METAMODELING

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Contents

Summary

The article starts with a description of models and modeling emphasizing the various relationships between conceptual models, formal models and (a perceived) reality, but alluding to some fundamental philosophical issues which are elaborated in later sections. It then sets out an overview of types of meta-modeling, including taxonomies and models-of-models. The taxonomies include guides to choosing models, such as those commonly used in strategic planning OR/MS and forecasting. There follows a brief description of simulation metamodeling and judgmental bootstrapping, using regression and neural network models. Technical details are referred to the bibliography. The remaining sections focus on conceptual meta-models, particularly models of strategic behavior or productive entities (i.e. strategy). Models as objects of choice and comparison, with the corresponding meta-rational arguments are considered. Other metamodels involve design, transition, renewal and replication. The problem of recursivity and the associations with chaos theory, cognitive science and a wider epistemology are then briefly discussed, together with some implications for future policy and decision making.

1. Introduction

The term metamodeling has been used in the context of human and technological systems, in several ways. In its broadest sense it can simply refer to discussions and conceptual models *of* models and modeling processes. More specifically it refers to the classification evaluation and selection of conceptual and formal models. A more technical usage describes the statistical modeling of the quantitative outputs from large complex models, such as computer simulations. Finally, metamodeling can also refer to a broader philosophical analysis and critique of a methodology, or total system of thought, within which various types of model are designed and deployed.

The article starts with a brief description of models and modeling in general, emphasizing the various relationships between conceptual models, formal models and (a perceived) reality, but alluding to some fundamental philosophical issues which are elaborated in later sections. Section 3 then sets out an overview of types of metamodeling, including taxonomies and models-of-models. The taxonomies (described in section 4) include guides to choosing conceptual models, such as those commonly used in strategic planning and analysis, as well as guides to selecting quantitative OR/MS and forecasting models. Section 5 of the article sets out a brief overview of simulation metamodeling, but then compares this to bootstrapping (ie. regression and neural network models of quantitative human judgements, with applications). The remaining sections focus in much more depth upon conceptual meta models. The idea of a conceptual model as an object of choice or comparison is reviewed in section 6, with other conceptual metamodels briefly considered in section 7. Since there is a pervasive recursivity (i.e. models of models of...) the discussion passes quickly into the domains of epistemology, cognitive science, philosophy of science and metaphysics.

2. Models

A distinction is often drawn between formal and conceptual models One can also distinguish formal mathematical expressions from the natural language, or meta-language, used to interpret and communicate them. A formal model can be

mathematical, statistical or a simulation. It is a set of variables, parameters and relationships, sometimes with derivation of solutions (the latter invoke a mathematical logic that can itself be formalised). Typical examples of models within the management sciences are linear programming and discounted cashflow models. The Newtonian equations of motion, or the General theory of relativity are examples of formal models in the physical sciences. Formal models are often interpreted and communicated with the aid of diagrams and natural (meta-)language, although these can sometimes be a source of ambiguity.

2.1. Conceptual Models

A conceptual model can be defined as: a set of images and natural language expressions that depict and describe a problem context, or a (perceived) reality (Figure 1). In managerial contexts, such a strategy formulation, these models typically refer to a set of entities (e.g. individuals, firms, networks, states, etc.) with their behavior and inter-relationships. Put differently, such a model is an framework for thinking about a managerial situation.

Sometimes, such models or frameworks are created in order to better communicate mathematical results already obtained from a formal theoretical analysis. For example, the industry attractiveness model depicts the competitive environment of an entity and has often been used in business strategy; but it is derived from, or at least informed by the mathematical work in game theory and oligopoly theory. In hard sciences, such as physics, a conceptual model can serve as an informal hypotheses, or a thought experiment.

