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ORIGINAL PAPER

Functional Entailment and Immanent Causation in Relational Biology

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Abstract I explicate the crucial role played by efficient cause in Robert Rosen's characterization of life, by elaborating on the topic of Aristotelian causality, and exploring the many alternate descriptions of causal and inferential entailments. In particular, I discuss the concepts of functional entailment and immanent causation, and examine how they fit into Robert Rosen's relational-biology universe of living, anticipatory, and complex systems.

Keywords Anticipatory systems · Closure to efficient causation · Functional entailment · Immanent causation · Robert Rosen

1 Prolegomenon: *Quid est veritas?*

Robert Rosen closed his book *Anticipatory Systems* (Rosen 1985a; I shall henceforth refer to the book as *AS*) with these words:

> The study of anticipatory systems thus involves in an essential way the subjective notions of good and ill, as they manifest themselves in the models which shape our behavior. 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.

(This last paragraph in Chap. 6 marked the end of his original 1979 manuscript. Chapter 7 was added as an Appendix just before the book's eventual publication in 1985.)

One may speak of *absolute truths* concerning formal systems, in the universe of mathematics. But there is no such luxury for natural systems, in the external world

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outside the realm of formalism. "Reality" is one of the few words which mean nothing without quotes. Natural systems from the external world generate in us our percepts of "reality;" these percepts are *not* universal truths. All we have are *opinions*, *interpretations*, or as Rosen put it, "subjective notions of good and ill," our individual *alternate descriptions* of "reality" that are our personal *models* of "truth." The models realized in the anticipatory systems that are ourselves are *relative truths*, and are in fact the "constitutive parameters" of our individuality. We can indeed agree about life, the universe, and everything, *if* (and what a big *if* this is!) we can agree on our answers to *the question*, in Pontius Pilate's immortal words: "What is truth?" (*John* 18:38).

2 Simultaneity and Temporal Succession

Rosen wrote Chap. 7 as an Appendix for *AS*, to sketch out some of the developments from 1979 to 1985. It was in this Appendix that Aristotle's *categories of causation* made their first appearance, albeit only in passing, in his publications.

The year 1985 simultaneously marked the untimely demise of the Red House, the quarters of the Biomathematics Program of Dalhousie University in Halifax, Nova Scotia. (Rosen spent the final years of his career at Dalhousie, from 1975 until his retirement in 1993.) We (I. W. Richardson, A. H. Louie, and Robert Rosen) jointly published a specimen of the output of the Red House program, as its memorial, the book *Theoretical Biology and Complexity*: *Three Essays on the Natural Philosophy of Complex Systems*. The Rosen tierce is entitled "Organisms as Causal Systems which are not Mechanisms: an Essay into the Nature of Complexity" (Rosen 1985b) [hereafter referred to as *NC*], in which he further explored the philosophical, mathematical, and methodological foundations of anticipatory systems, the modeling relation, organisms, and complex systems. Here, Aristotelian causality was more fully discussed. In the Foreword of *AS*, Rosen wrote this of Chap. 7: "I hope to enlarge this Appendix into a separate monograph in the near future, giving full details to justify what is merely asserted therein." In both *NC* and Chap. 7, we saw hints and genesis of the revolutionary ideas that would culminate in the realization of this anticipation, which is, of course, his iconoclastic masterwork *Life Itself* (Rosen 1991) [hereafter referred to as *LI*]. The modeling relation is the point of departure in a temporal succession leading to that destiny.

Robert Rosen's whole lifetime's work is embodied in his "trilogy." Part 1 is the monograph *Fundamentals of Measurement and Representation of Natural Systems* (Rosen 1978). Part 2 is *AS*. Part 3 is *LI*, which is supplemented by the posthumously published collection *Essays on Life Itself* (Rosen 2000) [hereafter referred to as *EL*]. In the present paper, I shall elaborate on the topic of Aristotelian causality, the analysis of which received its detailed treatment in *LI*. I shall explore the many alternate descriptions of causes, the unifying concepts found in the works of three natural philosophers, Aristotle, St. Thomas Aquinas, and Robert Rosen.

