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EPISTEMOLOGICAL FOUNDATIONS OF REQUIREMENTS ENGINEERING

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Abstract: *Epistemology deals with the acquisition, nature and limits of knowledge. In the case of information systems, it deals with formal models for the systematization and automation of information processing. The fact that information systems can make excellent use of knowledge from this discipline becomes evident in the area of requirements engineering (systematic description of features of future software), where the implicit application of epistemology is already established. This advantage is explained on the basis of examples which contain false expectations with respect to the descriptive and prescriptive modeling of enterprises and, therefore, turn out to be epistemological traps. The examples also lead to the evaluation of different epistemological approaches with regard to their benefit to information systems and their application in real-life projects. With this background, requirements engineering proves to be a form of applied epistemology in information systems. Independent of the choice of a special requirements engineering approach, methodical strategies in requirements analysis and the knowledge about its epistemological foundations lead to a reduction of the undesired effects of cognitive problems.*

INTRODUCTION AND OVERVIEW

This contribution deals with the relationship between epistemology and information systems, in particular, the relationship between epistemology and requirements engineering (see Figure 1).

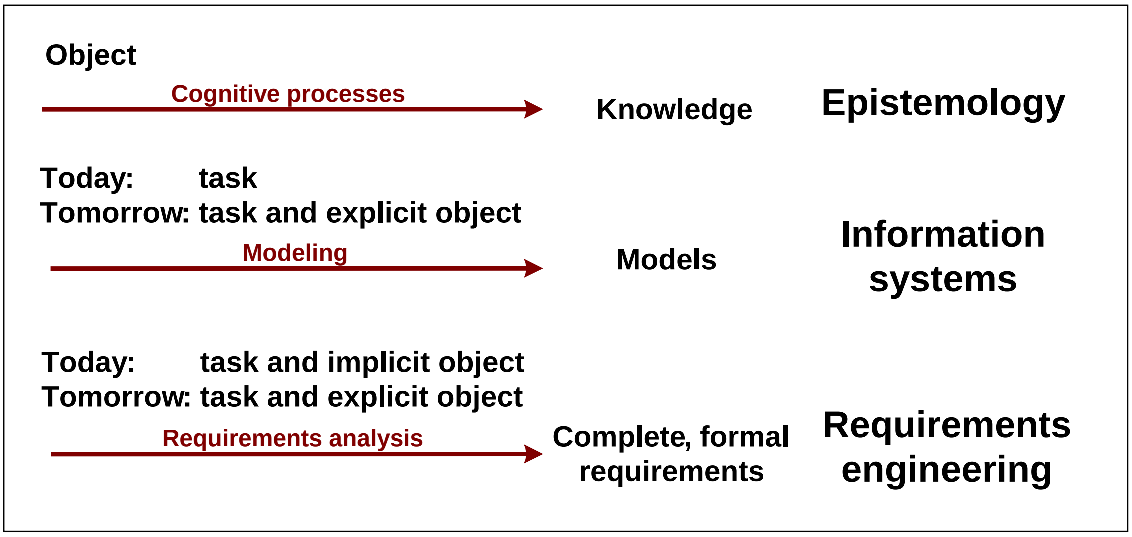

Figure 1: Epistemology, information systems and requirements engineering

In general, epistemology deals with the circumstances of knowledge acquisition (cognitive processes) and the qualities of the resulting knowledge. In the context of information systems, its research objects are enterprise modeling processes and the relation of the resulting formal models (the basis of business information systems) to the reality in companies (see Section 2 for details). In the domain of enterprise modeling, today's information systems only pursue knowledge acquisition, but do not reflect on circumstances and, therefore, do not make knowledge acquisition their research object.

Requirements engineering (see Section 3.1 for details) is a part of the software process where properties and performance of a future software product are systematically defined. Requirements engineering pursues knowledge acquisition and makes knowledge acquisition its implicit research object as it takes the conditions of cognition into consideration during its search for the best possible methods. Because of that, requirements engineering implicitly deals with applied epistemology, a fact unfortunately not generally known up until now. In order to really profit from epistemology and to establish itself better in the field of information systems, requirements engineering should explicitly deal with applied epistemology. Up until now, requirements engineering has been the only domain of information systems which is quite advanced from an epistemological point of view. Therefore, it deserves a higher reputation in information systems and can contribute a lot towards getting other areas of future information systems to pay the necessary attention to epistemological considerations.

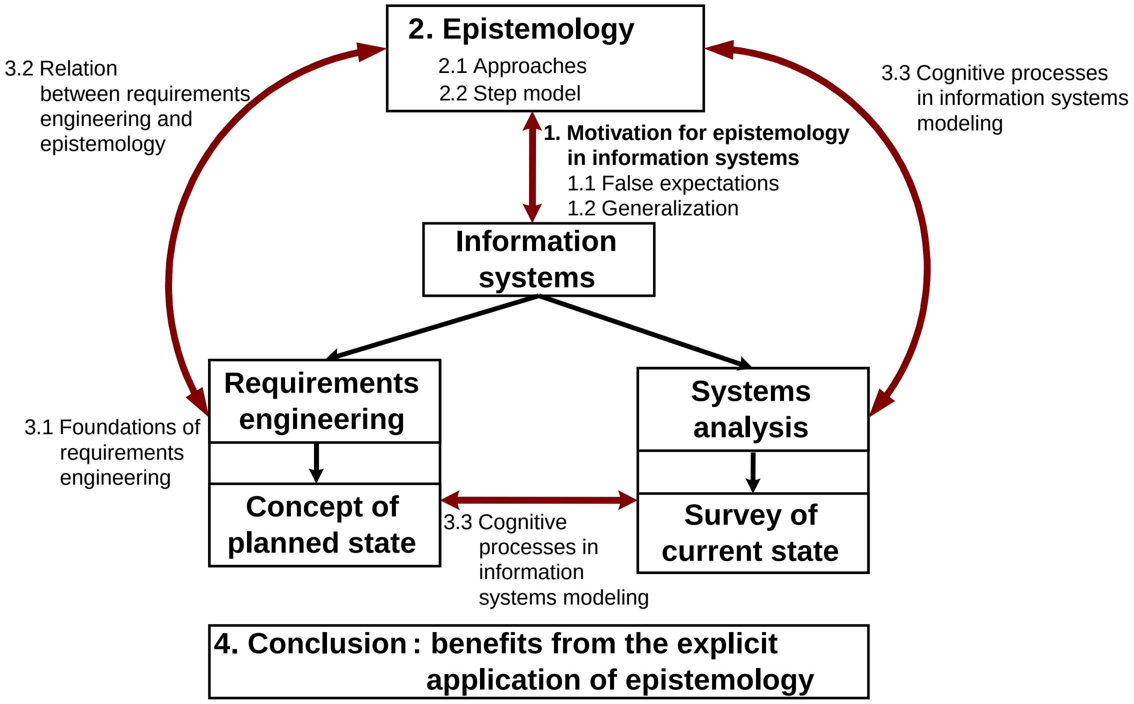

Figure 2: Structure of the contribution

In Section 1, the fundamental relation between epistemology and information systems is shown. For this purpose, it is briefly explained what epistemology is and why it is necessary in the field of information systems. Negative consequences, which arise from a naïve attitude towards modeling a company's reality and the ignorance of fundamental epistemological facts, are illustrated. In this context, four false expectations with respect to models and model design are mentioned and subsequently corrected (1.1). Finally, their generalization leads to four corresponding problem fields (1.2).

Section 2 presents epistemological approaches and shows their importance for information systems. The approaches introduced differ with regard to their judgment of the cognitive value of models (2.1). As one single approach cannot adequately describe all of the objects of cognition, an epistemological step model is recommended, which always chooses the most suitable approach for a concrete object of cognition (2.2).

Section 3 gives a brief overview of requirements engineering (3.1) and shows the relationship between epistemology and requirements engineering (3.2). It is explained why requirements engineering deals with applied epistemology. The fact that requirements engineering is not the only discipline of information systems which can benefit from epistemology is illustrated with regard to systems analysis (3.3).

In Section 4, the results are summarized. The benefits, which information systems and requirements engineering can gain for their tasks and their reputation by explicitly applying epistemology, are shown.

1. MOTIVATION FOR EPISTEMOLOGY IN INFORMATION SYSTEMS

“Epistemology is the branch of philosophy which deals with the acquisition (cognitive processes), nature and limits of knowledge” (Holl 1999, p. 165, translated from German), that is, with processes of cognition and their results. Cognition consists of a relationship between a subject of cognition and an object of cognition (cf. Beckmann 1981, p. 3). Knowledge can refer to both facts and processes. This brief characterization of epistemology, which will be detailed in Section 2, already shows that there is a close relation to information systems.

