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PROBLEMS OF WIDELY-DEFINED MEASUREMENT

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Abstract: The presentation examines fundamental problems of widely-defined measurement that lie outside the representation concerns of measurement theory, in order to act as a starting point of a research agenda. It shows that measurement is applied in a wide range of diverse domains of domains of knowledge and enquiry for which a wide-sense definition of measurement is necessary. It examines philosophical objections to the application of measurement. It considers problems of measurand concept formation, It examines problems presented by widely-defined measurements requiring further study.

Keywords: measurement theory, widely defined measurement.

1. INTRODUCTION

Measurement, the representation of the attributes of objects and events of the real world by symbols, on the basis of an objective empirical process, is a basic tool of modern human thought. It is the way in which we describe and reason about the world.

Measurement has been developed through the physical sciences, which serve as a paradigm. From this basis its application has been extended to virtually all domains of human knowledge and discourse. However, the concepts and methods of measurement in this wider and more diverse range of disciplines offer significant conceptual problems, compared with measurement in the physical sciences, which is the normative view of much metrological discourse.

These problems will be outlined in the present paper as a starting point of discussion and an agenda for research.

2. HISTORICAL DEVELOPMENT

The present concepts and principles of measurement are the product of a long historical development. An understanding of this process of development is very necessary to help the extension of the application of measurement to new domains, or to areas where measurement is still problematic. The literature of the history of mathematics and science does not, in general, treat the development of measurement explicitly in its general account. Some critical historical philosophical studies of the development of the concepts of measurement have, however also been published. The subject should be an important item on the research agenda.

Only a brief outline of the historical development can be presented here. The references are illustrative rather than exhaustive.[1-8]

Measurement originated in counting at the very dawn of human culture. It developed in antiquity, on an intuitive basis, through applications in crafts, trade, surveying and calendar determination,

The rise of modern science was promoted by the advance of methods of measurement and in turn drove them forward. The nineteenth century saw the development of concepts and methods of measuring intangible physical variables, such as those of thermal and electromagnetic phenomena. There was established for physical phenomena an arsenal of measurement techniques, and a system of scale and units, based on comprehensive theories of the relevant domains of physics. A theory of measurement, based on the concepts of the physical sciences was developed by Helmholtz and Hoelder and presented in detail in the works of Campbell.

The descriptive and explanatory power of the physical sciences made them a model for endeavours to extend the same concepts and methods to psychological and social domains of knowledge. The classical view of measurement was inadequate for the purpose and a wider concept of measurement was developed.

This historical development is well described in the literature. The present author discussed it in outline in [9]. More detailed analytical discussions are presented by Diez [10, 11] and Michell [12].

3. MEASUREMENT THEORY

Modern logical and philosophical understanding of the fundamental concepts of measurement is based on the representational theory. The theory is based on the viewing of the real world as empirical relational systems and measurement as a process of mapping it into symbolic relational systems.

The theory has been extensively presented in the literature.[13-18]. It is therefore not summarised here. An outline has been presented in [19]. The theory has been extensively considered and important contributions have been made by Mari and Rossi [20-23].

The representational theory is adopted as the basis of the arguments is this paper.

4. WIDELY-DEFINED MEASUREMENT

A widely defined concept of measurement is required for the wide and diverse application of measurement, This wide definition of measurement was presented in [9] and further considered in [24].

Measurement is here defined, in the wide sense, as any 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.

The wide definition of measurement is often disputed by those who consider the paradigm of measurement in the physical sciences as normative. 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.

5. APPLICATIONS OF MEASUREMENT

As was discussed above, measurement is extensively applied outside the physical sciences in domains where widely defined concepts of measurement are used. This outline of the range and diversity of applications illustrates the significance of measurement outside the physical science.

Measurement in psychology is the first example to be cited. It is the endeavour to apply measurement in psychology that first challenged the restrictive view of measurement of the physical sciences and led to the present wider concepts. An account of the historical and philosophical aspects of measurement in psychology is given by Michell [12]. Measurement in psychology embraces measurement of such attributes as intelligence, attitude and the like [25, 26]. It also concerns measurement of the subjective perception of physical stimuli such as loudness, colour, odour and the like [27]. There are at present major programmes of research in the field of the measurement of these sensory variables as well as in the measurement of emotions.

