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General morphological analysis as a basic scientific modelling method

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A B S T R A C T

General Morphological Analysis (GMA) is a method for structuring a conceptual problem space – called a morphospace – and, through a process of existential combinatorics, synthesising a solution space. As such, it is a basic modelling method, on a par with other scientific modelling methods including System Dynamics Modelling, Bayesian Networks and various types graph-based "influence diagrams". The purpose of this article is 1) to present the theoretical and methodology basics of morphological modelling; 2) to situate GMA within a broader modelling theoretical framework by developing a (morphological) model representing different modelling methods, and 3) to demonstrate some of the basic modelling techniques that can be carried out with GMA using dedicated computer support.

1. Introduction

This article is about General Morphological Analysis (GMA) as a basic, conceptual (non-quantified) modelling method. As such, it can be compared with a wide range of other scientific modelling methods, including System Dynamics Modelling (SDM), Bayesian Networks (BN) and various forms of "influence diagrams". As will be shown, all of these modelling methods are based on variations among a common set of components and properties, and are developed through the same iterative process involving cycles of *analysis* and *synthesis* (Ritchey, 1991, 2012). Indeed, these variations in modelling properties can themselves be modelled morphologically.

Firstly, the theoretical and methodological foundations of GMA as a modelling method are presented. This will include the task of providing a general operational definition of a (scientific) model, in order to identify its components and properties. Next, GMA will be situated within a wider modelling theoretical framework by developing a morphology of modelling methods, which will allow for the systematic identification, classification and comparison of different such methods. The construction of this morphological (meta-) model will also serve as an *example* of how to "build" morphological models in general. The meta-model also gives us a graphical representation of how a given modelling method can be transformed into another by altering one or more of its parametric values. Finally, a number of GMA modelling techniques will be demonstrated that have been made possible by the introduction of dedicated computer support in the early 1990s.

We begin by discussing the basic nature of a "scientific model", in order to identify those modelling properties by which to create a morphospace of modelling methods.

2. What is a scientific model?

The notion of a *model*, like that of a *system* or a *theory*, belongs to a class of concepts which essentially encompass an unbounded domain. The open-ended nature of these concepts makes it difficult to give them both an all inclusive and a precise definition (cf. Koperski, 2016; Portides, 2014). From the perspective of the philosophy of science it is understandable to opt for an all-inclusive account, and we often find the concept of a *model* being based on the notion of "representation", e.g. a model is a (mathematical, symbolic or conceptual) representation of the thing being modelled. This is certainly all inclusive, but is only a *nominal* designation. For our present purposes a" real" or operational definition needs to be put forward – even if it is not "all-inclusive" – in order to better clarify how models are actually developed and *how they do their work*, i.e. their *means* of representation.

Here, the notion of a (scientific) model is defined on the basis of 1) its components and structure (variables and links) and 2) its method of generation (analysis and synthesis). There is nothing essentially new in this operational description, but since we claim that GMA is a fundamental modelling method itself, with its own unique place in the menagerie of such methods, a review of these formal principles is warranted. (The following text is a further development of work appearing in Ritchey 2011a & 2012).

The following criteria are posited as necessary and sufficient for at least a *minimal definition* of a scientific model. (At this point I am going to drop the "scientific" qualifier and ask that this be understood.) The two criteria are:

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A. A model must contain two or more (mental) constructs that can serve as variables which can support a range of states or values – otherwise called the variable's *domain* or *value range* (since we are not necessarily working with directed mathematical functions here, these two terms are interchangeable). Such variables represent those aspects of reality (or an abstract system) one wants to treat, and which make up the dimensions of the *modelling space* to be developed. We shall call these variables the model's *parameters*. [The term *parameter* is being used here in its broader "systems science" sense, as being *one of a set of factors that defines a system and determines its behaviour, and which can be varied in an experiment* – including a *Gedankenexperiment*.]

B. One must be able to establish relationships (e.g. causal, statistical, logical, modal, normative) between the different parameters, such that each parameter is "connected to" (i.e. constrained or influenced by) at least one of the other parameters.

The development of these two components (variables and connective links) into a model is essentially an iterative process of analysis and synthesis. In the analysis phase, variables and their respective domains are formulated which represent the model's initial *problem space*. In the synthesis phase, connective relationships between parameters are defined which *bind* the modelling space and determine its topological properties. It also constrains the total modelling space in order to produce a solution or outcome space.

Thus the basic framework for a model is an internally connected, n-dimensional conceptual space which goes under a number of different names depending on the nature of the model, its area of application and the *properties of the space to be emphasised*: e.g. parameter space, configuration space, state space or phase space, or, in the case of GMA, a *morphospace*.