3 Robert Rosen's Imperative

Robert Rosen did not set out to be an iconoclast. His scientific writing, as he explained in his "Autobiographical Reminiscences" (Rosen 2006), is not proselytizing, not advocacy, not even instruction. It was simply a duteous report of the results of his lifelong quest, his Imperative, to find the answer to the ultimate biological question: "What is life?" (which is a terse and immediate abbreviation of the better-posed question "What distinguishes a living system from a non-living one?").

The Answer was given in Sect. 10A of *LI*:

Theorem 1 *A material system is an organism if, and only if, it is closed to efficient causation.*

The important point to note for the purposes of my paper here is that life is characterized through the use of *efficient causation*, one of Aristotle's four categories. The crux of relational biology is *throw away the matter and keep the underlying organization*. The characterization of life is not what the underlying physicochemical *structures* are, but by its entailment *relations*, what they *do*, and to what *end*. In other words, life is not about its material cause, but is intimately linked to the other three Aristotelian causes, formal, efficient, and final.

Rosen showed clearly in *LI* that an invocation to Aristotelian causality may be made in any entailment structure. There are two different realms in which one may speak of entailment: the outer world of causal entailment of phenomena and the inner world of inferential entailment in formalisms. These two realms of entailment are brought into congruence by Rosen's modeling relation, a concept first introduced in Chap. 3 of *AS*. Further discussions on the modeling relation also appeared in *NC*, and its category-theoretic basis may be found in my own tierce "Categorical System Theory" (Louie 1985) in the Red House memorial volume that I mentioned earlier.

The modeling relation embodies the concept of Natural Law, which is the bare minimum required to do any science at all. As Rosen explains in Sect. 3H of *LI*:

> [*Natural Law*] provides the explicit underpinning on which all of science rests. Natural Law makes two separate assertions about the self and its ambience:
>
> 1. The succession of events or phenomena that we perceive in the ambience is not entirely arbitrary or whimsical; there are relations (e.g., causal relations) manifest in the world of phenomena.
> 2. The relations between phenomena that we have just posited are, at least in part, capable of being perceived and grasped by the human mind, i.e., by the cognitive self.
>
> Science depends in equal parts on these two separate prongs of Natural Law. The first, which says something about the ambience, asserts that it is in some sense orderly enough to manifest relations or laws. Clearly, if this is not so, there can be no science, also no natural language, and most likely, no sanity either. So it is, for most of us at any rate, not too great an exercise of faith to believe this.
>
> The second part of Natural Law says something about ourselves. It asserts that the orderliness of the ambience is (to some unspecified extent) discernable to,

and even more, is articulable by, the self. It asserts then that the posited orderliness in the ambience can be matched by, or put into correspondence with, some equivalent orderliness within the self.
In other words, the first part of Natural Law is what permits science to exist in the abstract. The second part of Natural Law is what allows scientists to exist. Clearly, concrete science requires both.

The reader should continue Rosen's exposition in Chap. 3 of *LI*, "Some Necessary Epistemological Considerations." I shall now concentrate on the alligation of Aristotle's causation in Rosen's relational biology. [The following diagrams (1)–(15) and their discussions have been presented in detail in a recent paper published in this journal (Louie and Kercel 2007). They are précised here to make the present paper self-contained.]

4 Arrow Diagrams of a Mapping

Let A and B be sets and f be a mapping from A to B. The sets A and B are called respectively the *domain* and *codomain* of f. The relations among a mapping and its domain and codomain may be represented in an arrow diagram of the form.

$$f : A \to B \tag{1}$$

and, in the language of category theory, as the morphism

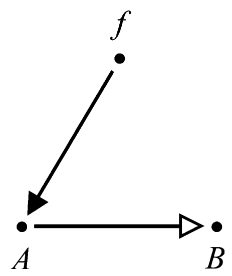
$$f \in H(A, B). \tag{2}$$

Sometimes it is useful to trace the path of an element as it is mapped. If $a \in A$ and $b = f(a) \in B$, I use the "maps to" arrow and write

$$f : a \mapsto b. \tag{3}$$

Rosen introduced *relational diagrams* in *graph-theoretic form*, in Chap. 9 of *LI*, to provide a succinct depiction of the entailment patterns in machines. Then in Chap. 10, he used them to represent the entailment patterns in organisms. By comparing the two classes of relational diagrams, the differences between machines and organisms became almost immediately apparent.

