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ADAPTING CLASSICAL TAXONOMY FOR MEASURING SYSTEMS

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Abstract: Classical Taxonomy is the reservoir of methods and techniques used in the life sciences to bring scientific order to the grouping of living things. Although the orders or problems of Taxonomy were not clearly described until the late 19th century the methods used can be traced back to the time of Plato and Aristotle. This paper commences by introducing the main ideas associated with classical taxonomy. A brief overview of the classification of the sciences is given. Subsequently, classification principles are used to show that Instrumentation and Measurement Technology is a sub-science of what may be called Machine Science. Taxonomy is then adapted and developed for general application in machine systems but more specifically in measuring systems. It is clearly shown that machines, and hence measuring systems should be grouped on the basis of "what they do", or function, "why they do", or purpose, "when they do", or signal form, "way they do", or energy domain, "where they do", or location, "how they do", or structure and "while they do", or sensors.

Keywords: Taxonomy, Classification Science, Instrumentation and Measurement Technology

1 INTRODUCTION

Classical taxonomy, which is concerned with grouping and ordering in the life sciences, seeks to extract the unifying relations among different things. A comprehensive classification of the sciences as quoted by [1] is given by Flint [2]. In this era of information machines, information is now regarded as an important resource. The view that it is just as vital to apply taxonomy or classification science, as it is in the life sciences, is highly regarded by Finkelstein [3]. The botanist De Candolle is given credit for the first use of the term taxonomy in the ordering of plants [4].

This paper is concerned with adapting classical taxonomy for measuring systems, which are widely regarded as one of the four kinds of information machine [3]. To assist with this task, an overview of the four orders, also called problems, of taxonomy are described. These are applied to provide a context for a classification of the sciences, which is well documented by Thomson [1]. From this standpoint the existence of machine science is pointed out. Subsequently, it is shown that Instrumentation and Measurement is a derivative, or sub-science, of this more general machine science. A comprehensive definition of measurement systems is used to highlight the classification of these systems based upon adapting the four problems of taxonomy to measuring systems.

2 CLASSICAL TAXONOMY - PUTTING THINGS IN SCIENTIFIC ORDER

2.1 The Four orders or Problems of Taxonomy

Since the time of Plato and Aristotle many attempts have been made to organise the sciences into hierarchical groupings. This logical ordering in terms of symbols and/or patterns with their predictive nature, which is associated with taxonomy or classification, has been an important aid in the human ability to observe, perceive and create machines. The last one hundred years have been an exceptionally inventive period for mankind. This has made the scientific classification [3] of non-living entities just as important as the taxonomy of living entities.

An account of the history of the classification of the sciences is given by Flint [2], who describes the work of Durand (De Gros) [5] as a new science as it is the first attempt to study the constitution of Taxinomy (its original spelling) itself. A clear distinction is thus drawn between the ordered organisation of the theory of taxonomy and its principal applications in a specific field. A science is a systematically organised body of knowledge. Hence classification, if it is truly to be referred to as a science, must possess a corporate body of knowledge with an organised structure. Table 1 [6] gives a summary of the problems or orders of taxonomy.

The significant contribution which Durand [5] made to the science of taxonomy was the proposal that there are four principle orders or problems of classification. In the *First Order* described as *Generality* or *Resemblance*, is embodied what many other theorists of classification have called the “likeness" of one thing with another thing. The thing concept is fundamental to the whole of categorical ordering not just in bio-science but also in earth science. Hence, this concept also has central importance in instrumentation. Likeness, of course, is that relation between several concrete things which unites them. Thus, the application of classification by zoologists and botanists in the discrimination between genera and species clearly shows how the problem of generality and resemblance is approached.

