Process and System – A Dual Definition, Revisited with Consequences in Metrology

Karl H. Ruhm
Institute of Machine Tools and Manufacturing (IWF); Swiss Federal Institute of Technology (ETH), Zurich, Switzerland
ruhm@ethz.ch

Abstract. Let’s assert that metrology life could be easier scientifically as well as technologically, if we, intentionally, would make an explicit distinction between two outstanding domains, namely the given, really existent domain of processes and the just virtually existent domain of systems, the latter of which is designed and used by the human mind. The abstract domain of models, by which we map the manifold reality of processes, is itself part of the domain of systems. Models support comprehension and communication, although they are normally extreme simplifications of properties and behaviour of a concrete reality. So, systems and signals represent processes and quantities, which are described by means of Signal and System Theory as well as by Stochastics and Statistics.

The following presentation of this new, demanding and somehow irritating definition of the terms process and system as a dual pair is unusual indeed, but it opens the door widely to a better and more consistent discussion and understanding of manifold scientific tools in many areas. Metrology [4] is one of the important fields of concern due to many reasons: One group of the soft and hard links between the domain of processes and the domain of systems is realised by concepts of measurement science on the one hand and by instrumental tools of measurement technology on the other hand.

1. Introduction
We say spontaneously that procedures and processing, where real things happen dynamically, occur in a dynamic process. Many of these natural and man-made processes are important to us, some are even vitally important. Therefore, we take an interest in them; we want to get to know them via measurement and identification. We examine them, describe them, and finally get them under control in an open or closed loop setting.

On the other hand we often use the term system; but when do we do so? Do we smell a certain abstraction? Or, are the terms process and system just synonyms? When we systematically check scientific documents we don't get a proper answer. However, a concise use of these terms should be guaranteed before we talk about complex models of reality for example. This is not just mandatory for natural sciences and technology, but for all other fields too, where questions have to be answered in a more than colloquial manner.

The following terminology mainly concerns the two terms process and system, but consequently also the terms model, quantity and signal later on. Thus, starting in an extremely general and
qualitative manner, applicable almost anywhere, we finally reach a quantitative level with structures, used to appropriately describe items in the physical domain in a deterministic and probabilistic way.

Important: It is inevitable that commonly accepted terms of everyday and technical use get a more refined and precise, but also a partly restricted and partly extended meaning. This may disturb us. But if we wanted to avoid this, we would have to talk science only by means of purely logical and mathematical formalisms. However, although the proposed terminology is logical, consistent and useful indeed, it is not common practice.

The following sections provide a novel concept, discussed from seemingly different standpoints, such as experimentation, modeling, identification, measurement, simulation, estimation, optimization, decision and control. But these fields are only part of a large overall concept, commonly called the domain of information.

2. The Term System

We metrologists, who are involved in measurement science, use the term system anytime and anywhere. The question is, if we use it too much. Is every configuration of items a system? Searching definitions of the term system is really amazing. If we exaggerate, we could claim that they differ altogether and in many respects. This fills whole books and leaves us disoriented and inclined to abandon the topic. It is not worthwhile to treat the spectrum of meanings here.

But we may briefly point out some causes of these discrepancies. The everyday language has an immense influence on the arbitrary handling and on the lack of precision, since everybody keeps using this term. Everybody refers to any of the countless historic definitions [5, 6], without using explanatory and reflective statements of his own. And even scientists have tiny and insignificant aspects in mind while trying to discuss the global meaning of the term system, although the definition has to be universally valid and should be simple. Most definitions are given in a bottom-up manner instead of a top-down strategy, the latter of which can only be our choice. To bear System Theory in mind one should envision some sort of logical and mathematical basis as a formal unambiguous language [7]. But logical and deductive reasoning to come to a formal concept is not so easy. That means that not everybody may participate in defining, not even every scientist.

However, from my point of view the major flaw lies somewhere else. Even in really serious and mathematical definitions we always find an impermissible mixture of two incompatible domains, namely the real, physical domain, composing the cosmos and the virtual, non-physical domain composed by products of the human mind. Items in both domains can never ever have the same identity and cannot be treated by the same tools. System Theory can only deal with abstract items. Therefore, systems belong to the abstract domain and only to it. Clearly, this disturbs our daily habits. Models, which describe items of the physical domain, are sub-sets of systems. But not all systems have something to do with the physical domain, like for instance the system of the primes, the health system or the system of the Roman Law.