Closely related to measurements in psychology are educational measurements. Tests of knowledge, both declarative and procedural, are extensively carried out on individuals in modern societies. Equally tests of aptitude and like personal characteristics are widely used. The tests result in the assignment of numbers, or more general symbols. Aiming at objectivity, they are measurements in the wide sense. They are immensely influential in the present world. The literature of educational measurement is immense and cannot be conveniently summarised in this presentation. A good survey with extensive bibliographic information is presented in [28].

Measurement is applied extensively in sociology. It is concerned with description class, status, segregation, attitudes, poverty, literacy and the like. It requires widely defined concepts of measurement. The theoretical concepts are discussed in [29-31]. A recently published encyclopaedia gives a very wide view of theory and applications of measurement in the social sciences [32].

Related to sociological measurement is its application in history as discussed in [33]. There is also application to political analysis [34].

A major area of application of measurement is economics. The important work brought together by Boumans [35] provides an overview of the theory and philosophy of those applications.

Accounting is concerned with the measurement of economic activity of enterprises. It is the basis of the management of all enterprises. Accountancy is the key measurement activity of modern civilisation. It presents, however, many problems of measurement objectivity and validity [36].

In recent decades there has been a significant application of measurement in linguistics, with the establishment of a discipline of quantitative linguistics. It is concerned with measurement of phonological, lexical, grammatical and other attributes of natural language communication. An important aspect of measurement as applied to natural language is content, or text, analysis, which can be considered the measurement of meaning of text. References [37-39] provide a view of the field.

A significant area of the application of measurement is, what can be described as that of the measurement of utility. Utility can be defined in the widest sense as the degree to which an outcome satisfies the objectives of a decision maker. Measurement of utility was at the very centre of the development of modern measurement theory and the treatise of Roberts [13] provides a very good statement of the issues. The encyclopaedia edited by Sage is an excellent introduction to utility and decision making [40]. Utility type measurements are extensively used in modern management. [41-44]. They are, of course related to accountancy information. Utility-like measurements are also extensively used in clinical management and public health, namely in the measurement of what is termed as health status [45].

A major area of application of measurement has been the use of so called software metrics. This is a measure of attributes of a software system. [46]

Classification based on objective empirical operations constitutes measurement in the wide sense. Such measurement, therefore, embraces objective, empirical taxonomies such as biological systematics [47], However, there are other taxonomies that, while they are based on objective principles and based on empirical information about the classified objects are not measurement, because they are based on a principle of classification that is based on convention rather than empirical observable properties. An example is the international classification of economic activities [48]. Such taxonomies have close similarities to measurement in the wide sense.

The above outline has demonstrated the range and diversity of measurement applications. There is an urgent need for their systematic analysis.

5. PHILOSOPHICAL CONSIDERATIONS

The wide application of measurement is driven by philosophical considerations. It is based on the belief that empirical observation represents the only secure basis of knowledge and that objectivity is possible.

One may view the present theory of measurement as having its roots in the philosophy of logical positivism, (better perhaps described as logical empiricism), that considers the meaning of statements to be the method of their verification [49]. More strongly, much practical approach to measurement is based on operationalism which defines concepts in science by the operations by which we measure them [50].

This approach though highly successful in much scientific inquiry has been significantly challenged. Popper has put forward the view that all scientific knowledge is conjectural [51] and that falsifiability, rather than verifiability, is the test of scientific validity. Kuhn questioned the nature of scientific theories from the point of view of history of science [52].

There are strong views that there is no unity of science and that the human sciences demand different methods from the social sciences. All measurements are theory laden and theories are not objective, but reflect the interests of their formulators.

There are ethical objections of treating human beings as objects of investigations, rather than he intelligent agents they are.

In this outline it is not possible to review the relevant philosophical discussions adequately. A good summary discussion is presented in [28].

