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Editors' introduction

1. Background

The term *morphology* (from the Greek μορφή, *morphé* = form) is used in science in a number of different contexts and on a number of different conceptual levels. On the most general level, it refers to nothing less than a philosophy of science, or at least what Lakatos (1968) calls a basic scientific research program, i.e. a set of theoretical (or ontological) assumptions and methodological ground rules upon which to approach scientific enquiry in general. Although the *term* "morphology" was only coined at the end of the 1700's, the scientific tradition it represents dates back to antiquity (see below).

On another level, we find morphology and *morphological analysis* denoting a general methodological approach used in a wide range of scientific disciplines concerning the study of *structural inter-relationships within the context of a developing systemic whole*. For example, geomorphology is the study of landforms and the processes that shape them. Urban morphology is the study of human settlements and the process of their formation. In linguistics, morphological analysis is the branch of grammar that studies the structure of word forms and their development over time.

However, it is in the field of biology – for which the term was originally coined by Goethe – that it developed into a method for the study of organic form in general, both in its structural and developmental (morphogenetic) sense (Russell, 1916; Thompson, 1917). More recently, with the advent of modern computer technology, the sub-discipline of *theoretical morphology* has been able to work with multivariate analysis of organic form based on the *morphospace* concept (McGhee, 1999).

Finally, on a purely technical-methodological level, *morphological analysis* (which in this context should actually be termed *morphological analysis and synthesis*) refers to a basic modelling method, on a par with other modelling methods such as System Dynamics Modelling (SDM) and Bayesian Networks (BN). Although morphological modelling is essentially "qualitative" (i.e. non-quantified and non-causal), it relies on the same principles of construction, and the same iterative process of analysis and synthesis, as all other scientific modelling methods (see Ritchey, this issue).

This Special Issue of the *Journal of Technological Forecasting and Social Change* is not about Morphology as a philosophy of science, or of how morphological analysis is applied to any specific scientific discipline (although both of these themes remain fluttering in the background). It is primarily concerned with this third, methodological context, i.e. morphological analysis as a *general method for conceptual modelling* and, as such, a procedure which facilitates discovery and invention. However, before proceeding it is instructive to take a look at some of the milestones in the history of what we now call *morphological modelling*.

2. Examples in the history of morphological modelling

As far as its ancient roots go, one of the earliest, explicit examples of a conceptual modelling procedure is that of Plato's *dialectic method of divisions and collections* (*diairesis and sunairesis*, usually simply referred to as the "method of divisions", see Philip, 1966). This was put forward around 350 BCE in the dialogues Phaedrus, the Sophist and the Statesman. Plato has Socrates alluding to "a certain pair of procedures":

> "The first is that in which we bring a dispersed plurality under a single form, seeing it all together – the purpose being to define each thing and thus make clear whatever may be chosen as the topic of exposition." … "The reverse [of this is] to be able to cut up each kind according to its species, along its natural joints, and to try not to splinter any part, as a bad butcher might do…"
>
> (Phaedrus, 265d)

Just as one must not *divide* arbitrarily, like a "bad butcher", one must also not *collect* indiscriminately, but "distinguish in what ways the several kinds can and cannot combine" (Sophist, 253d–e). Plato gives the analogy of how letters combine to form words, but that not all combinations of letters can be conjoined meaningfully. The two procedures are complementary; one can either begin by collecting lower-order concepts or dividing higher order concepts, depending on the problem to be treated. The procedures are also iterative and can proceed in steps "upwards" or "downwards" until one has reached a satisfactory understanding of the topic of discussion (cf. Ionescu, 2012; Meinwald, 2016).

Although Plato never fully systemised this process – that had to wait for the later neo-Platonic philosophers – these procedures are a tolerable description of the analysis-synthesis cycles involved both in scientific modelling in general (El Murr, 2006; Gill, 2006; Ritchey, 1991) and in engineering design (Arciszewski, 1984; Codinhoto et al., 2006; Norris, 1963).

Fast forward fifteen centuries: the Majorcan monk Ramon Llull (1232–1315), building upon earlier Neo-Platonic accounts of *diairesis*, developed what would later be called the Art of Combinations (*Ars Combinatoria*) as a way of dealing with all of the possible interconnections between analysed

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concepts. Among other things, he developed a conceptual calculator in the form of a circular slide rule that allowed for the display of all the combinations between the components of different concepts. Although principally concerned with theological concepts (he wanted to promote Christian theology within a "rational" framework), Llull seems to have been the first to systematically develop what we today is called a *morphospace* and the combinatoric process embodied in a *cross-consistency matrix* (Bonner, 2007; Llull, n.d.).

Three hundred years later, Llull's pioneering work made a great impression on the young Gottfried Wilhelm Leibniz (1646–1716). It inspired him, at the age of 20, to found the mathematical discipline of *combinatorics* (a term he coined). In his *Dissertation de ars combinatoria* (Leibniz, 1666), he presented a fully systemised version of morphological analysis (i.e. "analysis and synthesis by combinations") and gave twelve example applications, including an analysis of contemporary contract law and a means of discovering and demonstrating the full set of possible syllogistic forms.

