CHAPTER 1

SYSTEM

Every science studies systems of some kind, whether natural (physical, chemical, biological, or social) or artificial (technical). Moreover most sciences study nothing but systems. Thus biology studies biosystems, sociology sociosystems, and technology technosystems. Physics seems to be the only science that investigates not only systems, such as atoms and large scale fields, but also putatively simple or elementary things such as electrons and photons. Even so, physicists acknowledge that every such basic thing is a component of some system or other

Until recently every species of system was studied separately. About four decades ago a number of specialists joined efforts to launch various cross-disciplinary ventures, such as operations research and cybernetics. Their success suggested to some workers that a unified approach to problems in various fields was possible. They pointed out that (*a*) there are some concepts and structural principles that seem to hold for systems of many kinds, and (*b*) there are some modeling strategies – in particular the state space approach – that seem to work everywhere.

The discipline that purports to develop such a unified approach is often called 'general systems theory' (Bertalanffy, 1950, 1958; Boulding, 1956). Paradoxically enough, this is not a single theory but a whole set of theories – automata theory, linear systems theory, control theory, network theory, general Lagrangian dynamics, etc. – unified by a philosophical framework (Bunge, 1974c, 1977c). We shall call *systemics* this set of theories that focus on the structural characteristics of systems and can therefore cross the largely artificial barriers between disciplines.

Systemics has two related motivations, one cognitive and one practical. The cognitive or theoretical rationale of systemics is, of course, the wish to discover similarities among systems of all kinds despite their specific differences – e.g. between body temperature control systems and furnace thermostats. The practical motivation for systemics is the need to cope with the huge and many-sided systems characteristic of industrial societies – such as communications networks, factories, hospitals, and armies. This complexity, in particular the variety of components of such systems, violates the traditional borders among disciplines and calls for a cross-disciplinary approach.

Note the differences between the standard scientist, engineer or social scientist on the one hand, and the systems "specialist" (actually a generalist) on the other. Whereas the former do or apply some particular science, the systemics expert de-emphasizes the physics (chemistry, biology, or sociology) of his systems, focusing instead on their structure and behavior. Moreover he is interested particularly in duplicating or imitating (modeling or simulating) the behavior of any given system (e.g. a person) by one of a different kind (e.g. a pattern recognition automaton). This holds not only for the mathematician who takes systemics as an honorable pretext for playing with abstract structures but without any serious concern for practical problems in engineering or management: it also holds for the systemist intent on solving practical problems, such as modeling and simulating a grazing land system or a university.

The method employed by the system theorist is mathematical modeling and the experimental (or at least the computer) testing of system models. Both are of course part of the scientific method. What is peculiar to the way the systemics expert proceeds is that, far from incorporating any specific (e.g. chemical) laws into his model, he aims at building a black box, a grey box, or a kinematical model free from details concerning the materials composing the system, and noncommittal enough to cover some of the global aspects of the organization and behavior of the system on some of its levels. The scientific method is thus taken for granted: what is emphasized is the general or cross disciplinary approach in contrast to the specific or disciplinary one. In other words, the systemics expert is a jack of all trades – a quasi-philosopher if not a full blown one.

Systemics is not quite the same as *systems analysis*, a much advertised, ill defined, and sometimes controverted thing. Systems analysis too, when serious, uses the scientific method but, unlike systemics, it is not particularly interested in de-emphasizing the peculiarities of the components of the system concerned. What it does emphasize is that, because it studies many-sided and multi-level systems – such as ecosystems and transportation systems – it must adopt various points of view on different levels. For example, hospitals are not just buildings with medical equipment but social systems as well – whose components include medical personnel and patients – and moreover subsystems of a larger social system, namely a health-care system, which is in turn a subsystem of a society. The novelty of systems analysis resides less in its methods than in the objects it studies, namely complex man-artifact systems never before approached in a scientific manner. Unlike systemics, systems analysis is hardly interested in building extremely general models: it aims instead at drawing flow charts, network diagrams, and occasionally specific mathematical models accounting if possible not just for the structure and kinematics of the system but also for its dynamics, and thus enabling one to understand how it operates and malfunctions, hence how it can be repaired. (For a hilarious account of systems antics, see Gall (1977).)

