

General Morphological Analysis: An overview

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General Morphological Analysis (GMA) is a computer-aided, non-quantified modelling method employing (discrete) category variables for identifying and investigating the total set of possible relationships contained in a given problem complex. This is accomplished by going through a number of iterative steps which represent cycles of analysis and synthesis – the basic method for developing (scientific) models (Ritchey 1991; 2018).

The epistemological principle underlying discrete variable morphological modelling is that of *decomposing* a complex (multivariate) concept into a number of (“simple”) one dimensional concepts (i.e. category variables), the domains of which can then be *recombined* and *recomposed* in order to discover all of the other possible (multidimensional) concepts which can be generated combinatorially. Note that this (analytic) *decomposition* and (synthetic) *recomposition* process is exactly what we do – on a smaller scale and in a less complex format – when we create *typologies*, which are essentially low-dimensional (usually 2-D) morphological models. (Lazarsfeld (1937) called this modelling process *substruction* and *recombination*.)

The method thus begins by identifying and defining the most important variables of the problem complex to be investigated, and assigning each variable a domain of relevant *values* or *conditions*. This is done mainly in natural language, although abbreviative labels can be defined and utilized. A morphological field (or *morphospace*) is constructed by setting the parameters against each other in an n-dimensional configuration space (Figure 1). A *simple configuration* within this space contains one “value” from *each* of the parameters, and thus marks out a particular *state*, or formal *solution*, within the problem complex (dark cells).

The point is, to establish which of the configurations are possible, viable, practical, interesting, etc., and which are not. In doing this, we reduce the *total problem space* represented by the morphological field to a relevant *solution space*. The solution space of a morphological field consists of the subset of all the possible configurations which satisfy some criteria. The primary criterion is that of internal consistency.

Parameter A	Parameter B	Parameter C	Parameter D	Parameter E	Parameter F
Condition A1	Condition B1	Condition C1	Condition D1	Condition E1	Condition F1
Condition A2	Condition B2	Condition C2	Condition D2	Condition E2	Condition F2
Condition A3	Condition B3	Condition C3		Condition E3	Condition F3
Condition A4	Condition B4	Condition C4		Condition E4	Condition F4
Condition A5		Condition C5		Condition E5	
				Condition E6	

Figure 1: A 6-parameter morphological field. The darkened cells define one of 4,800 possible (formal) configurations.

Obviously, in fields containing more than a handful of variables, it would be practically impossible to examine all of the configurations involved. For instance, a 7-parameter field with 6 conditions under each parameter contains 279,936 simple configurations. Thus the next step in the analysis-synthesis process is to examine the *internal relationships* between the field variables and “reduce” the field by weeding out all configurations which contain mutually contradictory conditions. This is called a *Cross-Consistency Assessment (CCA)* and is performed on a Cross-Consistency Matrix (Figure 2). (Gottfried Leibniz, who was the first to systematically employ this modelling method, called this “synthesis by combinatorics”. In modern combinatorial mathematics it is called “existential combinatorics”.) All of the parameter values in the morphological field are compared with one another, pair-wise, in the manner of a cross-impact matrix. As each pair of conditions is examined, a judgment is made as to whether – or to what extent – the pair can coexist, i.e. represent a consistent relationship. Note that there is no reference here to direction or causality, but only to compossibility and mutual consistency (which is why only a “half-matrix” is required). Using this technique, a typical morphological field can be reduced by 90% or even 99%, depending on the nature of the problem space.

There are three principal types of constraints involved in the cross-consistency assessment: purely internal *logical* contradictions (i.e. “contradictions in terms”); external *empirical* constraints (i.e. relationships judged to be highly improbable or implausible on practical, empirical grounds), and *normative* constraints (although these must be used with care and clearly designated as such).