The aim of information systems, the science of systematic information processing in enterprises, is to develop business information systems. These IT systems are formal machines which cannot comprise the reality of a company in its entire complexity, but only in a reduced form: Only the formal aspects of reality are accessible as formal machines do not understand anything but formal languages (especially programming languages), that is, languages with well-defined semantics which do not allow any ambiguities and misunderstandings. In order to design business information systems, model designers (subjects of cognition) therefore have to observe the reality in companies (objects of cognition) and to map it to formal enterprise models (facts: data, class models; processes: information flow and business process models), that is, models represented in a formal language. These descriptive formal enterprise models are optimized to prescriptive formal enterprise models which finally serve as basis of business information systems. Therefore, formal enterprise models are the essential knowledge of information systems (cf. Holl 2004a, p. 13-15). In addition, formal enterprise models are a form of empiric knowledge as they are the results of empiric cognitive (knowledge-gaining) methods (observation, description, type construction, abstraction, formalization, model design) as in natural sciences. And the nature and limits of empiric knowledge always have to be judged with methods from epistemology. The fact, however, has to be added, that in contrast to natural sciences, the observed object of cognition (e.g. a course of events in a department of an enterprise) can verbally give information about itself via the human beings involved.

We summarize the considerations above: information systems acquire knowledge in the form of formal enterprise models which are the result of cognitive process (enterprise modeling). As the scientific object of epistemology (cognitive processes and the resulting knowledge) is the same as the task of information systems (see Figure 3), information systems are a profitable application area of epistemology.

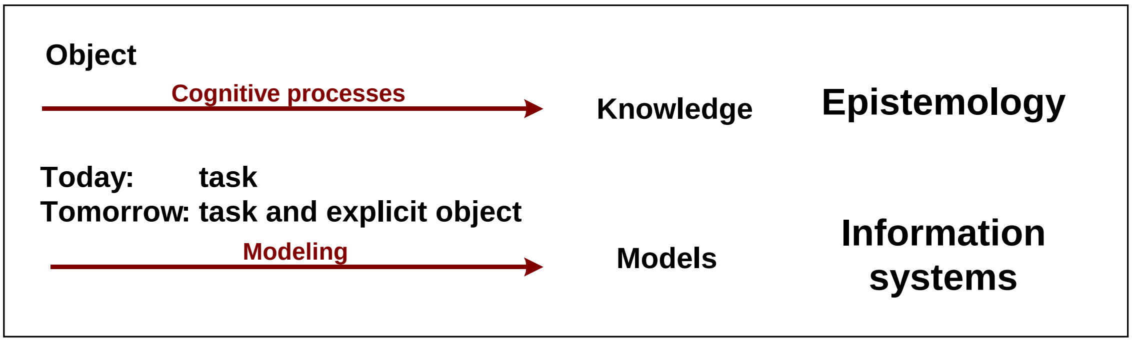

Figure 3: Relation between epistemology and information systems

But why do we need epistemology in future information systems at all? The fact that software often does not meet the customers' requirements and that projects exceed their budgets to a great extent, leads to the question for the reasons of this undesired situation. Are the software developers or the project managers responsible for the problems? Or are there any fundamental problems besides model notations and phase concepts? This question can be answered with a clear yes: the fundamental problems of modeling have epistemological quality. As they go beyond the scope of today's information systems, software engineering is often reduced to pure software technology and the modeling process is restricted to the application of notations (cf. Holl 2002). One example is the Unified Modeling Language (UML). It is a "purely graphically defined notation; neither is it defined formally nor does it respect procedural aspects of modeling" (Jeckle 2004, p. 14, translated from German).

An inexperienced view of modeling (that is, a view without epistemological knowledge) is often responsible for false expectations with respect to models and their design, which have negative influence on the quality of the resulting models. Four expectations of this kind, which serve as examples, are described and corrected in 1.1. Subsequently, they are put into a general context in 1.2.

1.1 False expectations and their rejection

Both in software producing and in software deploying organizations, naïve assumptions and false expectations with regard to models can be found. We mention four of them as examples and subsequently present the correct opinions.

1.1.1 Models as one-to-one images of segments of reality

Models would be one-to-one images (isomorphous images) of reality and therefore every kind of information could be described formally in models. One assumes that every segment of reality could be captured in models without distortions and losses of information and without any change of structure.

In this comic (Figure 4), you can see a girl showing her teddy bear a globe and asking him whether he knows why this world is so beautiful. In response, she tells him that the world is so beautiful because a globe is only a model. This caricature illustrates that it is not possible to map reality to a model without losses or distortions. "This *problem of isomporphy* results from the cognitive necessity of *complexity reduction*" (Holl 1999, p. 189, translated from German).

That is, “Models are images (“caricatures”) of real objects and processes, from which at least one essential feature is left out” (Holl 2001, p. 13, translated from German). Complexity is reduced necessarily, since the human mind often cannot comprehend the complete complexity of processes. In order to make facts better understandable, humans need abstractions. One distinguishes between negative and positive abstractions. Negative abstractions drop the properties *not considered as essential*; positive ones isolate and underline the features *considered as essential*. Using an abstraction, one tries to exclude “unimportant” properties and to conserve “relevant” ones (cf. Beckmann 1981, p. 101f.). In our example, “relevant” features are “geographic positions” and “scale image of continents and countries”, whereas “temperature”, “surface shape”, “people”, etc., belong to the “unimportant” ones.

Figure 4: Girl and globe (Quibeldey-Cirkel 1994, p. 15)

1.1.2 Similarity of all segments of reality with regard to their accessibility to modeling

Every segment of reality, for instance every department of a company, could be modeled completely without losing information, with the same precision and the same effort. No matter how complex a department were structured, or to which degree it were pre-formalized (pre-formalization means a pre-stage of formalization), the quality of the models would remain the same.

Figure 5 shows two photos. The left one is coarsely structured and the right one is finely structured. Different degrees of structure (granularity) of that kind occur within enterprises as well. One department is finely structured (pre-formalized). The model designer can perceive all of the business processes clearly and precisely; they can easily be modeled. Another one is coarsely structured (not or badly pre-formalized). Therefore, modeling it is difficult. For instance, accounting is a pre-formalized department, whereas in individual production processes, specific techniques which are not accessible to formalization can be found pretty often (cf. Holl 1999, p. 197).

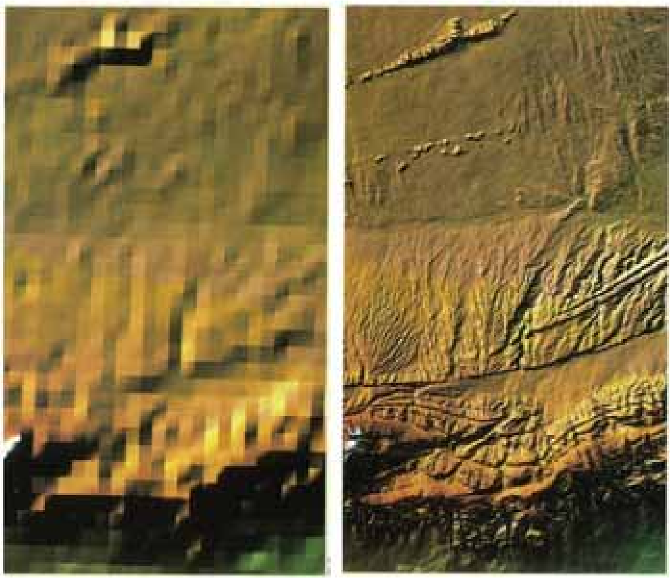

Figure 5: Coarsely and finely structured photo (Öttl 2000, p. 93)

1.1.3 Objective models independent of the individual observer

Models would be objective descriptions of segments of reality by the model designer and therefore independent of persons. Moreover, the models would be independent of the model designer's prior knowledge. Therefore, his individual mental disposition would not play any role.

"To perceive means to orient oneself towards an immediately given object or event and to acquire it *as something certain*" (Beckmann 1981, p. 74, translated from German). On the one hand, perception means sensory perception, for instance, the interpretation of sensations, which arise from outer stimuli which influence the sense-organs. Perception, however, is not only related to sensory perception. On the other hand, it is the initiation and the basis of a theoretical act, "of not only passively receiving sensory facts, but at the same time of actively "*orienting oneself towards*" something" (Beckmann 1981, p. 74, translated from German). Perception is not only seeing, feeling, hearing, etc., something, but seeing, feeling, hearing something *as something* (cf. Beckmann 1981, p. 74-75).

Figure 6 shows different people who are in the same surroundings (in a forest). The painter perceives the forest as beautiful, the woodcutter looks at the wood the forest consists of. Due to his particular prior knowledge, everyone perceives the same object of cognition differently. Different psychic instances, such as interest, needs etc., make certain features predominant in the situation of perception.

Figure 6: “Who sees the forest?” (Hajos 1991, p. 18)

Therefore, the “illusion of neutrality of the observer has to be abandoned, as the influence of various predispositions of the model designer cannot be excluded principally” (Holl 1999, p. 203, translated from German). As a consequence, there are not any objective models independent of the individual observer.

1.1.4 Segments of reality, which do not change when observed, and neutral observers

Subject of cognition (observer) and object of cognition (reality in a company) could be separated strictly from one another. That is, they could be examined independently of one another and would not have any influence on one another. An enterprise would behave like a simple piece of furniture, which would not be disturbed by observation. The model designer would have no influence on the reality in a company and vice versa.

