BRIDGING DISCIPLINARY GAPS IN STUDIES OF HUMAN-ENVIRONMENT RELATIONS: A MODELLING FRAMEWORK

Michael Hauhs, Baltasar Trancón y Widemann and Georg Klute

Abstract: Modern human-environment relations are problematic and difficult to analyse in terms of nature and culture. Many authors suggest to abandon and overcome the nature-culture dichotomy in order to reorganise the academic division of labour, not only on environmental questions. Anthropologist Philippe Descola, for example, surveyed the empirical evidence of patterns in human-environmental relations, suggesting four abstract cosmologies. Here, we propose a translation into a modelling terminology, which is compatible with the formalisation of programmes in computer science. The generalised framework contains four ideal types of modelling paradigms. It can be tested on various other classification schemes in a number of disciplines. In each application, the categories of classification can be translated and then the patterns of the four logic types can be compared with the phenomenology of each case. Implications for interdisciplinary cooperation between science and the humanities are sketched for some environmental issues. This work demonstrates how tools from computer science can help, metaphorically, conceptually and technically, to organise interdisciplinary exchanges between science and the humanities. The categorical approach of applying the “divide and conquer” technique to different disciplinary models serves as a yardstick for comparing the implicit logic and modelling assumptions across examples whose phenomenological contents appear as unrelated. It gives useful hints how a dilemma of choosing between rigorous or relevant models can be resolved (e.g., in environmental science) and how the nature-culture dichotomy might be replaced by a general and flexible framework of a few model types.

Modern Africa: Politics, History and Society
2017 | Volume 5, Issue 2, pages 35–76
https://doi.org/10.26806/modafr.v5i2.196

Keywords: *Nature-Culture Dichotomy, Descola Cosmologies, Model Classification, Interdisciplinary Modelling, Modelling Framework, Category Theory*

Introduction: Modelling as an Interdisciplinary Method

Division of labour has been a key feature of the modern worldview: Problems are recognised as reoccurring and their instances can be split into simpler parts, which can be solved by appropriate methods before a solution of the posed problem can be reassembled from the efficient solutions of its parts. In computer engineering this scheme is termed “divide and conquer.” In the scientific realm, division of labour takes the form of disciplines, characterised by abstractions, theories, subjects and methods. Here, we will inspect the role of this division of labour when dealing with environmental problems of modernity, which often require interdisciplinary cooperation. One of the responses in academia to contemporary problems of modernity involving several disciplines has been area studies (Hunt 2014). Splitting the globe into areas allows focusing on problems somehow simpler than those perceived for the global scale. A second response is division into disciplines, chiefly along the Cartesian nature-culture distinction with subsequent methodological refinements.

Though widely criticised the delineation into realms of nature and culture has been difficult to overcome (Ingold 2000, 2011; Latour 2010, 2013); in the natural sciences it still remains the most important analytical and management tool to deal with environmental problems. An integration of disciplinary results is sought either by working in the same area or by modelling. Hence, environmental problems are perceived and handled as *applied* science; criticism towards fundamental aspects such as the incompatibility of disciplinary languages and concepts across the nature-culture gap are often disregarded.[1]

Attempts at overcoming the familiar nature-culture dichotomy are no longer limited to the academic realm but have reached the wider public

---

[1] For example, global biodiversity is assessed by areal inventories of species. The goal and success of nature protection is measured in terms of surface area of the earth: with space being regarded as the “most effective tool in halting the biodiversity crisis” (Montesino-Pouzols et al. 2014). Spatial delineation along the nature-culture dichotomy remains deeply ingrained in the modern worldview (Tarnas 1996).

as well. The question is which other terms and tools are appropriate for a systematic/scholarly approach to human-environment relations. In sociology, the concept of reflexivity ("reflexive modernity") has been used as an analytical notion (Beck, Giddens and Lash 1994). However, considering environmental problems as self-referential or reflexive is difficult to translate into current notions of natural science, which idealises the human observer as "detached" and translates reflexive relations as feedback. While natural sciences have the advantage of offering models with mathematical formalisation they may have become methodologically limited under conditions of the Anthropocene. How can these limits be complemented with more appropriate views from other sciences, especially the humanities, while maintaining their mathematical rigour?

Thus, the goal of this article is to propose an appropriate form of integration between disciplines by an abstract modelling framework, capable of bypassing some (conflicting) metaphysical or epistemic presuppositions of disciplinary models. To this end, we describe and test a common logical framework behind (computer) model application in different disciplines. It is demonstrated that current attempts to overcome the nature-culture dichotomy in various disciplines may result from over-interpretations of the respective underlying models. Such interpretations either fail, or are impossible to translate into each other's languages.

Our approach seeks integration at an abstract level; it introduces a framework that puts four model types into mutual relations. We demonstrate the shared logic of different disciplines by relating this framework to some simple 2×2 classifications. First, a top-down step translates the distinctions of the formal framework into the axes of the various disciplinary 2×2 classifications and second, a bottom-up step relates the logical form of the classified subjects with the four abstract model types. Only the formal oppositions and not the content of these classifications are taken into account (Table 1). The comparison reveals a consistent pattern across a wide range of disciplinary content. The different viewpoints and interpretations within disciplines appear "naturally" from the framework and its possible simplification from three into two dimensions of modelling.

Table 1. Three Dimensions of Modelling

Dimension	**Empirics**	**Models**	**Mathematics**
used here as:	world-side	mediator	language-side
methodolog. notions (philosophy, Koch 2012)	phenomnological, transcendental	analytic, synthetic	hermeneutic, metaphysical
disciplinary classifications	4 cosmologies (Descola 2011)	4 simple computer models	4 logical types (computer science)

Empirics depicts the world-side of grounding models, mathematics stands for the language-side of models, models act as mediators and can be classified on the basis of their logical structure.

Fundamental Notions of Modelling

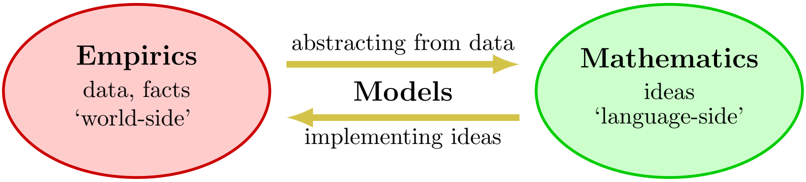
The three notions of truth in philosophy (Koch 2016), have served as a useful framing of this classification exercise. As an interdisciplinary task, model classification shares with philosophy the necessity of resorting to the use of a general language. Here, we benefited from the universal technical (software) background of computational models and from the universal mathematical language in which such models can be specified (Trancón y Widemann and Hauhs 2015). We employ the notions from Koch (2012, 2016) for illustrating philosophical implications of the approach.

Computational models are regarded as a special form of sentences signifying beliefs about the world in the form of propositions. They share with beliefs the basic structure of combining a designation (a concrete, individual subject) with a predication (a general variable). In their mediating, role computational models link the world we live in to the structures we think in. In computational models, data represent the world-side (of empirics), mathematics represents the language-side; the computer as mediator represents the practical aspect of discourses among disciplinary experts (Figure 1).[2]

---

[2] In philosophy the relation between reality, perception by human senses and beliefs about prepositions often puts perception into the mediator role in the middle. Here, we follow Rosen's modelling relation (2012) putting models into the centre.

Figure 1. Models as Mediators



Models act as mediators with links to a world-side (Empirics) and a language-side (Mathematics). The factual, world-side invites ontological interpretations about its status; the language-side invites interpretations about epistemology; models represent practical philosophy (after Rosen's modelling relation, 2012).

How is this scheme related to the nature-culture dichotomy? Table 1 gives an overview of the argument. A classification of abstract model types is used as a basis for comparison between disciplines. The respective ontologies of what the world-side "consists of" is not regarded as a given, realistic foundation but as an interpretation resulting from successful model applications. Likewise, these epistemologies reflect the role of subjects (actors, agents) in the respective modelling contexts only. These notions will not be used at the abstract level of model integration. The first, *abstract* link between empirics and mathematics does not refer to the nature-culture dichotomy at all (first row in Table 1). The second link between the three dimensions of modelling is provided by philosophical notions of interpretation (second row in Table 1). They can be used as coordinates of four abstract modelling types. Concerning the third, the *disciplinary* link, we argue that the nature-culture dichotomy results only from one or two out of three possible simplifications within the framework. The implicit assumptions behind these different simplifications are in conflict which each other and do not only impede interdisciplinary models, but interdisciplinary work as such. Hence, the dichotomy appears only as a part of model interpretations within the various disciplines. We argue that this can be avoided by more careful interpretations (epistemic hygiene).

Four different modelling types have been identified that represent prominent and simple examples of computational models in different disciplines. Here, they are used as types of model logic and will serve as a (universal?) yardstick by which disciplinary classifications are compared. A much more difficult task would be to agree on a joint ontological or epistemological approach that is shared by the various disciplines *before* selecting models for environmental problems. Environmental issues are often perceived as complex and their research tasks as interdisciplinary. In our approach, interdisciplinary modellers only need to agree on the logical model type following the advice by Robert Rosen (2012): "For in a profound sense, the study of models is the study of man: and if we can agree about our models, we can agree about everything else."

