AN INTUITIVE APPROACH TO MODELLING AND SIMULATION

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Abstract:

System modelling is a principal descriptive tool in all sciences. Such a model or set of models is a useful tool for prediction, control, explanation and diverse investigation in both science and enterprise. The observer (or system viewer) is the person defining the system under consideration and its properties and must therefore not be neglected. However in this process of definition there is a tendency to forget the role of the observer and his/her interaction with the system observed.

Models are often the bases of inter-disciplinary effort and in this situation inter-subjective communication is of great importance. However great difficulties are often encountered because the participants are trained and educated in very different disciplines.

This paper introduces a novel intuitive approach to the modelling process that underlines the role of the observer of the object or a system under consideration that could be helpful in such inter-disciplinary projects. The main idea is to pave the way for better understanding between the natural and social sciences by making the methodology of computer simulation available to the social sciences – and thus offering them the possibility to,in a sense, become experimental.

The proposed framework supports a good visual modelling analogy, which is easily grasped and could therefore assist in interdisciplinary understanding when making use of models. The intuitive approach proposed can also be used to ease/simplify the actual modelling process.

The relation between systems modelling and computer simulation is elucidated and the role of mathematical models in the social sciences is also discussed.

1. Introduction.

Models are used for description, prediction and control. These are the domains of discourse within areas such as; systems analysis, systems design, control theory, operations analysis, simulation, management information systems, information systems, decision support systems et cetera. The role played by the *system observer* – or system viewer (SW) - is very important for all scientific inquiry, and in particular when modelling the role is often misunderstood – or simply not included . The requirements specification is a crucial part of scientific modelling that specifies of the system under consideration and very often future predictions or system maintenance are severely jeopardized by neglecting the observer function. Very often the necessary *process of abstraction* is a source of severe misunderstandings and results in inter-disciplinary conflicts. This paper will concentrate on abstractions done to reduce the complexity of the world when modelling and thence the clarifications necessary to make use of a model as a tool of interdisciplinary communications. Focusing on such a task, we dwell on the concepts of the system and the model to underline their basic functionality, as the means to support this act of abstraction.

2. Why use an intuitive approach to modelling?

System's modelling is an activity that requires a clear conceptual framework within which to operate. There are many proposals for formal frameworks for use in systems theory [Kli69, Pad74, Mes75, Wym77, Zei84]. The formal approaches are the basis on which modelling environments are designed and operated. Such environments mostly provide user-oriented facilities that do not require in-depth familiarity with the theory-based concepts. When it, on the other hand, comes to inter-disciplinary cooperation in science, this lack of in-depth familiarity often even turns out to be an obstacle to clear-cut communications. This could, for instance, be the situation when the discipline of computer simulation encounters some discipline of the social sciences. In this situation we find a lack of understanding due to fundamentally different worldviews and the absence of an appropriate conceptual framework to be used. Discussing diverse modelling efforts can be very frustrating. This paper introduces a more intuitive approach to the modelling process, than the formal modelling frameworks normally in use. A crucial idea is to elevate the observer-centred part of modelling and to discuss in-depth the role of the SW and his/her influence on the modelling process. The proposed approach is easily grasped and could therefore better serve as a tool of interdisciplinary communications and for a better in-depth understanding of the modelling process, all at the cost of formal stringency of course.

Many different approaches have been advocated for use during systems modelling. This fact is reflected in the large number of books and articles that have appeared over the past decade and surveys that can be found covering both “soft” [Ros89] and “hard” [Mur90] modelling methodologies. New arguments have often emerged at the methodological level, while the underlying philosophy has remained somewhat controversial, but the advent of the computer and the awakening interest in *structural complexity* [Nic89] has brought new approaches to the surface. The branch of philosophy of science that deals with modelling the “things of the world” is called *ontology* (or metaphysics) and we turn to an ontological view to seek a formal base for the notation of a model [Bun77]. In doing so, however, we try to avoid presenting theories for interdisciplinary use in forms too difficult to grasp. The conceptual frameworks of physics and general systems theory (GST) lay out the foundations of modelling and are very mathematical in form. The theories of classical philosophy are most often presented in natural language (verbal models), but when we come to philosophy of science - a collection of intermingled interdisciplinary frameworks – we also meet with frameworks very mathematical in form, especially when they discuss scientific ontology, see Bunge () for instance.

The qualities mentioned here often make them too abstract and hard to grasp to serve as a useful tool when it comes to interdisciplinary communication. In contrast the framework proposed in this paper, supports an *appealing visual modelling analogy* that could enhance the understanding of the models used and the modelling process as such. This approach also reveals and highlights the often tacit abstractions performed when modelling and underlines the need for a set of clear-cut specifications in that respect.

The proposed framework also stresses the close relationships between *scientific activity, systems modelling and simulation methodology* also making clear that there is a fundamental difference in their respective development phases: A scientific model is (tacitly) part of a culture of science - a system's model is a dedicated model worked out from a captured part, object or system in the world of this culture - most simulation models are worked out directly from a model of the system or some requirement specifications – without direct contact with the very phenomenon modelled.

That is, the system's model has a very important role during the development phase and information interchange processes and the assumptions must be made clear to all participants independent of their discipline. The participants must be trained and educated to participate in a paradigm that has its formation from the basic principles underlying the system and its model and parallel to the strictly logical frameworks mentioned. There is thus a need for another conceptual framework to support the process of information exchange. The IFIP WG 8.1 Task Group FRISCO (FTG) [IFI91] proposes such a framework for use in the organizational area. This framework can be used partly to support a more intuitive interpretation of the modelling process and their ideas will now be elaborated upon.

Another reason for supplementing the formal frameworks of physics and GST theory and turning to a more intuitive notion is the fact that a purely mathematical approach is not well suited to organizational, economical and societal manipulations . This is so, partly because of the complexity encountered in these disciplines and partly because of the apparent lack of quantitative measures. This situation also enhances the need for computer-assisted computational methods when dealing with organization systems and models in the social sciences. The simulation methodology is, in that respect, very important as it often offers the only possibility to make use of an experimental technique in these disciplines. The above mentioned framework of the FTG could be useful as a working idea to developea framework within the simulation area, as an aid to clarify and standardize the terminology used within this area . [Kje91].

3. Systems modelling and real worldviews.

The importance of models and model building as an integral part of scientific inquiry has often been stated [Ros45]:

> `-- No substantial part of the universe is so simple that it can be grasped and controlled without abstraction. Abstraction consists of replacing a part of the universe by a model of similar but simpler structure. Models ... are thus a central necessity of scientific procedure.`

The notation "a part of the universe" or equivalently "a part of the real world" is usually called **a *system.*** The system concept has been extensively discussed during the 20th century but is still very confused - a situation that severely hampers the understanding of the modelling process. Sometimes our cultural habits and/or educational efforts have furnished us with an understanding of how to interpret the ideas involved when discussing such systems. This goes for phenomena such as atoms, particles, computer systems et cetera. However in general such assumptions cannot be taken for granted regarding the system of inquiry unless we run the risk of jeopardizing the model's quality to serve as a tool for knowledge and communication. Except in cases where we can rely on a high degree of consensus concerning the system under investigation, we have no other way to understand the model’s structure and the acts of abstraction undertaken, other than to ask the observer of the system, or the scientists in charge of dealing with the system on a daily basis.

By explicitly representing knowledge about the *components of the system and their relationships*, the SW specifies his/her particular abstraction of the system. This specification can be made verbally, but is very often done by means of a conceptual framework (formalism) firmly established in his/her scientific discipline. For this reason, it is argued; *models are to be seen as a system specification developed in a specific conceptual formalism. The choice of formalism strongly influences the explanatoryg power of the model and also its possibility to serve as a tool of prediction.* That is to say, the correct interpretation of a model assumes familiarity with the modelling facilities and the conceptual frameworks used during the modelling process.

4. The system concept and the perception process.

A cause for confusion when modelling is that we often think about "systems" as something that can be “objectively” decided, once and for all, for example by the specification of its parts and relationships. This is not so. The system and its properties, as seen by the observer, are applied to the system domain, the environment domain, the elements of these domains and the relationships between these elements. Together they represent *a system view,* which as a first approximation, is *strictly personal to the observer*. For instance, concentrating on a row of trucks, we could see a useful transportation system. On the other hand, an environmental activist probably sees a polluting system and a civil engineer could regard the row of trucks as a load test of a bridge. A representative from the labour union has another view and so has the physician. There are many possible system views - and this is a simple example. In the natural sciences a row of different views are possible – the physicist’s, the chemist’s, the biologist’s et cetera but when we come to organizations - or other phenomena in the social sciences - the number of possible views is enormous - sometimes as many as there are observers of the part of the real world that is about to be captured.