Thus, on the one hand the scientific method and the universal application of measurement have a sound record of success on the other hand its basic assumptions are challenged. The study and development of the relevant philosophical problems is an important item for the research agenda of measurement science.

6. MESURAND CONCEPT FORMATION

The establishment of a process and scale of measurement requires the formation of the concept of the measurand. This has been a central problem of the establishment of measurement concepts of such attributes as temperature, or electrical current, which unlike length and weight are not simply perceived by the human senses.

The process of measurand concept formation has been discussed in the literature of logical positivism [53] and considered in [54].

The consideration of widely defined measurement requires further study of the process of measurand concept formation in the light of the history of science, to understand how measurement was developed for intangible physical phenomena. The study of Chang on the measurement of temperature points the way [55].

It may be useful to consider here the measurement of intelligence as an example of the case where it is easier to devise tests than to establish what it is that they are measuring [56]. Another significant similar problem is the measurement of poverty, where substantive conceptual issues arise about what is measured [57, 58].

Finally we may consider the problem of what educational examinations measure [28]. A useful examination must be a valid test of some well-defined attribute of the examinee other than the ability to pass the examination. It is not clear that this attribute is always clearly defined and explained.

7. EXPERIMENT AND OBSERVATION

Measurement theory relies on an ability to perform experiments. The experiments consist of stimulating the system under test and observing the response. In many cases of measurement widely defined, such experiments are not possible, because the system under observation cannot be significantly disturbed.

We may illustrate the problem with the example of economic measurements. Economies cannot, in general be disturbed for the purpose of measuring economic attributes. It is necessary to measure such attributes under normal functioning of the economy. This is done by formulating a model of the system, based on theory, and estimating the measurands on the basis of measurements of the observables, by treating the measurands as parameters or internal variables of the model.

The problem is that it is difficult to test adequately the theoretical model used, so that the measurement process is theory laden. It is also usually necessary to adjust the model to permit the application of appropriate statistical techniques so that the model is not an adequate representation of reality. The subject is discussed in the literature of econometrics [59].

A similar problem occurs in biological and biomedical measurements. Measurements of some attributes can only be performed on intact, functioning, living organisms The possibility of disturbance of such organisms for experimental purposes is limited. Measurements are performed on the basis of theoretical models of the system, by estimation of parameters and internal variables on the basis of measurements of observables with minimal disturbance. [60]

8. REPLICABLE RELATIONS

Measurement is based on the existence of replicable relations involving the measurand. In many systems, however, there are no replicable relations for the measurand.

Humans are autonomous intelligent actors and may behave differently under apparently identical conditions. Human beings are also not passive objects of investigation, but are aware of the tests performed on them. There are thus conceptual and practical difficulties in measurements in systems of which humans are a component. These difficulties have been discussed in the section dealing with philosophical considerations.

Nevertheless, there is empirical evidence in measurement in the psychological and social science of regularities, which when statistically treated, represent an adequate basis for measurement in the wide sense.

The other reason for the absence of replicable relations involving the measurand is the fact that the measurand may be embedded in a complex system. It may not be possible to formulate adequate models of such systems. Hence they behave in a manner that appears to vary under apparently identical conditions. This is common in measurements on living organisms. [60] Further chaos theory has shown that even simple systems may behave chaotically and not show replicable relations between variables. [61]

9. UTILITY

Utility is an important application of measurement. It certainly is very influential concept in the modern management of human affairs. However, it is important to consider its status as measurement.

It is not in any way a measurement of the value of the entity under consideration, but only of the value assigned to it by the formulator of the utility criterion.

It may be considered to be the measurement of the value judgement of the decision maker, as it is objective and based on an observation of the evaluated object. However, the basis of the utility criterion is an arbitrary judgement and is not based on empirical laws. Social psychology provides ample evidence that practical decision making does not necessarily follow a rational model. While its usefulness as a tool is undoubted it probably does not constitute true measurement.

Quality and organisational performance measures represent essentially utility measurements.