The translation between a classification of disciplinary empirical findings and the four types of modelling logic (third row in Table 1) shall begin with Descola's cosmologies (Descola 2005). We argue that Descola's four epistemologies reflect the four types of model logic. However, the way in which Descola presents them also represents the hermeneutic-phenomenological version of a simplification of model use that is typical of anthropology. It appears as a metaphysically and epistemically loaded classification with notions from the second row in Table 1. In addition, five further similarly loaded translations from various disciplines are introduced, two of which represent the nature-culture dichotomy (third row in Table 1). The other examples illustrate the simplifications as analytical-metaphysical (typical of natural science) and as transcendental-synthetic (typical of religious studies). As can be seen from this list, the examples have been selected such that the content of these classifications is unrelated; only the formal relations in terms of dichotomies that are prominent in the respective discipline are compared.

The present article is written in the language of moderns in the sense of and for moderns (ibid.), i.e., for people who are biased towards one specific worldview[3] in their public discourses but who may also reflexively acknowledge its inconsistencies and limits. Describing and referring to other cosmologies in this language can only give a partial picture of them,[4] but will help to recognise and delimit the extent of implicit assumptions behind modern perspectives and illustrate potential (systematic) alternative approaches. The universalism of

---

[3] The distinction between knowing and being, between symbolic and sensory access stands in this legacy.

[4] See Ingold's critique on Descola's approach as well as Descola's response in *Anthropological Forum* 26(3) (Ingold 2016; Descola 2016).

the proposed framework and its yardstick is in this sense a “relative universalism” (Descola 2011: 305). Its foundation rests on the practical and theoretical universalism of contemporary computer science. The advantage of such an approach is that the discussion of the interpretation of terms used in models can be postponed to the selection of a model type. Philosophers and anthropologists have found it hard to agree on such questions (Ingold 2016; Descola 2016).

Engineering instead of Physics

This perspective takes the practical, mediating role of models as a starting point. Models are no longer regarded as *applied knowledge*, but as instantiations of worldviews, which mediate between reality and its mathematical representation in both directions.

In order to compare model usage among disciplines a *meta-language* is needed that allows a translation of concepts between scales and forms of local knowledge. In area studies such integration is delegated to the subject of study itself. It is hoped that integrations result automatically when different disciplines focus on the same area. Here, however, we seek an abstract, explicit integration by comparing the practices of modelling in different disciplines. It is proposed that modelling has already acquired an autonomous status (Morgan and Morrison 1999; Wendler 2010) and can therefore serve as a mediator between disciplines providing such meta-language. Computational models are widely used in environmental sciences, but rarely in the humanities (Erdbeer et al. 2017). That is why we shall base the typology of models first on *simple*, widely used concepts from science, economics and engineering, and second compare their abstract types with classifications of empirical material from these and other disciplines.

Models

How do humans solve problems involving reflexivity with mathematical machines? Since the widespread acceptance of the computer as a versatile tool throughout all disciplines, answers to this question will at least implicitly encompass references to the current computational technology. Especially the role of (computational) models are set into focus here. Computer science serves as a paradigmatic case of an engineering attitude. We will use its theoretical insights as a basis for a meta-language about models, which seeks to minimise metaphysical assumptions, while maintaining mathematical precision (Mahr 2009).

Software engineering shares with physics the affinity to mathematical expression. Yet, it has a different grounding in the empirical world as it deals more often with the implementation of *specified behaviour* (Mahr 2009), rather than with the abstraction of observed structures, as in physics. It thus broadens the range of modelling relations between the formal and the empirical in a manner that is particularly interesting for environmental research (Hauhs and Trancón y Widemann 2010), for economics (Abramsky and Winschel 2012) and for the social sciences (van Eijck and Verbrugge 2009).

Models can be used in an analytic or synthetic mode; the analytic mode is mostly employed in abstraction, the synthetic mode in implementation. Ontologies can be dealt with from a phenomenological or transcendental stance: the first, phenomenological mode, may regard senses as limits ("thing-in-itself"); the second, transcendental mode, seeks to get reliable perceptions from beyond the accessible world (e.g., when dealing with past events, while the observer experiences only the Here and Now). Epistemologies can be dealt with from a hermeneutic or a metaphysical stance. In the first, an observer interprets actions as if the inner world of intentions were accessible from the outside; in the second, a correspondence of sense output with reality becomes the norm of truth. These six notions (second row of Table 1) are used to describe distinctions within the three dimensions of modelling.

Computational models provide a diversity of examples how to match data from a disciplinary field with a potential formal language. They provide us with common coordinates for a joint conceptual scheme as required by Davidson (1984: 986). The relations of modern humankind to its environment are a topic rich enough to encompass a diversity of disciplinary approaches and modelling styles. Here, the wide cast of our examples may indicate that the four models may suffice to capture a major part of systematic human thinking (with models).

As with any abstract and general language, expressiveness at the meta-level is very weak. Only few things about the world can be stated in this language. For the meta-level, only formal consistency can be offered, but no (meta-) criterion of truth. As a principle we will seek "epistemic hygiene," i.e., avoid metaphysical assumptions at the meta-level, especially those about nature and culture.

Three Dimensions of Modelling

In this section the three dimensions of modelling (Figure 1, Table 1) are linked to four model types. Consider models that can be executed on a computer.[5] Their realm ranges over many disciplines and into many areas outside sciences, too. In contrast to Ingold (2016), we claim that scientific models link mathematical structures of knowing about the world with ways of being in the world (Figure 1).[6] Mathematical languages can be adopted from physics, where they are predominately employed to encode changes of natural systems under dynamic law (algebra, *language of necessity*) or from computer science where they are employed to encode choices of automata (coalgebra, termed here *language of possibility*, Jacobs 2016).

The three aspects of Figure 1 are regarded as independent of each other. In other words, the choices of model selection shall be depicted along three independent axes as empirics, mathematics, and tests (Figure 2). Later we shall discuss possible mutual dependencies among these aspects as restrictions or loadings on model interpretation.

Empirics: Links to reality or actuality are illustrated by the differences between observation (seeing) and memorisation (doing). This distinction follows Pearl (2000), who suggested the labels "science of seeing" and "art of doing." Seeing relates to the reality encountered by a passive observer, as in natural science, whereas doing relates to the actuality in a sequence of events in which an agent may be actively embedded, as in anthropology. The empirical dimension of modelling contains the distinction of these data types.[7]

Mathematics: the mathematical language is apt to describe a behaviour or a state. A possible behaviour can be thought of as

---

[5] Our starting point is narrower than other model definitions (e.g., Mahr 2009; Trancón y Widemann and Winter 2012).

[6] Examples are process models in business software, games, etc.

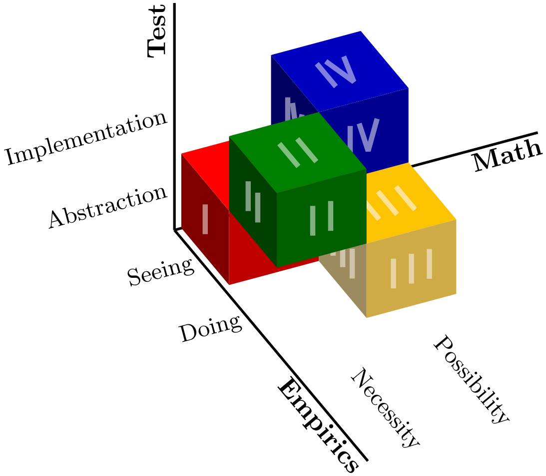
[7] Data from seeing support the evaluation of symmetries, whereas data from doing support the evaluation of order relations.

a sequence of events at an interactive interface. Computer science has developed a language of possible choices (*language of possibilities*, Figure 1). A causal state of a dynamical system can be formalised by a *language of necessity*, for example, when states of a system inevitably change in time under the restrictions of a law of nature. This choice of mathematical language manifests the way in which a model represents data. The mathematical dimension of modelling contains the distinction between languages of the possible and the necessary.

Tests: models can be tested in two ways. Which side, the empirical or the formal, is modified in order to improve a model? This distinction sets the direction of modelling: when the empirical part is taken as given and the formal representation is modified, this is termed abstraction. In the reverse direction, when a formal specification is given and its application in the empirical world is modified until it matches specifications, this is termed implementation (Figure 1). The practical dimension of modelling contains the distinction of analytic and synthetic modelling approaches (Figure 2, Table 1).

These above distinctions are regarded as heuristic, not as fundamental. We regard the observed combinations of coordinates as characteristic of model types.