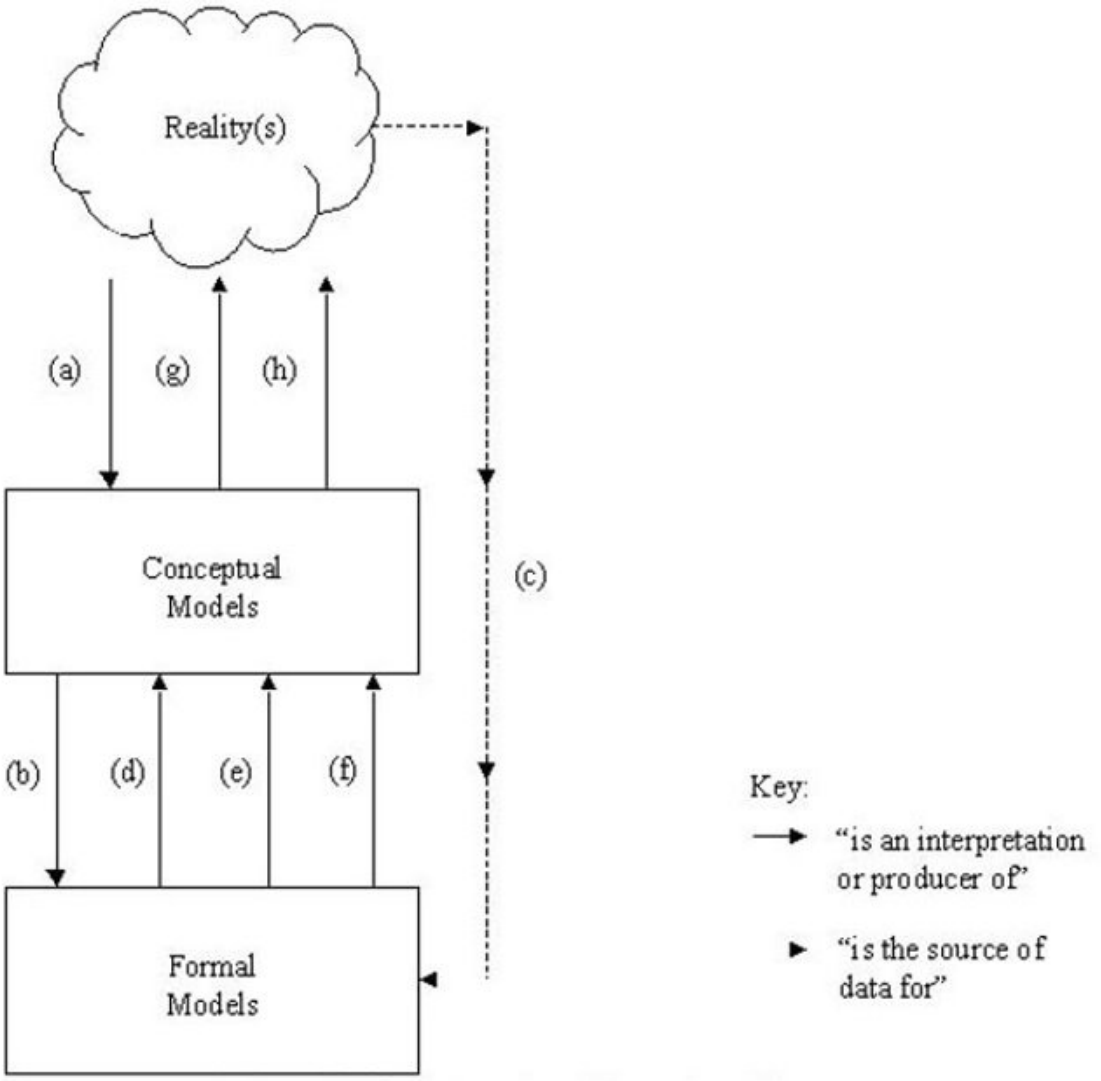

Figure 1. Conceptual and formal models.

