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The signal relation diagram – A Metrological Tool?

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A R T I C L E I N F O

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A B S T R A C T

Relations between signals are important issues in modelling and simulation practice, especially in the field of Metrology. As a formal and descriptive "language", the so-called signal relation diagram (SRD) represents relations between quantity models graphically. It visualises relational structures and generally makes relations more transparent. Signal relation diagrams base on logical and mathematical phrasing. Only a few basic elements are necessary. A straightforward synthesis unites these elements in typical arrangements in a holistic and consistent way. They serve as basic elements and structures in varied fields of Metrology (chemical analysis, environmental investigation, medical imaging, particle observation, flow measurement, surveying), for modelling, description, simulation, error and uncertainty analysis, reconstruction, filtering, verification, and so on. The key task is information, insight, understanding and knowledge.

1. Introduction

There are several graphic-based tools with different aims, which support the description and understanding of scientific and technological phenomena. One of them is the *Signal Relation Diagram* (SRD). Its task is twofold.

Firstly, it is a medium which methodically and holistically describes *nets of interrelations* of continuous and/or discrete *time and space signals* according to the *cause and effect principle* (CEP). The standard question therefore is always: How does a signal influence another signal? How does the second signal depend on the first one? Are there mutual features between signals? Especially in Metrology these questions must be answered thoroughly and with minimal uncertainty. One way to do this, is the graphical representation of relations by meaningful symbols in a signal relation diagram, which is easily interpretable and therefore serves as a most welcome base of qualitative and quantitative discussions in all fields of Science and Technology, not only in Metrology.

Secondly, it is a catalyst for an immediate creation of computer instructions, which allow simulation and analysis of quantities and processes on the one hand and model based activities by *observers* and *controllers* on the other hand.

This dual aspect is crucial, since comprehension and implementation are closely linked. In this respect, the signal relation diagram is one of several formal "languages", appreciated in countless fields of application.

More to the point: We recognise *signals* as *models of quantities* in and around a *real-world process*, revealing and retaining its *properties* and *behaviour*. Therefore, a signal relation diagram is a qualitative and quantitative *graphical map* or *model*. Establishing such a model means that we systematically define and describe signal relations in and around a process by analytical and/or empirical means. Although such a model is well defined, it always remains more or less rudimentary and incomplete, by necessity or on purpose. The model is injective; it represents a one-to-one correspondence. Therefore, the logical and mathematical language of the model with *its* terms and definitions is transformable into one of the graphical languages with *their* terms, symbols and definitions and vice versa (Cause and Effect Principle, Conservation Concept, Mason Gain Rule, Block Algebra, Fussy Sets). The usual mathematical potentialities as well as constraints of model development apply throughout. On the other hand, seemingly intransparent or incomprehensible mathematical structures are clarified and become understandable by graphical representations. Even certain analogies and symmetries of other fields may emerge, which enable additional structural insight.

A signal relation diagram is not a tool of its own, there is no special theory! It just fosters the competence to express oneself. Only a few guidelines of implementation have to be observed. But, here too, habits and terms from the past dominate the scene and discourage improvement, and these are not always rational.

Summing up, the model, on which such a diagram is based, describes *relations* between *signals* only: *neither more, nor less*! Consequently, signal relation diagrams have nothing in common with those block diagrams, which represent real-world items

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(object, entity, artefact, apparatus, instrument, particle, device, article, product, processor, subject, person, individual, body, matter, asset, constituent, element, field, organisation, target, reality, cosmos), although this keeps being suggested. Of course, stated relations are always *ascribed* to interesting processes or subprocesses.

It has to be mentioned that quantities in Nature Sciences and Technologies like mass, energy, power, momentum, impulse and especially their flow in a dynamic process, are considered as ordinary quantities too, modelled by corresponding signals. They often appear in the context of so-called back-loading effects, represented by *backward directing signal paths*. The term "back" is then meant in a figurative sense. Accordingly, this is also true of course for Human und Social Sciences.

Furthermore, signals may not just be models of *real-world quantities* (hard quantities), but also models of *abstract definition quantities* (soft quantities). Examples: efficiency value, performance index, observability, comfort factor, signal to noise ratio, effort, error, residuum, uncertainty, variance, reliability, probability density function and so on. They are well-defined, *measured* and *observed* by *indirect* means and thus visualisable in signal relation diagrams too.

Sometimes it may be helpful to consider a signal as *information on a real-world carrier* and to interpret signal relations as *information relations* or even as *information fusion*.