Figure 2. Three Dimensions of Modelling depicted as Three Independent Axes



In Figure 2 the three dimensions of modelling are depicted as three independent axes, each with a characteristic distinction. The numbers I-IV indicate the coordinates of examples of the four model types (I: dynamic systems, II: Markov chains, III: games; IV: L-systems). In the application they also depict the four cosmologies distinguished by Descola (I: Naturalism, II: Analogism, III: Animism, IV: Totemism).

At the meta-level of the framework, the three choices along the coordinates of Figure 2 provide a total of eight possible distinctions. At this point we employ the central conjecture of this article: the four model types observed in simple computational models are taken as exhaustive for our classification task of conceptual approaches, including those in the humanities. The reduction from eight to four may be a result of the (hidden) dependencies among the three axes.

In order to apply this framework of four model types to different disciplines, two translations are needed: top-down from the dimensions of modelling into the various axes of classifications, and bottom-up of the four model types into the various classified subjects. These translations shall be discussed in the two next sections, respectively.

Interpretations of the Three Dimensions of Modelling

The key feature of the proposed framework is that its model types are related in a non-hierarchical manner; any model type taken as a starting point requires two steps to reach any other model type.[8] Interpretations will be discussed at the level of applications and do not need to be considered fundamental. There are six possible interfaces of shared coordinates among the four model types.

In this section we provide an overview of the notions used for classifying model types to illustrate the role of the dimensions of modelling and their distinctions (Figure 2). The respective philosophical notions (after Koch 2012) appear in column 3 of Table 2. With these notions a method of translation between the dimensions of modelling and the disciplinary classifications is provided. The philosophical notions (third column) are organised as interpretations of the three axes of modelling (Table 2).

Table 2. Top-Down Translation

dimension of modelling	**on axis** of Fig.2	**methodolog. notions** from Koch (2012)	**other sources**	**applications,** this article
empirics	seeing	phenomenological	science of seeing Pearl (2000)	physicality (Descola) rivalry (economics)
	doing	transcendental	art of doing Pearl (2000)	holism, animism (Taylor) creative nature (Eriugena) natural religions (Latour)
test of model	abstraction	analytic	predicate implied (Kant)	rationality (Meixner) futures (Adam)
	implementation	synthetic	predicate carries input (Kant)	supernaturalism (Taylor) created nature (Eriugena) terrestrialization (Latour)
mathematics	necessity	metaphysical	lower sensible faculty (Kant)	person-connoted (Meixner) futures (Adam)
	possibility	hermeneutic	upper cognitive faculty (Kant)	interiority (Descola) excludability (economics)

Summary and overview of translations between the model framework and corresponding notions used by other authors (second column: Koch 2012; third column: Pearl 2000; Kant 1845[1784]; the last column gives a preview of the disciplinary example from applications of the framework). Each case consists of a classification into four items: In economics rivalry and excludability classify goods, in anthropology Descola (2011) classifies worldviews by interiority and physicality, in philosophy Meixner (2002) classifies Aristotelian causalities by person-connoted and rationality, in sociology, Adam (2010) classifies futures.

---

[8] That is the main purpose of the three independent axes here. The simpler 2×2 projections into matrices will no longer have this property.

In religious studies Latour (2017) and Taylor (2010) classify environmental attitudes by science/religion and natural religion. In a similar way Eriugena differentiated created versus creative nature (Moran 2004).

Empirics offers two ways of interpreting data ontologically. First, as the results of what subjects perceive *phenomenologically* (e.g., by a science of seeing). In this interpretation it becomes natural to address environmental problems by the finiteness of resources. An anthropological approach is to address the physicality of different entities (Descola 2014). Conservation laws can also become invoked when economic goods become classified under the notion of "rivalry," i.e., they are used up by consumption (Mankiw 2014).

Second, a documentation of data yields an order of events that subjects can actually experience in the present. Other instances of time can only be assessed indirectly. The ontic character of past events must remain *transcendental* from the present stance of subjects. The interpretation of historical events includes an active, interpretative, creative aspect. Pearl (2000) describes this *historical* experiencing of the world as the "art of doing." In this interpretation it becomes natural to address the creativity of nature; Latour (2016, his table 5-4) employs this view to distinguish between science and religion.

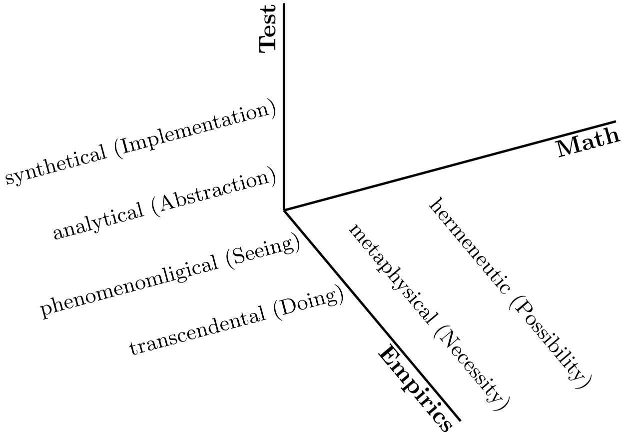
Mathematics offers two approaches of formal languages. First, as a way of expressing law-like temporal changes in the state of systems. In category theory these languages are characterised as algebra (Jacobs 2016). Logical assertions take the form of equations between terms. Such equations may be interpreted as laws of nature. They may even be granted an independent existence, i.e., a *metaphysical* interpretation. This interpretation of state changes of a system as perceived through sense corresponds with Kant's lower sensible faculty. In philosophy and sociology this can be used by expressing (non-) person connoted, i.e., a "disenchanted nature."

Second, interpretations of formal language may start from the choices that an agent can have in a given situation. Choices can be assessed by a *hermeneutic* approach in the humanities. This interpretation corresponds with Kant's rational or upper cognitive faculty. In the applications in anthropology and economics it can be used to express continuity in notions of the interior world, as does Descola (2013), thus justifying a hermeneutic approach. In the economic example, it describes whether the right of access can be checked or not (excludability: misuse of a good can be observed).

Models offer two discourses of organising practical tests. First, as an abstraction in which observations are translated into a symbolic form as data. The properties encoded as data are interpreted as local features of building blocks of or events in the world. The world is conceptually decomposed into building blocks and events. Observers take passive roles in such observations. The factual world may appear as irrational and data may be chaotic. The modeller has an *analytic* attitude in this process.

Second, models can be employed for an implementation in which agents actively specify a new structure or behaviour in the world. Phenomena in the world can be created through this rational process. This process comes with a *synthetic* attitude of the modeller.

Figure 3. Three Dimensions of Modelling



Methodological notions from Koch (2012) are used for labelling the three dimensions of modelling

This interpretation can be regarded as top-down (Figure 3); it follows from the way the framework of model types is set up. In subsequent examples the corresponding bottom-up aspects shall be discussed, suggested by the various classification schemes.

Interpretations of Four Modelling Types

The following four cases from different disciplines (see Table 1) represent relatively simple and prominent models, which can be executed on a computer. In each of the four cases both the empirical and the mathematical sides are involved. They differ according to the following criteria: whether *necessity* (algebra) or *possibility* (coalgebra) is in focus on the formal side, whether *seeing* or *doing* serves as the main empirical foundation and whether *abstraction* or *implementation* is used for testing.

The mutual relation between ontic and epistemic aspects of models is expressed in Pearl's "science of seeing" and "art of doing." In the former (e.g., physics) a language of necessity is linked with data derived from "seeing." In the latter (e.g., economics) a language of possibility is linked with data derived from "doing." Here we introduce these dependencies by restricting the direction of model testing to abstraction when world and language conform in this way. Reversely, implementation is imposed as the direction of model testing when they do not conform. Then only the following four combinations remain (Trancón y Widemann and Hauhs 2015). Each of them is characterised by specific "blind spots," relating to features which are not considered fundamental, but derived under typical interpretations of this model type. The next section provides summaries of these four model types.

Dynamical Systems and their Time Series (Type I)

This example consists of time series, which contain historical documentation about the epistemic states of a system. Epistemic states appear at interfaces and can be used as indicators, e.g., about appropriate interventions. For instance, take the charge status indicator of a mobile phone. The light signal itself is not causal for the status of the battery.

First, the possibility of distinguishing causal (ontic) states from mere epistemic (indicator) states points to the primacy of observations, of seeing over doing. Dynamic systems are best observed (seeing) as autonomous deterministic systems for which an observation of a single state in time fixes the complete trajectory. They determine past and future states, which are compatible with the respective dynamic law. Second, the focus in the mathematical representation rests on the algebra.[9] Third, the causal states are assumed to possess referents in the "real world" and are in principle observable. Here, the goal of a model is to represent these data in the chosen algebraic form. Hence, the direction of modelling constitutes an abstraction (see Figure 2). Models are revised until they match data, including non-trivial predictions of future observations.

In its deterministic form, e.g., as celestial mechanics, this model type, first introduced by Newton, stood at the beginning of the modern epoch. It can be taken as paradigmatic for the natural sciences. This model type, however, is unable or has at least difficulties to represent decisions or strategic choices. Such events are its "blind spot."