The caricature in Figure 7 shows a mole which is observed by a person. The ethologist camouflages himself with a molehill, in order not to influence the mole with his observation. Using this camouflage, the observer can observe the natural behavior of the mole without disturbing it. Without camouflage, this would not be possible. In the illustration, the subject-object separation is conserved. Separations of that kind can only be conserved if the observed object does not notice anything of the observation. As every kind of observation is detected in an enterprise, a separation of that kind is not possible in the reality of a company. As soon as the observation is perceived by the object, subject and object can no longer be regarded separately from each other. They mutually exert an influence on each other. In an observation, the model designer extends the object of cognition. As a consequence, he has to add himself to it and thus define a new, larger one (cf. Holl 1999, p. 204). The observer, who in turn is influenced by the object of observation, observes how the employees of the enterprise behave in the situation of his observation.

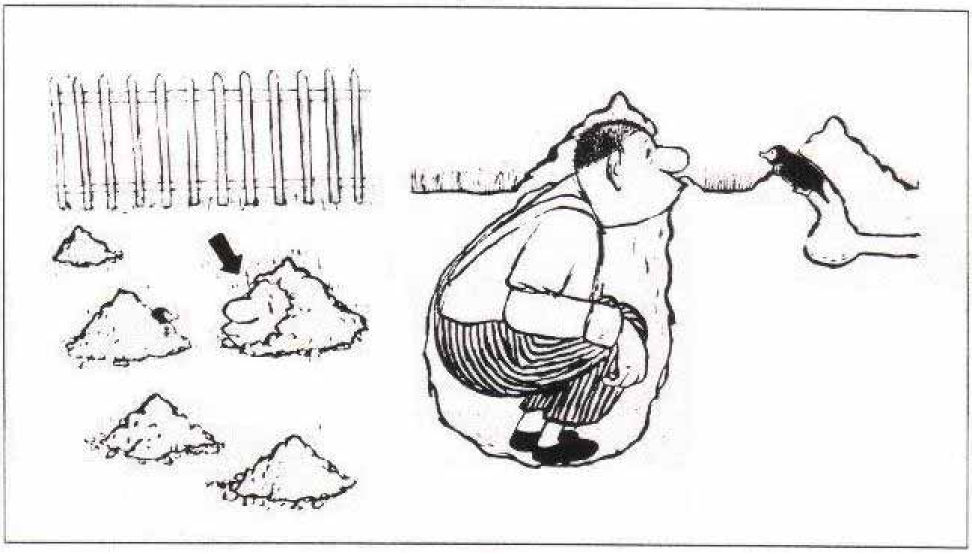

Figure 7: Ethologist and mole (Loriot 1968, p. 219, quoted from Schmidt 1993, p. 12)

1.1.5 Summary

The illustration of a modeling process in Figure 8 refers to several epistemological aspects at the same time:

1. The modeling process is reduced to mapping an object of cognition with a camera. This corresponds to a one-to-one image of reality (cf. 1.1.1). It is true that photos are abstractions as well, but we have learnt to ascribe to them an objective and documentary value.

2. It is considered as unimportant which object in the real world is photographed, assuming that there were no relevant differences between them. It is assumed that mapping always works with the same camera, which always delivers the same image quality (cf. 1.1.2).

3. The fact that the model developer is responsible for the modeling process is not made explicit. Therefore, his importance for the modeling process remains unclear. From an epistemological point of view, however, it is important to know that the model designer has not only a passive, mapping role, but that he has to be considered as an active component of the modeling process (cf. Holl 2002, p. 59). In Figure 8, the model designer neither has a passive, mapping role, nor is he an active component of the modeling process. He simply does not exist. Instead, he is replaced by some strange “custodial activities“ represented by a camera which maps passively up to a high degree and produces an “objective“ image. The subjective influence, which a model designer would have on the image, is ignored due to his absence (cf. 1.1.3).

4. Because of the absence of the model designer, the mutual influence between subject and object cannot be illustrated, either. In order to excuse the authors of Figure 8, one could say that an object is also influenced by an automatic camera (without any photographer) if he notices it (cf. 1.1.4).

Figure 8 is a bad example to illustrate modeling processes, as it supports the false expectations mentioned in 1.1.1 to 1.1.4 and ignores important "components", such as the model designer.

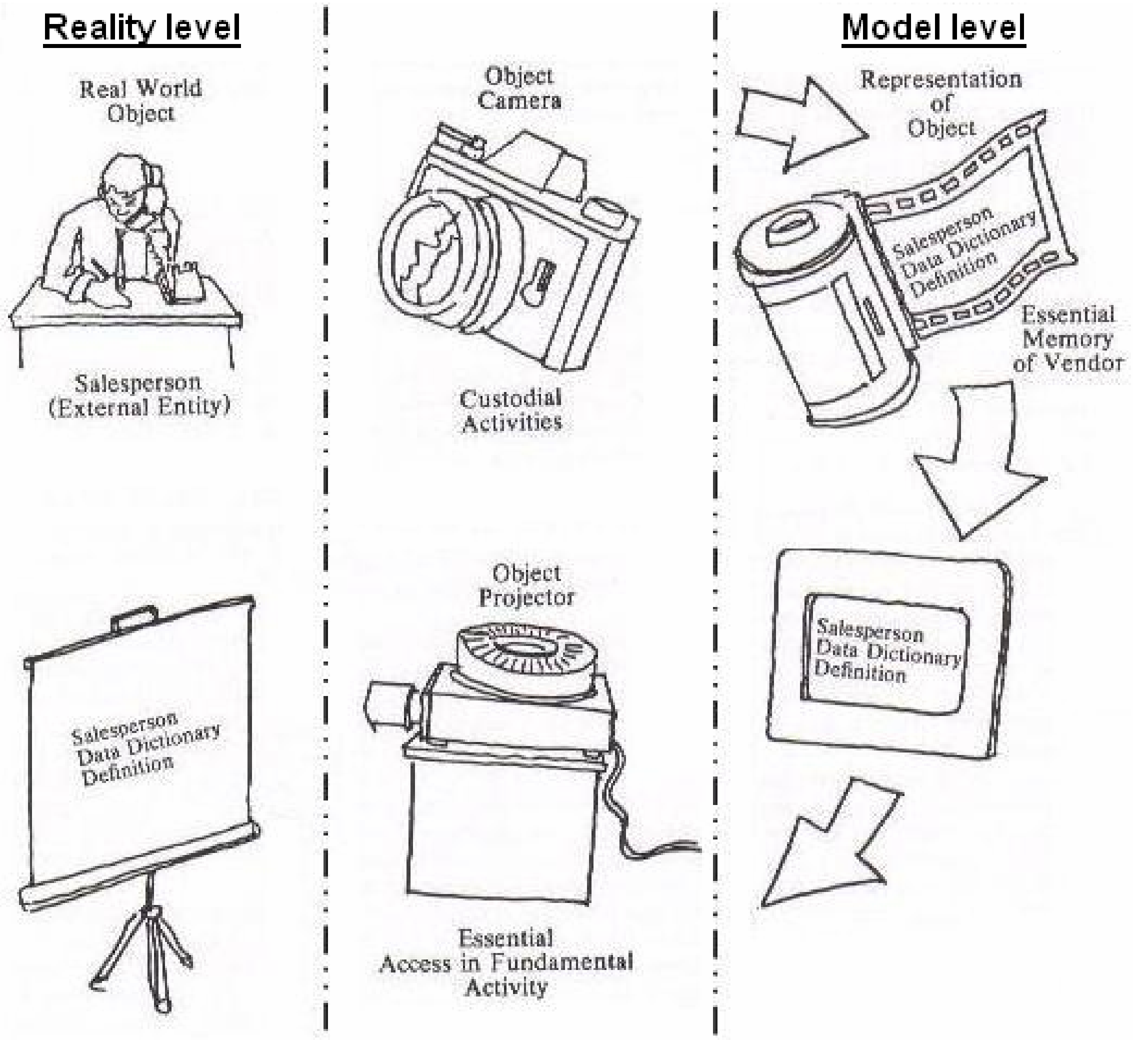

Figure 8: Illustration of the modeling process without epistemological foundation (McMenamin 1988, p. 54)

1.2 Generalization

After the four false expectations and their corrections were illustrated above, the fundamental epistemological problem complex can now be explained with regard to the four aspects corresponding to the examples in 1 (see Figure 9). These aspects cannot be completely disjoint, as every partition leads to gray areas.

