that they should form an agenda for the development of measurement theory.

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