Table 1. A summary of the problems or orders of classification

TAXONOMY the **SCIENCE OF CLASSIFICATION** (Putting *THINGS* in a *SCIENTIFIC ORDER*)		
Problem/Order	**Definition and Aspects**	**Comment**
Generality or Resemblance	1. Concerned with the *likeness* of *separate things* 2. *Likeness* is that *relation* between *things* which *unites* them 3. The *thing concept* is fundamental to all *Categorical Ordering* (*i.e.* Taxonomy)	Also called the *Metaphysical Order* because terms are concerned with theoretical or *fictitious* things
Composition or Collectivity	1. Concerned with the *relationship* of a *part* of a *thing* to the *whole thing*	All other orders are concerned with the actual things to be classified
Hierarchy	1. Concerned with the *relations* between *heads* or *central members* of *groups* of *things* which are 2. Related to the *order* of *composition/collectivity* especially in the places occupied in each *order* relative to other things of the *same order*	
Genealogy or Evolution	1. Concerned with the *kinship* of *one thing* with some *other thing* 2. Hinges upon *notions* of *kinship* by *relationships* of (a) ascent, (b) descent and (c) collaterality	

In taxonomy there is an important tendency to group things on the basis of there *Composition* or *Collectivity*. Durand distinguished this as the *Second Order* of taxonomy. While this order is concerned with the relationship of the part to the whole and vice versa the *Third Order* of taxonomy, called *Hierarchy*, takes account of the relation of rank between the heads or central members of groups of things. In their turn these are related in the order of composition but address each concrete thing in the assessment of the place it occupies in each order relative to the other constituents of the same order. Perhaps the most important *Fourth Order* in Durand's theory of taxonomy, especially in bioscience, is that known as *Genealogy* or *Evolution*. This order hinges upon the notions of kinship through the relations involved in the characteristics of ascent, descent and collaterality. As with the orders of Composition and Hierarchy, Genealogy and Evolution are also concerned with the actual objects or events which are to be classified. Although there have been developments of this theoretical constitution of taxonomy, it is still fair to say that the basis laid by Durand has not been largely altered. As this theory of taxonomy was formulated in the context of bioscience it requires modification before being applied to instrumentation.

Another possible interpretation of classification [7] emphasises the objectives of classification as discrimination , standards of description and systematisation. At the same time its functions are to organise information communication and retrieval, to acquire new information and to highlight unifying factors without diminishing differences. It can be seen that there is a well developed theory of classification for use in the life sciences.

2.2 Classification of the Sciences

Although classification is largely a matter of convenience it is of significant practical importance as it provides a clear perspective of the divisions of knowledge. It also depends upon our own particular scientific convictions as pointed out in the quotation [8]

"We are apt to think of classification as a sort of 'natural history stage' through which all sciences pass in their youth before they grow into something handsomer, more mathematical and explanatory. .... classification is a highly theory-laden activity. .... What one thinks one is classifying may make a big difference to the system of classificatory categories one uses."

Notwithstanding the apparent influence of subjective criteria it is still possible to give some deep insight into the division of science into its various constituents. In the first instance it is possible to distinguish between those abstract sciences, which are really about methodology, and the other concrete sciences, which deal with the facts of experience. Thus the fundamental abstract science is Mathematics with Metaphysics having a somewhat supreme importance. At this level Logic and Statistics must also be included. The primary concrete sciences are concerned with either the purely physical domain or the purely animate domain. Two examples, which are concerned with the Physics of real things on the one hand and the Biology of real things on the other, are highlighted in the dendrograph, or tree diagram, Figure 1 [6]. The other constituents at this level are chemistry in the physical domain and sociology and psychology in the animate domain. Progressing through the levels from the fundamental sciences it becomes clear that there are many and varied derivative sciences.

Tree diagrams, which are important for showing the hierarchical classification of different things may be used to obtain an insight into classification. The tree of Figure 1 also illustrates the ideas of classical taxonomy by showing (1) the generality and resemblance of the physical and life sciences, (2) the principles of division or ordering by hierarchy or level using the bioscience names for the various levels and (3) the composition or collectivity of each kingdom. Another important graphical aid which can be used to illustrate classification is a key diagram [9], which will not be considered further here.