FTG defines a system as follows:

> `-- involves a distinction between system domain and system and the notation that systemic properties are only subjective and associated with the system domain by the viewer, when it as a whole is seen as a system. Awareness of this principle is the most important prerequisite to avoid misunderstanding about system.`

The most important feature of this interpretation is the stress put on the fact that behind the system view is always a person - the SW - who interprets the world in a certain way. This feature will become clearer if we separate the “system domain of the real world” from the “image of perceived system", - a system image in the mind of the SW.

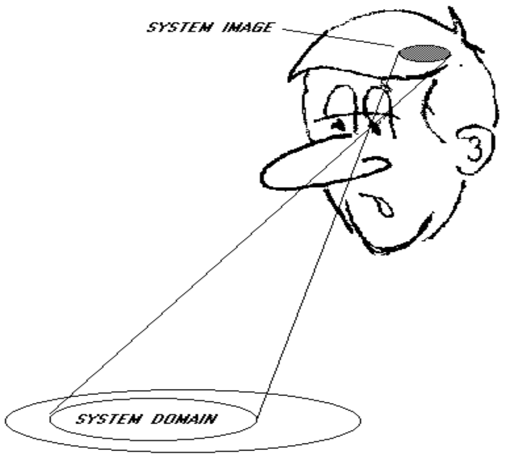

Figure 4.1

The system domain is the source of mapping and we can thus perceive a "system" as in Figure 4.2. I shall call this mapping a projection, to support the intuitive visual analogy of this process.

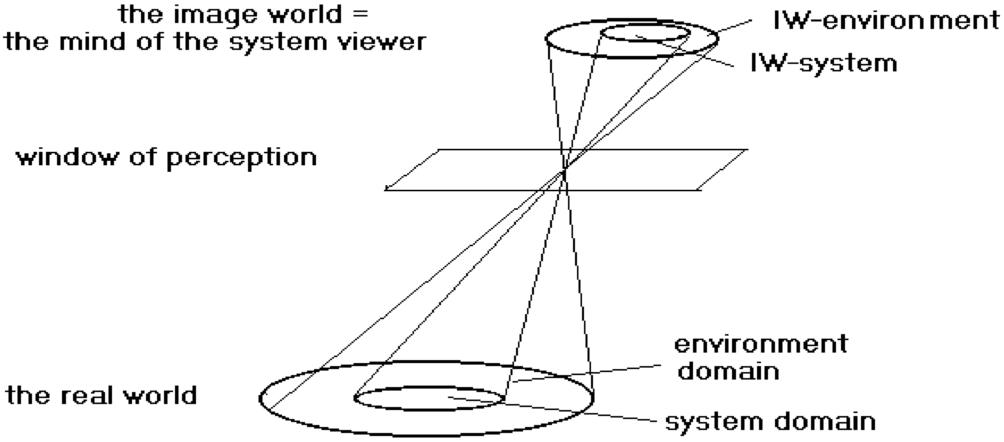

Figure 4.2

We will make a clear distinction between the real world (RW) and another *imaginary world* (IW). The IW-system is the captured part of the RW-world as seen by the SW, that is, the *mental representation* in his/her mind. The area of interest of the RW is projected via *a window of perception* into a *system image* ∈ IW. *The IW is the private conceptual world of the SW and as such is heavily affected by the purposes of the* SW. This “window of perception” must, of course, be interpreted in its most general way, i.e., perceptions by means of the senses and their extension in the form of possible physical measuring devices. We will continue to keep this separation between RW and IW in concession to Cartesian dualism and elaborate the system and model concepts accordingly.

Here it is important to note that we in this situation have no means of identifying the *conceived properties of the IW-system* – which is what we normally call *system properties.* These properties are defined by the SW's "system view" and in the case where this view is not established in a common agreement such properties cannot be found in the RW - in spite of the traditional naïve interpretations pretending so. As a matter of fact it is not even possible to find such a "system" in the RW unless we have a common agreement regarding what counts as the "system" and what counts as the "environment". We conclude that generally the two IW-images specifying the system view and the system properties are *abstract subjective phenomena* best described as the "inner images" or mental representations which have arisen in the mind of the SW.

Another complication is that the system properties the SW associates with the RW-domain (his/her personal view), i.e., the relationships between the IW-system and IW-environment in his/her mind, *can only be presented (laid out) in the form of a model to the surrounding world.*

So we might rightfully ask: "Where then is the "real system?" As seen, there is an RW-system domain, an IW-system and associated abstract properties of the IW-system in the mind of the SW, but no "RW-system" in its traditional sense. The actual system is born, as a fragmentary picture of the captured RW-domain, **as an abstract mental image in the mind of the SW**. **What do we then mean by the "real system?" To be useful, this IW-system must also be given an RW-interpretation as a back-projection of the IW-system onto the RW. This projection of the IW-system image onto the RW is the equivalent to the RW-system in its traditional sense.** The *subjective projection "formula"*, which gives the personal IW-system view an RW-interpretation, is clearly of crucial interest - but in fact the SW might not even be aware of the existence of such a subjective projection "formula" . When this "formula" is known, on the other hand, it is wise to openly state the rules as to how to accomplish such an RW-interpretation. In this way these rules become the common property of all the involved observers.

But such rules are never explicated – why? Not even the presumed exactness of the natural sciences has called upon such unambiguous specifications. We watch light-emission spectra coming from "atoms" envisioned as a solar system – and photons behaving like tiny particles. We say we do not really believe that they are "real" – that they only behave as if they were. What do we really believe – that they are just useful illusions? In that case what is the justification for the Newtonian way of thinking about "matter" that we now use? Do such illusions also bounce during collisions?

To scrutinize this interpretation and the idea of subjective projection suggested it is assumed that the SW considers the system in the "real world" to be *a closed system.* Such IW-systems are easily created in the mind of the SW (and frequently are) – and such IW-systems can be given plausible RW-interpretations. However a *closed system* can in principle never be observed – which in a sense proves that the system under consideration is a "true" imaginary IW-system (abstraction) and the corresponding "real system" accordingly *a projective illusion* – in this case a plain fantasy. Maybe the "image" of a closed system is not the only imagination we construct – maybe all our images are projections or projective illusions? How could we ever know – maybe the things of the "real world" are mainly the products of our imagination. ***This seems to be a crucial question that science hitherto, with few exceptions, has refused to address in a satisfactory way.***

5. The idea of the real world system.

For the moment we leave the question open as to whether the RW is just imaginary and concentrate on how we traditionally envision this world. It is well-known that any RW-domain is normally seen as a collection of interrelated parts, called *elements*. These elements are the phenomena conceived in the UoD that we think belong to the RW and when these elements are projected onto the IW-system, we call them *entities*. We thus continue to use the term *entity* as it is normally used in the simulation community. It is worth noticing that when we focus solely on the entities , i.e., disregarding their possible interaction, the *system* disappears so to speak, since such a set of entities devoid of interaction is called an *aggregation*. This is the essence of the *system approach of investigation*.

Knowing that a *system is* an *abstraction in the mind of a SW* we are now able to develop Figure 4.2 further, considering the system domain as the real world seen through *a window of perception*. To emphasize the presence of a specific purpose for the SW to apply this particular system view, we insert a *purpose filter*, in this projection path. (Figure 4.3)

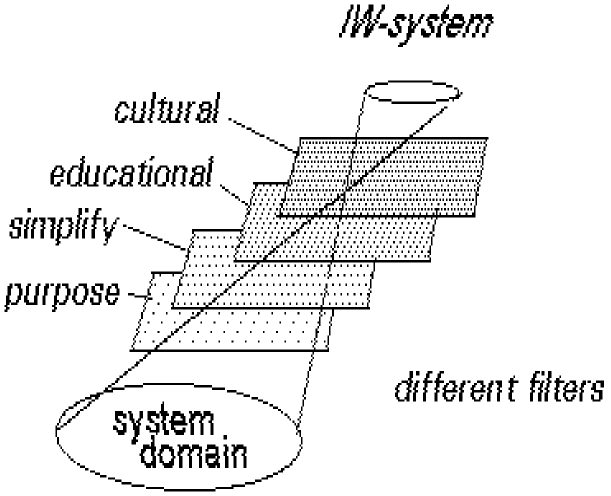

Figure 4.3

Different purposes of modelling will create different IW-images in the SW's mind, i.e., a different purpose filter will generate different IW-systems in the mind of the SW. We can also find further filters in this projection path since processes of *simplifying* and *idealizing* are undertaken to reduce the complexity - in fact, all these filters are prerequisites to obtaining a manageable IW-system and are inserted in the observation path by the SW sometimes unconsciously. Most modelling efforts would be in vain without this act of data reduction. We group purpose, simplification and idealization filters together into one *observation frame of the SW*. Figure 4.4.