But what then are assemblies of items in the physical domain and how are they to be distinguished properly from the assembly of items in the virtual domain? Here I launch the new / old term process, or for especially sensitive people the term dynamic process, in order to unmistakably pose variability in time and space.

In order to endorse this message and to envisage the consequences, the following sections will start with a concept by K. R. Popper, whose Three Worlds serve as a starting point. In a sequel it will be shown that the duality of process and system leads to still another pair of terms, namely quantity and signal, which is of immense importance in metrology. Additionally, we discuss the special type of links between the two defined domains, which consequently are always of dual character too: hard and soft links.

3. Three Domains

It is worthwhile looking shortly at a famous structuring concept, delivered by the Philosopher of Science, Karl R. Popper (1902 – 1994) [1; 2]. Doing so, we are able to pose the terms process and
system more easily and more meaningfully. Here, his concept is presented intentionally from the point of view of System Thinking and System Theory. Nevertheless, the concept itself is universal.

3.1. Domain of Processes

We start with the cosmos (universe, world) and we state: The cosmos is the totality of matter, energy, forces and fields in space-time in which we live. It itself is not affected by our physical relations and has no initial and boundary quantities with the exception of those defining the Big Bang. The cosmos is the only process. Plants, objects, devices, things, items, units, parts, entities, artefacts, products, substances, components, elements, particles, machines, instruments, cells, organisms, bodies, creatures, beings and so on, constitute sub-processes of this process. The process and all sub-processes are infinitely manifold without exception. Each sub-process, which is just called process for convenience further on, is infinitely cross-linked to other sub-processes (inter-dependence of everything). And we may distinguish between natural and man-made processes, but this is not relevant here. This rigorous and global procedure makes the whole endeavour of defining the terms of intent easier.

We should understand the term process in a rather general and comprehensive way, applicable to all fields of the physical, technological, economic, cultural and social reality. And we should always think of processes as dynamic processes and very often as dynamic processes in steady state conditions (equilibrium).

All measurement, control and experimentation procedures are done on and with processes by means of special designed equipment, which, of course, are always processes too.

In this context it makes sense and is helpful to use the term domain of processes for the spatio-temporal reality of the physical domain. K. Popper calls it «World One». Here, world and domain are synonyms.

3.2. Domain of Human Consciousness

It is reasonable to claim a special status for the human being. Of course it is a natural sub-process too, based on matter, energy, forces and fields. Thus it consequently belongs to «World One». But we have to give evidence concerning its consciousness and mind, which are not part of the category of matter, energy, forces and fields at all.

But consciousness needs «World One» as a physical carrier of mental processing and procedures. Consciousness is able to observe, measure, reflect, analyse, differentiate, describe, design and handle processes («World One») as well as intellectual products («World Three»). In other words, the domain of consciousness, which K. Popper calls «World Two», is the source of man-made intellectual products.

We do not have to refer to this delicate and rather unknown domain in our context further on.

3.3. Domain of Intellectual Products

The domain of processes has a counterpart in the third domain, the domain of intellectual products (mental construct, thought result), developed individually and jointly primarily by human consciousness. K. Popper assigns these intellectual products to «World Three». However, though there are intellectual products that come from automatic processes like computers, instrumentation and similar devices, the concepts always base on products of the human mind.

These brain products assume all sorts of realisations, arranged in two significant groups: On one hand there are ideas, visions, thoughts, imagination, prejudices, concepts etc. in our very mind. On the other hand there are drawings, bills, pictures, flowcharts, notes, articles, novels, instructions, theories and theorems in textbooks, sets of equations, computer programs, acoustical and optical verbal documentation, and so on, outside of our mind. Of course, nothing is said thereby about objectivity or subjectivity nor about quality or usefulness of these products.

It is important to realize that both groups of products need physical carriers from the domain of processes (technology e.g.) for the intellectual products (science e.g.) to appear in reality and to take
on informative and communicative tasks. We assume that under ideal circumstances information provided by these products is independent from its respective carrier. If this should not be the case, we must consider and incorporate the non-ideal carrier concerning its properties and behavior in any discussion and investigation, to define subsequent errors and uncertainties.