Markov Chains and their Stationary Distributions (Type II)

This model type is also widely used in (applied) natural sciences. The main difference to the above type of dynamic systems is that Markov chain models include stochastic processes or random events. Their formal side, with a focus on algebra, remains the same as in the case of dynamic systems. However, Markov chain models cover situations in which the causal states of the system remain hidden, even to indirect observations. The empirical access to these phenomena is focused on the historical documentation of behaviour (*doing* in Table 2).

In this case, the distinction between ontic and epistemic states is not helpful. The mathematical description (algebra, *science of seeing*) does not match the temporal empirical focus (coalgebra, *doing*). By the above rule, this implies implementation as direction of modelling (Table 3). The modelled process realises a random process in the world. This random behaviour of state transitions is formalised as a coalgebra (of the Markov chain). An appropriate characterisation of such systems can be achieved by assuming stationary distributions of possible events.

---

[9] The role of the coalgebra is in this case relegated to a mere specification of the temporal logic of events.

Table 3. Translations

	Meta-Level distinction	Empirics doing–seeing	Testing abstr.–impl.	Mathematics Language of
I	**dynamical system**	seeing	abstraction	necessity (algebra)
II	**Markov chain**	doing	implementation	necessity (algebra)
III	**game**	doing	abstraction	possibility (coalgebra)
IV	**L-system**	seeing	implementation	possibility (coalgebra)

Four model types and their respective coordinates in the three dimensions of modelling listed in Figure 3.

This model type is unable to represent subjects or active observers. In attempts of naturalistic reconstructions of the origin of life, this inability is even a desired feature, i.e., in artificial life models it emerges from random fluctuations.

Games and their Pay-off (Type III)

These models have been developed in economy (Von Neumann and Morgenstern 2007); today they are also widespread in the social sciences and biology (Erickson 2015). Multi-player perfect information games can be brought into the form of a coalgebra (Abramsky and Winschel 2012). This coalgebra describes the possible decisions in a game as branching points of a tree, which is rooted at the initial configuration of the game (e.g., chess or Go). The mathematical focus in these models is on the language of possibility, here encoding the decision tree as coalgebra; the models were developed to represent (interactive) behaviour of agents. Their goal is not to explain why agents select a particular decision, but to evaluate possible options in any situation.

The evaluation of a given position may not be feasible to compute, even for games like chess, which do not contain random elements. The decision tree and the immensity of possibilities are still beyond modern computational resources. Hence, information to evaluate any given situation may not be accessible until much later in the game. This is typical of human decisions and actions, where an evaluation is often revised in retrospect. The assignment of the outcome to the options in the game is the role and contribution of the algebra, technically termed "backward induction." The historical information about played games and the decisions taken by players form the relevant data set for such models. This is why the "doing" represents the empirical foundation for this model type (see Table 2). Data represent decisions and strategies, which actually took place in these games, their mathematical representation as coalgebra is an instance in formalisation of the "art of doing" (Pearl 2000).

In terms of testing, these models are examples of abstraction. They abstract and represent realised human behaviour. The side of the model providing a virtual context of the game is modified until it becomes indistinguishable in its behaviour from a human player. This model type is not well suited to represent objects and causal states.

L-Systems and their Graphs as Fractal Curves (Type IV)

Lindenmayer systems were developed to model the development and growth of plants (Prusinkiewicz and Lindenmayer 1991, Prusinkiewicz et al. 1995). The application of L-systems consists of two parts: A grammar to construct strings representing stages of the growth process as a (potentially infinite) sequence of substitutions, and the strings interpreted geometrically as a graph illustrating the resulting form, e.g., of a plant. The first of these two steps is expressed as coalgebra, the second as algebra (Trancón y Widemann and Winter 2012).

In the case of L-systems, one has a formal description of interactive behaviour (e.g., among the cells or organs of a plant), but this behaviour is not accessible to observation. The empirical grounding of these models rests on the structure of the resulting plant phenotype. That is why "seeing" is the empirical grounding in Table 2. The contribution of the algebra in these models is the construction of the corresponding graph, which results from the growth behaviour, simulated as iterated substitutions of plant organs.

The situation is thus mirror-like to type II (Markov chains) where a formal instance of the "science of seeing" combines with an empirical grounding in "doing." That is why the above rule applies assigning the testing mode as implementation. For L-systems, a formal instance of "art of doing" is combined with an empirical instance of "seeing." The formal side of the model specifies a potential behaviour, not directly accessible to observation. A species genotype may encode behavioural options, which remain without traces in a specific environment. What can be observed as a plant phenotype is the outcome of the genetically specified behaviour once it has unfolded in interaction with a context. In testing such models, the realisation is rerun until it matches the specification. This model type is unable to represent universal laws; the growth potential is an individual characteristic of its carrier, here the genotype of a plant.

With these four abstract model types and the relation within the framework of the three dimensions of modelling we can now proceed with the bottom-up translation and extend applications outside the area of computational models. 2 × 2 classifications have been proposed in many disciplines. We shall start with the four examples from anthropology and add other cases in cursory forms.

Four Empirical Examples from Anthropology

In mathematics, category theory serves as the unifying language between different branches of modelling (Jacobs 2016), here between the languages of necessity and possibility (Trancón y Widemann and Hauhs 2015). In anthropology, Descola (2013) proposed a unifying scheme of worldviews, e.g., in the form of four "ethno-cosmologies" (Descola 2005).[10] Descola's cosmologies, coined by him as "anthropological models" (Descola 2016), are shortly summarised below, before inspecting their conjectured correspondences with the four model types presented above. In the following, the correspondences are indicated by the "blind spots" of the model types, resembling analogue deficiencies in the respective cosmologies.

This first application of the framework demonstrates the top-down and the bottom-up translation steps from our modelling framework into the various disciplinary applications. The top-down translation yields alignment of axes: The two axes used by Descola can be derived by selecting a language of possibility on the math-axis, enabling a hermeneutic view ("interiority" for Descola). On the empirical

---

[10] The initial conjecture leading to the present article was that the four cosmologies correspond in their implicit logical forms to the four model types and examples I-IV from the preceding section.

axis "seeing" is enabling a phenomenological view ("physicality" for Descola). For Descola, the human subject is in the centre of this classification and its ontological presupposition. The second step, the bottom-up translations for his four ethno-cosmologies is summarised below:

Descola regards **naturalism** (type I) as the dominating worldview of modern humans, including himself and his readers. This worldview implies a naturalist monism (living and non-living things consist of the same building blocks) and a cultural relativism (conscious beings have unique perspectives). In Descola's categories, the exterior (physical) world is continuous, i.e., made from the same elements whereas the inner world of subjects is discontinuous. In this respect it is an opposite of animism (see below). The blind spot of naturalism are strategic decisions of subjects.[11] In a mechanistic cosmos, free choices of subjects appear as an emergent feature, very challenging to explain (Deacon 2011).

Analogism (type II), a neologism proposed by Descola, is based on the idea that the world consists of an infinite totality of unique beings. As it is difficult apprehending such a world, one has to resort to analogies in order to perceive and classify patterns. Descola finds examples of large-scale systems of such analogies in China or India, but also historical societies of the Aztecs or in Renaissance Europe fall into this class.

For moderns, analogism is translated as a genuinely discontinuous cosmos in which continuous nature and culture result from an imposed organisation, which mirrors that of a human society (Descola 2011: 407). Cosmos and society may become identical (ibid. 394). Societies adopting this worldview are characterised as totalitarian, with little individual freedom (ibid. 403).

In analogism, the world is perceived as discontinuous in both its exteriority (physicality) and its interiority. Order must be actively imposed and maintained. Hence, the dominating attitude is one of implementing. The implementation takes place in a cosmos of objects and laws of nature; it does not necessarily require a subject. The blind spot here is in relation to the subject and matches the historical

---

[11] The notion of free will is an example of emergent property (Metzinger 2009).

examples suggested by Descola; none of them emphasised individual rights or freedom.

Animism (type III) grants the inner life also to non-humans, but distinguishes them from humans by outer bodily signs. In this worldview, any social collective, humans and non-humans, is organised after the model of human societies (ibid. 368). Relationships among humans appear as more formalised, with explicit rules and norms (ibid. 374). However, the use of the human model for non-humans is not a mere metaphorical projection, as animists themselves do not make the distinction between humans and non-humans (ibid. 370). Descola classifies the animist cosmology thus as anthropogenic: it uses relationships among humans for classification of all relationships; including those with and among non-humans (ibid. 380).

Descola defines animism as a perceptional modus, "antithetical" to that of naturalism, the main modus of moderns (see above). Each agent including non-humans is capable of the same inner life of feelings and intentions. Any material form can just be a masquerade taken by a soul. The soul stands here for the inner perspective of a sentient subject and gives rise to cultural monism. In an animist cosmology objects (in the modern sense) do not exist and this lack of objects constitutes the "blind spot" of animism. In the history of Europe this attitude can be traced in the thought of Thales from Milet, whom Aristotle quoted in *De anima* (411a) as "all things are full of gods" (Ross 1928).