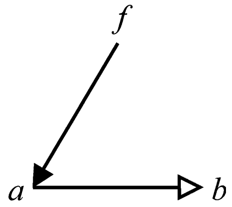
A simple mapping $f : A \to B$ has the relational diagram



(4)

where a hollow-headed arrow denotes the *flow* from input in A to output in B, and a solid-headed arrow denotes the induction or generation of this flow by the *processor* f.

When the mapping is represented in the element-chasing version $f : a \mapsto b$, the relational diagram may be drawn as



(5)

(where I have also eliminated the dots that represent the vertices of the graph). The processor and output relationship may be characterized "*f entails b*" (Sects. 5H and 9D in *LI*). I denote this entailment as

$$f \vdash b \tag{6}$$

5 The Four Causes of a Mapping

The interrogative "Why mapping?" provides an excellent illustration of Aristotle's four causes.

Aristotle's original Greek term αἴτιον (*aition*) was translated into the Latin *causa*, a word which might have been appropriate initially, but which had unfortunately diverged into our contemporary notion of "cause." The possible semantic equivocation may be avoided if one understands that the original idea had more to do with "grounds or forms of explanation," so a more appropriate Latin rendering (in hindsight) would probably have been *explanatio*. It is with this "grounds or forms of explanation" sense of "cause" that I apply the four Aristotelian causes interchangeably to components of both the causal entailment in natural systems and the inferential entailment in formal systems.

The *material cause*, that out of which the mapping $f : a \mapsto b$ (alternatively $f : A \to B$) comes to be, is its input $a \in A$. One may choose to identify the material cause as either the input element a or the input set, the domain A.

The *formal cause*, the mapping's form or its statement of essence, is the *structure* of the mapping itself as a morphism. Note that the Greek term for "form" is μορφή (*morphé*), the etymological root of "morphism." The fact $f \in H(A, B)$ implies the relational diagrams (4) and (5), so the formal cause of the mapping is the ordered pair of arrows

(7)

The arrows implicitly define the processor *and* the flow from input to output. The compositions of these arrows also need to follow the category rules. Alternatively, when the material cause, the exact nature of the input, is immaterial (which is the essence of relational biology), the formal cause may just be identified with the entailment symbol

$$\vdash \tag{8}$$

which implicitly defines the processor and the output. The identification of a morphism with its formal essence (7) or (8) is an interpretation of the category axioms in "arrows-only," i.e., graph-theoretic, terms.

The *efficient cause*, that which brings the mapping into being, the source of change, is the *function* of the mapping as a processor. The difference between the formal cause and the efficient cause of a mapping is that the former is what f *is* (i.e., $f \in H(A, B)$), and the latter is what f *does* (i.e., $f : a \mapsto b$). One may simply identify the efficient cause as the processor itself, whence also the solid-headed arrow that originates from the processor

$$f \longrightarrow \tag{9}$$

The *final cause*, the purpose of the mapping, why it does what it does, is its output $b \in B$. One may choose to identify the final cause as either the output element b or the output set, the codomain B. The Greek term τέλοζ (*te͂los*, translated into *finis* in Latin), meaning "end" or "purpose", covers two meanings: the end considered as the object entailed (i.e., b itself) or the end considered as the entailment of the object (i.e., the *production* of b). In both cases, the final cause may be identified as b, whence also the hollow-headed arrow that terminates on the output

$$\longrightarrow\!\!\triangleright\, b \tag{10}$$

Material and formal causes are what Aristotle used to explain static things, i.e., things as they are, their *being*. Efficient and final causes are what he used to explain dynamic things, i.e., how things change and come into being, their *becoming*.