		Parameter A					Parameter B				Parameter C					Parameter D		Parameter E					
		Condition A1	Condition A2	Condition A3	Condition A4	Condition A5	Condition B1	Condition B2	Condition B3	Condition B4	Condition C1	Condition C2	Condition C3	Condition C4	Condition C5	Condition D1	Condition D2	Condition E1	Condition E2	Condition E3	Condition E4	Condition E5	Condition E6
Parameter B	Condition B1																						
	Condition B2																						
	Condition B3																						
	Condition B4																						
Parameter C	Condition C1																						
	Condition C2																						
	Condition C3																						
	Condition C4																						
	Condition C5																						
Parameter D	Condition D1																						
	Condition D2																						
Parameter E	Condition E1																						
	Condition E2																						
	Condition E3																						
	Condition E4																						
	Condition E5																						
	Condition E6																						
Parameter F	Condition F1																						
	Condition F2																						
	Condition F3																						
	Condition F4																						

Figure 2: The cross-consistency matrix for the morphological field in Figure 1. The dark cells represent the 15 pair-wise relationships contained in the configuration given in Figure 1.

Thus the CCA-matrix functions as a *heuristic search space* involving two seemingly opposing tasks. On the one hand, incompatible concepts are identified in order to reduce the problem space to an internally consistent solution space – which is a form of *constraint-based modelling* and *inference by exclusion* (Ritchey, 2015). *At the same time* one also needs to keep an open mind for the discovery of strange and novel combinations, which may initially seem impossible or implausible (or just plain weird), but which represent *emergent conjunctive concepts*. This has variously been termed “conceptual integration” (Fauconnier & Turner, 1998) and “combinatorial creativity” (Boden, 1999).

When the solution (or outcome) space is synthesized, the resultant morphological field can function as an *inference model*, in which any variable (or multiple variables) can be selected as “input”, and any others as “output”. Thus, with dedicated computer support, the field can be turned into a “what-if” laboratory with which one can designate drivers and different initial conditions, and examine alternative outcomes or solutions.

In a survey of the literature from 1950-2015 (Álvarez & Ritchey, 2015) it was found that most of the applications of *general* morphological analysis (i.e. excluding traditional discipline-specific forms such as geomorphology, urban morphology, linguistic morpho-

logical analysis, etc.) could be divided into four broad (admittedly not water-tight) categories. These are:

- Engineering design, architecture and general design theory
- Scenario development, technological forecasting and futures studies in general
- Policy analysis, operational research/management science (OR/MS) and social/cultural modelling (SOCUMOD)
- Creativity, innovation and knowledge management

This breadth of application is not surprising, given that GMA is essentially a general method for non-quantified modelling and problem structuring (Ritchey, 2006). It has also been used extensively for initiating long-term projects by modelling the “project-problem-space” as a baseline to evaluate its development over time. (cf. Ritchey, 2019).

We present an elementary example of a morphological model in the area of OR/MS in order to demonstrate its basic features and principles. Figure 3 is an *organizational design* model which was developed for the Swedish National Defence Research Agency in preparation for a major organizational change in the late 1990’s (for this and additional examples, see Ritchey, 2011, 2018). It contains seven parameters which together generate $6 \times 6 \times 6 \times 6 \times 4 \times 6 \times 6 = 186,624$ distinct *simple configurations* – i.e. configurations consisting of a single value given under each parameter.

Organisation TYPE	Leadership culture	Buyer structure	Dominate product/service	Co-operation strategies	Main employee incentive	Employee profile
Official state agency	Bureaucratic hierarchy	Ministry dominated	Process + method support	Outside help when needed	Money	Life-long service
Government owned enterprise	Strong scientific leadership	Military and material dominated	Soft studies	Joint ventures	Managerial career	Career researcher
Academy (à la university)	Marketing division leadership	Defence Industry	Hard studies	Consultant purchasing	Pleasure in one's work	Development engineer
Trade institute	Umbrella management	Civilian agencies	Basic research	Mediator only	Educational motivation	"Consultant"
Consultant firm	Gate-keeping	Private markets (national)	Testing, construction		Titles, specialist career	"Entrepreneur"
"Learning organisation"	Skunk-works (ad hoc/rati)	International markets	Second opinion		Organisation gives status	Elite troops

Figure 3. Seven-parameter organizational design model

Organisation TYPE	Dominant leadership culture	Buyer structure	Dominate product/ service	Co-operation strategies	Main employee incentive	Employee profile
Official state agency	Bureaucratic hierarchy	Ministry dominated	Process + method support	Outside help when needed	Money	Life-long service
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Figure 4. Organizational design model with “Organizational type” and “Leadership culture” designated as drivers (red).