Totemism (type IV) emphasises the material and moral continuity between humans and non-humans. It uses myths of origin to explain the distribution of features among both humans and non-humans. Everything originating from the same totem has these features or properties. In the modern world, nationalism can be regarded as a form of totemism. Ethnographic examples stem from studies of the Australian Aborigines. In totemism, characteristic differences among non-human species or other phenomena from the ambience of a society are used to classify relationships among humans. Descola destribes totemism as "cosmogeneous." The cosmos produces (here: implements) these forms by itself, but in contrast to the naturalistic view this is a cosmos that includes subjects from its very beginning. Humans share properties with their eponymic species, because both were generated together.

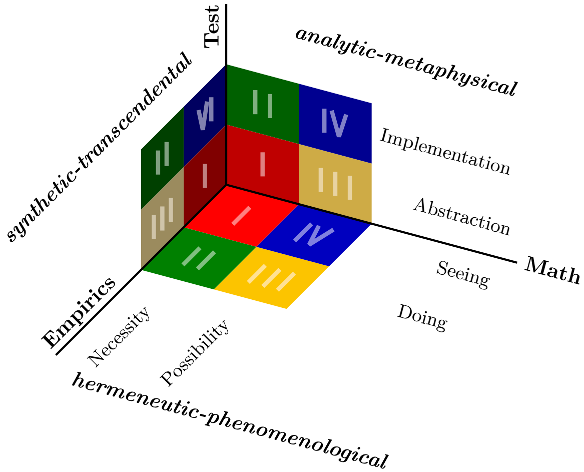
Descola translates totemism for moderns as a participating mode in which nature and culture are continuous (Descola 2011: 406). Ontologically, it is about implementation. Epistemically, it is about an interactive (embedded) relation with a world. The blind spot here lies in universal law-like behaviour, which cannot be expressed explicitly. Everything is determined by place, read here as objects.

Next Steps

Our conjecture is that these four model types from computer science on the one hand and from anthropology on the other can be aligned due to the underlying logic of distinguishing their subjects and of organising the axes of classification. The unifying power of this modelling framework, however, is only available at the meta-level of the three dimensions of modelling.

Since only four model types are needed in the subsequent applications any two axes of Figure 3 suffice to classify them. However, these two dimensional projections will no longer keep the four cases at the same mutual distances. In the projected versions, opposites occur and in the applications these opposites will be used for identifying the projection (Figure 4). The projections come with additional assumptions about the world. In the tradition of the modern West (Gillespie 2008), however, it is common to discuss but three realms on which metaphysical assumptions are directed: human beings (as for Descola), material world (as in natural sciences), and a transcendental or Platonian world (as for some mathematicians); these ontic foundations are often presented as a triangle (e.g., Penrose 2005).

Figure 4. Three possible 2-d Projections



The labels of the projections derive from the methodological notions of Table 3. They indicate which emphasis is chosen on the respective axes in Figure 4. Note that three different diagonal opposites appear in the projections for each of the model types.

Figure 4 serves as a translation between a quaternary realm of model types and a trinitary realm of disciplinary projections. In our framework, any of the projections comes with a typical interpretation of the two remaining axes. In other words, each projection preselects the respective focus on the coordinates. The aspect chosen is turned into a category of classification, e.g., by its presence or absence.

Hermeneutic-phenomenological: Descola’s classification corresponds with the plane spanned by the empirics- and math-axes of the 3d-framework (Table 2 and Figure 4). Cases I (naturalism) and III (animism) form opposites. Methodologically, his scheme can be termed “hermeneutic-phenomenological.” It sets the human subject at centre stage and supposes anthropological universalities. There are two more projections, which shall be discussed in the following, before we proceed with the remaining examples.

Analytical-metaphysical: in this projection, “nature” becomes the ontic cornerstone for reference of truth values. For classification, the language of necessity (algebra) is selected, resulting in distinctions between matter under laws of nature and human freedom (person-connoted versus non-connoted). On the other axis abstraction is selected leading to the opposition of the rational (human) versus the irrational (world). In summary it will place model type I and IV into opposition. This opposition will lend itself to be easily interpreted as the Cartesian object-subject dichotomy.

Synthetic-transcendental: in this projection "transcendental" entities serve as reference of interpretation. For classification, the empirical access by "doing" is selected, resulting in distinctions between creative and non-creative aspects of the empirical world. On the other axis implementation is selected leading to the opposition between a created and a non-created world. In summary such a classification puts model type I and II into opposition. The distinction in religious studies between the secular and the sacred realms can be translated as the corresponding dichotomy. In contrast to the first two examples this third case lacks criteria for testing the models and thus falls outside the scientific realm. We have included it to complete the exhaustive scheme of three projections and to help clarify the role of religious connotations in environmental issues such as climate change (e.g., Latour 2016).

Applications

The framework based on four patterns of model reasoning can be recognised not only in anthropology, but in other disciplines too. In each disciplinary application the classifying categories are translated into the three dimensions of modelling, regardless of their content. To this end we have introduced three simplified projections, which we hold as typical modern combinations of methodological approaches: analytic-metaphysical, hermeneutic-phenomenological and synthetic-transcendental. The projections fix the relative positions of the four types of model logic (Figure 4). It can thus be checked (preferentially by experts in the respective disciplines) whether our tentative mappings are consistent with the content of the six classifications that we shall demonstrate as examples below. A diagnostic of the three simplified classification schemes of models are their respective diagonals, i.e., the types of model logic that appear as opposing each other. Only the diagonal entries shall be discussed below, the rest is left as an exercise to the reader.

Type I of model logic (dynamic systems) will serve as a reference point in all applications. Models of dynamic systems are among the most widespread scientific tools today. Naturalism, the corresponding worldview in Descola's classification, is the dominant mode of moderns.

We present each of the following classifications in the form of a 2 × 2 matrix. The main point is to test how well the logic of each disciplinary classification aligns with one of the three possible projections of the general modelling framework. In some examples (e.g., Adam 2010), authors do not make their meta-classification explicit, leaving room for interpretation when assigning them to one of the three projections. In these cases, we will justify the interpretation selected here.

Analytic-metaphysical classifications

The classification of concepts of the future from Adam (2010), a sociologist, and the four causalities of Aristotle (Meixner 2002) are examples of this projection.

The four concepts of future are presented as a history (Adam 2010). Even though Barbara Adam does not explicitly state her criteria by which she delineates four futures, her text stands clearly in the context of a modern worldview.[12] In the history of modernity as told by Adam human subjects find themselves either in a passive (fate, fact) or active role (fortune, fiction) with respect to the future. Therefore, a translation of the passive attitude to the math-axis, encoded as a distinction between non person-connoted (objects) and person-connoted (subjects) is straightforward (Table 4). This correspondence puts the focus on the language of necessity and assigns the causal states as an ontic feature of objects (metaphysical). On the test axis the focus is on abstraction (analytic). The world serves as a reference of truth statements and is reflected in the distinction between rational humans and an irrational (chaotic) world.

---

[12] That is why we in this case identified the axes of classification inversely from its content.

Table 4. Analytic-Metaphysical Projection of the 3d-Framework

Philosophy & Sociology	**Necessity** (algebra) not person-connoted	**-** person-connoted
Abstraction (world given) irrational	**Type I** causa materialis future as fact	**Type III** causa efficiens future as fortune
- rational	**Type II** causa formalis future as fate	**Type IV** causa finalis future as fiction

On the math-axis the language of necessity is selected and interpreted as person-connoted. On the test-axis abstraction is selected and interpreted as indicating rationality. Filled with examples from Aristotle (Meixner 2002) and Adam (2010).

Starting from an antique worldview, fate is imagined as originating from gods and ancestors, who “set the world in motion and move it to future directions” (ibid. 47). This description matches the notion of implementation on the test-axis. The key aspect of fate is that the passive recipient of this information cannot do anything about it. Experts and message-bearers can only lift the state of ignorance. “The unknowable future is projected onto the sacred realm and has a particular status; it pre-exists as fate” (ibid.). It can thus be classified as not person-connoted (type II). Its rationality is a divine one.

Future as fortune sees the potential for action of informed humans. “Prophecy and divination were abandoned in favour of scientific methods. Focus shifts from individuals to collectives and averages” (ibid.). Estimates about the probable future could be derived from data of the past as long as conditions do not change radically. However, when the present becomes innovative the future will be fictional, constantly made by humans, but with unexpected side effects. Hence, these two forms of future are “person-connoted.” Fortune takes the world as given (changing at most slowly) and can thus use past records to anticipate future; however, this may be a caprice of nature or the gods. In the notion of future as fiction modern humans become the authors of their future. This is a rational version reflecting the rationality of its human author.