6 Functional Entailment and (M,R)-Systems

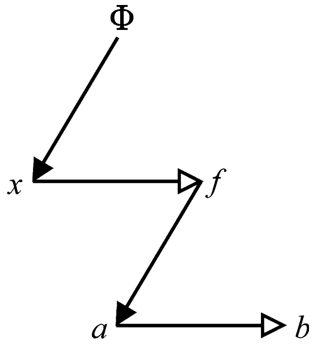
Relational diagrams may be composed. For example, if $f \in H(A, B)$ and $f : a \mapsto b$ as in Sect. 4, and there is a morphism

$$\Phi : X \to H(A, B) \tag{11}$$

such that

$$\Phi : x \mapsto f, \tag{12}$$

then one has



(13)

and

$$\Phi \vdash f \vdash b. \tag{14}$$

$\Phi \vdash f$ is a "different" mode of entailment, in the sense that it entails a mapping: the final cause of the first morphism is the efficient cause of another morphism. It is given the name of *functional entailment* (Sect. 5I of *LI*). When one is concerned not with what *entails*, but only what *is entailed*, one may simply use the notation

$$\vdash f. \tag{15}$$

Note that there is nothing in category theory that mandates an absolute distinction between sets and mappings. Functional entailment is therefore not categorically different; it warrants a new name because it plays an important role in the "closure to efficient causation" characterization of life.

Definition 1 A natural system is *closed to efficient causation* if its every efficient cause is entailed within the system, i.e., if *every efficient cause is functionally entailed* within the system.

Note that "closure to efficient causation" is a condition on efficient causes, *not* on material causes. Thus a system that is closed to efficient causation is not necessarily a "closed system" in the thermodynamic sense. (In thermodynamics, a *closed system* is one that is *closed to material causation*, i.e., a system that allows energy but not matter to be exchanged across its boundary.)

Let N be a natural system and let $\kappa(N)$ be all efficient causes in N. If N is closed to efficient causation, one may symbolically write

$$\forall f \in \kappa(N)\ \exists\ \Phi \in \kappa(N) : \Phi \vdash f. \tag{16}$$

Closure to efficient causation for a natural system means it has a formal system model that has a closed path containing *all* of the efficient causes in its causal entailment structure. This is Rosen's characterization of life, as I quoted as Theorem 1 above, "The Answer" given in Sect. 10A of *LI*. Explicitly in terms of efficient causes, one has

Theorem 2 *A natural system is an organism if and only if it has a closed path containing all of its efficient causes.*

Rosen devised a class of relational models called (M,R)-systems that define organisms. Rosen has discussed them on numerous occasions, including Example 6 in Sect. 3.5 of *AS*, Sect. 10C of *LI*, and Chap. 17 of *EL*. I have also recently published two papers on the subject in this journal (Louie 2006, Louie and Kercel 2007). Details may be found therein. I shall simply demonstrate here an (M,R)-system's cyclic functional entailment structure. There are three mappings in an (M,R)-system on three hierarchical levels:

$$\text{metabolism} \quad f \in H(A, B) \tag{17}$$

$$\text{repair} \quad \Phi \in H(B, H(A, B)) \tag{18}$$

$$\text{replication} \quad \beta \in H(H(A, B), H(B, H(A, B))) \tag{19}$$

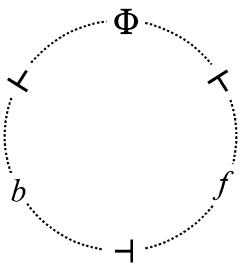
The genius in Rosen's construction is that he establishes a correspondence between the hom-sets $H(H(A, B), H(B, H(A, B)))$ and B, so that the replication map β may be replaced by the isomorphic b. The entailment patterns of the three (M,R)-system maps are therefore

$$\text{metabolism} \quad f \vdash b \tag{20}$$

$$\text{repair} \quad \Phi \vdash f \tag{21}$$

$$\text{replication} \quad b \vdash \Phi \tag{22}$$

whence they functionally entail one another in cyclic permutation in the entailment diagram:



(23)

7 An Anticipatory System is Complex

Definition 2 An *anticipatory system* is a natural system that contains an internal predictive model of itself and of its environment, which allows it to change state at an instant in accord with the model's predictions pertaining to a later instant.