Formal and conceptual models represent an assumed or perceived reality (Figure 1) or problem world. As such, there are many latent philosophical issues, concerning the existence of an objective reality, with the idea of correspondence between elements of the model and that reality. In the last two decades, however, assumptions of objectivity and the associated "correspondence" have been challenged, not only within postmodern philosophy, but also across the spectrum of the social and managerial sciences.

In the field of business strategy, for example, there are many well known models, such as the input-output model of the firm, the stakeholder model, the hypercompetition model, the industrial competitiveness model and the competitive strategy and advantage models, to mention but a few. Yet it is increasingly being recognized that these are often mere claims about what's new, what works, or what's really going on, so to speak; with "reality" variously conceived. Furthermore, the "claims" are often defended with reference to quite different types of knowledge. At the same time increasing emphasis is being placed upon the subjective, political, social and moral dimensions of modeling and the communication of models. This is indicated in Figure 3 (below) by the

placement of the "reality" and "conceptual model" within the wider domains of epistemology and cognitive science.

2.2. Relationships

There are various possible relationships between formal models, conceptual models and a (notional) "reality" (Figure 1). These have the general form "model 1 ..is an *interpretation* of..model 2", or "...is a *product* of...". The "interpreter" or "producer" in this context refers to a manager, an OR analyst or a strategist; but in principle it can be any cognitive entity (e.g. a team, a computer program, etc). The six metamodeling relationships depicted in Figure 1 are:

(a) *Conceptualization*. A entity constructs a view of the relevant parts of reality. This is a creative act of design and it is often carried out with an application in mind. (In the case of physical sciences, it is with experimentation in mind).
(b) *Formalization*. Elements of the designed conceptual model are then re-described in terms of quantifiable parameters and relationships between the elements are re-stated in mathematical or programmable form (eg. equations)
(c) *Measurement*. Data is then gathered from the "reality" being modeled, such as firm or industry. The parameters of the formal model are measured, or estimated. (Then, in some cases, such as relativity theory, the model is then tested; in other cases, such as many OR/MS models, prescriptions or recommendation are extracted)
(d) *Interpretation:* The results of the measurement (and any testing) are then interpreted and re-expressed in terms of the conceptual model with a correspondingly revised understanding of reality. In some cases, this revised understanding provides a basis for actions, interventions and policies.

However there is an alternative way of depicting and describing the above relationships. Models can themselves be re-conceptualized as producers, or productive entities. This is because models produce effects, in the sense that computer programs do, such as changing the focus of a person's attention, co-producing of a new reality, or promulgating an ideology, as follows:

(e) *Narrowing of focus*: A formal model can be embedded in institutional practices and processes, whereupon it can reinforce (or induce changes in) a collective conceptual model of a problem, within the institution (or entity). Put differently, the formal model can direct attention towards particular aspects of reality, away from others. For example, when working with a cashflow model, one might be inclined to overlook social and ecological factors. Working with the mathematics of agency theory, one might be inclined (for better or worse) to focus on contractual relations (not to mention relations of capital) rather than human relations, trust and identity.

(f) *Broadening of focus*: formal models, if used in a different way can also direct attention to a wider set of considerations, or factors (or cues). For example, the processes of attempting to produce a quantitative forecast for a cashflow model cannot produce reliable forecasts (hence "fake-cast" in the figure), but it can induce a more thorough consideration and discussion of the diverse strategic issues, or factors, such as stakeholder reactions and other macro environmental trends. In this

case a formal model indirectly activates (in users' minds), or co-produces an improved conceptual model of the "reality" (Figure 2).