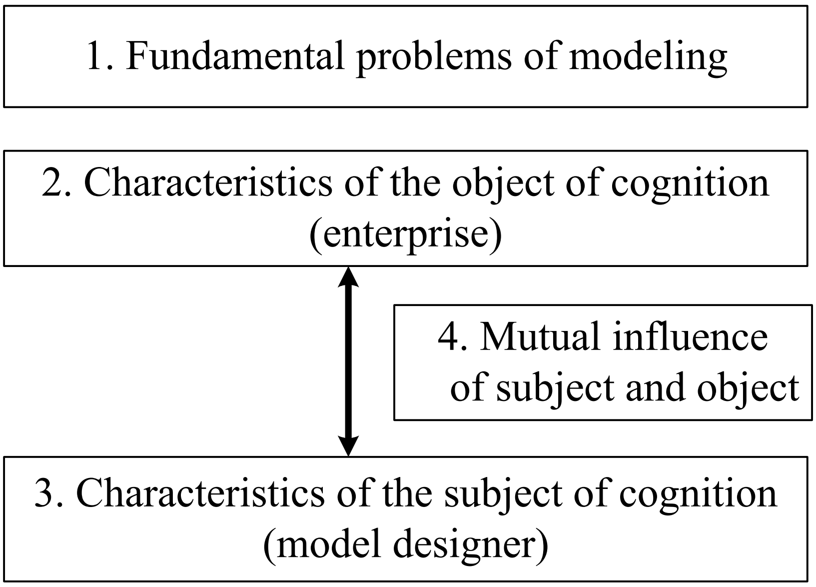

Figure 9: Epistemological aspects

1.2.1 Fundamental problems of modeling

Computers are formal, technical systems, which only understand formal language. They cannot deal with natural language. Therefore, models are represented in formal language. It is, however, not possible to map the entire reality or a segment of reality to a formal model without losing information. Reality is not completely formal and, therefore, can only partly be described in terms of a formal language (cf. Holl 2001, p. 13). As reality is only partly accessible to formalization, modeling leads necessarily to losses of information: A model will never exactly describe the reality it is supposed to represent. Reality is abstracted and distorted. Because of that, isomorphy between a segment of reality and a model of it can never be achieved.

In addition, the corresponding false expectation (cf. 1.1.1) is intensified by the following error: Frequently, there is no terminological distinction between objects of cognition on the reality level and those on the model level. In information systems, for instance, the term *business process* is used to describe a real sequence of events in a company, as well as a model of it.

In order to achieve a clear separation between the reality level and the model level, the terminology used must be defined in such a way that one can clearly distinguish between the model and reality (cf. Holl 2000, p. 198).

1.2.2 Characteristics of the object of cognition (enterprise)

An enterprise is an open, socio-technical system, which permanently exchanges information with other enterprises. Besides technical machines, it mainly consists of humans, who are not accessible to formalization. Knowledge that can be acquired about humans is only very vague when compared to knowledge about machines. Because of that, the latter possesses more formal quality than the former.

A company’s accessibility to modeling depends on the degree of its pre-formalization and the degree of its accessibility to formalization. Not every object domain is pre-formalized to the same degree, equally accessible to formal modeling and requires the same level of effort to formalize. According to these criteria, the following object domains are distinguished in Holl 1999, p. 196-197:

- “Scarcely pre-formalized object domains”, which are hard and difficult to formalize, such as certain forms of production. They require a considerable effort to formalize and exclude complete formalization.

- “Rudimentally pre-formalized object domains”, which are based on implicit formal models. The employees unconsciously use a formal model, whose terminology is scarcely established. Object domains of that kind can often be formalized comparatively well with an increased level of effort to achieve formalization.

- “Well pre-formalized object domains” which are based on highly explicit formal models. Employees consciously use a formal model, whose terminology is well established. Object domains of this kind, such as accounting, are easy to formalize and require a low level of effort to achieve formalization.

1.2.3 Characteristics of the subject of cognition (model designer)

Modeling in information systems is often considered as a purely artistic act, which is not accessible to a set of systematic methods and is determined by unconscious intuition. This opinion, however, does not reflect the *real* situation, as the model designer unconsciously uses cognitive strategies, such as abstract, analogic, associative and parallel thinking. Therefore, models are the result of the model designer’s cognitive processes. In their totality, they form a modeling process. It is at least partly accessible to methodic systematization and to human consciousness (cf. Holl 2002, p. 56).

The naïve assumption that modeling processes are independent of subjects, leads to the conclusion that models are objective. In this case, the properties of the model designer, such as his prior knowledge, which considerably influences the modeling process and the quality of the result, are totally ignored (cf. Holl 2002, p. 56). Glasersfeld comments: “Objectivity is the illusion that observations are made without an observer” (Glasersfeld 2002, p. 17, translated from German). Objective models can only be designed if no model designer exists. Without a model designer, however, there are no models, either. As the existence of a model designer is inevitable for the design of models, there are only subjective models and no objective ones.

1.2.4 The mutual influence of subject and object (model designer and enterprise)

Subject and object cannot strictly be separated, as “there are no subjects of cognition without objects of cognition and vice versa” (Holl 1999, p. 204, translated from German). The subject and object of cognition together form a new open system, where observation is executed. Due to that, there is mutual influence, which is explained in detail below.

Enterprises notice any kind of observation and change their behavior as soon as they are observed:

- While an employee is interviewed by the model designer, it can occur that the employee notices that he could make some of his activities more efficient. In this case, one can imagine the following reactions:

    - The employee changes his activities, but does not inform the model designer about the modification. The latter still knows the old ones.

    - The employee informs the model designer about the possible improvement, but keeps his old business processes unchanged.

- The employee intentionally describes his activities in a palliative way, e.g. to hide inefficiency (cf. Holl 1999, p. 205).

At the same time, the enterprise (directly or indirectly) exerts influence on the model designer:

- Depending on the personal chemistry between model designer and employee, the information flow is influenced positively or negatively: In case of antipathy, a tense atmosphere will predominate in a conversation. The model designer is less motivated and does not adequately take the employee's statements into consideration. If mutual sympathy predominates, however, the conversation will take place in a relaxed atmosphere. The model designer is more motivated, shows more interest in the employee's arguments and, therefore, can solve open problems more easily.

- Every human has different capabilities of presentation. Some can present facts exactly while others have difficulties in expressing and organizing their thoughts. If an employee cannot express his ideas exactly, the model designer has to interpret the statements to the best of his knowledge. As a consequence, facts are possibly understood wrongly or incompletely.

1.2.5 Summary

The naïve and false expectations mentioned, as well as the ignorance of the fundamental epistemological problems with regard to models and their design, are essential reasons for the failure of projects. Therefore, it is necessary in information systems to epistemologically examine the cognitive processes, which run during modeling, as well as the quality and limits of models.

2. EPISTEMOLOGY

In the scientific discussion of epistemology, there is not only one single approach. Many epistemological approaches, which take different and often strange opinions of the cognitive value of models, have their origin in philosophy as part of the humanities. Approaches useful for information systems did not arise before epistemological theories were established in the natural sciences. They were developed in the course of the 20th century.

In order to gain insight into different arguments, the following epistemological approaches are explained in 2.1 (see Table 1): naïve realism (2.1.1.1), critical realism (2.1.1.2), evolutionary epistemology (2.1.2), moderate constructivism (2.1.3.1) and radical constructivism (2.1.3.2). It will turn out that there is not a single particular epistemological approach which is suitable for every kind of object of cognition. This leads to an umbrella step model, which is illustrated in 2.2.

Table 1: Overview of epistemological approaches

Epistemological approaches	Relation reality - model
Naïve realism	One-to-one relation
Critical realism	Reality is only perceived with distortions.
Evolutionary epistemology	Gives explanations for distortions.
Moderate constructivism	Asks the questions whether and in which segments reality exists.
Radical constructivism	What humans perceive as reality, is pure construction. No matter whether reality exists, only descriptive categories are accessible to humans.

2.1 Epistemological approaches

Five epistemological approaches, which differ in their judgment of the relationship between reality and models, are explained below. Their views become obvious in the relation between *descriptive categories* and *immanent categories*. For a better understanding, these terms are briefly explained in advance: Descriptive categories are components on the model level, immanent categories belong to the reality level. Humans do not have any direct cognitive access to the reality level, but only an indirect one via images of the reality. They are described verbally with descriptive categories on the model level (cf. Holl 1999, p. 190).

2.1.1 Realism

Realism deals with reality or, as this word is often understood, the reality of humans, a reality which can be observed and perceived with the senses. In epistemology, the term *realism* means the opinion which has no doubt about reality outside of human consciousness. In this view, the world exists, whether we perceive it or not (cf. Popper 1993, p. 35).

There are different forms of realism. Naïve and critical realism are discussed below.

2.1.1.1 Naïve realism

“There is one real world; it has just the qualities that we perceive” (Vollmer 1994, p. 35, translated from German). That is, naïve realism takes the opinion that things are perceived exactly in the same way as they are in reality and that “objective” knowledge about reality can be acquired. Therefore, models are one-to-one images of reality, which is represented exactly, without losses and distortions. Every descriptive category corresponds to an immanent category and there is no constructed part. That is why the model designer can understand all of reality accurately in every detail, faithfully conserves its structure and describes nothing but reality. The model designer’s process of observation is purely passive mapping. The designer takes a passive role, as he only perceives and does not interpret.

It is true that this point of view is quite suitable for standard objects of cognition of everyday life. As soon as one deals with other domains, such as optical illusions or enterprise modeling, however, naïve realism quickly reaches its limits. This leads to its improvement in the form of critical realism.

2.1.1.2 Critical realism

Critical realism assumes the existence of reality as well. A one-to-one relation between segments of reality and models, as assumed by naïve realism, is rejected. In contrast to naïve realism, however, the model designer can only perceive reality with distortions. “There is a real world; not all of its features, however, have the same qualities as those which appear to us” (Vollmer 1994, p. 35, translated from German). These distortions arise from active and interpretive modeling processes. Critical realism, however, does not give any information about the reasons and the degree of the distortions.