Systemics, or general system theory, is a field of scientific and technological research and one of considerable interest to philosophy. Because of its generality it has a sizable overlap with ontology or metaphysics construed in the traditional, pre-Hegelian sense as well as in our own sense of scientific ontology (Bunge, 1973a, 1977a). Both sytemics experts and ontologists are interested in the properties common to all systems irrespective of their particular constitution, and both are intrigued by the peculiarities of extremely general theories, which are methodologically quite different from specific theories (Bunge, 1973a, 1977c).

The main differences between systemics and ontology seem to be these: (*a*) while systems theorists take certain concepts for granted – e.g., those of property, possibility, change, and time – ontologists take nothing for granted except logic and mathematics; (*b*) while systems theorists are often interested in the details of the couplings of the components of a system, ontologists seldom are; (*c*) while systems theorists focus their attention on input–output models of systems that are largely at the mercy of their environment, ontologists are interested in free systems as well (in which respect they do not differ from physicists); (*d*) while systems theorists are mainly interested in deterministic (or rather nonstochastic) models – partly because theirs are large scale things – ontologists are also interested in stochastic ones; and (*e*) while some systems theorists focus their attention on the search for analogies among systems of different kinds, and particularly on different levels, ontologists are primarily interested in analyzing and systematizing concepts referring to all kinds of system.

In this chapter we shall propose a number of definitions and principles concerning concrete systems in general. These ideas will be used in succeeding chapters, where certain system genera will be studied. Details on mathematical models of systems are found in the two appendices.

1. Basic Concepts

1.1. *Aggregate and System*

An *aggregate* or assemblage is a collection of items not held together by bonds, and therefore lacks integrity or unity. Aggregates can be either conceptual or concrete (material). A conceptual aggregate is a set. (But not every set is a conceptual aggregate: a set equipped with a structure is a conceptual system.) A concrete or material aggregate, on the other hand, is a compound thing, the components of which are not coupled, linked, connected, or bonded, such as a field constituted by two superposed fields, a celestial constellation, and a random sample of a biological population.

Because the components of an aggregate do not interact – or do not interact appreciably – the behavior of each is independent of the behavior of the others. Consequently the history of the aggregate is the union of the histories of its members. On the other hand the components of a concrete system are linked, whence the history of the whole differs from the union of the histories of its parts. We shall take the last statement to be an accurate version of the fuzzy slogan of holistic metaphysics, namely *The whole is greater than the sum of its parts.* But we shall go far beyond this characterization of wholeness or systemicity. To this end we shall make use of a few elementary mathematical concepts as well as of a number of common notions – such as those of thing, property, and time – that have been clarified in our companion volume (Bunge, 1977a).

A system, then, is a complex object, the components of which are interrelated rather than loose. If the components are conceptual, so is the system; if they are concrete or material, then they constitute a concrete or material system. A theory is a conceptual system, a school a concrete system of the social kind. These are the only system kingdoms we recognize: conceptual and concrete. We have no use for mixed systems, such as Popper's "world 3", allegedly composed of conceptual objects, such as theories, as well as concrete objects, such as books (Popper, 1968; Popper and Eccles, 1977). We do not because, in order to be able to speak of the association or combination of two items, we must specify the association bond or operation. And, while mathematical theories specify the way conceptual items combine, and ontological and scientific theories take care of the combination of concrete items, no known theory specifies the manner whereby conceptual items could combine with concrete ones – and no experience suggests that such hybrids exist.