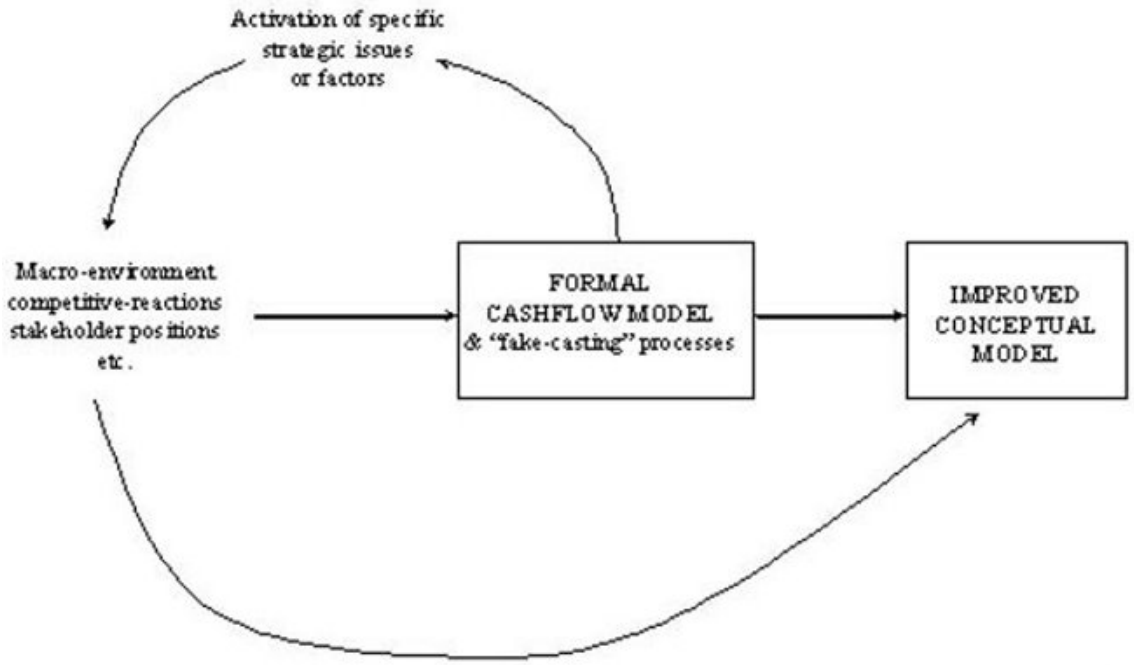

Figure 2. A formal model co-produces an improved conceptual model.

(g) *Co-Production of reality* A conceptual model can also be a co-producer of a perceived reality (Figure 1). Put differently models construct reality. Once an entity has produced a model, or a theory, the productive entity's behavior typically changes in ways that reflect that model. The changed behavior, in turn, can substantially influence other entities and brings real consequences, hence the idea of "production" of reality. This process can be likened to Heisenberg's uncertainty principle in physics, according to which an act of observation (of the direction of spin of an electron) can alter (or produce) the actual spin.

(h) *Promulgation:* Intentional political activity provides yet another way in which a conceptual model can co-produce a reality. Explicit descriptions can be used as political instruments. They can be endorsed and widely communicated by powerful entities (e.g. within an organisation, or state), whereupon they influence other decisions and actions. Put simply, fictions on paper can be made to prevail on the ground. See *Formal Approaches to Systems* and *The Quantification of Systems Domain.*

3. Metamodels

The preface "meta" means about, of, or going beyond. For example, a meta-language statement *about* an equation, a model *of* the outputs from another model, or, going *beyond* immediate context to consider ultimate meanings. Thus, metamodeling implicitly reifies a model, treating it as a thing (e.g. a producer). In a stricter interpretation, the term metamodel also implies that the model and metamodel are of the

same kind. For example, if the model is formal, a metamodel should also be formal. However, metamodeling is interpreted here (Figure 3) as including a variety of combinations, with their interrelationships.

A taxonomy, or classification scheme is also a form of metamodel. This is a structured way of thinking about a particular *set* of models. These might be formal models, as in the metaforecasting literature and classifications of OR/MS models, or conceptual models, such as those found in the business strategy literature. In each case, the metamodel provides a guide to evaluating or choosing from amongst some "given" or well- documented models.