Reality is mirrored in human consciousness via perceptions and mental performances. According to critical realism, there are recognizable relations between real objects and phenomena (in human minds) so that, for example, two persons, who perceive the same physical object, get images which are at least similar. Critical realism assumes cognitive progress, that is, approximation of knowledge towards the actual relations in the external world.

2.1.2 Evolutionary epistemology

Evolutionary epistemology provides explanations for the distortions detected by critical realism. It considers the human “world-depicting apparatus” (Konrad Lorenz) as a product of evolution, which cannot commit mistakes that expose human existence to danger. Therefore, the tension between models and reality cannot go beyond certain limits. The technical-cultural evolution of the past 5000 years, however, ran considerably faster than the biological one. Therefore, the human “world-depicting apparatus” has not had any possibility to adapt itself in full extent to objects of cognition, which meanwhile have completely changed. The result is that cognitive strategies of the stone age are still used today, with the effect that considerable tensions between models and reality can arise with regard to complex cultural objects of cognition, such as enterprises and business processes. The human “world-depicting apparatus” still uses the cognitive strategies learned in the course of biological evolution. They are not always automatically advantageous for the design of formal models, particularly as the model designer is not aware of them (cf. Vollmer 1994, p. 188-189).

On the basis of this analysis, evolutionary epistemology can explain the defects of cognitive strategies in modeling processes in detail. Thus, on the one hand, it permits a judgment of the degree of non-isomorphy and, on the other hand, it shows ways leading to counter-measures, that is, to the reduction of the tension between reality and model.

2.1.3 Constructivism

Constructivism questions the importance of a reality outside of humans for human knowledge acquisition and even its mere existence. There are different forms of constructivism. In the following, we distinguish between moderate and radical constructivism.

2.1.3.1 Moderate constructivism

As mentioned above for critical realism, moderate constructivism does not consider humans as passively perceiving beings, but as beings who construct their world on their own. In comparison to critical realism, the constructed part of human descriptive categories is emphasized more strongly. The question remains up to which degree certain segments of reality exist at all, to what extent we can recognize them and whether there is a corresponding immanent category to every descriptive category. One does not know whether there is some segment of reality "behind" every part of knowledge. There are at least some domains of human knowledge without any relation to a segment of an external reality, for instance, equations with algebraic numbers and an unknown, as in schoolbooks, and particular definitions in advanced pure mathematics.

2.1.3.2 Radical constructivism

"Radical constructivism is especially radical, as it breaks conventions and develops an epistemology in which cognition no longer affects objective reality, but exclusively the order and organization of experiences in the world of our phenomena" (Glasersfeld 1985, p. 23, translated from German). That is, radical constructivism takes the view that reality, as it appears to humans, is an independent human construction. What humans experience as reality, is pure construction. It makes no difference whether the world exists or not, humans only have access to descriptive categories and not to immanent categories. They consider their constructions as reality no matter whether an independent external reality exists or not (cf. Fischer 1995, p. 9).

Radical constructivism is the exact opposite of naïve realism. In the discussion of epistemological questions, advocates of radical constructivism repeatedly refer to naïve realism. In this context, naïve realism serves as a negative example which supports radical constructivism (cf. Diesbergen 1998, p. 24).

This approach goes too far for information systems, as the question would arise whether reality in a company exists at all.

2.1.4 Summary

The diagram in Figure 10 shows how some of the epistemological approaches discussed above judge human knowledge: naïve realism, which assumes an objective view, critical realism and moderate constructivism, which assume subjective views and, in addition, radical constructivism, which does not recognize any object of cognition that is outside of humans and accessible to human cognition and, therefore, permits constructed views only.

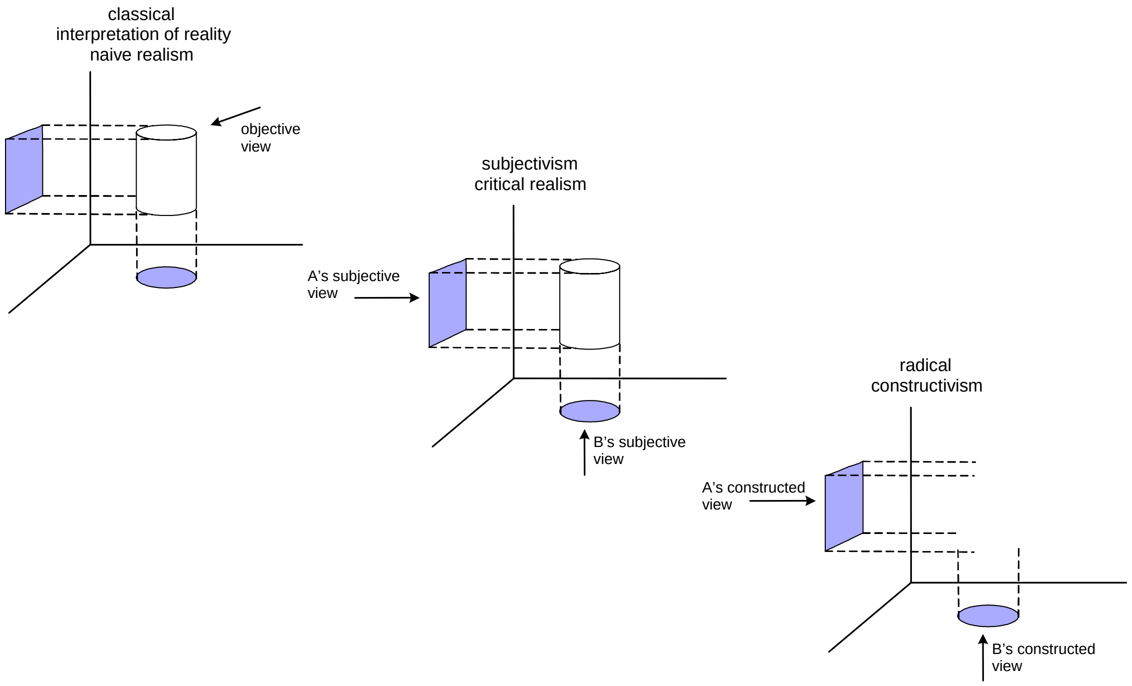

Figure 10: From objectivity via subjectivity to constructivism (Goorhuis 1994, p. 83)

There are, however, constructed parts of human knowledge with regard to everyday objects already. This is due to the fact that every interpretation of reality is determined by biological and social norms of cognition. An example for the dependency on the former can be found in the field of color perception. Humans with defective color vision experience colors in another way than people with normal color vision. That is why a person with defective red-green color vision has a color perception of a “red” strawberry which a person with normal color vision would call “yellow”. Defects of color perception can be detected with the help of color contrast pictures, as shown in Figure 11. Humans with a special form of red-green blindness cannot see the 74, which is visible for humans with normal color vision (cf. Goldstein 1997, p. 143).

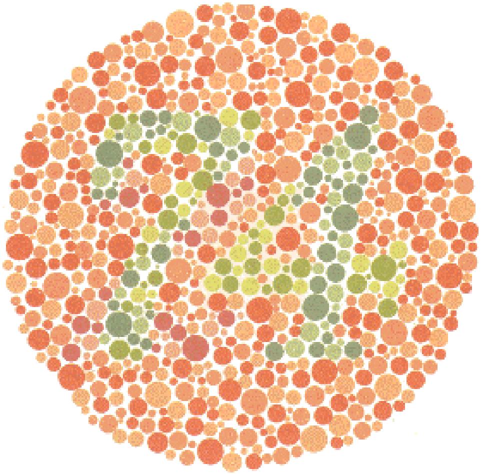

Figure 11: Ishihara table (Goldstein 1997, Farbtafelserie 2 – Farbtafel 4.6)

Not only humans with defective color vision have different color perceptions, but also persons with normal color vision (at least in a certain degree). These differences are assumed to have their origin in very small differences in the structure of visual pigments. Visual pigments are photosensitive molecules in the outer segments of rods and cones. The latter are located in the retina of the eye; they are responsible for the detection of black-and-white contrasts (rods) and for the color perception (cones) (cf. Goldstein 1997, p. 153). Because of these small differences, humans do not have exactly the same color perceptions. That way one person can perceive, for instance, the color red "a little bit differently" than someone else. This results in the fact that "the change of one single nucleotide can put people into different phenomenal worlds" (Mollon 1992, p. 378, translated from German).

As every interpretation of reality is influenced by biological and social norms, already on a "simple" physical-chemical level, where one would hardly assume it at first sight, every piece of knowledge always contains a constructed part. This fact is illustrated in Figure 12, which shows the different relative sizes of the constructed part of human knowledge with regard to some exemplary objects of cognition.