Finally, when the character of modernity becomes self-referential through unintended feedback effects as in the Anthropocene, the future ceases to be open and empty; future becomes “something that has already taken (unalterable) form” (ibid.). The pending climate change debate is a prime example. Part of the future has become already a factual status by past decisions. Hence, through history the relationship of the modern human has returned to a not person-connoted version of future. These four “historically distinct understandings and assumptions about the future” (ibid.) lead to the modern dilemma exposed in the introduction. Adam uses at least implicitly the naturalistic metaphysics of the Cartesian subject-object distinction when retelling this history of concepts of futures.

Aristotelian causalities

Materialis, *formalis*, *efficiens*, and *finalis* can be regarded as antique forms of necessities (Meixner 2002). They assume phenomena as given in the world and to be truly represented by models; hence abstraction lies on the test-axis. *Causae materialis* and *efficiens* translate into the irrational facts of a given world of objects and subjects (Meixner 2002: 23). The implementation direction takes up ideas specifying a new structure or behaviour into the world; *causae formalis* and *finalis* stand for the rational aspects of agents or impersonal laws of nature shaping the world (ibid.).

Opposites

In modern physics *causa materialis* takes the form of natural laws acting on the (physical, observable) state of autonomous systems. These laws typically have the mathematical form of an algebra, in a language of necessity. The empirical access is by observing the states (“seeing”), and the role of the model is to mediate abstraction by representing the observations (Table 2). Type I represents deterministic dynamic systems and thus corresponds with notions of future which are already determined by the present state (fact), while the human observer may still be ignorant about them.

In this classification the opposite case of *causa materialis* is *causa finalis*. The purpose of actions can be expressed as a specification of events in a coalgebra representing strategic behaviour. The abstract specification becomes implemented in the world, as in the example above of plant phenotypes modelled with L-systems. This situation matches therefore Type IV models (Table 2). In sociology, the notion of "future as fiction" stresses the role of human actions in specifying their future. The "being of objects" given in the world and the "making by subjects" form opposite positions along the diagonal of the 2 × 2 matrix, as might be expected in a worldview based on the Cartesian divide.

Hermeneutic-phenomenological classifications

Besides the four cosmologies of Descola (2005), the second example in this projection is a classification of goods (Mankiw 2014), which is common in economics. By the above top-down and bottom-up translations, Descola's cosmologies become aligned with the four modelling types (see Table 5): naturalism (I), analogism (II), animism (III) and totemism (IV). The opposition between naturalism (I) and animism (III) places this case into the "hermeneutic-phenomenological" classification model types.

Table 5. Hermeneutic-Phenomenological Projection of the 3d-Framework

Anthropology & Economy	**-** - interiority discontinuous excludability	**Possibility** (coalgebra) interiority continuous no excludability
Seeing physicality continuous rivalry	**Type I** naturalism private goods	**Type IV** totemism allmende goods
- physicality discontinuous no rivalry	**Type II** analogism club goods	**Type III** animism public goods

On the math-axis the language of possibility is selected and interpreted as indicating access of interiority (by Descola) or as indicating excludability (economy). On the empirics-axis "seeing" is selected and interpreted as indicating physicality (Descola) or rivalry in the consumption of goods (economy).

Goods in economy

In the classification of goods, rivalry and excludability are used as principal axes. Rivalry relates to properties of the good: does its consumption diminish its usability? Excludability describes the relationship among users: can misuse by other, not entitled subjects be identified? Again, this classification results in four types: Private goods are typical of market economies. Due to the proposed translation they are here matched with model type I. Club goods allow the exclusion of non-club members, but their use is non-rival (e.g., watching a movie in a cinema; type II). Common goods are the opposite: their usage is rival, but access cannot be excluded (e.g., to all members of a commonly owned forest). This is matched by the translation of axes to type IV. Finally, public goods like air cannot be traded; they are matched with type III.

Translations

The classification imposed by the hermeneutic-phenomenological projection puts the emphasis on the language of possibility (on the math axis) and on "seeing" (on the empirical axis). The former becomes the basis for granting access rights (excludability of users of goods); the latter results in rivalry in consumption (e.g., conservation laws; goods can be used up). In economy, goods are often considered as scarce. This can be achieved under a conservation law (the multiplication of gold is physically prohibited) or by human law (the multiplication of bank notes is legally prohibited). The role of the law is to provide a societal infrastructure in which banknotes turn into private goods. These are modelled on conserved material objects. Thus the realm and model type of physics apply. For other goods and services, especially of ecosystems, it is harder to demonstrate that they are scarce and can be turned into private or common goods (e.g., biodiversity). As "seeing" is the corresponding entry for dynamic systems (model type I), excludability can be achieved by the societal infrastructure, placing "private goods" along with model type I and naturalism.

Opposites

In this classification the opposite case to type I is type III, here exemplified by animism (anthropology) and public goods (economy). For Descola, animism is reversing the features of naturalism: the internal world is continuous for animists, whereas exteriorities may be discontinuous. In economy, the opposite to private goods are public goods, for which neither a rivalry nor an excludability can be achieved or observed.

In a society, it may be the purpose of an infrastructure to turn a technical and scarce resource into a public good (e.g., free Wi-Fi). Anthropologists have studied hunting and gathering societies that can be labelled as animists in the sense of Descola. Such societies sometimes do not know private goods; they share resources among them effectively lifting them to the status of public goods. This may be a result of the logical parallels between the two classifications. Haim Ofek (2001) hypothesised that economic relations among humans started with club goods when humans were hunter/gatherers. Ofek argued that excludability, e.g., for early fire technology, required very little organisational overhead. In totemistic societies the joint origins of humans and other beings allow access to their inner worlds as a precondition to granting collective rights to resources, which are scarce in the modern sense and require much organisational overhead for sustainable utilisation (Ostrom 2015). In biology the transition from pro- to eukaryote changed the status of genes from public goods by lateral gene transfer to club goods by sexual mating (McInerney et al. 2011).

Synthetic-transcendental classifications

The third projection is illustrated by the writings of the medieval theologian John Scottus Eriugena, and by two classifications of (nature) religions in dealing with the notion of Gaia (Taylor 2010; Latour 2017). The classification imposed by the synthetic-transcendental projection puts the emphasis on implementation (on the test axis) and on “doing” (on the empirical axis). The former results in distinguishing between the effects of the natural and the supernatural forces of creation; the latter results in a distinction of creative versus non-creative changes in the empirical world.

Eriugena used a notion of nature that is completely inclusive (Eriugena 1983). He made distinctions within this all-encompassing nature by using criteria of creation and creativity.

Eco-religions in the face of Gaia

Bron Taylor distinguishes various versions of Gaia, a metaphor that considers the whole planet Earth as a living organism (Taylor 2010). He presents his classification in the form of a matrix with axes labelled in one direction as "Animism"[13] and "Gaian Earth Religion"; this distinction is mapped to our "empirics" axis focussed at "doing." In the other direction labels read as "naturalism" and "supernaturalism"; this has been mapped to our "test" axis focussed at implementation. In Latour (2017) the distinction between creative and non-creative nature along the "empirics"-axis is labelled as epistemological versus anthropological versions of science, whereas his distinction between "natural religions" and "terrestrialization" (in his table 5.4) corresponds with the not-created and created interpretations of the test-axis.

Two model types, II & IV, fall under the created derived from the focussed synthetic aspect of the test axis (animated with Latour, super-animism with Taylor). The version of "Gaian naturalism" corresponds with the attempts of natural scientists to establish a "secular Gaia" as geophysiology (Lenton and Watson 2011); in Latour (2017) the corresponding set of features is termed "Nature one (epistemological)." Versions in which the role of nature up to a whole living planet is active, i.e., taking actions such as "revenge" (Lovelock 2007), are classified as "animism" (here naturalistic animism) by Taylor (2010), "Nature two" by Latour. In both classifications, of Eriugena and of Taylor/Latour, the criterion of creativity can be aligned with the empirical axis (doing). Taylor puts the Gaian Earth religions into the organismic tradition and holistic notions of the biosphere. This includes a scientific understanding of a geophysiological Gaia.

---

[13] Note that Taylor employs the notions of naturalism and animism at the level of intermediate classifications (Taylor 2010), whereas Descola uses these terms at the level of model types, which he presents as (ethno-) cosmologies (Descola 2011).

In Latour (2017) the distinction between creative and non-creative nature along the empirics axis is labelled as epistemological versus anthropological versions of sciences, whereas his distinction between "natural religions" and "terrestrialization" corresponds with the not created and the created interpretations of the test-axis (Table 6).

Taylor uses "naturalism" for this case, with Gaian naturalism closest to a scientific understanding of the biosphere as a whole (Taylor 2010: 93). In the case that this naturalistic (not-created) world is also internally creative, it becomes the "naturalistic animism" of Taylor.