10. RELIABILITY, VALIDITY AND GENERALIZABILITY

There is a need to discuss briefly the concepts of reliability, validity and generalizability in connection with measurement as widely defined. These terms are commonly used in measurement in the social and psychological sciences.

Reliability is the extent to which a measurement procedure yields the same result on repeated trials. This is well discussed in the literature [62]. Reliability may be difficult to achieve in practice, but it does not present conceptual difficulties.

Validity is the degree to which a procedure of symbol assignment accurately reflects or assesses the specific concept that it purports to measure. A method can be reliable, consistently measuring the same thing, but not valid. This is a significant problem in many wide sense applications of measurement.

The term generalizability is used to describe extent to which research findings and conclusions from a study conducted on a sample population can be applied to the population at large.[63]

In this connection one may contrast wide sense measurement with strict sense measurement in the physical sciences in which there are well established theories for broad domains of knowledge and the above problems do not arise to a significant extent.

11. THEORIES

The aim of the scientific method is, in general, to establish a well-defined theory for a domain of knowledge providing descriptive, explanatory and predictive power. Such theories are not developed in the psychological and social sciences and, as been discussed above, the possibility of such theories is widely denied.

It is necessary to recognise that the value of the concept of a measurand depends upon the number of relations with other variables into which it enters. Thus for example the discussion of the definition of a measure of intelligence depends is concerned with the absence of adequate theories.[64]

Nevertheless there are wide applications of economic models that are essentially such theories. While they are limited in predictive power they are deemed to have practical use.[65]

Further the techniques of systems dynamics are extensively applied to model social and like systems. [66, 67]

Even in physical measurements there are examples of physical attributes for which adequate theories are not available. Hardness is one of them. It is defined as resistance of solid matter to local deformation, Scratch hardness, penetration hardness and rebound hardness are recognized, Measurement tests are available, but there is no adequate theory to relate them.[68]

12. VERIFIABILITY

One of the principal pragmatic strengths of measurement is that measurement statements are verifiable. A measurement statement consists of a symbol assigned to the measurand, together with the specification of the scale of measurement employed. Given such a statement the measurement can be replicated by any other observer.

In the strongly-defined measurement in the physical sciences a measurement result consists of a number and the specification of the unit.

In physical and chemical measurements the system of units is defined by international agreement and there is an international organization, together with a network of national organizations to maintain it [69]. Valid measurements should always be traceable to the international standards. They are thus verifiable.

In measurements in the wide sense such systems of measurement scales do not, in general exits. It is therefore important to analyse carefully the scales and units employed in widely defined measurements.

Consider for example measurements in economics and accountancy. They are expressed in units of a currency. However, the value of a unit of a currency changes over time. In such measurements it is significant to specify precisely how the change of value of the currency is taken into account. [70, 71]

Similar problems arise in economic and accountancy measurements involving international comparisons and multiple currencies. The exchange rates between currencies vary and measurements must specify exactly how the exchange rates are taken into account. There may not necessarily be a satisfactory objective basis for the exchange rate used.[72]

Another case that may be examined is that of educational standards. Of the large number of examples that may be given, consider the standards of educational attainment set out in the OECD Programme for International Student Assessment. The desired competences of the student are set out in a set of statements in natural language. They are translated into a set of tests. The results of the tests are statistically treated. for the cohort of students. This is typical for an educational attainment test. The question arises with such tests as to how the test relates to the stated objectives and what is the uncertainty involved.[73]

11. CONCLUSIONS

Measurement is applied in a wide range of human inquiry and discourse. Measurement in the physical sciences is the dominant paradigm. However, in significant areas of application of measurement that paradigm is inapplicable and a wide-sense definition of measurement is necessary.

Measurement science should address the whole range of applications of measurement. It should endeavour to provide a universal framework of concepts and principles to address all applications of measurement.

Measurement theory, on representational principles provides a basis for a universally applicable measurement science.

There are, however, a range of problems of widely defined measurement that require addressing. They constitute a research agenda. Among them are the need to engage in the history and philosophy of science and the methodology of the sciences in which measurement is applied.

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