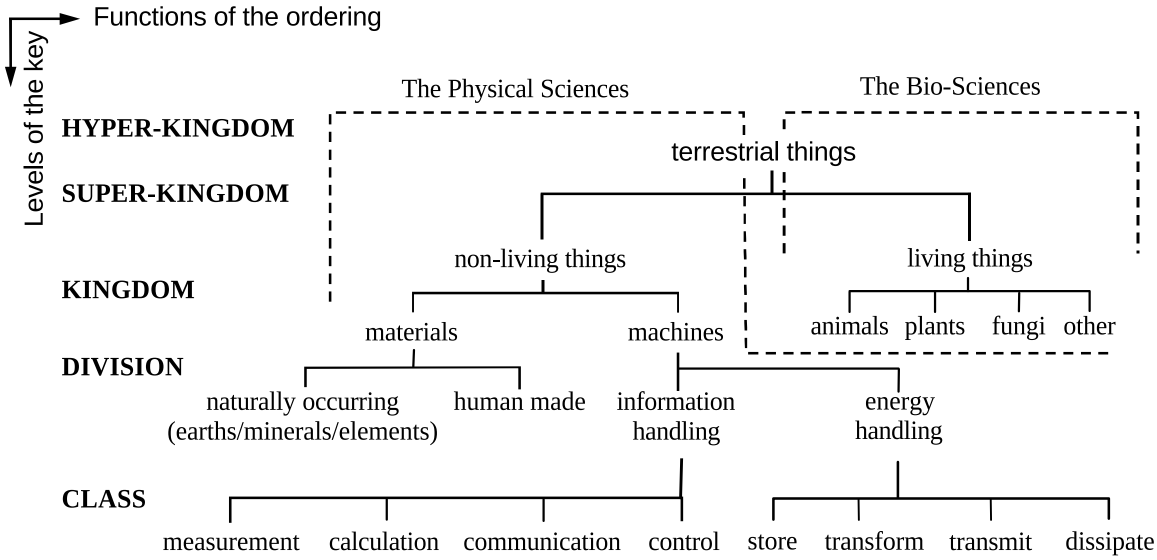

Figure 1. A dendrograph or tree diagram Illustrating the classification of the sciences and the context of Machine Science and Materials Science

3 CLASSIFICATION FOR MEASUREMENT SYSTEMS

3.1 Importance of Classification in Measurement

Some may regard the topic of classification as not really of much relevance to measurement. The authors hold the opposite point of view. Although it is probably true to say that the actual classification which is adopted does not matter, it should be emphasised that some form of classification is essential since it helps to promote clear thinking by arranging things in an incisive order. In this way a kind of philosopher's benchmark is given to our scientific considerations so that inter-relations are suggested on the route to a consistent and complete view. Another justification for developing a classification of measurement is that classification raises the deepest and largest scientific questions. Its boundaries express some conclusions about the autonomous nature of measurement and its relationship to calculation, communication and control. There are many conflicts in the classification of measurement as distinct from other areas. It has already been pointed out [10] that a legitimate scheme of classification of measurement must ensure that all of its divisions are always determined by one common principle. Classification in measurement will thus be erroneous if it is based upon its ends as this merely leads to a catalogue of different kinds of measuring instruments. Rather, measurement should always be arranged according to its basic nature, its inherent characteristics, and not upon anything lying outside itself. Hence measurement classification is about its co-ordination.

3.2 Primary Factors in Measurement Classification

An alternative summary of the theoretical constitution of taxonomy [11], especially applicable to measurement, points out that instrument classification has six principal features. These amount to its objectives and functions, its materials and activities together with the methods of discrimination and hierarchical ordering.

A good starting point in determining the primary factors in a classification of measurement is a comprehensive definition. Such a definition is given in Figure 2. This definition is based upon the functions performed by measurement systems, the structures, which allow them to perform the function, and the energy form from which the information is acquired. It should be regarded as the study of the methods and techniques of extending the human abilities to handle information using information machines. Since information is predominantly carried by signals, measurement is concerned with the acquisition, handling, analysis and synthesis of signals in measuring instruments.