True to the spirit of relational biology, the crux in this definition is not what an anticipatory system itself *is*, but the embedded internal predictive model, i.e., the entailment *process* of anticipation. The most important notion Rosen introduced in *AS* is his definition of a *model* as a commutative functorial encoding and decoding between two systems in the *modeling relation*.

The concept of *complex system* appears many times in *AS*. For example, in Sect. 5.7, one finds this:

> "…*we are going to define a system to be complex to the extent that we can observe it in non-equivalent ways.*"

Later, in Sect. 7.1, one finds this:

> …this category of general dynamical systems, in which all science has hitherto been done, is only able to represent what I call *simple systems* or *mechanisms*. Natural systems which have mathematical images lying outside of this category and which accordingly do not admit a once-and-for-all partition into states plus dynamical laws, are thus not simple systems; they are *complex*.

The last section of the Appendix, Sect. 7.5, is entitled "An Introduction to Complex Systems", and in it one finds:

> I am going to call any natural system for which the Newtonian paradigm is completely and eternally valid a *simple system*, or *mechanism*. Accordingly, a *complex system* is one which, for one reason or another, falls outside this paradigm.

The final refinement of the definitions of simple and complex systems appears in Chap. 19 of *EL*:

> A system is *simple* if all of its models are simulable. A system that is not simple, and that accordingly must have a nonsimulable model, is *complex*.

After careful mathematical arguments, Rosen stated an alternate characterization of complex systems:

Theorem 3 *A natural system is complex if and only if it contains a closed path of efficient causation.*

Chapter 18 of *EL* contains a detailed discussion of Theorem 3 and its consequences. Functional entailment is an iteration of "efficient cause of efficient cause," and is inherently hierarchical. A closed path of efficient causation must form a *hierarchical cycle*, both the hierarchy and the cycle being essential attributes. In formal systems, hierarchical cycles are manifested by impredicativities. In other words, a complex system has a formal system model with an impredicative cycle of inferential entailment.

Note that a complex system is *not* necessarily closed to efficient causation. A complex system, according to Theorem 3, is only required to have a cycle containing *some*, but not necessarily all, efficient causes; on the other hand, an organism (i.e., a living system), by Theorem 2, has a cycle that contains them *all*. A complex system is "not-a-mechanism"; a living system requires a little bit more. This is how one distinguishes between complex systems and living systems.

Herein lies another cause of the confusion on the term "closure to efficient causation." Some people use it to mean "a closed path containing *some* efficient causes exists," instead of "*all* of the efficient causes are contained in a single closed path" that is a consequence of Definition 1. The discrepancy is, however, simply due to their different usage of the word "closure" (or "closed"), rather than an outright error on their part. It still remains that a system satisfying the former (*existential*) condition is complex, while a system satisfying the more stringent latter (*universal*) condition is living (and therefore living systems form a *proper subset* of complex systems—for a thorough exposition of the etymology of Rosen's lexicon, see Louie 2007). In the Definition 1 usage that is inherent from Rosen's work, a complex system is *not* necessarily closed to efficient causation (while, of course, with a definition of "closure" based on the existential condition it tautologically is). Note that a "universal characterization" is consistent with other mathematical usage of the term "closure." For example, in topology, a subset of a metric space is *closed* if it contains *all* (not just some) of its cluster points; in algebra, a set is *closed* under a binary operation if the result of combining *any* pair (not just some pairs) of elements of the set is also included in the set.

In Rosen's relational diagrams in graph-theoretic form, an efficient cause is identified with its corresponding solid-headed arrow. So Theorems 3 and 2 may equivalently be stated thus:

Theorem 4 *In the relational diagram of a complex system, there is a cycle that contains solid-headed arrows.*

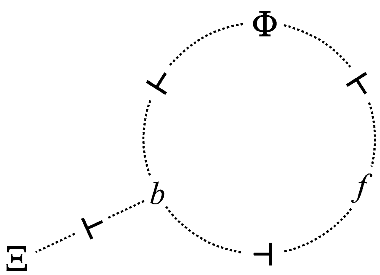
Theorem 5 *In the relational diagram of (a formal system model of) a living system, there is a cycle that contains all the solid-headed arrows.*

Functional entailment is identified with the entailment symbol $\vdash$. So one also has

Theorem 6 *In the entailment diagram of a complex system, there is a cycle that contains* $\vdash$.