Table 6. Synthetic-Transcendental Projection of the 3d-Framework

Medieval & Eco-theology	**-** non-creative Gaian	**Doing** creative animism
- origin naturalism	**Type I** not created Gaian naturalism	**Type III** not created naturalistic animism
Implementation origin super-naturalism	**Type IV** created Gaian spirituality	**Type II** created spiritual animism

On the empirics axis "doing" is selected and interpreted as indicating creativity in the world (by Eriugena, Latour) or as indicating animism (Taylor). On the test axis implementation is selected and interpreted as indicating naturalism of origin (Taylor, Latour) or of being created (Eriugena)

In this classification scheme one can imagine any phenomena as being created by and being an expression of a super-agency. Implementation can thus be extended widely beyond the human realm. Eriugena terms these phenomena "created," Latour calls them animated, Taylor refers to them as super-naturalism.[14]

---

[14] "[T]he biosphere or the entire universe to be an expression or part of God" (Taylor 2010: 93).

Opposites

For Eriugena, the notion of nature is all-encompassing, in contrast to Descartes. In this case type I model is placed as "not created," "not creative" along with geophysiology. The interesting situation is its opposition along the diagonal, where we find type II models (created, creative) along with the elusive "spiritual animism." Two of the three features of a type II model are explicit (the third axis is the projected one). In Taylor's version of spiritual animism, the relevant empirical access is the history of (potentially meaningful) events by which animistic powers act in the world ("empirics" axis: doing). With respect to the testing of models the direction is implementation: the world results from super-natural interventions, whose meanings remain hidden for humans: clearly an untestable, non-scientific proposition.

These transcendental examples demonstrate that the applications were based on the formal background of classifications and not on their phenomenological content. Six classifications from quite different disciplines have been placed in relation to the abstract general modelling framework by including three different metaphysical assumptions: about things (*res*), about social meaning space, and transcendentally about meaning in history.

Discussion

Paradox of environmental research

There is an apparent conceptual paradox behind the modern (scientific) worldview, which is based on the natural sciences. Physics is the paradigmatic case and provides a powerful method of a systematic study of "nature." Much current technology can be regarded as applied physics and embodies this worldview as the source of human civilisation, which, however, has become a global geological force. Conceptually, this worldview presupposes a Cartesian split between "subjects" and "objects," or "human free will" and the "laws of nature." However, as Crutzen (2002) pointed out, an appropriate scientific model of global dynamics requires the inclusion of humans as an internal part of it. The very success of the scientific view applied during the modern epoch therefore seems to be enforcing its own abandonment (Tarnas 1996). The effects of a model, when applied globally, appear in opposition to a key assumption of its theoretical foundation. How to resolve this (apparent) paradox in environmental research?

We proposed here a new perspective of interdisciplinary bridging and cooperation. Instead of selecting a common topic, as in area studies, or compatible methods and organisational forms, we used a mediating model framework. Four logical types of models (I-IV) contain interfaces to mathematics (logical forms) and to the phenomenology (content) of different disciplines.

The content and the approaches of scientific disciplines are captured by the way they structure classifications of phenomena in their respective fields. Even if not stated explicitly, all scientific disciplines base some of their assumptions on models or classifications. We assume that the general modelling framework as proposed by Trancón y Widemann and Hauhs (2015) is able to tie together modelling assumptions from different disciplines, while bypassing many of the corresponding epistemic or ontic loadings. The critique of Ingold (2016) on the Descola scheme challenges only the implicit assumptions behind categories of classification, not their content. Our proposed modelling framework is able to resolve this dispute as the avoidable confusion can be shown to result from the 2d projection (hermeneutic-phenomenological).

In the proposed framework three intermediate levels of abstraction can be aligned with typical assumptions of the natural and cultural sciences and of other (metaphysical) interpretations. The nature-culture and other dichotomies appear at the intermediate level of projections, but they are not essential for the combination of models across disciplines. Establishing a more formalised cooperation between the natural sciences and the humanities can therefore seek translations directly in the more abstract language of the model framework, while avoiding the intermediate level of interpretation. In fact, the “traditional” nature-culture dichotomy is a prime example of such a metaphysical assumption at the intermediate level, which appears in the framework as derived and which can thus be avoided. Environmental research is an interdisciplinary field and hence it may profit from a meta-language as a joint reference point for the disciplines involved. How can a usage of the abstract meta-level be organised in the field of environmental research?

Self-references through global impact

Besides technical progress, the emancipation from nature is another great narrative of modernity. It came under critique in the light of surprising environmental problems encountered as limits to growth on a finite Earth. The "limits to growth" perspective represents the traditional nature-culture dichotomy, i.e., modelling Earth under the dynamic system paradigm as in model type I (Table 2). Resources are modelled as scarce goods.

In the Anthropocene the human impact has become global, which opened a new perspective (Crutzen 2006). Given the reflexive character of modern networks, the notion of the Anthropocene includes an endo-perspective of an embedded subject dealing with events at (environmental) interfaces (e.g., model type III). This perspective is closer to the abstractions and concepts of the humanities. It is illustrated most prominently in topics like climate change, but occurs also in debates on biodiversity, critical zones, or global hydrology (Latour 2014, 2017). Reflexivity of globalised modern progress thus turns into a fundamental challenge to human emancipation from nature, as humans and non-human living nature cohabit the same reflexive epoch.

The nature-culture dichotomy is usually depicted as a spatial delineation: wilderness is defined as those regions that have remained (almost) free from human impact. On a finite Earth such regions have become a limited resource and require active protection by humans, i.e., as wilderness areas defined by the IUCN.[15] Hence, something that is negatively defined as "nature" by being free from any human influence may persist into the future only if it is culturally protected.[16]

---

[15] International Union for the Conservation of Nature, https://www.iucn.org/.

[16] This problem can be categorised as domestication: We use a wide, behavioural definition of the notion of domestication here; anything that in its reproduction and survival depends on human civilisation has been domesticated. It has been suggested that human culture itself started as a self-domestication (e.g., Hare, Wobber and Wrangham 2012).

Instead of a spatial delineation of nature, conservation in the Anthropocene needs to explicitly consider human agency and management (Lorimer 2015; Marris 2013). At this stage the formalised forms of an "animistic worldview," e.g., models of type III, may offer help, as they are able to describe management operations at an interactive interface. They translate management for a conservation goal into skilled behaviour similar to the training of pilots in a flight simulator. What has been perceived as a prediction goal under the dynamic, physical modelling paradigm may be translated into a documentation, communication and training goal among experts of practical management such as in the example of silviculture (Hauhs and Lange 2008). For national parks this would imply recognising the experience of wilderness by visitors as a management goal. This would implement the conservation and presentation of "wildlife" at the visitors' interface; the difference between zoos and national parks hence only becomes a gradual one. However, under a changing climate the expertise to be represented in these models may require continuous updating.

Outlook on reflexivity

The modern history not only of ecology but of many sciences can be interpreted as repeated attempts to avoid reflexivity. First, the search for an objective reality on which empirical knowledge can be founded positively; second, the search for a Platonic truth in mathematics; and third, the search for a universal ethical basis of humanity. Today, all three appear to have failed in their original, non-reflexive versions. The hope for an automated integration by factual observation in area studies appears as a naive form of interdisciplinary research. In physics theories have to include their observational limits. In mathematics formal foundations offer axiomatic choices and the role of assertive statements is disputed (Awodey 2004; Shapiro 1997). Several consistent formal worlds are possible. Also in ethics normative foundations require a contract among humans that reacts to the consequences of their actions.

According to Descola (2011: 375), the human species is endowed with a "reflexive privilege," by which he refers to the ability of mentally reflecting on one's own knowledge. Human beings in the Anthropocene may be experiencing a "reflexive curse" as the implication of modernity and technical progress reached a global scale. The nature-culture dichotomy can be seen as a relic of the naive, non-reflexive phase of modernity. How then to handle reflexivity, when it has become unavoidable?

The formalisation of computer languages introduced mathematical tools that allow taming reflexivity in novel ways (Jacobs 2016; Rutten 2000). We have argued elsewhere that such tools may be particularly suited for addressing human-environmental relations (Hauhs and Trancón y Widemann 2012). An important step in this direction is to replace the nature-culture dichotomy when analysing human-environmental relations by a more abstract model framework. Mathematics so far has been much more useful to scientists of nature than to those of culture. If the "ontic" difference between nature and culture is no longer useful then the different attitudes towards formalisation may also begin to vanish.

Acknowledgements: This research was supported by the German Federal Ministry of Education and Research (grant number FKZ 01UC1201).

References

Abramsky, Samson and Winschel, Viktor. 2012. "Coalgebraic Analysis of Subgame-Perfect Equilibria in Infinite Games without Discounting." *arXiv* 1210(4537): 1–9.

Adam, Barbara. 2010. "Future Matters: Challenge for Social Theory and Social Inquiry." *Cultura e comunicazione* 1: 47–55.

Awodey, Steve. 2004. "An Answer to Hellman's Question: Does Category Theory Provide a Framework for Mathematical Structuralism?" *Philosophia Mathematica* 12: 54–64.

Beck, Ulrich, Giddens, Anthony and Lash, Scott. 1994. *Reflexive Modernization: Politics, Tradition, and Aesthetics in the Modern Social Order.* Stanford, CA: Stanford University Press.

Crutzen, Paul J. 2002. "Geology of Mankind." *Nature* 415(6867): 23.