At this point we need to distinguish between so-called *static* and *dynamic* models. (These terms are used somewhat differently in different modelling contexts, but are here generalised.) In *dynamic models*, the variables have explicitly defined, specified domains; and the connective links between variables are connections between their respective domains. This means that the modelling space can be manipulated by treating one or more of the model's variables as "independent", varying its values (as inputs) and realising the results on the remaining "dependent" variables (as outputs). This is what we usually think of as a proper "model" in science. Included here are SDM, BN and GMA.

In *static models*, the variables are treated as black boxes and only an overall (graphic) connective structure is indicated. No dynamic input-output variability is obtainable. Indeed, this is why such "models" are often referred to as diagrams, charts or graphs. Included here are flow charts, classical influence diagrams and so-called system dynamics (SD) diagrams. Although we are primarily concerned with *dynamic models*, we will include *static models* in the meta-model in order to mark out the interface between these two basic modelling types.

It is interesting to note that this general operational definition of a model is quite similar that of an *experiment*. In experimental research the aim is to design an environment by which one is able to manipulate designated ("independent") variables in order to examine the effect on the remaining ("dependent") variables. Thus the very definition of an experiment involves the identification of variables and a "set up" that both creates and allows one to examine the (e.g. causal) connections between such variables. In this sense, dynamic models in general can be regarded as *conceptual experiments* or *thought experiments* (although this is only one aspect of the notion of thought experiments; see e.g. Sorensen, 1992). This is why we have often referred to morphological models as *conceptual laboratories*.

3. A morphology of modelling methods

On the basis of this operational definition of a model, we will proceed to develop a theoretical morphospace by which we can identify and compare a range of different modelling methods, including GMA itself. The development of this *meta-model* will also serve as a procedural example of how to create a (relatively simple) morphological model.

We begin with the analysis phase of defining the parameters (i.e. variables and their respective domains) which represent the meta-model's initial "problem space". Note that variables in morphological models consist of *discrete category variables*. There are no metric relationships or numerical calculations involved. Even if a variable in a morphospace may *look like* a magnitude or interval scale variable (e.g. age, weight, income bracket), they are nonetheless treated as discrete categories and assessed as such. The only scaling property utilised in classical morphological modelling is "rank order". (Some extended forms of GMA allow for the use of probabilities or other numeric relationships but, as we shall see, this in effect is a shift into another modelling type.)

For the purposes of this (meta-) model, we employ the following five parameters (further developed from Ritchey, 2012):

P1. Variable type: Are the domains of the variables (a) continuous, (b) discrete or (c) unspecified (black boxes)?
P2. Directionality of connective links: Are the connections between the variables (a) *directed* (asymmetric) or (b) *non-directed* (symmetric)?
P3. Quantification of connectivity: Are the relationships of connectivity between the variables (a) *quantified* or (b) *non-quantified*?
P4. Cyclic relationships: Does the model allow for (a) *cyclic connectivity* (closed loops, circular feedback) between the variables, or is the model (b) *acyclic*.
P5. Type of connectivity: What is the nature of the connective relationships between variables? For instance, are they (a) *mathematical/functional*, (b) *probabilistic*, (c) *non-causal* (e.g. logical, modal, normative), or (d) *unspecified* (or *quasi-causal*).

First of all, one may ask why just these five particular parameters have been chosen to represent the basic properties of the meta-model. They were chosen because 1) we have to start somewhere and 2) they make up some of the simplest and fundamental operational properties that can be identified (note that P1 is given, and P2, 3 & 4 are basic parameters in mathematical graph theory, the *skeletal form* of a modelling theory). A more complete morphology could certainly treat a wider range of modelling properties, including the distinctions between e.g. different scaling types; open vs. closed modelling contexts; hierarchical vs. non-hierarchical variable structure; the distinction between different types of uncertainty; and whether or not mereological (whole-part) interactions and self-reference is accounted for. However, the present five variables will provide a relatively broad field of modelling methods which will give a first illustration of how GMA can be situated within such a meta-modelling framework.

These variables thus make up the parameters of a morphospace as shown in Fig. 1. This 5-dimensional space contains 96 ($= 3 \times 2 \times 2 \times 2 \times 4$) *formal configurations* or *potential morphotypes*, each represented by one condition selected under each of the parameters. This represents the model's total problem space. The specific configuration shown in Fig. 1 (dark cells) represents the modelling properties of one particular modelling type – in this case a *morphological model*.

[Note that this morphological (meta-) model is unusually small. A "normal" scenario, strategy or policy model will typically have 7–12 parameters and a problem space of between 50,000 and several million configurations. See the examples used to describe GMA modelling techniques below.]