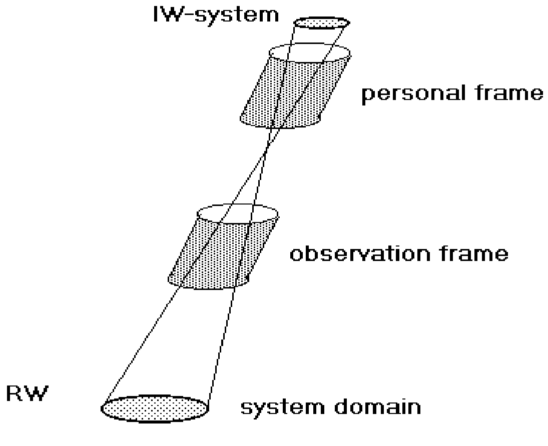

Figure 4.4

Metaphysics is the faculty that studies the most general categories in which we think. These enter our thinking in various ways, including the way we perceive the world, the way language is organized and the choice of concepts to describe the world. When modelling the important categories are *space-time, substance, quality, quantity and relation.* The categories are in a way a frame of reference within which we can put forward questions about the real world. The category of substance is concerned with *material stuff* and *individual things* and as such is concerned in the classification and identification of things. These categories are indispensable helping us to bring order to the perceived complexity of the real world; Nevertheless, this act of classification and identification can differ considerably from one scientific discipline to another. Educated and trained in a specific scientific discipline, we are thus trained to observe the real world in the light of a certain conceptual framework. As a consequence we can find another filter here that influences the projection path, after the passage of the window of perception. We call this filter *an educational* filter and the idea of scientific paradigm originally coined by Kuhn [Kuh62] pinpoints the existence of such a filter.

We do not even have to be trained in any specific scientific framework to perceive the world in a certain way. In Kuhn’s own words: *”one suspect that something like a paradigm is prerequisite to perception itself. What a man sees depends both upon what he looks at and also upon what his previous visual-conceptual experience has taught him to see. In the absence of such training there can only be, in William James's phrase, ‘a bloomin' buzzin' confusion’.”*

Our perceptions are the result of training embraced by long lasting human traditions and cultural habits, and therefore we must insert another filter - called *a cultural* filter. There are also, of course, reasons to insert more filters in this projection path caused by our *personality, expectations* and *mental mood*. We call all these filters *psychological filters* and assemble them into a single *personal frame***.** This frame is imposed by the observer in person and is truly subjective. To get to the point of consensus that we usually call “objectivity”, we have to exercise a rigorous control to minimize the influence of the personal frame.

The personal frame is different from the observation frame; in the sense that the personal frame often unconsciously adds (or fills in) the data that seems to be missed along the perception path - in a sort of correction phase. We are just in the beginning to understand how human beings process and store sensory information and to better understand the role of the personal frame we must turn to the cognitive sciences and artificial intelligence.

However this is not enough since human conceptualization is so important and therefore we must also turn to metaphysics where the most general ideas used in science and everyday life are investigated. The theories of modern physics such as the quantum theory, the theories of relativity and the theory of chaotic dynamics, for instance have a crucial influence on modelling methodology, especially when it comes to discussions about the personal frame. Figure 4.4 shows that the SW’s IW-system is heavily influenced by the all filters mentioned here and that it is impossible to trace the projection from the real world to IW, without an elaborate specification of what has happened in the perception path of the SW. Inserting a measuring device into this perception path make things more complicated, but has no principal bearing on the discussions which follow.

6. Modelling and the model concept.

Next we ask what are the relationships between the mental IW-system and the model? Marvin Minsky once gave a very useful model definition [Min65]:

> To an observer B, an object A* is a model of an object A to the extent B can use A* to answer questions that interest him about A. The model relation is inherently ternary. Any attempt to suppress the role of the intentions of the investigator B leads to circular definitions or to ambiguities about ‘essential features’ or the like.

This definition focuses on the possibility of considering a model as a database system for future questions about prediction and control. It takes the observer of the system into consideration, which is very important and highlights the observer’s intended *purpose of model development* – that has a deciding influence on the outcome of the modelling process. In this light, we argue, the modelling process is *not to be seen as a direct mapping* of the appointed RW-area into a model, as often visualized. The proposed model of modelling (metamodel) very much benefits from the recognition of two distinctive steps:

1) - A projection from the real world into the observer’s mind (IW-system)
2) - A mapping of this IW-system into a model.

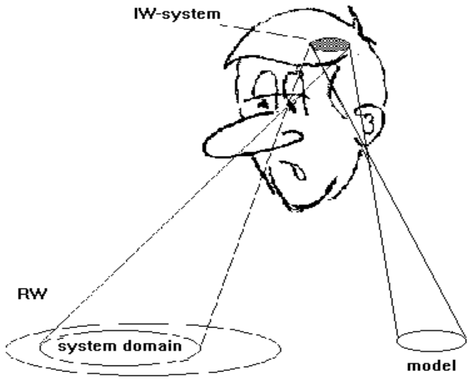

Figure 5.1

We call this metamodel *the 2-step model of modelling* and when perceiving the modelling process in this manner, we get a useful visual interpretation, which points out, that every model is associated with and restricted by the way it is represented. (Figure 5.1) Every attempt to establish a direct projection path from the RW to the physical model will suppress the role of the SW – and the presence of the SW and his/her “inside” IW-system is vital to the modelling process. Encouraged by this definition and the visual 2-step metamodel we conclude that a physical model is an image, not of the RW-area captured, but of the IW-system as imagined by the SW. Bearing this observation in mind we will modify the interpretation of the model concept to read as :

> To an observer SW, the mental system image A* is a model of an RW-object A to the extent the SW can use A* to answer questions that interest him about A. The corresponding *physical model is an “external” presentation of the system image A* which has emerged in the mind of the system viewer (SW) - and as such cast in a conceptual form chosen by the purpose of the presentation. Due to computation and/or inter-subjective communication there is a need for an external model.*

The process of idealization is nearly always regarded as an imperfection forced upon the modelling process by the complexity and intangibility of reality. A more rewarding posture is to regard this process as a means for the SW to *bring out the essentials of the system under consideration*. This process takes place firstly in parallel with the purpose-filtering, along the perceptual path when the RW-domain is projected onto the IW to produce the system image. Secondly another forced part of this idealization takes place in the modelling path between the IW-system and the model, imposed because here we have to conceptually represent the model – the modelling framework.

The mental representation of the system in the mind of the SW is often called a *mental* (or internal) *model*. According to the interpretation given above, the notion of a "mental model" is the equivalent of the IW-system concept and we have deliberately called this real world-projection *an image* (or mental representation) to leave the concept of a physical model to denote a “real” phenomenon “outside” the SW. That is to say, *not until the IW-system is laid out in some conceptual framework could we speak about a physical model* – the reason is obvious: *A physical model is then always a non-abstract presentation of some captured real world-phenomenon.*

The form of the presentation is generally chosen with respect to the intended receiver and the conceptual frameworks available to present an IW-system are numerous, each one displaying certain facets of the portrayed RW and relevant to dedicated receivers. We derive further advantage from the 2-step model by the ease of exemplifying the use of different modelling formalisms. This, we visualize by inserting another filter, called the *conceptual frame,* into the projection path as shown in figure 5.2. We insert, this filter on the path between the IW-system and the physical model and there it is possible to find different filter components such as the medium of communication - the purpose of modelling – and the receiver of the model and so on. However here is not the place to develop this subject matter any further.