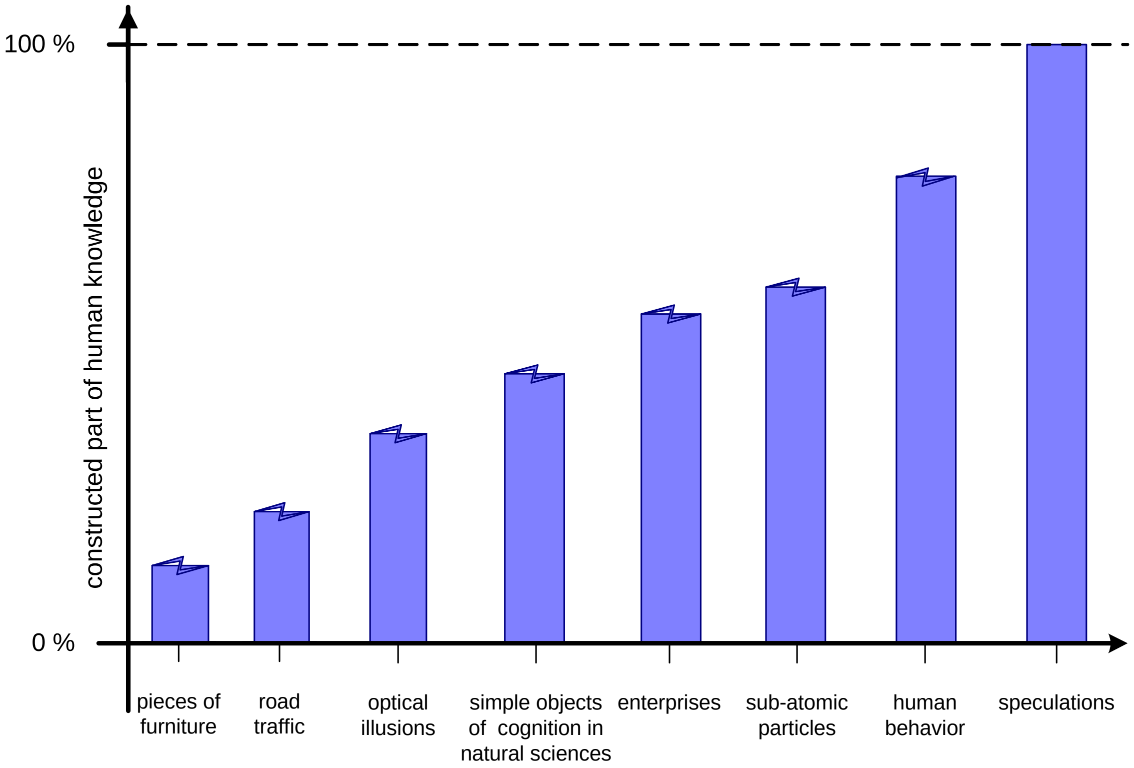

Figure 12: Constructed parts of human knowledge and exemplary objects of cognition (1)

The size of this part cannot be determined precisely. An improved illustration is shown in Figure 13.

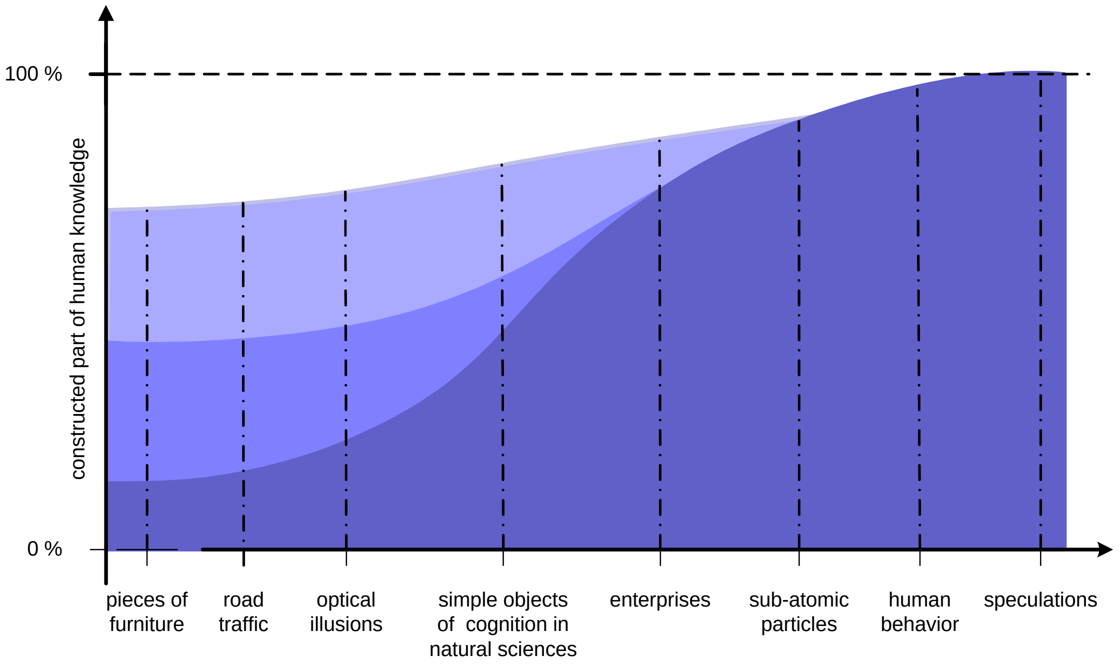

Figure 13: Constructed parts of human knowledge and exemplary objects of cognition (2)

2.2 Step model

At the end of the discussion, the question arises which epistemological approach can be considered as correct. One single epistemological approach is not suitable to adequately describe all of the objects of cognition and all of the situations of perception. Therefore, a more abstract epistemological step model is required, under whose roof the gap between naïve realism and radical constructivism can be bridged. The basis of the step model is that different epistemological approaches assume different sizes of the constructed part of human knowledge, as shown in Figure 14.

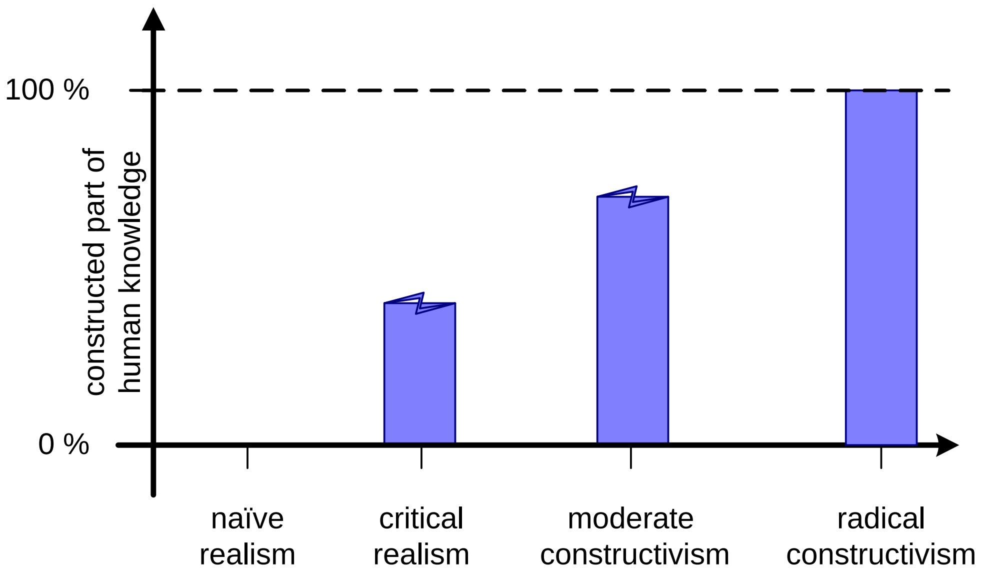

Figure 14: Constructed parts of human knowledge and epistemological approaches

Therefore, the step model postulates that different theories are needed for different objects of cognition. In a concrete case, the best suitable epistemological approach has to be selected (cf. Holl 1999, p. 186). Table 2 joins Figure 12 and Figure 14 and assigns the best suitable approach to each exemplary object of cognition.

Table 2: Epistemological approaches and exemplary objects of cognition

Epistemological approaches	**Objects of cognition**
Naïve realism	Pieces of furniture; road traffic
Critical realism	Optical illusions; simple objects of cognition in natural sciences; enterprises
Moderate constructivism	Sub-atomic particles; human behavior
Radical constructivism	Speculations (mental and abnormal)

The conditions of cognition for simple objects of cognition in the physical everyday world, such as pieces of furniture and road traffic, are described by naïve realism. Objects of cognition with a slightly higher constructed part of cognition, such as optical illusions, simple objects of cognition in natural sciences and enterprises as objects of cognition of requirements engineering require critical realism. Aspects of human behavior and sub-atomic particles (often only represented by mathematical formulae), however, are described best by moderate constructivism. Mental and abnormal speculations only consist of pure constructions and do not have or need any corresponding immanent categories. Therefore, these object domains are only adequately described by radical constructivism.

Information systems require a view which is based upon realism. In this case, one can generally say that objects of cognition are not oriented towards epistemological approaches, but that every object of cognition fits to a certain approach in a particular way.