### 3.3.1. Sub-Domain «System»

For intellectual products, which we create and handle qualitatively and quantitatively by system thinking, system theory, system design, system engineering and system administration, we use the term system. So it is not applicable for items we defined to be processes, since they are not members of the domain of intellectual products. This definition of the term system originates solely from the standpoint of System Theory. This approach may seem to be quite reasonable, but it is not commonly accepted.

So there is a domain of systems within the domain of mind products («World Three»). Note too the explanatory relations between the abstract terms system, systematic, systemic, systemise, and so on.

System thinking produces systematic and structured concepts and relations of any kind. They may have no obvious counterparts in the process domain, like languages or mathematics for example.

### 3.3.2. Sub-Domain «Model»

We always name processes, associate symbols and meaning to them. This happens in the domain of intellectual products. We talk and reason about them qualitatively and attribute to them known, or only suspected, or even still undiscovered and unknown properties and behaviour. The results of these simple mental activities are models indeed.

On the other hand, models must describe processes by logical or mathematical structures and notations, as soon as we want to work quantitatively and to argue at least to some extent objectively. There always remains the opportunity to arbitrarily construct different model versions of one single process. All will offer specific advantages and disadvantages regarding their information content and information quality.

Models may contain a finite number of sub-models (sub-systems), combined by accepted connection rules. It is worthwhile to mention that the separation of sub-models according to special demands may not be possible in the real domain of processes.

From the perspective of the formal rules of System Theory, we wonder, according to which principles, concepts and strategies we should observe, measure, analyse, treat, test and describe those processes optimally in a desired sense. Quantitative models describe defined parts of the domain of processes by uniformly structured tools under the constraints of given ubiquitous demands. They facilitate understanding, planning, design, implementation, maintenance, experimentation, simulation, optimisation, control, reconstruction and prediction.

Of course, the term model also comprises the physical models, which are part of the domain of processes. Here we treat abstract models of the domain of systems only.
3.3.3. Performance of Process Models

Quantitative models look for properties of a process first. As properties we do not consider only basic physical properties from first principles but also derived properties like efficiency, stability, robustness to disturbances, observability and controllability, capacity in terms of power and load, and so on.

Subsequently quantitative models cover the behaviour (trajectory behaviour, procedure, progression, evolution, transient, transfer, event, action, reaction, phenomenon, etc.) of a process according to those properties and under certain assumptions and constraints as well as under chosen initial and boundary conditions.

The phenomena concerning a process to be described are endlessly complex. If we would like to describe a process or sub-process completely, we should indeed make an infinite effort. However, this is not possible in practice and it is not opportune either. We restrict the horizon necessarily and deliberately by just focusing our attention on items, which concern and interest us ad hoc.

Furthermore, the general and personal state of knowledge, skill and expertise restrict significance, completeness and performance too. Accordingly, the explanatory power of such a description is limited. But we cannot, and we do not want to achieve completeness. And we know that we can approach truth, whatever this term may mean, only to a certain extent.

We assume that the cause and effect principle relates properties and behaviour temporally and locally. We neglect the ongoing discussions of Quantum Mechanics about the delicate terms space time and locality.

Systems in the special function as models of processes describe how these processes behave the way they do. But they do not explain why they behave as they do. Yet some people claim that they do so.

The investigation and declaration of usefulness, performance and quality of a system (model) is always an important endeavour of its own. We, who create the model according to accepted demands, are responsible, far more than the tools we eventually use.

Which type of system (model) we finally apply, depends on relevant demands, on personal preferences and expertise as well as on allowable effort. Modelling always requires a-priori knowledge of the way the model will be used.

Quantitatively, the performance of a model has to be judged by an error analysis provided by Signal and System Theory; model errors have different causes.

3.4. Interfaces between the Three Domains

Clearly, there are interconnections (functional, hard) and interrelations (relational, soft), called interfaces I, between all three domains, always in both directions. For example in technology, actuators and sensors manage these links between «World One» and «World Three» directly.
Counter clockwise action in the process domain represents back-loading effects: information transfer on the soft side is always connected with energy flow on the hard side. Back-loading effects give raise to back-loading errors.