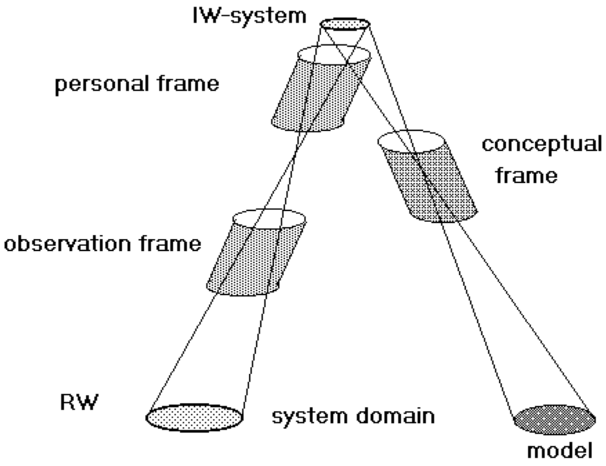

Figure 5.2

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Models are categorized in different ways, the broadest scheme classifying them as *ionic, analogous or symbolic.* Such models do not necessarily have to be expressed in a scientific formalism, we can just as well chose an expression of a *natural language, such* as sentences , which is called *a verbal model.* A picture, photo, sketch or graph are also clearly very useful models. A change of conceptual filter is equivalent to using another presentation form and this will in turn changes the whole presentation. When changing from one filter to another, we can generate a whole spectrum of different types of models outgoing from one and the same IW-system. For instance we can set out a mathematical, statistical, conceptual, logical or verbal model – it is our own choice. (Figure 5.3)

The careful choice of conceptual filter is a very important step in the modelling process and each scientific discipline has its own favourites of well-known modelling filters that are, on a regular basis, used to project different IW-systems into a familiar conceptual form. Thus the model's ability to serve as an efficient tool for knowledge communication within the scientific discipline in question is maintained . We conclude that a physical model is a very important knowledge communication tool.

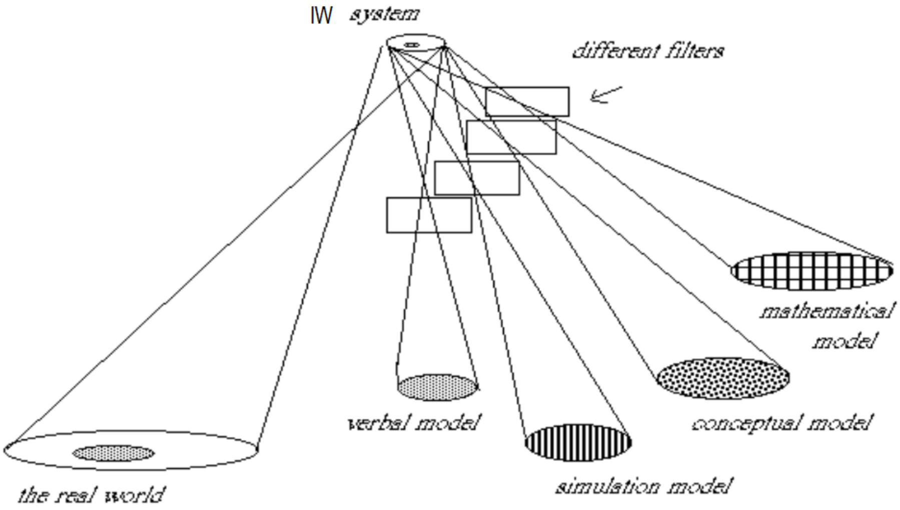

Figure 5.3

The different filters must not necessarily be interpreted as conceptual filters whose output is only of significance to a specific scientific discipline. The filter set could just as easily be chosen as to cover a spectrum of models at a *different level of abstraction.* See for instance [Fish89]. The use of such a modelling strategy is proposed by B. Zeigler [Zei84] among others. Different filters are also used regularly to produce a conceptual standard output belonging to different well-known modelling methodologies, e.g., the entity-relationships-models, object-oriented models, industrial dynamics models, flow graphs and so on .

7. The model interpretation and non-formalized languages.

There are certain types of knowledge that cannot be laid out in the form of model. Knowledge related to intuition, feelings, creativity, artistic performance etc. belong to this category. For obvious reasons difficulties are met to describe this knowledge-category sometimes called *empation more specifically* . Management science often refers to this category as "know-how" or "fingertip feelings[1]" and is often used to explain the "untouchable" skills of an experienced manager. The FTG group defines *knowledge* as "that, which is known by human beings" and thus states that *information* and e*mpation* are two complementary subtypes of knowledge. Information is defined as: *"the formalized knowledge of states in a system that can be transferred in a reproducible way and with complete certainty."* Thus the eventual "non-formalizable kind of knowledge" contained in an observer's IW-system could not be part of a model since *the empational part of the knowledge cannot be projected into the model by definition*. (Figure 5.4) Here we find another filter, *an information filter*, which is transparent only to *formalizable knowledge* revealing that a substantial part of the SW's subjective experience and knowledge can never be incorporated into a model. To put this partly fragmented knowledge and unconscious skills into a useful form is a challenging problem dealt with in decision-making and AI.

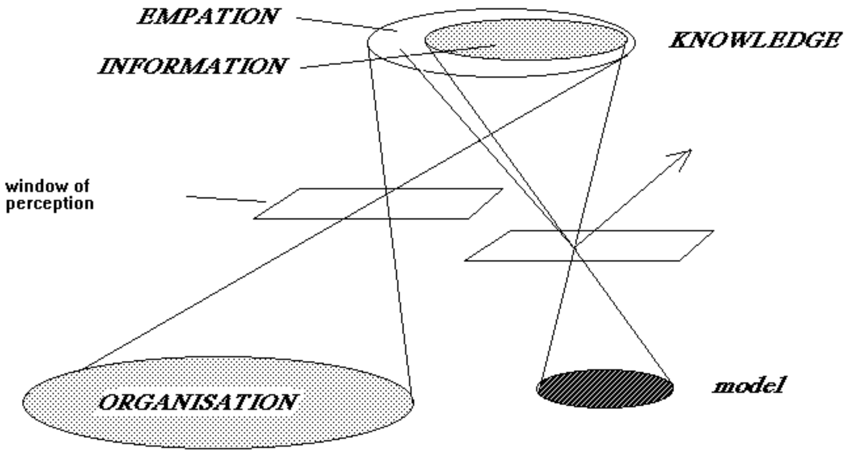

Figure 5.4

When an IW-system is shown in the form of a model, then the knowledge and experience "contained" in it is explained to others. When I, as person A, present my model to another person B, it becomes the RW domain for another SW, namely B. (Figure 5.5) In this situation it is important that the observation frame of B is as transparent as possible. That is, B must know my objectives and purposes to be able to interpret the model correctly. However this is not all, B must also be able to find out or imagine all other abstractions I have done – deliberately or not. My observation frame is possible to describe and take account of , but things are different when it comes to the personal frame, which can hardly be removed that way. The educational filter – imposed by the paradigm - will always be a particular obstacle for interdisciplinary understanding and this is why physicists, for instance, do not understand economists very well and vice versa. When B tries to interpret a model displayed and formulated by me, the personal frame of B has a somewhat different role: The personal frame of B is responsible for creating an imaginative IW-system in the mind of B, for filling in all tacit assumptions, abstractions and details missing in this observed simplified model description . A truly creative and intuitive task , which relies on both educational and cultural experience and habits, will always cause

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[1] German: Finger-spitzen gefühl

interdisciplinary research to be awkward. In our attempts to bridge the gap, we often try to improve the explanatatory power of our models with graphical presentations and/or stating some verbal models in parallel – in consequence most of our modelling attempts are *multi-faceted*, a term coined by Zeigler [Zei84].