Whatever its kingdom – conceptual or concrete – a system may be said to have a definite composition, a definite environment, and a definite structure. The composition of a system is the set of its components; the environment, the set of items with which it is connected; and the structure, the relations among its components as well as among these and the environment. For example, a theory is composed of propositions or statements; its environment is the body of knowledge to which it belongs (e.g. algebra or ecology); and its structure is the entailment or logical consequence relation. The merger of these three items is a propositional system, i.e. a system $\mathscr{T}$ composed of a set P of propositions, embedded in a certain conceptual body B, and glued together by the relation $\vdash$ of entailment: in short, $\mathscr{T} = \langle P, B, \vdash \rangle$. And the composition of a school is the union of its staff and pupils; the environment is the natural and social milieu, and the structure consists of the relations of teaching and learning, managed and being managed, and others. The environment must be included in the description of a system because the behavior of the latter depends critically on the nature of its milieu. But of course in the case of the universe the environment is empty, and so it is in the case of the important fiction known as the free particle (or field).

One way of characterizing the general concept of a system is this. Let T be a nonempty set. Then the ordered triple $\sigma = \langle C, E, S \rangle$ is (or represents) a *system over* T iff C and E are mutually disjoint subsets of T (i.e. $C \cap E = \varnothing$), and S is a nonempty set of relations on the union of C and E. The system is conceptual if T is a set of conceptual items, and concrete (or material) if $T \subseteq \Theta$ is a set of concrete entities, i.e. things. However, the preceding is not a definition proper, because it does not tell us what exactly is the membership of the coordinates C, E and S of the ordered triple. We must therefore define the notions of composition, environment, and structure of a thing.

1.2. *Concrete System: Definition*

Let us start by defining the composition of a system. A social system is a set of socially linked animals. The brains of such individuals are parts of the latter but do not qualify as members or components of a social system because they do not enter independently into social relations: only entire animals can hold social relations. In other words, the composition of a social system is not the collection of its parts but just the set of its atoms, i.e. those parts that are socially connectible. This particular notion of composition is that of atomic composition or A-composition for short. It will be defined thus: The *A-composition* (or *composition at the A level*) of a thing x is the set of parts of x that belong to A. In symbols: let $A \subseteq \Theta$ be a class of things and let x be a thing (i.e. $x \in \Theta$). Then the (absolute) *composition* of x is the set of its parts, i.e.

$$\mathscr{C}(x) = \{y \in \Theta \mid y \sqsubset x\},$$

where '$y \sqsubset x$' designates "y is a part of x". And the *A-composition* of x is the set of its A-parts:

$$\mathscr{C}_A(x) = \mathscr{C}(x) \cap A = \{y \in A \mid y \sqsubset x\}.$$

Let us introduce next the concept of link, connection, or coupling among the components of a thing. We must distinguish between a mere relation, such as that of being older, and a connection, such as that of exerting pressure. Unlike a mere relation, a connection makes some difference to its relata. That is, two things are connected just in case at least one of them acts upon the other – where the action need not consist in eventuating something but may consist in either cutting out or opening up certain possibilities.

In turn, we say that one thing *acts* upon another if it modifies the latter's behavior line, or trajectory, or history. The acting of thing a on thing b is symbolized

$$a \rhd b.$$

If a thing acts upon another, and the latter does not react back, the former is called the *agent* and the latter the *patient*. If neither action nor reaction are nil, the things are said to *interact*. Finally, two things are *connected* (or *coupled*, or *linked*, or *bonded*) if at least one of them acts on the other. The *bondage* of a set $A \subseteq \Theta$ of things is the set $\mathbb{B}_A$ of bonds (or couplings or links or connections) among them. So, the total set of relations among the components of a complex entity may be decomposed into its bondage $\mathbb{B}_A$ and the set $\bar{\mathbb{B}}_A$ of nonbonding relations.

We can now introduce the notion of the *A-environment* of a thing x with A-composition $\mathscr{C}_A(x)$. It will be defined as the set of all things, other than those in $\mathscr{C}_A(x)$, that act on or are acted upon the latter:

$$\mathscr{E}_A(x) = \{y \in \Theta \mid \neg(y \in \mathscr{C}_A(x))\ \&\ (\exists z)(z \sqsubset x\ \&\ (y \rhd z \vee z \rhd y))\}.$$

Finally the *structure* of a thing will be defined as the set of all the relations among the thing's components as well as among these and the things in the thing's environment.