These interfaces always have dual character, physical and abstract, according to the domains they connect. Therefore, they require a well-defined input-output structure too.

Of course there still remain the primary interfaces across the domain of consciousness of the human mind («World Two») with their specific sensing and actuating structures (relational) and components (functional).

4. Information In, Around and About the Process

In the process domain we use two specific types of description for process properties and behaviour.

**System of Matter and Energy**

One concept describes, of what parts (items, elements, components, constituents, organs, cells, molecules, particles) a process consists and how these are ordered in space and time in a structured pattern. Equally important is the identification of the distribution of energy in a certain state. From these constellations we infer on material and energetic properties and on the behaviour of a process in a specific application. This is a system building strategy, used successfully in chemistry, biology, medicine, material science etc.

**System of Relations**

The other model building strategy, characterised by Signal and System Theory, focuses less on such a matter set-up of a process. On the one hand we look at certain structural and parametric properties on a logical and mathematical level and on the other hand we study the spatial and temporal behaviour of important quantities under defined demands and conditions, both inside the process and in connection with its surroundings. This strategy is pursued here. Typical areas are physics, all technical sciences, economics, sociology, psychology, politics, pedagogy, culture etc.

The goal is to combine properties of the process with models of definable and maybe acquirable quantities within and at the surface of the process. The result will be a model of the behaviour of the process under defined circumstances. This is summarized in a signal effect diagram for easy interpretation.

Quantitatively we describe the properties of the process by structures of equations and by their parameters $p(t)$. The overall-behaviour links internal quantities $x(t)$ and output quantities $y(t)$ as responses to diverse excitations (stimulation, impact, action, effect, drive, question, disturbance) of the input quantities $u(t)$.

The so-called eigen-behavior describes the behavior of the process completely independently from external influence quantities. It is a special case of the overall-behavior. The analysis of stability of a system requires this concept for example. This corresponds exactly to the strategy for the solution of linear ordinary differential equations (ODE): We get two solutions, the homogenous solution for the eigen-behavior without any influence of external (disturbing) quantities and additionally the particular solution for the behavior due to the influence of input quantities. The sum of both solutions describes the overall-behavior.
4.1. What is a Quantity, What is a Signal?

Until now we have only rarely mentioned quantities in the processes. Indeed, they are part of the real domain of processes, too. Is there a counterpart in the domain of systems again? Of course; we have the signals in the process model. So we meet the pair of terms quantity and signal, which inseparably belongs to the pair of terms process and system like Siamese twins.

In notational associations we assign relations, dependencies and impacts (interrelation, correlation, interaction, influence, stimulus, correspondence, property, effect, event) within and around a process to the process domain. We call the entire result of such a description model of quantity or signal. Signals are part of the system domain. They too offer only limited information about the infinite manifold quantities of processes.

Well defined internationally accepted declarations (Système International d'Unités (SI)) define the surroundings of physical quantities. Unfortunately, this is not the case in many scientific fields, so that we call those quantities soft quantities.

A remarkable side glance: The model (description) of a real process is primarily defined by the models (description) of its quantities and their interrelations.

4.2. Process, System and Quantity, Signal

The general relations between process and system or quantities and signals respectively are manifold. The most important ones are modelling, measurement, identification in one direction and estimation, forecasting, control in the other direction.

4.3. Sources of Information – Metrology

If we define measurement as the extraction of information from processes [4], then there are two sources of information: the process itself on the one hand and the model of the process on the other hand, which is a system in the abstract domain. That means we get information from the process domain as well as from the system domain. Sometimes these two strategies are called direct measurement and indirect measurement. Anyway, it is important to state, where measurement information is coming from.

The classical strategy of direct measurement uses the measurement process, itself a physical process and attached somehow to the physical process of interest. The mapping of the process quantities on resulting quantities, done by this measurement process, follows abstract concepts and strategies of metrology.

The model-based strategy of indirect measurement has to rely on a suitable model (system) of the physical process of interest. On principle, all quantities, not available at the process for some reason, can be measured within the model. This model-based concept of measurement is realised for example in observer and Kalman-filter, the best known devises of this type. By the way, this is self-evident practice with any model-based control.
Obviously, the results of indirect measurement rely extremely on the quality of the model of the process. Model errors and uncertainties go directly into measurement errors and uncertainties. Besides this, a certain amount of direct information about the process is necessary for synchronization reasons of course. A sound mixture of direct and indirect measurement results is the goal normally.