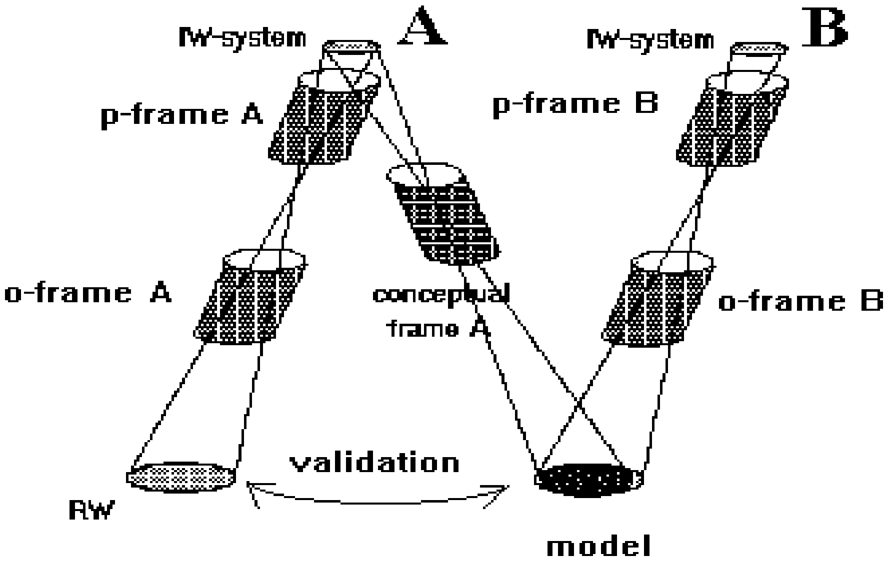


Figure 5.5

8. The intuitive approach - some illustrative examples.

To illustrate the ideas presented above, in the following we will capture some areas of the RW, chosen to pinpoint the influence of different frames exerted on the *projection path of modelling*. First a very simple phenomenon found in the real world, *a single server queue.* The scenario could be given as *a verbal model:*

> "A single server queuing system consists of one server unit that provides service of some kind to arriving customers. Customers who, arrive to find the server unit busy, join a queue in front of the server unit. Such scenarios are, for instance, found in banks and post offices, manufacturing lines etc."

Such a queuing system consists of two parts: *a queue and a server unit.* Contemplating such an open single server queuing system our ideas, by virtue of daily experience, are presumably very similar and this IW-system could for instance be modelled in the following way:

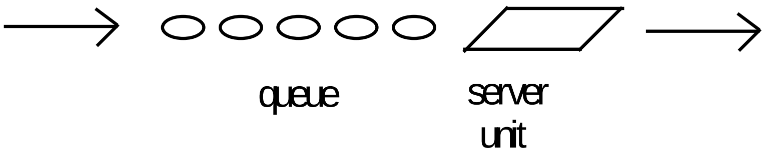


Figure 8.1

Figure 8.1 is a common conceptual form of a physical model, a picture, and its explanatory power is brilliant but on the other hand its predictive power is very limited. How come the explanatory power of this simple model is so good - just three small figures and three words? There are two obvious reasons: Firstly, we can all interpret the meaning inherent in this sketch and secondly it illustrates a well-known RW-phenomenon from which we all have great experience. That is, when observing this model we are, by means of cultural habits and experience, able to apply a personal frame that creates or reinstates a universal IW-image of a single server queue. However this is not self-evident - it is the marvel of human communication.

<u>*The system view - the domain of investigation:*</u>

When we capture such a simple part of the real world, we have no difficulty in identifying *the parts and their relationships*. Queuing systems can be characterized in terms of entities *queues, service stations and customers.* To handle the input to and output from the system, we also often add entities that are not equally self-evident such as *sources and sinks.* By concentrating on different *concrete things* (objects) that are known to exist in this RW-area, then we can specify the different abstract *entities* belonging to the IW-system. We call this *the object-oriented view* of this scenario – because the actual objects of the world are taken for granted.

This is not all, however, because by this choice we have also decided on a particular system view - a choice as to *the level of decomposition*. We specify that we have no interest, apart from the service times, in the inside of the server unit, which is a very complex phenomenon. We also take a decision to consider the customer as an "atomary" element. That is, although the customers themselves could also be regarded as a system (or subsystem) we are not interested in further subdivisions. We thus apply an observation frame that filters out all details below a certain level and this level is not decided by some geometrical dimensions but rather by the purpose of the investigation.

In this IW-system we can readily identify three important entities: c*ustomers, a queue* and a *server unit.* We can, for example, present this IW-system in two different forms by drawing the system domain boundary in different ways:

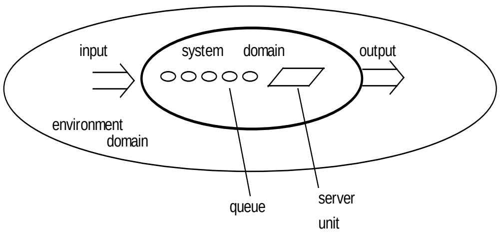


Figure 8.2

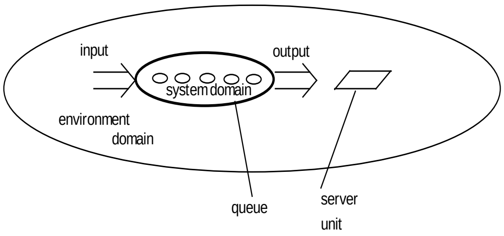


Figure 8.3

By removing the environment domain and hence also the input and output to the system domain, we get the image of *a closed system:*

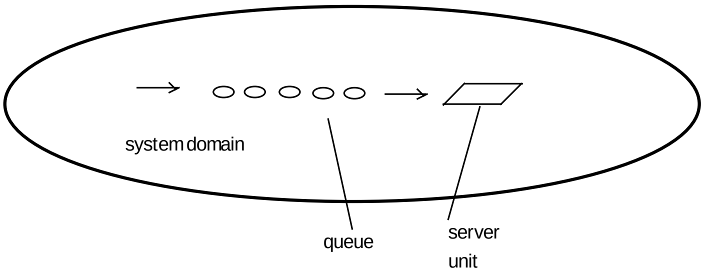


Figure 8.4

What about the rules to decide whether an object belongs to the system or not? Here a common modelling trick is used, where the elements are *created and consumed inside the system* by means of *a source* and *a sink* – thus all entities belong to the system. However we can observe the use of an idealizing filter when approximating the behaviour of the arrival process and the service unit by means of the statistical distributions as expressed in their mathematical form. The SW does not belong to the system and we regard his/her acts of observation have no influence on the system’s function. However this is not always the case when watching human systems.

The block diagram is another model:

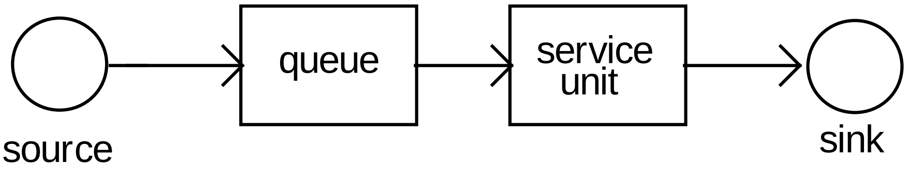


Figure 8.5

Leaving out some details of the captured real world-area, the block diagram is used to show the *process view* of this scenario.

The modelling path - the conceptual frame:

It is very rewarding to notice how the choice of *conceptual frame* influences the outcome of the modelling process. We often choose a certain modelling approach guided by the possibility of future computational solutions and/or the presence of an appealing conceptual framework, for instance mathematics with its accompanying possibility of numerical experimentation. Simulation methodology here offers a very appealing alternative. Such considerations reveal that the choice of conceptual frame is important and sometimes enforces both unnecessary and restricting abstractions that can influence the whole investigation.

Let us, as an example, have a look at *the mathematical formalism used in statistics:* In a queuing system the arrival process is characterized by the time distribution between the arrivals of successive customers. The two most important cases are, when the times between arrivals are exponentially distributed and when they are constant. When the time between arrivals is exponentially distributed, its probability density function is:

$p(t) = \lambda\, e^{-\lambda t}$ where λ is the expected mean time between the arrivals

The traffic intensity ρ is defined as $\rho = \dfrac{mean\ service\ time}{mean\ time\ between\ arrivals}$

Let the mean service time be s and the standard deviation σ, queuing theory gives the following queue characteristics as a solution: *mean queue length (w), mean queuing time (*t_W*)*

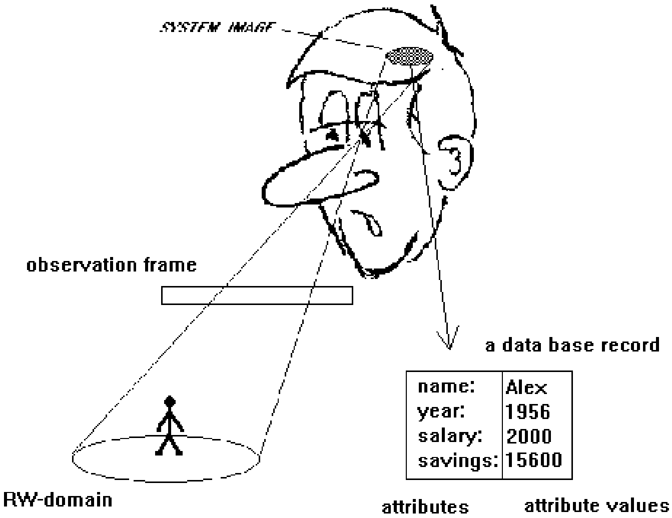
$$w = \frac{\rho^2}{2\,(1-\rho)}\,P \qquad t_w = \frac{\rho s}{2\,(1-\rho)}\,P \qquad F = 1 + (\frac{\rho}{\sigma})^2$$