3. EPISTEMOLOGY IN INFORMATION SYSTEMS

Up until now, only the basic relationship between epistemology and information systems was made evident. This chapter shall now explain in detail the relation between epistemology and requirements engineering. For this purpose, a brief overview of requirements engineering is given in 3.1. Its relation to epistemology will be investigated in 3.2. Requirements engineering, however, is not the only area of information systems which could profit from epistemological knowledge. Cognitive processes run during the elicitation of a current state in the context of systems analysis could benefit as well. They are demonstrated in 3.3 and compared with the design of a planned state in the context of requirements engineering.

3.1 Foundations of requirements engineering

“Requirements are statements about properties and performance of a product, a process or the persons involved in the process” (Rupp 2004, p. 11, translated from German). In the context of this paper, a requirement describes a feature to be met by a software product. Figure 15 shows the general method for the construction of requirements and, therefore, represents the life cycle of a requirement. The *inquiry* of requirements has the aim to establish the features which a future information system has to meet. For this purpose, methods, such as interview or questioning, are used frequently. After the requirements are acquired, they are *recorded* in a requirements document. Next, during the requirements *analysis*, the quality of the requirements descriptions is checked by verification and validation. Verification shall find out whether a requirement description meets certain criteria, e.g. completeness. Validation, however, shall detect whether a requirement description represents the customer's wishes adequately. Finally, when *accepted,* the requirements are handed over to the next step in the software process (cf. Partsch 1998, p. 27-37).

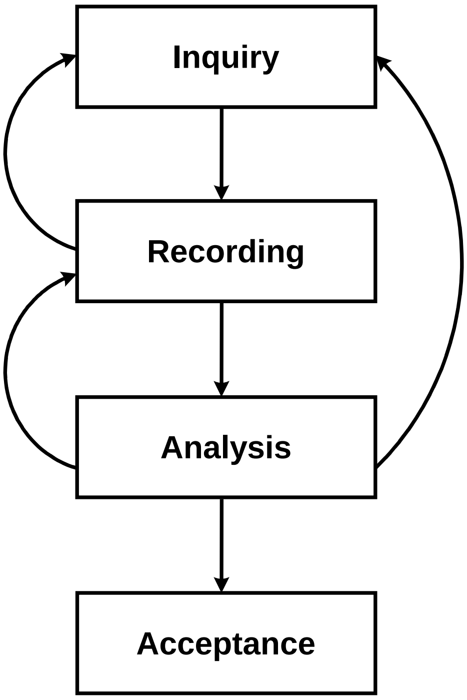

Figure 15: Life cycle of a requirement (Partsch 1998, p. 27)

Requirements engineering as a part of problems analysis in a software life cycle covers, above all, the following partial tasks: requirements acquisition, requirements definition and requirements analysis. Furthermore, other tasks, such as the management and adaptation of requirements, are often mentioned. It is not considered as a task of requirements engineering to check the observance of the requirements in the course of software development and to provide a general version management with regard to modifications (cf. Partsch 1998, p. 20).

As an independent discipline of information systems, requirements engineering possesses a wide range of tasks: "Requirements Engineering is a systematic approach to the development of requirements through an iterative process of analyzing the problem, documenting the resulting requirements, insights, and checking the accuracy of the understanding so gained" (Rzepka 1985, p. 9-12 quoted from Partsch 1991, p. 26). Requirements shall systematically be acquired, described, analyzed and completed (cf. Rupp 2004, p. 11).

Requirements have different tasks in software development. They can be divided into primary and secondary ones. Primary requirements immediately affect the software process, for instance they serve as a communication basis of all of the persons involved. Secondary requirements, however, affect the planning phase and, additionally, the time after the completion of the future information system. They do not have an effect within the software process, but outside of it. An example for a secondary requirement is the recognition of rationalization potentials in business processes (cf. Rupp 2004, p. 11-12).

As requirements serve as a basis for the entire software process, they should be described as complete, consistent, comprehensible, unambiguous and correct as possible. All of the requirements established during the requirements analysis are recorded in requirements documents (cf. Rupp 2004, p. 21-24). To improve their readability, to guarantee their reusability and to simplify their analysis, requirements can be classified in different ways (cf. Rupp 2004, p. 140).

A more detailed method to systematically derive more precise requirements from inexact ones is, for instance, the "SOPHIST set of rules" developed by Sophist. Methods from other disciplines, such as linguistics, psychology and psychotherapy, are combined to systematically recognize and eliminate errors in requirements in a natural language (cf. Rupp 2004, p. 198). The "SOPHIST set of rules" is now briefly explained.

To cope with the loss and distortion of information during the requirements inquiry, linguistic transformations which occur during the verbal formulation must be eliminated and requirements must be extended by further knowledge. It is necessary that the information systems expert possesses knowledge about the possible types of transformations, such as *deletion*, *generalization* and *distortion* (cf. Rupp 2004, p. 199-200).

Deletion means a "process which reduces the world of dimensions we can handle" (Rupp 2004, p. 204, translated from German). One kind of deletion leads to incompletely specified statements; a requirement is not formulated completely and raises questions. An example is: "The development of software ..." In this case, questions arise, such as: who develops, when and why? To establish transparent requirements, they must be formulated in such way that questions of that kind never appear.

"*Generalization* is a process separating an experience from the original experience, the former is then considered as generally valid" (Rupp 2004, p. 214, translated from German). Incompletely specified conditions are a form of generalization. In this case, requirements often only describe the necessary actions if a condition occurs, but not the ones if it does not occur, as in the following statement: "If the error X occurs in the last phase of program Y, then...". But what shall be done if the error occurs in another phase or if it does not occur at all?

"*Distortion* is the process where facts, reality and experience are changed and even falsified" (Rupp 2004, p. 220, translated from German). A type of distortion is normalization: verbs are converted to nouns, as for instance "losing data" in "data loss". The normalized expression need not be complete. "Data loss" leads to the questions when, how and why which data was lost.

Further types of deletion, generalization and distortion could be listed. This, however, would exceed the scope of this contribution. Explanations in detail with counter-measures can be found in Rupp 2004, p. 204-229.

3.2 Relation between requirements engineering und epistemology

After the range of requirements engineering was defined in 3.1, the question has to be answered, why requirements engineering can be considered as a form of applied epistemology in information systems.

The information systems expert receives the company's requirements at first in natural language, in the form of "pre-requirements" (pre-stage of a requirement). Contrary to formal language, natural language is ambiguous and, therefore, leaves room for interpretation. To remove verbal ambiguities, the information systems expert has to transform the "pre-requirements" into formal requirements. On both levels, requirements are special forms of knowledge, as the result of cognitive, empiric methods, such as, for instance, observation and formalization. During requirements inquiry and analysis, knowledge in the epistemological sense is gained. Requirements engineering is probably the only field of information systems which already practices epistemology – even if only implicitly –, in so far as it reflects its knowledge-gaining processes systematically and methodically, that is, not just applies them. Therefore, requirements engineering does not only have knowledge acquisition as its task, but, additionally, makes knowledge acquisition its implicit research object (see Figure 16).

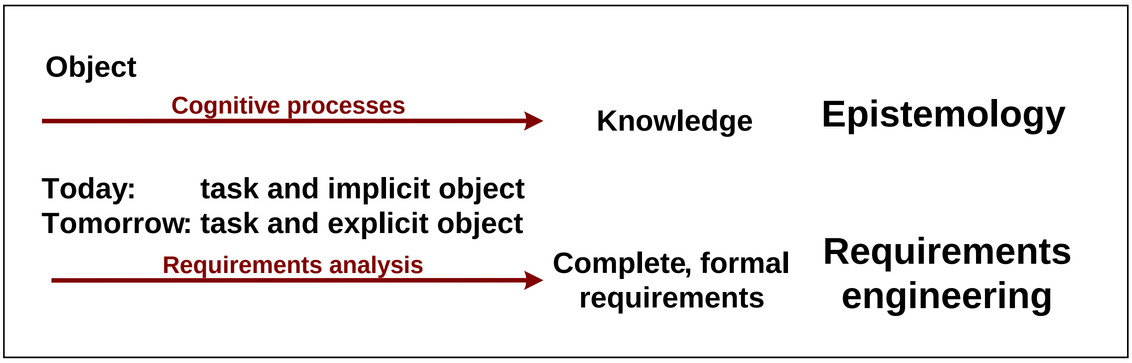

Figure 16: Relation between epistemology and requirements engineering

Requirements engineering, however, is not the only discipline of information systems where epistemology can be applied successfully. In the area of systems analysis, cognitive processes run as well. Therefore, epistemology should be taken into consideration there as well. It is a pity that this has not been done in practice up until now.

In order to more clearly present possible applications of epistemology in information systems, the cognitive processes of systems analysis and requirements engineering are explained in parallel in the next section.

3.3 Cognitive processes in information systems modeling: systems analysis and requirements engineering

While eliciting the current state, the information systems expert acquires knowledge about the enterprise, on the one hand, by direct observation, and on the other hand, by questioning (interviewing) the employees (see Figure 17). In the case of pure observation, facts and business processes are elicited via sensory perception by the information systems expert, without the need of verbal communication with employees (for instance, via form analysis). The employees continue working on their usual activities. In the case of interviews, however, the information systems expert asks the employees verbal questions and receives (if possible) immediate responses, which he records right away (cf. Häuslein 2004, p. 49 and 58). On the basis of combining observation, questioning and his prior knowledge, the information systems expert creates "pre-models" (pre-stage of a model) of the regarded domains in his mind (cf. Holl 2000, p. 201-202).