Theorem 7 *In the entailment diagram of (a formal system model of) a living system, there is a cycle that contains all the* $\vdash$.

Stated otherwise, an organism must be complex; a complex system may (or may not) be an organism. As an example, in the simplest (M,R)-system, its three maps $\{b, \Phi, f\}$ of replication, repair, and metabolism entail one another in a cyclic permutation (diagram (23)). An (M,R)-system is therefore a formal model of a living system, hence also complex. Now consider a system, containing an additional efficient cause Ξ, with entailment diagram



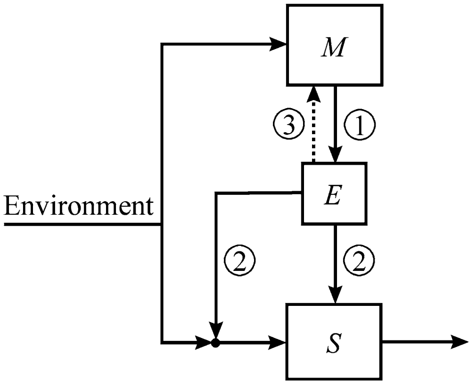
(24)

This system is complex, because the three maps $\{b, \Phi, f\}$ still form a cycle in its entailment structure. But it is not closed to efficient causation, because Ξ is not entailed, whence it cannot be a model of an organism.

Anticipatory, model-based behaviour provided one basis for what Rosen later called complexity. In the final paragraph of Sect. 7.5 of *AS*, Rosen wrote

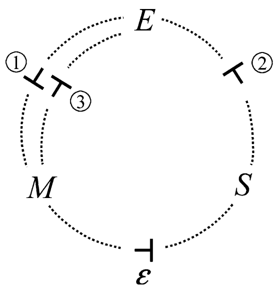
> In the present discussion, we have in effect shown that, in order for a system to be anticipatory, it must be complex.

Let me demonstrate this explicitly here. Consider the definitive block diagram of an anticipatory system (Fig. 1.1.1 in *AS*):



(25)

I shall use the same symbols for the object, model, and effector systems, respectively S, M, and E, to denote their efficient causes. In other words, let each symbol represent the *processor* associated with the block (the "black box") as well as the block itself. Then the entailment diagram for the anticipatory system is



(26)

The maps labelled with circled numbers correspond to those in diagram (25). The map $\varepsilon : S \rightarrow M$, completing the cycle, is the *encoding* of the object system S into its model M. The entailment of the three maps $\{M, E, S\}$ in cyclic permutation renders this anticipatory system complex.

An anticipatory system has more structure in its entailment pattern than the cycle $S \vdash M$, $E \vdash S$, $M \vdash E$. (In particular, the model-updating map ③ : $E \vdash M$, an inverse efficient cause, cannot be present in every hierarchical cycle.) Thus: "an anticipatory system *must* be complex; a complex system *may* be anticipatory." (cf. Sect. 7.1 of *AS*).

8 Immanent Causation and Exemplary Causation

Now let us consider the "inverse problem" of entailment. If an object b is entailed, then *there exists* a morphism f such that $f \vdash b$ (which implicitly implies the existence of a set A, the domain of f, whence $f \in H(A, B)$, and the existence of an element $a \in A$ such that $f : a \mapsto b$). In other words, *entailment itself entails the existence of an efficient cause*. In particular, if a morphism $f \in H(A, B)$ is functionally entailed, then *there exists* a morphism $\Phi \in H(X, H(A, B))$ (which implicitly implies the existence of a set X and an element $x \in X$) such that $\Phi : x \mapsto f$. Symbolically, this situation may be summarized

$$(\vdash f) \vdash (\exists \Phi : \Phi \vdash f) \tag{27}$$

The entailment of the *existence* of something (often on a higher hierarchical level) is termed *immanent causation* (Sect. 9F of *LI*) in philosophy. There are many different nuances in the various definitions of immanent causation in the philosophical literature, but they all involve "an external agent causing something to exist", hence *ontological* in addition to *epistemological* considerations.