The signal relation diagram is also known under several other terms (synonyms): relationship diagram, signal graph, signal coupling diagram, signal diagram, signal flow diagram, flow chart, function diagram, context diagram, signal path diagram, integration diagram, block diagram, data graph and so on.

But, since models just describe interrelations between signals, the term *signal relation diagram* (SRD) seems most appropriate. It is not very common and no established terminological standard supports it.

On the other hand, the frequently used term signal "flow" diagram is misleading indeed: *Nothing flows*. This in contrast to a *wiring diagram* in Electronics, to a *piping diagram* in Hydraulics, to a *free body diagram* in Mechanics, to a *binding diagram* in Molecular Modelling, to a *workflow diagram* in Business Process Modelling (BPM), and so on. Even if a signal models a flow, the *influence* or *impact* of the quantity flow on the quantity fluid level or gas pressure is meant, and not the flow itself. Or: If we consider a temperature within an object, it influences something else, but does not flow.

We know of useful model types of other graphical representations concerning signal relations. There is for example the *Bond Graph* [1]: It concentrates on the omnipresent, intrinsic *conjugate pair* of physical quantities, which represents the generalised *effort quantity* and the generalised *flow quantity*. This accounts for the important, but often neglected role of mass, energy and impulse as carrier quantities of information, also frequently neglected in Metrology.

Another representation is the popular Cause and Effect Diagram (CED) (fishbone diagram, Ishikawa diagram). However, it merely offers limited qualitative, and no quantitative possibilities [2]. It may be useful for general documents and for meetings for a first discussion of scientific and practical tasks. But it is definitely not a scientific tool. It is limited in several respects: It can only be used for one output signal (MISO) but not for multivariable systems (MIMO), which measurement systems normally tend to be. There is no way to realise *quantitative* considerations or descriptions. There is no possibility to show quantitatively the interconnections between different influences. It cannot show any feedback relations at all. Last but not least: The presence of *dynamic phenomena* cannot be shown or described. All these deficiencies are solved systematically in signal relation diagrams, on a simple mathematical basis in plus.

There are more, highly specialised signal relation diagrams, like the Mohr Circle, where stress quantities in measurements induced by force quantities in material are handled and visualised graphically in the important three-dimensional case.

Prerequisite of any type of signal relation diagram is a systematic and consistent model, which is developed on the basis of *logical and mathematical structures and parameters*. Even if some values of the parameters are still unknown, an intense discussion about a process is already possible. Structures of relations are prime issues, once we start modelling. This makes signal relation diagrams valuable in fields, where numerical values of quantities and parameters are not or not yet available, as in Metrology of Humanities and Sociology for example. Of course, eventually we will need in-depth process knowledge for quantitative information. Consequently, signal relation diagrams are known to grow according to gradual development of curiosity, demand and insight.

Although there are only *four basic elements* concerning the signal relation diagram and although the systematic rules of relating signals are quite simple, design, handling and analysis are often demanding due to the complexity of the real processes involved. In any case, an application of signal relation diagrams has to be practised and optimised.

2. Signals and systems – Models of quantities and processes

At the beginning of each model development, we postulate and acknowledge the difference between a *process* to be modelled, and the *system* as a model of this process. Process and system belong to two different domains. There is the *real-world process domain* and the *abstract system domain*, a dual pair. The mentally designed system describes the process, but of course, is not identical with it. Properties and behaviour, which are identified by the model analytically and/or empirically by measurement and observation, are ascribed to the process of interest, but, of course, do not have any influence on the process whatsoever. So, the *description and identification of the process* is a purely *mental procedure*. Its informational content is imbedded in the system.

The same is true for the models of quantities. There are the *real-world quantities* to be modelled. We call these models *signals* in the abstract signal domain. We ascribe the identified properties of the signals to real-world quantities.

3. The four elements of the signal relation diagram

A signal relation diagram uses only four graphical tools, visualised by four metaphoric icons (symbols)

- relation line: identifying signals
- connection circle: connecting signals
- branch point: branching signals
- relation block: relating signals

We have to mention one major restriction concerning these four elements: They are only partly suitable for *systems with distributed parameters*, described by *partial differential equations*, since they can only be drawn in the single dimension of the paper or screen surface. Unfortunately, other popular tools, for example those with colour assisted three-dimensional capabilities (Finite Element Method (FEM), Mohr Circle), are only partly able to fill the breach.

Yet the four graphic elements suffice for *linear and nonlinear, multivariate dynamic systems* [6]. They combine ubiquitously and thus can visualise models in a broad field of applications as in Metrology. In particular, they foster the modelling of multivariate situations with *signal sets*, *signal vectors* and *signal ensembles*. The

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