	MEASUREMENT SYSTEMS		
perform	**FUNCTIONS**	*"what they do"*	refine, extend and supplement the human senses for capturing **INFORMATION**
acquiring	**INFORMATION**	*"why they do"*	the entity characterising **ENERGY** flow the raw material to gain **KNOWLEDGE**
carried by	**SIGNALS**	*"when they do"*	the physical variable to be handled by generation and processing operations
extracting	**ENERGY**	*"way they do"*	the physical domain of the captured **INFORMATION** classified by **COMETMAN**
from	**PROCESSES**	*"where they do"*	the principal source of the **INFORMATION**
possess	**STRUCTURE**	*"how they do"*	the physical means of **FUNCTIONING**
using	**SENSORS**	*"while they do"*	the principal element of their **STRUCTURE**

Figure 2. A comprehensive definition of data measurement

Hence, an instrument is defined as a system which extends the human abilities to perform information handling operations. Using this definition as the key it van be seen that measurement ordering should discriminate between the various functions performed by instruments using a diversity of structures. In other words functional and structural reticulation or breaking down is essential in any taxonomy of instrumentation. This statement is similar to a previous declaration by Stein [12] who asserted that Measurement combines "INFORMATION transfer about" and "ENERGY transfer from" a "process" using "SYSTEMS}" which are made up of "components or TRANSDUCERS" forming a "STRUCTURE or network". The systemic nature of instruments implies a holistic approach in their classification. Thus, the ordering of information machines, depends upon the holistic relations among specific instrument structures performing diverse functions within different energy domains for the acquisition, capture, communication or distribution of information in a variety of signal forms.

It is easily seen that the first order of classical taxonomy is of immediate interest in measurement. Another important factor is the application of the Order of Hierarchy. When combined with the Second Order of Collectivity and the fourth Order of Genealogy (suitably adapted for inanimate instrumentation) a holistic view using dendrographs or tree diagrams is realised. This has been pointed out already in Section 2.2. These ideas have resulted in introducing the concept of a machine kingdom which has information handlers and energy handlers as its two divisions [6, 9]. Information handlers (*i.e.* information machines) extend the human abilities to handle information. Energy handlers extend the human ability to do useful work.

3.3 Classification of Energy

Questions about energy and information are of cardinal importance in measurement. There is a number of different ways of classifying energy [6]. Physical science uses the approach which represents the largest number of possibilities by the smallest number of physical models or considerations. Physical considerations allow the discrimination of energy in the most fundamental groups as **g**ravitation, **a**tomic, **m**agnetic and **e**lectric. As a memory aid the acronym **GAME** may be proposed. These groups lie at the top of the hierarchical grouping of energy domains. In measurement they are not very informative. The GAME energy domains can also be written as the expanded measurement sub-domains of mechanical, chemical, thermal, magnetic, electrical and radiation. Each of these sub-domains is associated with at least one characterising physical phenomenon. These six were used by Kurt S. Lion [13] in his work on classification in instrument systems. Middelhoek and co-workers [14] also used them in their description of the *"sensor effect cube"*. The classification of energy using the GAME acronym, and its expanded groups, may be regarded as the most precise, since the grouping results from the application of the formal principles of taxonomy. It provides an entirely consistent physical view.