Compared to eliciting the current state, where "pre-models" are created, an analogous method is used for designing the planned state. The information systems expert establishes "pre-requirements" by direct observation and interviewing of the employees (analysis of the current state) or receives them in lists from the employees or management (see Figure 17). In order to transfer knowledge about the enterprise to the information systems expert or to formulate requirements by himself, an employee must at first interpret reality in a company he is part of. Every one perceives reality differently and constructs an individual image, his personal reality, with the help of cognitive processes. During formulation, communication and assessment of requirements (requirements construction), misleading modifications are made where information is lost and, therefore, reality and, as a consequence, requirements are distorted (cf. 3.1 and Rupp 2004, p. 199). If an employee establishes requirements by himself, assessing cognitive processes run in his mind by means of which he judges segments of reality in a company, and subsequently creates requirements, which in his opinion improve the business processes.

"As a principle, the starting point for any model system is an, at first roughly outlined, idea of a model" (Kulla 1979, p. 52, translated from German). In the same way, information, which the information systems expert initially receives in natural language, is only a set of "rough" ideas of models, that is, a set of "pre-models" or "pre-requirements". They are inconsistent, fragmentary, contradictory and, therefore, do not have the desired quality. In order to eliminate these defects, he has to examine the "pre-models" or "pre-requirements" whether they are formally useable. Only then can he arrive at a formal survey of the current state (descriptive model) and a formal concept of the planned state (prescriptive model) (cf. Holl 2000, p. 203) (see Figure 17). In contrast to the elicitation of the current state, methods of requirements engineering can be used for the design of the planned state, which in this case already today runs in a methodic and structured way (see below).

While eliciting the current state, as well as while designing the planned state, the information systems expert inductively gains general knowledge from single observations and previous experiences and thus creates descriptive and prescriptive models (see Figure 17). In this process, "a multiple change of the original perceptions takes place" (Kulla 1979, p. 50, translated from German). According to Popper, safe knowledge can never be acquired, even less so in a purely inductive way. The observation of whatever quantity of white swans cannot exclude the existence of black ones (cf. Popper 1971, p. 1). For the development of models of the current state or of the planned state (requirements), inductive methods have to be accompanied by deductive ones. That is, predictions about reality have to be derived from the model and to be checked on the basis of further observations, interviews and simulations. If it turns out that the present model does not represent current or planned reality precisely enough, it will be modified considering the recently gained knowledge and checked once more (cf. Holl 2004, p. 383). "That way, the model is made safer than the previous version" (Kulla 1979, p. 53, translated form German). By means of the integration of induction and deduction in a maieutic cycle (experiencial learning model), models are improved iteratively until a satisfactory result has been achieved (cf. Holl 2004, p. 385).

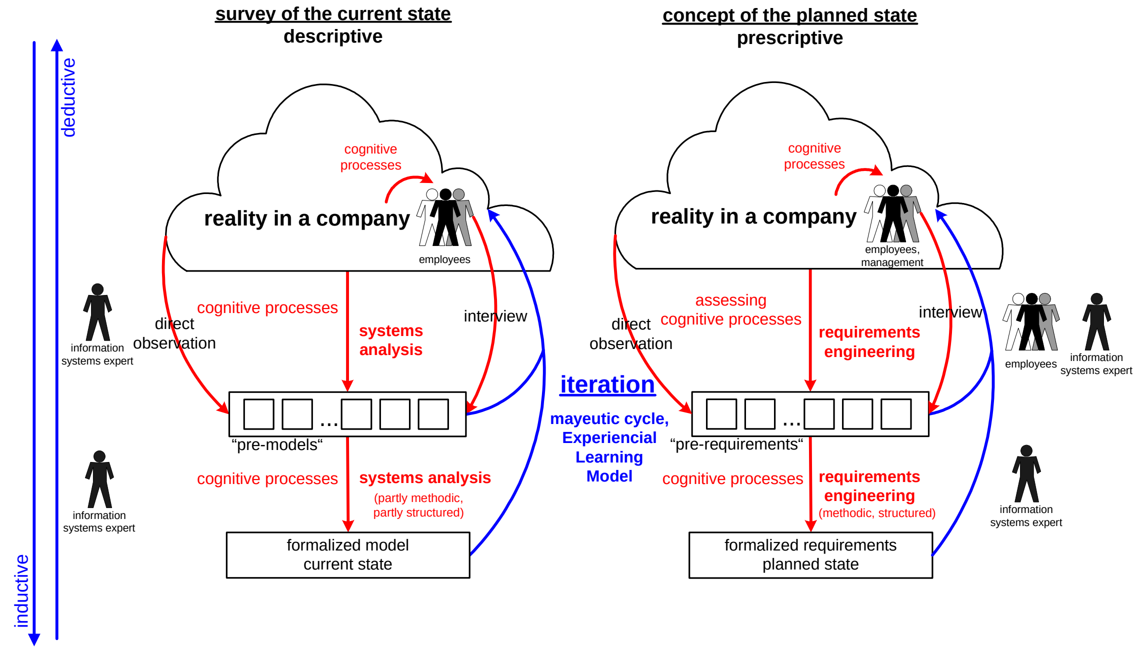

Figure 17: Cognitive processes in information systems

Figure 17 shows that cognitive processes run in parallel in the cases of current and planned state modeling. Contrary to requirements engineering, systems analysis is only little a systematic and partially structured. Therefore, today's systems analysis would profit from an epistemological foundation on the basis of cybernetic systems theory (see Table 3).

Table 3: Partly methodic and structured vs. epistemology-based methods of information systems

Level	**Partly methodic, partly structured**	**Epistemology-based**	**Epistemological foundation**
Eliciting the current state	Systems analysis	(Missing)	Systems theory
Designing the planned state	Business concept modeling	Requirements engineering	Linguistics, psychology, …

Unfortunately, this fact is not yet recognized in today's information systems. According to Kulla "the original demand of cybernetics and systems theory researchers for an interdisciplinarily applicable approach to finding universal laws in different domains of reality cannot be considered as accomplished" (Kulla 1979, p. 15, translated from German). Therefore, systems analysis would also be a profitable application area for epistemological considerations.

In the next chapter, the results of this contribution are joined and the benefit is illustrated which requirements engineering can gain from explicit knowledge about epistemological connections.

4. CONCLUSION: BENEFITS FROM THE EXPLICIT APPLICATION OF EPISTEMOLOGY

Up until now, it has been shown that epistemology is implicitly applied in the field of requirements engineering, as one already deals with the cognitive processes of requirement construction in a relatively conscious systematic and methodic way. In information systems, however, this fact has not yet been noticed sufficiently. Three positive effects can arise from this situation.

- **Benefits for requirements engineering:** The requirements engineering community should realize that it already implicitly applies epistemology. In the future, one should not only do it implicitly any longer, but explicitly and emphasize it strongly. One should apply epistemological considerations consequently, systematically, explicitly and consciously. Thus, one can, on the one hand, better demonstrate the theoretical foundation of requirements engineering and gain more benefit from it. The more detailed and the more exact the epistemology-based knowledge about cognitive processes is, the more one can improve requirements analyses. On the other hand, requirements engineering can strengthen its position in information systems and take over a leading function.

- **Indirect benefits for information systems:** Requirements engineering is an excellent example for the application of epistemology in information systems. Thus, requirements engineering plays a pioneer role and shows the value of epistemology in information systems. The success of requirements engineering in its projects and its reputation in information systems and software development, however, are still far apart. Requirements engineering deserves a fairly large recognition and propagation, as it is the discipline of information systems which is epistemologically far advanced. Thus, requirements engineering can also help other disciplines of information systems (in particular systems analysis) to recognize the benefits of epistemological considerations.

- **Direct benefits for information systems:** A great deal of the phenomena encountered in information systems cannot be explained completely and definitively by information systems itself. One must go beyond its borders and, among others, consult epistemology. This is necessary as formal enterprise models inevitably form the necessary basis for every business information system and, therefore, the ignorance of the fundamental cognitive problems with regard to models and their design are essential reasons for the failure of projects. As a result, it is important for information systems experts to be profoundly conscious of the difference and the conflict between the reality in companies and formal enterprise models. This consciousness is developed by learning about epistemological issues, that is, the epistemological examination of the cognitive processes, which run during modeling, as well as the epistemological judgment of the quality and limits of models. Thus, an increased epistemological understanding is obtained and an appropriate epistemological theory is consciously chosen: naïve realism is renounced in favor of critical realism and moderate constructivism. Epistemological considerations generally characterize the reasons and the nature of the inevitable discrepancies between reality and model. Although there is no single all-encompassing result, which can be formulated in one sentence, there are a lot of partial results. It is true that knowledge of epistemological connections does not eliminate the fundamental cognitive problems (no modeling method can do that) and does not provide recipes for perfect enterprise models. It does, however, considerably reduce the undesired effects of cognitive problems in the design of business information systems.

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