This is very much the normal view of a queuing system as presented in Figure 8.2. Here the *conceptual filter* in use obviously blocks out all the other possible attributes we can assign to a customer, leaving just his "property of oneness" intact. This type of abstraction lumps the behaviour together into two average values (attributes) that are attached to the queue entity, i.e., is seen as a property of the queue. This act of abstraction is clearly recognized by the structure of the block schema above. By lumping the individuals together we create a new type of entity – the queue – we witness the emergence of a queue. This queue interacts with the service unit (see block schema) – and the service unit is another emergent object that "comes out" of the behaviour of its parts. Which view is the correct one – or rather the most useful one? This question cannot be addressed until we know what questions about the system we are supposed to answer. Since the conceptual frame here forms the modeller's personal system view we here can trace the tight connection between the conceptual and personal frame – *the conceptual framework in use influences the worldview of the modeller*.

<u>The perceptual path - the personal frame as part of the observation frame:</u>

To exemplify the use of filters in the perceptual path, we consider the system view B above and we dismiss the "queue-view." Suppose, for instance, we are instead modelling individual humans in a specific area of the RW, for instance customers lining up in a queue in front of a bank teller. Suppose the purpose of this investigation is to store data about the customers in the bank's database. Such a system view has a well-defined area of interest and the level of decomposition seems here self-evident. The properties attributed to a customer could be, for instance, *a name, a year of birth, a salary and savings.* By doing so we use the observation frame to filter out all other properties we otherwise could ascribe to a human being – concentrating on the customer aspects. As a second step we also have to specify a set of *underlying domains* and assign to them a *range of possible attribute values.* This is an act of filtering, the knowledge of which is given by the personal frame – our experience. When we, for instance, add the attribute of "hair colour", then we suddenly find ourselves involved in a messy situation trying to classify hair colours – for no practical use at all. But how do we know?

Well after solving all these problems the IW-system could, for instance, conceptually be specified by a specific set of attribute values assigned to an individual that in systems engineering is called a *record.* (Figure 8.6)



name:	Alex
year:	1956
salary:	2000
savings:	15600

Figure 8.6

Another facet of the same system view occurs when we consider the number of customers lining up and here the idea of a *number* offers a good opportunity to display the role of the personal frame. We are all very familiar with these words "one," "two," "three" etc. but what objects do we assign those names to? Consider, for instance, the number "three." We all have the intuitive idea of "three-ness." The mathematicians turn to set theory to sort this out, considering the set of all sets having exactly three elements. They all have in common the *property of three-ness.* In this way we try to convey the idea of N-ness to the number N. (Figure 8.7)

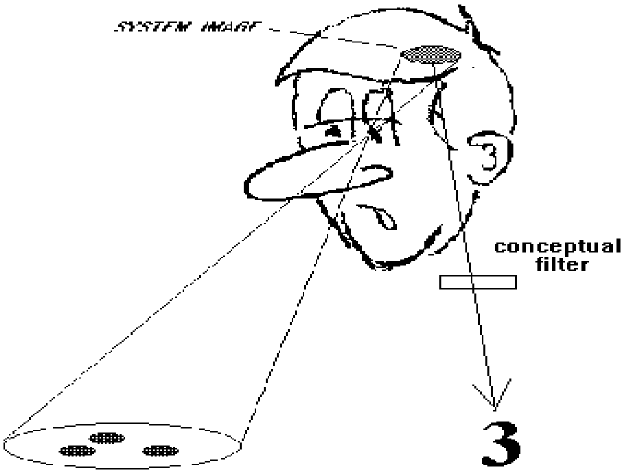


Figure 8.7

That is a natural number N can be interpreted as *a model of a set* containing N elements. *In fact, every set containing N elements is modelled by its cardinal number N.* In this case we can observe a magnificent abstraction. Every possible property to assign the individual element of the set is filtered out, except their "property" of one-ness, which is given to them as individuals, i.e., *the individual has cardinality "one"*. Then this group of individuals is collected under the name of a *set* which in turn is attributed the *single property of cardinality*, which is assigned a value between 1 and some very large number indicated by ∞. **So a number is a property value that we assign to sets** – objects that are devoid of other qualities but cardinality. We must credit the personal filter with this ingenious act of filtering and **we now start to understand that the "property of oneness" that is attributed to *each element of the set* is just a reflection of the level of decomposition chosen by the SW.**

This interpretation also provides us with a model to visualise the use of different number systems. The mental idea of a number could be projected by means of different conceptual filters into different symbolic representations. (Figure 8.8)

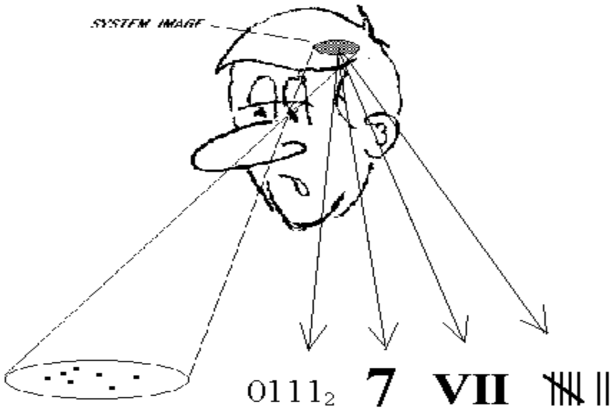


Figure 8.8

9. What happens to reality?

We now begin to understand that most properties (qualities) attributed to an object of observation are reflections of the worldview held by the SW. In last section we even demonstrated that the conceptual entities identified in the UoD were a matter of choice of the SW. Now when the concepts we use to form the quantitative measures we also assign to our observations – the natural numbers – this mostly seems to reflect the level of decomposition chosen by the SW. That is the personal frame of the SW seems more and more to be the reason why he/she sees the world the way he/she does.

When we try to model a piece of landscape onto *a sheet of paper – producing a map* for instance - the filter action of our personal frame is even more predominant. Here we tend to regard the percept of this landscape, i.e., the IW-system in our mind, as the “true image” of the landscape. However both filtering and corrective processes are undertaken on the perceptual path on the way to the mind and we must turn to the cognitive sciences to come to grips with the personal frame and its role in human observation.

We should take care to notice that here the notion of the “true image” of the landscape, can only stand for the SW’s image – the IW-system.

The land surveyor, for instance, specifies the area of interest, the specification of the geometrically interesting parts of the landscape and we observe the presence of the purpose filter, as he does not map non-stationary objects such as cars, human beings, animals, etc. However the most important part of the filtering occurs in the conceptual frame, which is established by the rules of mapping given by the land surveyors. The normal three-dimensional space is filtered away and replaced by one dimensional lines of altitudes and all colours including numerous confusing details are left out. The level of decomposition is given by the purpose – hills, paths and lakes and so on are included but stones, trees and flowers are left out.