5. Process Description by External and Internal Signals

In simple cases System Theory just deals with the temporal and local relations between input and output signals (input-output-description; external description). We also speak of the transfer response behaviour of a system.

Depending on the task and on the mathematical tools available, there are numerous methods to illuminate the internal behaviour of a system. The possibilities vary between completely missing information about the interior of the system (idea of the Black Box) and a complete knowledge (idea of the White Box).

We systematically characterize the diversity of possible systems in a typology, which is mirrored in the diversity of their internal structures and parameters. A typology again is a member of the domain of systems.

It is understandable that we try to describe a process by simple system structures whenever possible. The simplest system is therefore mono-variable, deterministic, time-invariant, linear, non-dynamic and stable with concentrated parameters. Linear multivariable dynamic systems can still be treated conveniently. If we go further on, a description tends to get rather laborious.

Again, these items concern only systems, which describe processes, not the processes themselves.

6. Process Description by Characteristic Values and Functions of Signals

We now refine the relations between process quantities and system signals insofar that we do not just allow the mapping of measurable real quantities, but also virtual characteristic quantities (characteristic values and characteristic functions). Virtual means that there is no correspondence of these quantities in the real domain. Virtual quantities are man-defined quantities, for example distributions, mean values, correlations, convolutions, spectra, intervals, bounds, errors, uncertainties, efficiencies and so on.

This does not change the question about system properties and their transfer (propagation) behaviour at all: How do characteristic values and characteristic functions of the input signals affect characteristic values and characteristic functions of the output signals? We complete the signal effect diagram accordingly:

These characteristic values and functions of signals evolve due to operations on data, which have been generated and acquired at the process of interest (acquisition, measurement, observation, estimation, presumption, hypothesis). Sometimes we speak of signal transforms (Fourier-, Laplace-, Hilbert-Transform, etc.).
7. Task Definitions Concerning a System
If we consider the input / output transfer behavior of a system, there are three and only three task definitions. We indicate this best in a table.

| given: | searched: | scope of functions |
|--------|-----------|-------------------|
| 1. input signals \( u \) | output signals \( y \) | conversion, forward mapping, forward analysis, experimenting, control, transformation, simulation, measurement, convolution, forecast |
| 2. output signals \( y \) | input signals \( u \) | backward inference, backward analysis, inversion, reconstruction, deconvolution, diagnosis, estimation |
| 3. input signals \( u \) | output signals \( y \) | forward and backward identification, model building, calibration, test |

8. Conclusion
This paper presents a new, restricting definition of the term system, together with a new definition of the term process. It was necessary to keep these terms well apart, since they concern different domains with different structures indeed, a real domain and an abstract domain. But in certain fields, especially in metrology, we find a strong duality between the two domains, where models of processes, which are systems, are counterparts of the respective real processes. There is a duality, never an identity. The concept of model-based measurement needs a clearly defined terminology, which is not the case up to now. Today both terms of interest are not treated systematically and consistently. These new definitions influence concepts of information acquisition in general too.

References
[1] Popper, K. R. Objective Knowledge
Clarendon Press, Oxford (1972, 1. edition)
[2] Popper, K. R. Three Worlds
The Tanner Lecture, Michigan (1978) >>
[3] Ruhm, K. H. Process and System – A Survey
ETH, Zurich (2009) >>
[4] Ruhm, K. H. What is Metrology?
IMEKO – Bulletin 37 (2009) 1, pages 18 – 24 >>
[5] Müller, R. Geschichte des Systemdenkens und des Systembegriffs (in German)
(History of System Thinking and of the Systems Terminology) >>
[6] Müller, R. Definitionen von "System" (1572 - 2002)
(in German; Definitions of "System"; many citations in English) >>
[7] Backlund, A. The Definition of System
Kybernetes, 29 (2000) 4, pages 444 – 451
[8] von Bertalanffy, L. General Systems Theory – Foundations, Development, Applications
Braziller, New York (1968)