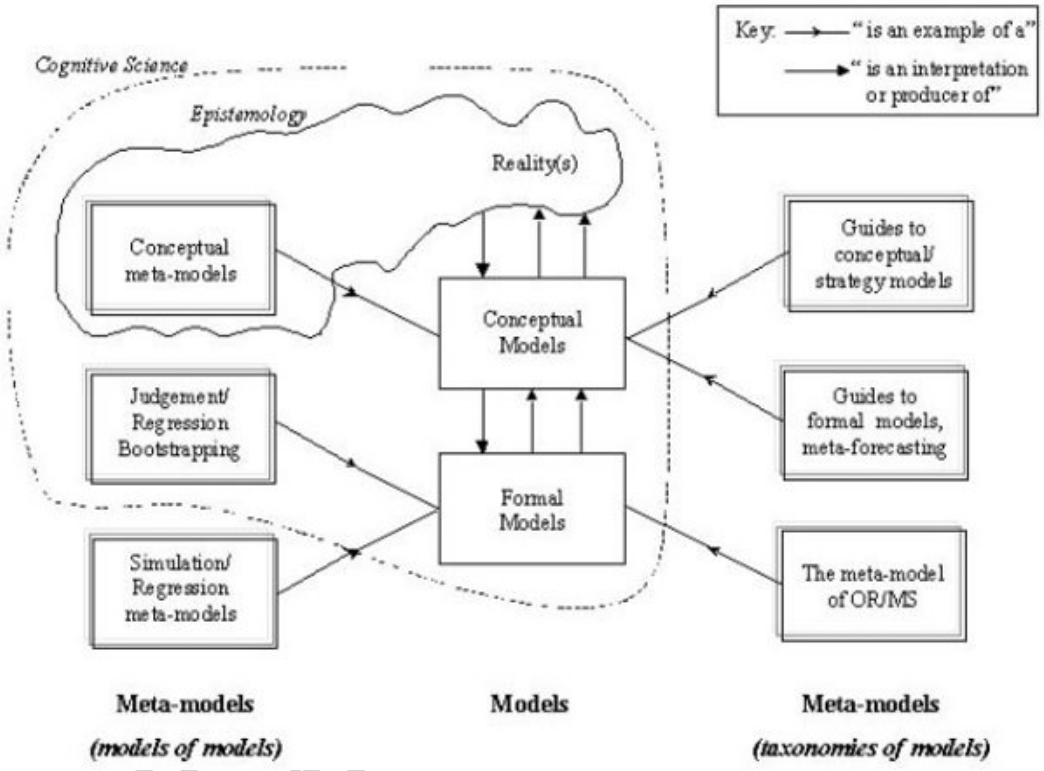

Figure 3. Types of Meta-Models and their inter-relationships.

Models of models and their outputs also exist in a variety of forms (refer to the left hand side of Figure 3). In OR/MS the term metamodel is now most closely associated with statistical and neural-net models of the outputs from large scale expensive models, such as computer simulations. Here, the quantitative metamodel provides a much cheaper and simpler way to forecast and understand aspects of the "simulated" reality.

A rather similar approach has been used within the fields of experimental behavioral decision theory and the psychology of judgement. Here, human judgements of quantity, such as a one period forecast of a time series, which must be based on some kind of cognitive or mental model, are re-modeled, using a regression or neural network (formal) model. A final category of metamodel (top left of Figure 3) consists of conceptual models *of* conceptual models. These are various depictions and descriptions of what conceptual models are and what they do (refer to sections 6 and 7).

4. Taxonomies

There have been several attempt to construct useful taxonomies of formal and conceptual models. They include guides to evaluating and selecting models and techniques for strategy, forecasting and decision making, as follows.