Ontological considerations necessitate an escape from the Newtonian trap of mechanistic simplification, in which epistemology entails and hence swallows ontology. In the pre-Newtonian science that is *natural philosophy*, a natural system is studied in terms of its *existence* (ontology) and *essence* (epistemology). See Chap. 17 of *EL* for a succinct discussion. The equation therein

CONCRETE SYSTEM = EXISTENCE + ESSENCE

is something that could have come directly from St. Thomas Aquinas. Aquinas's writings include *De Principiis Naturae* (The Principles of Nature) and *De Ente et Essentia* (On Being and Essence), which explain Aristotelian (and post-Aristotelian) physics and metaphysics. Apart from his commentaries on Aristotle, Aquinas did not write anything else of a strict philosophical nature. But his theological works are full of philosophical insights that would qualify him as one of the greatest natural philosophers.

Before Aquinas, theologians like St. Augustine placed their activities within a Platonic context. Aquinas absorbed large portions of Aristotelian doctrine into Christianity. It is, of course, not my purpose here to digress into a comparison between Plato and Aristotle. With gross simplification, one may say that Plato took his stand on idealistic principles, so that the general implies the particular, while Aristotle based his investigations on the physical world, so that the particular also predicts the general. Plato's method is essentially deductive, while Aristotle's is both inductive and deductive. Stated otherwise, for Plato the world takes its shape from ideas, whereas for Aristotle ideas take their shape from the world (cf. Natural Law discussed in Sect. 3 above).

Aristotle's teleological view of nature may be summarized as "Nature does nothing in vain." Using this regulative principle, Aristotle realized that the understanding of function and purpose is crucial to the understanding of nature. Aquinas elaborated on Aristotle's science of *ens qua ens* (beings in their capacities of being), and developed his own metaphysical insight in so doing. To Aquinas, the key factor of any "reality as a reality" was its existence, but existence was not just being present. A being is not a being by virtue of its matter, but a being of what it is, i.e. its essence. This constitutive principle is called *esse*, or "the act of existing". Aquinas frequently used the Aristotelian dictum "*vita viventibus est esse*" ("for living things, to be is to live").

One can see in these Aristotelian and Thomastic principles the germ of relational biology: a natural system is alive not because of its matter, but because of the constitutive organization of its phenomenological entailment. The *esse* of an organism is its impredicative causal loop.

With the distinction between the concepts of essence and existence, Aquinas added a fifth cause, called *exemplary cause*. It is defined as "the causal influence exercised by a model or an exemplar on the operation of an agent". The best way to illustrate this is with an example, say a bronze statue of Aristotle. The material cause is the bronze. The formal cause is the specifying features of the sculpture. The efficient cause is the sculptor. The final cause is to commemorate Aristotle. Before the statue is realized, however, the *model* of the sculpture must already be in the mind of the sculptor. The *bauplan* in the mind of the agent is the exemplary cause.

9 Anticipation: *In beata spe*

There is thus an intimate relationship between the formal and exemplary causes. Readers familiar with Rosen's anticipatory systems will have no problem recognizing that Aquinas's exemplary cause is the morphism of anticipation, the *predictor*. An exemplary cause itself is an actuality in the agent, but it is also a potentiality that *anticipates* another actuality, the becoming and being of the formal cause of something else. A natural system with an exemplary cause model of an entailed formal cause, whence also the other causes (see Sect. 5), *is* an anticipatory system. When a morphism $f \in H(A, B)$ is functionally entailed, the morphism $\Phi \in H(X, H(A, B))$ that entails it may be considered its exemplary cause. Thus the statement (27) (whence also (16)) are as much about immanent causation as exemplary causation.

Finally, note that an exemplary cause, in anticipation, implies that something else is imminent. While the statement (27) is thus an alligation of *immanence* and *imminence*, the two similar words have distinct etymological roots. The Latin *immanere* means "to remain in," and evolves into "inherent," whence "to naturally *exist*". The Latin *imminere* means "to project over," and therefore "impending." With respect to the entailment symbol $\vdash$, immanence and imminence are, indeed, on opposite ends: in essence, that which entails and that which is entailed, the alpha and the omega.

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