We now have all we need to define the notion of a concrete system:

DEFINITION 1.1 An object is a *concrete system* iff it is composed of at least two different connected things.

(a) (b)

Fig. 1.1. Two systems with the same composition but different structures and environments.

Example A molecule, a coral reef, a family and a factory are systems. On the other hand a set of states of a thing and a collection of events, even if ordered, are not concrete systems. Symbol: Σ.

And now the three characteristics of any system:

DEFINITION 1.2 Let $\sigma \in \Sigma$ be a concrete system and $A \subset \Theta$ a class of things. Then

(i) the *A-composition* of σ at a given time t is the set of its A-parts at t:

$$\mathscr{C}_A(\sigma, t) = \{x \in A \mid x \sqsubset \sigma\};$$

(ii) the *A-environment* of σ at time t is the set of all things of kind A, not components of σ, that act or are acted on by components of σ at t:

$$\mathscr{E}_A(\sigma, t) = \{x \in A \mid x \notin \mathscr{C}_A(\sigma, t) \ \& \ (\exists y)(y \in \mathscr{C}_A(\sigma, t) \ \& \ (x \rhd \mathrm{y} \vee y \rhd x));$$

(iii) the *A-structure* (or *organization*) of σ at time t is the set of relations, in particular bonds, among the components of σ, and among them and the things in the environment of σ, at t:

$$\mathscr{S}_A(\sigma, t) = \{R_i \in \mathbb{B}_A(\sigma, t) \cup \bar{\mathbb{B}}_A(\sigma, t) \mid \mathbb{B}_A(\sigma, t) \neq \varnothing \ \& \ 1 \leq i \leq n,\}$$

where $\mathbb{B}_A(\sigma, t)$ is the set of bonding relations, and $\bar{\mathbb{B}}_A(\sigma, t)$ that of non-bonding relations, defined on $\mathscr{C}_A(\sigma, t) \cup \mathscr{E}_A(\sigma, t)$.

Example The simplest possible system is one composed of two connected things, a and b, in an environment lumped into a single thing c. That is, $\mathscr{C}(\sigma) = \{a, b\}$, $\mathscr{E}(\sigma) = \{c\}$. This system can have either of the following internal structureses: $a \rhd b$, $b \rhd a$, or $a \bowtie b$: see Figure 1.2. (These are the conceivable internal structures. But some of them may not be nomologically possible, let alone technically feasible or even desirable.) As for

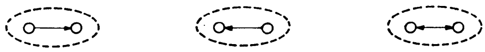


Fig. 1.2. A two component system with three possible internal structures.

the external structures, they can be any of these or their unions: $\{a \rhd c\}$, $\{b \rhd c\}$, $\{c \rhd a\}$, $\{c \rhd b\}$.

An exhaustive knowledge of a system would comprise the following items: (*a*) the composition, the environment and the structure of the system; (*b*) the history of the system (particularly if this is a biosystem or a sociosystem), and (*c*) the laws of the system. Such complete knowledge is seldom attainable, particularly with reference to complex systems. But in order to be able to speak of systems at all we should know at least their composition, their environment and their structure. Thus we can say that the model constituted by the ordered triple

$$s_A(\sigma, t) = \langle \mathscr{C}_A(\sigma, t), \mathscr{E}_A(\sigma, t), \mathscr{S}_A(\sigma, t) \rangle$$

is the *minimal model* of system σ at time t. Obviously, this qualitative model will not suffice for quantitative purposes, such as predicting the rate of formation or breakdown of a system. We shall therefore supplement the above minimal model with a quantitative model to be introduced in Sec. 2.2. However, before doing so we shall use the minimal model to clarify a number of issues that are often obscure in the literature on systems.