10. The use of models.

A given description or presentation form thus qualifies as a model in some respect of the RW, when a projection (mapping), which is homomorphic with respect to the relationships involved, is established from relevant phenomena of the RW to the formal representation of the abstract system entities. The projection is done via the SW and is affected by the objectives and limitations of his/her particular system view. Every model description consists of at least the following three principal components:

- A set of abstract phenomena (entities)
- Relationships among these phenomena
- A homomorphic projection that gives the phenomena a real world interpretation

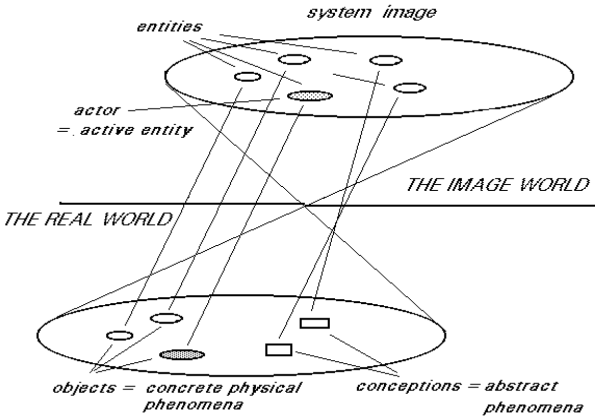


Figure 9.1

The mental representation – the IW-system – must be explicated to become the subject of inter-subjective discussions and this model we have called the ***concept^2 model*** *(c-model).* We thereby assume there is a basic conceptual (or philosophical) level of understanding (meaning) that can be modelled (explicated) apart from some more syntactic traits included in the modelling framework used. The modelling of objects in object-oriented programming (OOP) seems to be such a basic approach. Such c-models are used at a more basic level in the process of understanding, prediction and control and to be more specific, there are reasons to develop c-models for:

a) - Making predictions regarding a phenomenon or system

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[2] we cannot use the term conceptual model for the reason it means something else

b) - Making appropriate decision and taking actions by which, for example a phenomenon or system can be controlled

c) - Making experiments with existing or planned system (system simulation)

d) - Understanding the structure or/and the function of a phenomenon or system

e) – Finding out the boundaries of a given scientific theory

f) - Prescribing operations by which a desirable artificial object or system can be constructed (systems design)

Regarding the points d) to f) the central feature of modelling is a contribution to the understanding and experience of the phenomenon in question and the resulting model could then be used for the sake of communication and education. Turning to the points a) to c) we intend to use the model somewhat differently – as a calculator or predictor or an aid for such operations. Using the model for predictions, we in the abstract feed our models with *some sensible input values and calculate some output values that represents an estimated future state or behaviour*. When the c-model is a mathematical or logical model we have to solve the model equations analytically or numerically. This is nearly always a difficult task and can only be used for simple models . In physics using RW-experimentation – a methodology that has become central in modern natural science, circumvents this difficulty. Through f the modern computer we have learnt to "imitate" RW-experimentation (or RW-behaviour) – which was the original meaning of simulation, we make experiments with the model to observe the model's response and are accordingly able to draw conclusions from these experiments.

11. Computer simulation:

The simulation technique makes uses of computer programs and computers to do simulation experiments and when the complexity builds up this is sometimes the only way to handle the situation. We argue, that modelling and simulation are two separate tasks. The *c-model* and the realized simulation model- let us call it the *s-model* for short, are different at the fundamental level and there is a need to keep the two notions apart. The fact is most easily seen by understanding that a c-model can be the source of many different s-models, all intended for use in simulation experiments.

Simulation has its roots in *the analogue simulation* technique, which means, that the model used analogously resemble the RW-system in question, e.g., when we use the water analogy of electromagnetic current to explain these phenomena in physics. In **digital simulation**, as a contrast, the s-model takes the form of *a computer program* and the *simulation experiment* is accomplished by the *execution of this program on a computer*. Here is not the place to delve more deeply into simulation methodology but there are reasons to place this useful methodology in its proper place in the chain of observation-modelling techniques available to science. To explain the usefulness of the intuitive approach to modelling as presented in this paper, we will however use it to explicate the relation between modelling and the simulation methodology.

The normal technique used to develop a s-model is to start with a well-known physical or verbal c-model and develop a computer program that resembles the c-model in some respect – that is we develop a ***model of a model***. It is important to notice that now the c-model becomes our new RW-system and to develop the s-model we have to accomplish another modelling process, different to the one producing the original c-model.

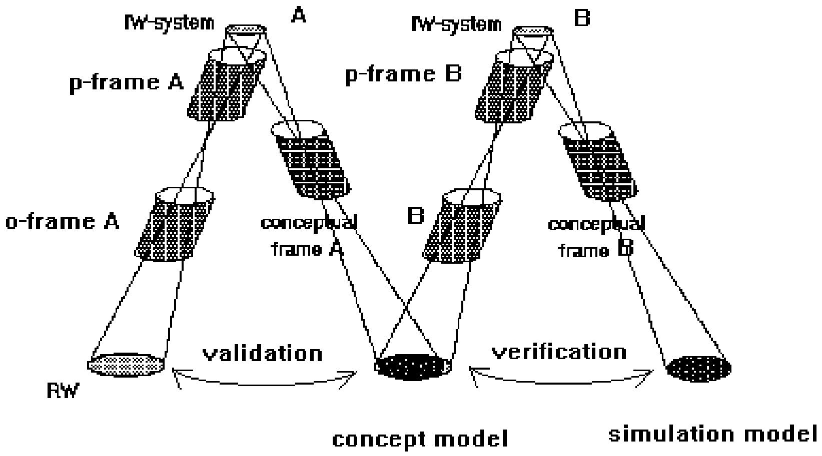

Figure 11.1

S-models are developed in some computer language, an all-purpose language such as Pascal or C++ or more a dedicated language like SIMULA or GPSS. In this case the choice of programming language is unimportant. However the crucial point here is the person B (in figure 11.1) the one developing the computer program. When the same person develops the c-model and the computer program (s-model), we have *the same filter set A* in use in both steps. When we, on the other hand, ask a dedicated computer programmer B for assistance, a person that was not involved in the original development of the model or for some other reason was not acquainted with this way of modelling, we have to face a *new set of filters both in the path of perception and modelling*.

This deceitful four-step projection-modelling path is the cause of many unsuccessful simulation projects and we can find no better way other than through this figure, to point out the desirability that the same person is the one developing both the c-model and the s-model. That is to say that every scientist building simulation models should be an experienced programmer in exactly the same way that we have assumed every physicist to be a skilled mathematician. This situation pinpoints a well-known problem in present day research – a researcher’s lack of modelling skills. We can push this situation to its extreme by asking what is the use of a researcher who cannot use the spoken language? The situation is a bit precarious because to gain the programming experience to be able to develop effective s-models takes time as it does to master mathematics. This fact offers a partial explanation as to why simulation technique is mainly used in sciences that are close to mathematic/physic and thus also to computer science.

Perhaps it is unrealistic to ask every researcher willing to use simulation techniques to gain this programming experience. Clearly the solution is to further develop tools and techniques that make it possible to develop simulation software without the need for extensive programming. However some further reflection makes us understand that programming experience is not the key point here – what is needed is the understanding of the modelling process and that cannot be improved merely by the development of new tools. What we need is a deeper insight into the different aspects of modelling – and recognize the crucial and determining role of the observer.

Another approach is to pose the question: What is the role of the c-model and its relation to reality? Is there really a need to develop c-models as an intermediate stage when developing s-models? Could we remove this step, thus the cumbersome 4-step projection will be replaced by a 2-step metamodel of modelling which will surely benefit simulation methodology. This insight has fundamental implications for the modelling process and offers future possibilities to extend the use of simulation techniques. This research has already been partiallyaddressed by the AI-community but the parallels between computer simulation and AI have not yet been fully recognized.

The next step, when developing simulation models is to prove the correctness of the *simulator*. That is, to verify that the s-model, the computers and the experimental techniques to be used in the simulation experiments are correct. This process is called *verification* and stands for "validation of the s-model " relative to the c-model used. The change of terminology is well founded, as this is principally a different process from the validation of the c-model. When verifying we have access to the structure of both the c-model and the s-model and can make direct comparisons. The *validation process* is experimental and can only be based on a comparative observation of the output values and trajectories of the c-model and the real world, under certain given experimental conditions.

12. Model validation

Traditionally we say that the modelling process has not ended until another important process is carried out - the *validation process*. Such validation is concerned with the *correspondence* between the physical model (or rather the intended set of models) and the observable RW. Validation is concerned with determining whether the physical model is an accurate representation of the RW system under study. If a model is "valid," then the decisions made, aided by the model, should be similar to those that would have been made by physically experimenting with the system – if this is at all possible .

However a poor performance is not always due to an insufficient philosophical understanding of the RW-phenomenon under consideration – it could very well arise from the inappropriate use of the modelling framework. This situation has been very obvious in the simulation community where the modelling path has, for practical reasons, always been split up in a 2-step procedure (figure 5.5). The reason is that the computer programmer is a specialist in programming and is often not very familiar with the RW-system he is supposed to model. In building the model, it is thus imperative for the modellers to involve people in the study who are intimately familiar with the operations of the actual system. To make this situation clear we introduce a *2-step procedure along the modelling path* – the first step is the explication of the mental model of the observing scientist, a concept model, and the second step ”transforming” that c-model into a computer program. We say we **realize the concept model.** This realization step must not necessarily have anything to do with computer programming. The need of this step could as well rise when developing a mathematical model or a verbal specification.