4.1. Guides

Guides have been developed to evaluate techniques of competitive (strategic) analysis along various dimensions, such as: resources needs (time and skills needed to use the techniques), data needs, advantages (e.g. draws attention to cultural factors, etc.) and limitations (e.g. a model ignores competitors' motivations, etc.), the use of historical information and the repertoire of strategic behaviors recognized in the model, etc. Many given models meet only a few of the criteria set out in the guides. However, in practice, such "limitations" or omissions might be substantially overcome by the "broadening of focus" role of models, as identified in 3(f) above.

Within the OR/MS literature, several authors have set out lists of attributes that determine the appropriateness of a formal model for any given managerial situation. The include insight generating capacity, as in 3(f) above; descriptive realism or correspondence, as in 3(a); usability, and predictive ability. Earlier classifications of models, proposed in the '60s and 70's set out criteria relating to the form and content of models (e.g. queuing, search, competition, etc.); difficulty of formulation (e.g. simple and transparent vs. "insufficient data"; and presence *vs* absence of feedback.)

4.2. Metaforecasting

Metaforecasting is a systematic description of the strengths and weaknesses of various forecasting methods, including judgemental and statistical methods. A major theme of metaforecasting is that statistical methods do not predict fundamental changes in established patterns and relationships, as new factors emerge and come into play. As discussed in section 3(f), these factors must be considered alongside a model based forecast. A famous case occurred in 1973, with the OPEC decision to greatly increase oil prices. The widespread failure to forecast this event precipitated a change in attitude, in the corporate world, towards quantitative forecasts. Metaforecasting also describes the sources of systematic bias in judgemental forecasts, such as wishful thinking, misapplied cognitive heuristics and political pressures. Metaforecasting offers guidelines for choosing forecasting models, improving forecasting practice, by, for example, keeping track of errors, as well as exploring the ways in which different types of forecast can be combined, in order to provide more reliable forecasts.

4.3. Metamodel of OR/MS

The meta-model of OR/MS is a distinctive approach to "identifying the characteristics of a problem and the selection of the appropriate model for solving it". Unlike the schemes mentioned earlier, it is itself a *formal* model. Thus, "meta" is used in the stricter sense. The metamodel sets out an "approach for classifying (OR/MS) models

according to their conceptual features". 24 categories of model are specified, depending on (i) the type of decision maker (eg. single vs. group) (ii) the types of uncertainties (i.e. "internal"/"external", or dependant upon actions of project members /non-members), and (iii) the type of project-dependencies that are considered in the given model.

Once the category is chosen the metamodel has four further steps: 1. determination of the problem "category", as above; 2. determination of the raw "data" which means the working assumptions to be made about decision-makers, uncertainties and dependencies in the context of a given problem. Step 3 is the evaluation and quantification of this "data". This involves consideration of such factors as the set of control points for the project, a set of binary decisions (such as continuation vs. termination of project), a set of all possible actions, etc.). The final steps involve evaluation of utilities and various forms of optimization. This formal metamodel is unique, in that it formalizes many aspects of the modeling process that are normally considered in more qualitative or casual way, or as part of methodology.

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Biographical Sketch

Alan E Singer is an Associete professor at the Department of Management, University of Canterbury, Christchurch, New Zealand. He has degrees in mathematics from Oxford University and psychology from London University, with a PhD in Management from Canterbury. He worked for Emile Woolf and Associates in the UK before moving to New Zealand in 1982. He is author of "Strategy as Rationaity" (Avebury series in philosophy) and editor, with P Werhane, of "Business Ethics: Contributions from Asia and NZ", Kluwer Dordrecht He has over 100 publications including papers in Human Systems Management, Strategic Management Journal, OMEGA, Decision Sciences, Systems Practice, Journal of Business Ethics, Psychology and Marketing. His most recent work is on metatheory, strategy and intellectual property. He is a member of the NZ Strategic Management Society, a former member of the NY Acadaemy of Sciences and he serves on various journal editorial boards. He is listed in Who's Who in the World (1998-2000).