1.3. *More of the Same*

Before continuing our study of systems and their models we must make sure that the concept of a concrete system is not idle – i.e. that some things are systems while others are not. That some things are not systems follows from the assumption that there are basic or elementary things, i.e. things without parts (Vol. 3, Postulate 1.4). And that other things are systems follows from the ontological hypothesis that every thing – except the universe as a whole – acts on, and is acted upon by, other things (Vol. 3, Postulate 5.10). In sum, we have proved the nontrivial

THEOREM 1.1 (i) There are concrete systems. (ii) Every thing is a component of at least one system.

Surely the identification and modeling of a concrete system may be an extremely difficult task. Thus it is not always clear what the composition, hence also the environment, of a system is, particularly if it is strongly coupled to other systems – as is the case with the economic and the political systems of a society. However, this is a scientific problem not an ontological one.

Note that actions and the corresponding connections have been defined for things not for properties. The latter can be *interdependent* but not *interacting*. That is, the common phrase 'Properties P and Q interact' should be understood either as "Properties P and Q (of a given thing) are interdependent", or "Things with property P interact with things with property Q".

Connections can be permanent or temporary, static or dynamic. In the latter case they are often called *flows* – of energy, as in heat transfer, of matter, as in migrations, or of fields, as in a television network. If a physical flow happens to carry information, the connection is called *informational* and the entire system an 'information system'. However, the physical/informational distinction is one of emphasis, not a dichotomy, for every information flow rides on some energy flow. (See Appendix A, Sec. 1.4.)

Our definition of the environment of a system as the set of all things coupled with components of the system makes it clear that it is the *immediate* environment, not the *total* one – i.e. the set of all the things that are not parts of the system. Except in extragalactic astronomy and in cosmology, we are interested not in the transactions of a system with the rest of the universe but only in that portion of the world that exerts a significant influence on the thing of interest. This immediate environment or *milieu* is the cell in the case of chromosomes, the rest of the organism in the case on an organ, the ecosystem in the case of an organism, the solar system in the case of a biosphere, and so on. In other words, the immediate environment of a thing is the composition of its next supersystem. (More in Sec. 1.4.)

A system that neither acts on nor is acted upon by any other thing is said to be closed. In other words, we make

DEFINITION 1.3 Let σ be a system with environment $\mathscr{E}(\sigma, t)$. Then σ is *closed* at t iff $\mathscr{E}(\sigma, t) = \varnothing$ – otherwise σ is *open*.

Since every thing but the universe interacts with some other things, we infer

COROLLARY 1.1 The universe is the only system closed at all times.

This holds whether or not the universe turns out to be spatially infinite, for the universe may be defined as that thing which has a void environment (i.e. which is self-contained).

So much for the concept of total closure. We need also the notion of partial closure, or closure relative to a given property, since a system may be open in some respects and closed in others. (Thus all systems are gravitationally open, but some are electrically closed, others are closed to the exchange of matter, still others to cultural influences, and so on.) We make then

DEFINITION 1.4 Let P be a property of a system σ in an environment $\mathscr{E}(\sigma, t)$. Then σ is *open with respect to P at t* iff P is related, at t, to at least one property of things in $\mathscr{E}(\sigma, t)$ – otherwise σ is *closed* in the respect P.

Comparing this definition with the previous one we realize that a system is closed iff it is closed in every respect.

Finally some comments on the concept of structure. Our use of it is common in mathematics and in the social sciences. Thus a famous anthropologist: for the biochemist an organism "is a complexly integrated system of complex molecules. The system of relations by which these units are related is the organic structure. As the terms are here used the organism is *not* itself a structure; it is a collection of units (cells or molecules) arranged in a structure, i.e. in a set of relations; the organism *has* a structure" (Ratcliffe-Brown, 1935). Biologists use 'structure' sometimes in the above sense and at other times as a synonym for 'anatomic component'. In the latter case they run the risk of talking about the structure of a structure.