By recognising this the validation model also splits into two steps: *validation and verification*. Figure 11.1. Verification is determining that the realized model performs as is intended, i.e., that the c-model is correctly translated into the realized model, for instance the debugging of a computer program. Even if verification is simple in principle, debugging a large-scale simulation model is a difficult task. Validation, on the other hand, is concerned with determining whether the c-model is a good representation of the RW-system under study. A model is considered "valid" in this respect when the decisions made using the c-model are ”similar” to those that would have been made by physically experimenting with the RW-system - if such a system was available.

Some authors extend the validation process to also include the socio-cultural aspects of validation: When a model and its results are accepted by its user community as being valid, and are used as an aid to making decisions, the model is said to be credible, see Carson (1986). The importance of model credibility is one reason for the widespread interest in animating simulation output since this provides an impressive output to the decision maker and an uninitiated person. For these reasons the simulation community frequently considers the problem as to how to make a model ”valid” in its widest sense,including the processes of *verification, validation, and attaining credibility*. In the case where a model fails to pass these tests any conclusions derived from the model will be of dubious value.

Since any simulation model we develop is only an abstraction of the real system being studied, we should always retain a healthy scepticism about the eventual correspondence between the presumed RW-system and its realized model.Frequently it is impossible to compare the RW-system and the physical model structurally and the model is said to have *validity* if the output measures of the model have close correspondence to the same measures of the real system. For instance a time-series of output data from the model can be compared to some historical data produced by the RW-system. However this approach is not unproblematic as Hoover/Perry points out:

> An often-cited criterion for judging a model's validity is the ability of the model to duplicate the past, the present, and possibly the future behavior of the real system. This may not be a very useful operational criterion and can, in some cases, be an inappropriate criterion for judging the model. Simulation models often exclude certain real world aspects of the system because they do not bear directly upon the questions the model is intended to answer. By not including these parts of the real system, the model becomes a much more useful decision making tool. There is no one set of universal

> criteria for evaluating a simulation model, but whatever criteria are finally selected, they should reflect the intended use of the simulation model and the questions that the simulation model is expected to answer.

We will here underline the assertion that the “intended use of the model” and its “capacity to answer questions” are the criteria that should be finally selected, which immediately connects us to the question: “What is the aim of modelling?” with its obvious scientific undertones. What the relation is between the RW-system and c-model seems to be the deciding question here. However we cannot dwell on this issue any longer as we merely conclude that when discrepancies are found one has to repeat the perception-modelling procedure. This process is called *successive refinement* and reveals the iterating nature of the modelling process.

13. The use of mathematical models in the social sciences.

There are many ways to describe or display models that fulfil the requirements given above and one could rightfully ask why one form should be chosen over another . In practice the choice made is often guided by the paradigms and habits set up by the community of the scientific discipline involved. Since the time of Euclid, however, the very ideal of science has been that whenever possible, it should attempt to make use of mathematics and mathematical models to represent the quantitative knowledge we possess about the real world. A mathematical model enables the quantitative relationships between the different concepts defined in the model to be specified – and has become very precise on the basis of its consistent use of basic definitions. The mathematical model is the undeniable scientific ideal, but we must ask whether this ideal has the same significance today. Hundreds of years ago when paper and pencil were the obvious means of presentation and communication, the very compact and unambiguous language of mathematics was probably the ideal choice. It is well-known that mathematics is very useful today but the development of modern computers and computer software has given us totally new dimensions for modelling. We must understand that this invention has made it possible for the social sciences to become experimental in the form of simulation experiments.

The usefulness of mathematical models in physics and technology is well documented and the origins of the mathematical model can be traced back to physics. Since the days of Galileo and Kepler scientists have consequently striven to develop their models by means of mathematical formalism. The widespread use of the abstract mathematical language of physics has sometimes imposed a belief that mathematical formalism is the only true way to describe the real world - or at least highly desirable . Mathematics and physics have developed hand in hand, and the evident purpose is to describe the real physical world. Objects in motion are idealized as *particles*. The idea of vectors, which is the origin of the state space approach, is a convenient way to describe bodily motion and forces in the four-dimensional time-space independent of the system of reference. Once we grasped the general rules governing motion we started to investigate the interactions responsible for such motions. To describe these interactions we introduced the *field idea*, which meant that the cause of a physical property was extended over a region of space. Two of the four different types of interaction known today, gravitation and electromagnetic, lend themselves to a fairly simple field description and these fields are frequently approximated to be both homogeneous and time-invariant. In this world however, the object is taken for granted – and is the very basis of human conceptualization.

When we turn to the social sciences this RW-view is of less use, there are no particles, no well-defined spaces and no homogeneous time-invariant fields. The attributes met with here lack conceptualization which of course is the very reason we meet with few measurements in these disciplines – and thus it is unlikely that mathematical formalism is an appropriate conceptual framework . There are many spheres of human activity where mathematical formalism does not fit well and can even prove to be an obstacle to further developments. Here we also find researchers who are unfamiliar with mathematical formalism or are unwilling to use it for a variety of reasons – and they are also likely to be sworn opponents of simulation.

When we turn to qualitative and heuristic models, on the other hand, they tend to deal with classes of concept and the relations between them is conceptualised to propagate attributes and values among them through acts of communication. The object-oriented programming paradigm uses a similar approach and this specification technique is intuitively much easier to assimilate for non-mathematicians. Computer science and programming have evolved tremendously over the last decade and there is no longer a strong reason for the exclusive use of mathematical models when modelling . On the contrary! From the point of view of the social sciences benefits can be gained by trying to find out concepts that are more easily visualized and grasped and also methods that are anchored in a non-mathematical framework. Computer science offers an alternative but the process-oriented worldview used is also, in a sense, very technical in its approach. For a non-mathematician the object-oriented worldview is easier to grasp and this worldview also supports a homomorphic projection of the model onto the real world that is so often desirable in social science. When everything comes together it is a question of communication and it is only possible to have discussions by means of a framework familiar to both ends of this human communication link.

14. Conclusions

The professional conceptual frameworks within systems theory and other closely related areas are too abstract to be used for communication. Such a framework must be easy to grasp at an intuitive level rather than a strictly logical structure and could therefore benefit from an appealing visual analogy. The most important thing here to achieve is a high level of a consensus - not just within the actual discipline involved but also between different scientific disciplines. The framework proposed by the FTG, is a step in this direction and this framework was used, with adjustments, to develop a model of the modelling process that highlights the role of the observer. By the explicit introduction of a 2-step metamodel of modelling, the potential to explain the fundamentals of the modelling process and communicate the ideas involved was considerably enhanced. By introducing a “filter analogy", each stage representing a step in the modelling process was brought out and the parallels to cognitive psychology became very obvious – not a surprise since the information-processing approach also dominates there.

Using the intuitive approach, however, we very soon reached the point where it was unclear which domain the observer was refering to when modelling – the RW or the IW. Sometimes we almost found ourselves in a state of total confusion as to whether the real world we all refer to when doing physics for instance is nothing other than t a projection. Here we identify an urgent demand for further research.

The intuitive approach used also elevated the conceptual filters’ restricting influence on modelling, and revealed that the main obstacle for an interdisciplinary understanding is the filter of education – the paradigm in use. The natural language is a formal framework we have in common in a language culture, but this situation unfortunately does not remove the filter of education. One way to remove this filter is to develop a common conceptual scientific language of communication that is readily understood by us all .

The proposed modelling approach also gives simulation technique a proper interpretation, as it makes a clear distinction between the different concepts of *c-model* and *s-model*, and pinpoints that modelling and simulations are two quite separate activities. The proposal also indicates it could be fruitful to focus on object-oriented rule-based models rather than the classical mathematical modelling and simultaneously develop an experimental simulation methodology for more widespread use.

Mathematical formalism was imposed by the tools we had available during the 17th century namely paper and pencil. Today's tools are computers and the graphical possibilities offered are dynamic, coloured and three-dimensional pictures on the computer screen. We need mathematics to calculate the coordinates on the screen but we must not assume that it is necessary to model social society. When this technique is further developed, then the experimental methodology of computer simulation will become more generally available to both natural and social scientists . To support such a development there is an urgent need to develop a conceptual framework of modelling to be used when developing models for simulation. We propose that this framework could be guided by the worldview used in object-oriented programming with great care being taken to ensure that an intuitive approach to modelling is encouraged. From the natural sciences viewpoint it is highly desirable that this framework is also compatible with the terminology used in general systems theory, control theory and AI.

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