Another possibility, preferred by the authors, recalls the organisation of energy classification given by Peter K. Stein [12] in his presentation of *"the transducer space"*. Stein has often given verbal credit to the work of Kurt S. Lion as the inspiration for his own work in measurement systems. Stein perceived that the sensor measurement grouping of energy forms, although very close to the GAME grouping are not very easily remembered. His resolution to assist the learning process resulted in his scheme for classifying energy using the memory aiding acronym COMETMAN. Whereas the previous classification is based upon a more rigid linking of the energy by similarity, COMETMAN is specifically formulated as a memory aid. The acronym comes from classifying by **C**hemical (*i.e.* molecular), **O**ptical (*i.e.* radiation), **M**echanical (*i.e.* including gravitation and mass), **E**lectrical (*i.e.* both electric circuit forms and electromagnetic radiation), **T**hermal, **M**agnetic (*i.e.* including electrical and atomic forms), **A**coustic (*i.e.* correctly speaking within the mechanical group) and **N**uclear (*i.e*. strictly speaking within the atomic group) energy forms. Once again, the important point to emphasise here is not whether one form of classification is more correct than another. Rather it is from the convenience of that which is most easily remembered. Convenience is an important factor in classification.

3.4 Modelling Input-Output Relations in Measurement Systems

Measurement systems do not exist in isolation. The human-machine super-system environment, within which they are embedded, regards them as sub-systems. Hence, the bilateral impacts of this linking must be considered. Adapting the boundary view of human-machine super-systems [6] allows this. A complete spatial representation for the boundary inputs and outputs of a measurement system requires a multidimensional space with a total of three groups of inputs and three groups of outputs. The original work of Kurt S. Lion [13] was developed by Peter K. Stein [12} and later by Middelhoek and Noorlag [14]. Subsequently the sensor effect tetrahedron was developed by McGhee and others [15]. Each of the axes in this tetrahedron uses the *COMETMAN* energy form classification.

In the tetrahedron model of energy and information flow in a measurement system the inputs represented by the measurand energy form, the contamination energy form and the support energy form make up the input triangle as the base of a tetrahedron. In principle any measurand input supported by a specific energy form and contaminated by another specific energy form may be linked to a particular output energy or information form. Since many possibilities are allowed by the tetrahedron it has an important predictive property. It will be remembered that this is an important benefit which taxonomy brings to the generalised classification.

4 CONCLUSIONS

The paper has introduced classical taxonomy by describing its four main problems or orders. Subsequently a classification of the sciences provided the foundation for classification in measurement as a derivative science of what may be called machine science. It has been shown that a comprehensive definition of measurement provides the key to an organised classification of measurement. It has been shown that the essential aspects of measurement classification consider them on the basis of the functions they perform, the structures they posses, the energy forms in which they function and the manner in which they acquire, process, transmit and transform information.

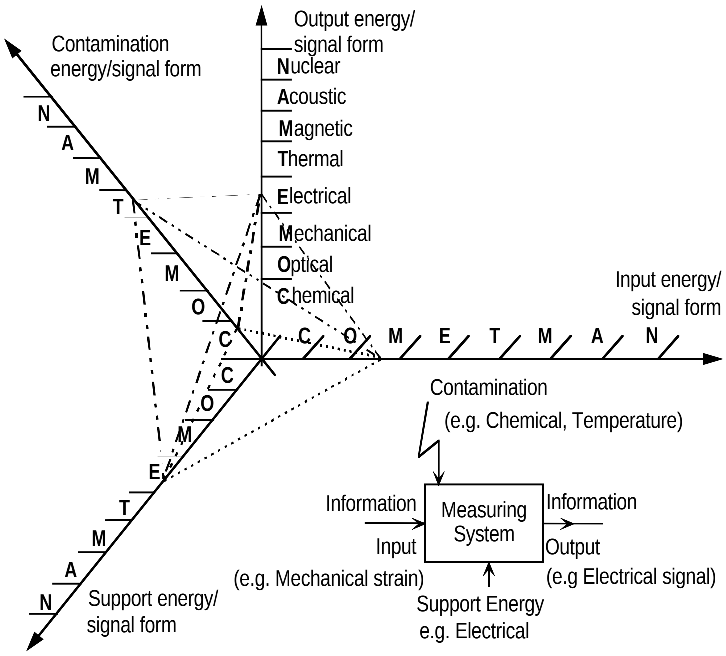

Figure 3. The Information and Energy Tetrahedron for a modulating sensor

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