At this point we need to distinguish between two main types of “parameters”: i.e. those whose domains consist of mutually exclusive values, or Boolean OR-lists; and those consisting of non-mutually exclusive values, or Boolean AND-lists. Both of these types of parameters can be employed in morphological models as long as they are properly defined, such that the logical relationships between dependent parameters are treated properly. Most morphological models concerning policy-driven problems are hybrids in this manner, although “pure” OR-list models are also common. It depends on the nature of the problem and the goals to be obtained. This model is a mix of OR-lists (the first two variables “Organisation type” and “Dominant leadership culture”) and AND-lists (the rest of the variables).

In Figure 4, the first two variables (red cells) have been temporarily designated as the independent variables or “drivers”, and the cluster of dark blue cells is the “output”, i.e. the compatible values along the remaining parameters. The red “dot” in the “Bureaucratic hierarchy” cell tells us that this was the only other viable “Leadership culture” value considered available for an “Official state agency”.

Since any variable, or combination of variables, can be designated as drivers/inputs, this gives these models great flexibility. For instance, Figure 5 shows the organizational consequences from a completely different perspective – i.e. from that of employee types and incentives. Here, the designated drivers generate significantly different organizational requirements.

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Figure 5. The organizational structure from the perspective of a selected employee type and incentive.

GMA seeks to be integrative and to help discover new relationships and novel configurations. Importantly, it encourages the identification and investigation of boundary conditions, i.e. the limits and extremes of different parameters within the problem space. The method also has definite advantages for scientific communication and – notably – for group work. As a process, the method demands that variables, conditions and the issues underlying these are clearly defined. Poorly defined concepts become immediately evident when they are cross-referenced and assessed for internal consistency. This is a form of “garbage detection” which is highly valuable, especially when modelling complex, multi-stakeholder, policy driven problems.

References

- Álvarez, A. & Ritchey, T. (2015). Applications of General Morphological Analysis: From Engineering Design to Policy Analysis, *Acta Morphologica Generalis*, Vol.4 No.1.
- Boden, M. (1999). Computer models of creativity. In Sternberg, R. (Ed.) *Handbook of Creativity*, Cambridge University Press, pp. 351–373.
- Fauconnier G. & Turner M. (1998). Conceptual integration networks, *Cognitive science*, 22 (2), 133-187.
- Lazarsfeld, P. (1937) “Some Remarks on the Typological Procedures in Social Research.” *Zeitschrift für Sozialforschung*, VI, 119-139.
- Ritchey, T. (1991/1996). Analysis and Synthesis - On Scientific Method based on a Study by Bernhard Riemann”. *Systems Research* 8(4), 21-41. (Reprint available at Academia.)
- Ritchey, T. (2006). “Problem Structuring using Computer-Aided Morphological Analysis”. *Journal of the Operational Research Society* 57, pp. 792-801.
- Ritchey, T. (2011). *Wicked Problems/Social Messes: Decision support Modelling with Morphological Analysis*. Berlin: Springer.
- Ritchey, T. (2015). Principles of Cross-Consistency Assessment in Morphological Modelling, *Acta Morphologica Generalis* (AMG) 4(2), 1-20. (Available at Academia)
- Ritchey, T. (2018). “General morphological analysis as a basic scientific modelling method”, in Ritchey, T. & Arciszewski, T. (Eds.) (2018) “General Morphological Analysis: Modelling, Forecasting, Innovation”, Special Issue of *Technological Forecasting and Social Change*, Vol. 126, 81-91. (Preprint available at Academia.)
- Ritchey, T. (2019) Modelling Project Problem Spaces with General Morphological Analysis, *Acta Morphologica Generalis* (AMG), Vol.7 No.1. . (Available at Academia)