In "On Universal Synthesis and Analysis, or the Art of Discovery and Judgment" (Leibniz, 1679), Leibniz established the modern notion of analysis and synthesis as reciprocal procedures both for structuring and defining a given area of inquiry, and for facilitating discovery and invention within that area. Indeed Couturat (1902), in his seminal work on Leibniz's philosophy of science, sums up this methodology in a way that essentially defines modern morphology as a conceptual modelling procedure:

> "In sum, analysis consists of decomposing concepts into their simple elements by means of definition; and synthesis consists of reconstituting concepts starting from these elements using the art of combinations."
>
> (Couturat, 1902, Chapter 6, p 4.)

However, this "universal" conceptual modelling method was for Leibniz only part of a much larger program. While the English-Scottish-French enlightenment was making great strides in "mechanising" the philosophy of natural science, Leibniz thought that they were throwing the preverbal baby out with the bathwater. He took Renaissance neo-platonic science, secularised it from all occult qualities and formulated the epistemological-ontological ground-rules for an "organic" approach to scientific enquiry (*Discourse on Metaphysics*, Leibniz, 1686; *Monadology*, 1714). This so-called "relational" or "holographic" approach (Bohm, 1980; Bortoft, 1996; Rosen, 1985; Smolin, 2013) concentrates not only on how parts of a system interact with one another (i.e. mechanically), but also on how the parts of a system relate to and interact *reciprocally* to the developing system as a whole (i.e. mereologically).

It was upon this scientific program that Johann von Goethe (1749–1832) was inspired to develop *morphology* both as a holistic philosophy of science and as a method for studying the life sciences (Goethe, 1995). In this approach, living systems are treated as open-ended and emergent; the *process of structural development* is fundamental, not the structure itself; and *functional teleology* (as an *architectonic principle*, not as supernatural design) is applied as a necessary complement to mechanical or efficient causes (Lenoir (1982) termed this the "teleo-mechanical" approach; Rosen (1985) called it "anticipatory systems"). Indeed, Goethe developed "morphology" with the expressed purpose of methodologically distancing the life sciences from the "ontological misuse" of a purely mechanical natural philosophy in biology (Hegge, 1987; Lenoir, 1987).

According to Fritz Zwicky himself, it is principally from Goethe that he gained inspiration to develop his "morphological method of analysis and construction" (Rudnicki, 2005). He also mentions Ramon Llull, but it is indeed odd that he totally "misses" Leibniz's earlier development of the method. This is especially interesting in that Zwicky's doctoral thesis advisor, Herman Wyle, was thoroughly steeped in Leibniz's physics and metaphysics. But a discussion of this issue will have to wait for a more suitable occasion.

3. Fritz Zwicky

> "Attention has been called to the fact that the term morphology has long been used in many fields of science to designate research on structural interrelations – for instance in anatomy, geology, botany and biology. … I have proposed to generalize and systematize the concept of morphological research and include not only the study of the shapes of geometrical, geological, biological, and generally material structures, but also to study the more abstract structural interrelations among phenomena, concepts, and ideas, whatever their character might be."
>
> (Zwicky, 1969, p. 34)

Fritz Zwicky (1898–1974), Professor of Astrophysics at the California Institute of Technology (Caltech), developed the "morphological approach" as a conceptual (non-quantified) modelling method which, like all scientific modelling, is based on an iterative process involving cycles of *analysis* and *synthesis*. (The theoretical basis and methodological description of this process is given in Ritchey (this issue) – and we need not go into further detail here.)

Zwicky was born in Bulgaria (1898) to a Swiss father and a Czech mother. At the age of six, he was sent to his ancestral canton of Glarus, Switzerland, in the middle of the Schwyzer Alps (Zwicky was a life-long mountain climber). In 1914 he moved to Zurich where he studied engineering, mathematics and experimental physics at the Swiss Federal Institute of Technology (ETH). There he took his doctorate under the great theoretical physicist and philosopher of science, Herman Wyle.

In 1925 he moved to the United States to work at the California Institute of Technology (Caltech) in Pasadena. From this point onward, until his death in 1974, Zwicky was essentially based at Caltech, but considered himself a "free world citizen" with a totally global perspective (see Ströckli and Müller, 2012, for a biography of Zwicky). In addition to being professor of astrophysics at Caltech and the Mount Wilson Observatory, he was also research director at Aerojet Engineering Corporation for nearly twenty years. In this later position he worked as an inventor, producing some 50 patents, mostly related to the development of jet and rocket propulsion systems. At the end of World War II, he was appointed head the U.S. research team that travelled to Germany and Japan to evaluate inter alia the development and use of jet aircraft during the war. Because of this, and his subsequent work at Aerojet, he was considered by some of his contemporaries as being "the father of the modern jet engine."

Fritz Zwicky is not a household name in science today. He was not a superstar of the likes of Albert Einstein, Ervin Schrödinger or Robert Oppenheimer. Yet his influence was significant; far more than his present-day lack of recognition would suggest (and his recognition is presently growing, cf. Ritchey, 2012). He was one of the most innovative scientists of his time, combining "high-flyer" theoretical studies with practical, inventive engineering design. He was also a great humanitarian, engaged in a number of charitable activities including years of personal toil to help rebuild scientific libraries in Europe destroyed during the war and participating in the Pestalozzi Foundation's program to establish war orphan villages.

Zwicky is primarily known for his work in astrophysics and especially his comprehensive galaxy surveys. He coined the term supernova and was the first to hypothesise the existence of neutron stars (1934). He was also the first to discover evidence for *dark matter* (Zwicky, 1933), which is at the very forefront of astrophysics today. He thrived on investigating and theorizing about extreme phenomena and *boundary conditions*. This led him to