Crutzen, Paul J. 2006. "The 'Anthropocene'." In: Eckart Ehlers and Thomas Krafft (eds.) *Earth System Science in the Anthropocene*. Berlin and Heidelberg: Springer, pp. 13–18.

Davidson, Donald. 1984. *Inquiries into Truth and Interpretation*. Oxford: Clarendon Press.

Deacon, Terrence W. 2011. *Incomplete Nature: How Mind Emerged from Matter.* New York: W.W. Norton & Company.

Descola, Philippe. 2005. *Par-delà nature et culture.* Paris: Gallimard.

Descola, Philippe. 2011. *Jenseits von Natur und Kultur.* Berlin: Suhrkamp Verlag.

Descola, Philippe 2016. "Biolatry: A Surrender of Understanding (Response to Ingold's *A Naturalist Abroad in the Museum of Ontology*). *Anthropological Forum* 26(3): 321–328.

van Eijck, Jan and Verbrugge, Rineke. 2009. *Discourses on Social Software*, Vol. 5. Amsterdam: Amsterdam University Press.

Erdbeer, Robert Matthias, Kläger, Florian and Stierstorfer, Klaus. 2017. "Introduction: Across Philologies, Aesthetic Modelling and Literary Form." *Theories – Dynamics – Cultures. Perspectives on Literary Modelling*, ed. iid. Beiträge zur neueren Literaturgeschichte 371: 9–27.

Erickson, Paul. 2015. *The World the Game Theorists Made*. Chicago: Chicago University Press.

Eriugena, Johannes Scotus. 1983. *Über die Einteilung der Natur.* Hamburg: Felix Meiner Verlag.

Gillespie, Michael A. 2008. *The Theological Origins of Modernity.* Chicago: University Chicago Press.

Hare, Brian, Wobber, Victoria and Wrangham, Richard. 2012. "The Self-Domestication Hypothesis: Evolution of bonobo Psychology is due to Selection against Aggression". *Animal Behaviour* 83(3): 573–585.

Hauhs, Michael and Lange, Holger. 2008. „Die Waldbilder der Forstwissenschaften aus der Sicht der Ökologischen Modellbildung." *Allgemeine Forst- und Jagdzeitung* 179(8–9): 154–160.

Hauhs, Michael and Trancón y Widemann, Baltasar. 2010. "Applications of Algebra and Coalgebra in Scientific Modelling: Illustrated with the Logistic Map." *Electronic Notes in Theoretical Computer Science* 264(2): 105–123.

Hauhs, Michael and Trancón y Widemann, Baltasar. 2012. *A Critique of Agent-Based Simulation in Ecology.* 26th European Conference on Modelling and Simulation. Available at: www.bayceer.uni-bayreuth.de/bayceer/en/pub/html/120637/Hauhs_Trancon_ECMS_2012.pdf

Hunt, Lynn. 2014. *Writing History in the Global Era.* New York: WW Norton & Company.

Ingold, Tim. 2000. *The Perception of the Environment: Essays in Livelihood, Dwelling and Skill.* London and New York: Routledge.

Ingold, Tim. 2011. *Being Alive.* London and New York: Routledge.

Ingold, Tim. 2016. "A Naturalist Abroad in the Museum of Ontology: Philippe Descola's Beyond Nature and Culture." *Anthropological Forum* 26(3): 301–320.

Jacobs, Bart. 2016. *Introduction to Coalgebra: Towards Mathematics of States and Observations.* Cambridge and New York: Cambridge University Press.

Kant, Immanuel. 1845[1784]. *Beantwortung der Frage: Was ist Aufklärung?* Potsdam: Stuhr.

Koch, Anton Friedrich. 2012. Antinaturalismus, lecture online (http://www.philosophie.uni-hd.de/md/philsem/personal/koch_antinaturalismus.pdf; accessed 7 December 2017).

Koch, Anton Friedrich. 2016. *Hermeneutischer Realismus*. Tübingen: Mohr Siebeck.

Latour, Bruno. 2010. "An Attempt at a 'Compositionist Manifesto'." *New Literary History* 41(3): 471–490.

Latour, Bruno. 2013. *An Inquiry into Modes of Existence*. Cambridge, MA: Harvard University Press.

Latour, Bruno. 2014. "Some Advantages of the Notion of 'Critical Zone' for Geopolitics." *Procedia Earth and Planetary Science* 10: 3–6.

Latour, Bruno. 2017. *Facing Gaia: Eight Lectures on the New Climatic Regime*. Cambridge: Polity Press.

Lenton, Tim and Watson, Andrew. 2011. *Revolutions that made the Earth.* Oxford: Oxford University Press.

Lorimer, Jamie. 2015. *Wildlife in the Anthropocene: Conservation after Nature.* Minneapolis: University of Minnesota Press.

Lovelock, James. 2007. *The Revenge of Gaia: Earth's Climate Crisis and the Fate of Humanity*. New York: Basic Books.

Mahr, Bernd. 2009. "Die Informatik und die Logik der Modelle." *Informatik-Spektrum* 32(3): 228–249.

Mankiw, Gregory N. 2014. *Principles of Macroeconomics.* Stanford, CT: Cengage Learning.

Marris, Emma. 2013. *Rambunctious Garden: Saving Nature in a Post-Wild World*. New York: Bloomsbury Publishing.

McInerney, James, Pisani, David, Bapteste, Eric and O'Connell, Mary J. 2011. "The Public Goods Hypothesis for the Evolution of Life on Earth." *Biology Direct* 6(1): 1–17.

Meixner, Uwe. 2002. "Der Begriff der Notwendigkeit in der Antike und in der Gegenwart." *Kriterion* 16: 19–38.

Metzinger, Thomas. 2009. *The Ego Tunnel: The Science of the Mind and the Myth of the Self.* New York: Basic Books.

Montesino-Pouzols, Federico, Toivonen, Tuuli, Di Minin, Enrico et al. 2014. "Global protected area expansion is compromised by projected land-use and parochialism." *Nature* 516(7531): 383–386.

Moran, Dermot. 2004. *The Philosophy of John Scottus Eriugena: A Study of Idealism in the Middle Ages.* Cambridge and New York: Cambridge University Press.

Morgan, Mary S. and Morrison, Margret (eds.) 1999. *Models as Mediators: Perspectives on Natural and Social Science.* Cambridge and New York: Cambridge University Press.

Ofek, Haim. 2001. *Second Nature: Economic Origins of Human Evolution.* Cambridge and New York: Cambridge University Press.

Ostrom, Elinor. 2015. *Governing the Commons*. Cambridge: Cambridge University Press.

Pearl, Judea. 2000. *Causality: Models, Reasoning, and Inference.* Cambridge and New York: Cambridge University Press.

Penrose, Roger. 2005. *The Road to Reality: A Complete Guide to the Laws of the Universe*. New York: Knopf.

Prusinkiewicz, Przemyslaw and Lindenmayer, Aristid. 1991. The Algorithmic Beauty of Plants. Hamburg: Springer.

Prusinkiewicz, Przemyslaw, Hammel, Mark, Mech, Radomír, et al. 1995. "The Artificial Life of Plants." *Artificial Life for Graphics, Animation, and Virtual Reality* 7: 1–10.

Rosen, Robert. 1991. *Life Itself: A Comprehensive Inquiry into the Nature, Origin, and Fabrication of Life.* New York: Columbia University Press.

Rosen, Robert. 2012. *Anticipatory Systems: Philosophical, Mathematical, and Methodological Foundations*. New York: Springer.

Ross, William David. 1928. *The Works of Aristotle translated into English*. Oxford: Clarendon Press.

Rutten, Jan J. M. M. 2000. "Universal Coalgebra: A Theory of Systems." *Theoretical Computer Science* 249(1): 3–80.

Shapiro, Steward. 1997. *Philosophy of Mathematics: Structure and Ontology.* Oxford: Oxford University Press.

Tarnas, Richard. 1996. *The Passion of the Western Mind: Understanding the Ideas that have Shaped Our Worldview.* London: Pimlico.

Taylor, Bron. 2010. *Dark Green Religion: Nature Spirituality and the Planetary Future.* Berkeley, CA: University of California Press.

Trancón y Widemann, Baltasar and Hauhs, Michael. 2015. "Scientific Modelling with Coalgebra-Algebra Homomorphisms." *arXiv* 1506(07290): 1–18.

Trancón y Widemann, Baltasar and Winter, Joost. 2012. *Lindenmayer Systems, Coalgebraically*. Proceedings 11th International Workshop on Coalgebraic Methods in Computer Science (CMCS 2012). Short contribution. Available at: www.mimuw.edu.pl/~jwinter/articles/cmcs12b.pdf

Von Neumann, John and Morgenstern, Oskar. 2007. *Theory of Games and Economic Behavior.* Princeton: Princeton University Press.

Wendler, Reinhardt. 2010. *Das Modell zwischen Kunst und Wissenschaft.* Paderborn: Wilhelm Fink Verlag.