It is sometimes useful to distinguish a system's internal structure from its external one. The former is the subset of the total structure formed by the relations (in particular connections) among the system components. And the external structure is of course the complement of the internal structure to the total structure. Though distinct, the internal and the external structure are interdependent. Thus the internal structure of a molecule, far from being a permanent and intrinsic property of the molecule, depends critically upon its external structure – i.e. the interactions between the molecule and its milieu (e.g. the solvent).

Another distinction worth making is that between total structure and spatial structure, or set of spatial relations among the parts of a thing. (Spatial structure or configuration should not be mistaken for shape. The great majority of systems in the universe, i.e. the hydrogen and helium atoms, are shapeless. Nor do social systems have a shape although they have a spatial configuration since they are made up of living beings that stand in definite spatial relations to one another.) Every system has both a system structure (or bondage) and a spatial structure (or configuration). On the other hand aggregates or assemblages have spatial structures but no system structures.

For ease of reference we collect some of the above elucidations in

DEFINITION 1.5 Let σ be a concrete system with A-structure $\mathscr{S}_A(\sigma, t)$ at time t. Then

(i) the *internal A-structure* of σ at t is the subset of $\mathscr{S}_A(\sigma, t)$ composed of the relations among the A-parts of σ at t;

(ii) the *configuration* (or *spatial structure*) of σ at t is the subset of $\mathscr{S}_A(\sigma, t)$ composed of the spatial relations among the A-parts of σ at t.

1.4. *Subsystem*

A system component may or may not be a system itself. If it is we call it a 'subsystem'. More explicitly, we make

DEFINITION 1.6 Let σ be a system with composition $\mathscr{C}(\sigma, t)$, environment $\mathscr{E}(\sigma, t)$ and structure $\mathscr{S}(\sigma, t)$ at time t. Then a thing x is a *subsystem* of σ at t, or $x \prec \sigma$, iff

(i) x is a system at time t, and

(ii) $\mathscr{C}(x, t) \subseteq \mathscr{C}(\sigma, t)$ & $\mathscr{E}(x, t) \supseteq \mathscr{E}(\sigma, t)$ & $\mathscr{S}(x, t) \subseteq \mathscr{S}(\sigma, t)$.

By definition, the subsystem relation $\prec$ is an order relation, i.e. it is reflexive, asymmetric, and transitive. So, in particular, if $\sigma_1 \prec \sigma_2$ and $\sigma_2 \prec \sigma_3$, then $\sigma_1 \prec \sigma_3$. We shall make use of this property when defining the notion of a system of nested systems (Definition 1.7).

Example 1 Factories, hospitals and schools constitute subsystems of any modern society. On the other hand the persons composing them are not themselves social systems: they are biosystems. *Example 2* A foetus is a subsystem of its mother; it becomes a system in its own right after birth: before that it does not fall under any of the laws, natural or social, that hold for independent systems.

Systems of different kinds have different compositions or different structures. (A difference in composition induces a structural difference but not conversely, as shown by the existence of isomers, i.e. systems with the same composition but different structures.) However, all systems of the same genus seem to have the same overall structure or "general plan" –

pardon the anthropomorphism. For example, all atoms consist of nuclei surrounded by electrons, all solids are atomic or ionic lattices inhabited by wandering electrons, and even the overall structure of the skeleton and organs is the same for all vertebrates. (However, the precise characterization of the notion of overall structure is an open problem.)

Structures are often said to come superposed or nested like systems of Chinese boxes. Thus a polypeptide is said to have two structures, one primary or basic (the linear sequence of amino acids), the other secondary and consisting in the configuration of the entire coil. The helical configuration of the DNA molecule is an example of a secondary structure. In turn the secondary structure may determine a tertiary structure, e.g. the folding of the whole double strand into a regular configuration. See Figure 1.3.

In our view there is no such thing as a hierarchy of structures. (Etymologically 'hierarchy' means a set of sacred components ordered by a power or domination relation.) What we do have here is a system of nested systems, i.e. a collection of systems each of which is a subsystem of a larger system (or supersystem). And what molecular biologists call 'primary structure' is the structure of the innermost or core system, the secondary structure is the structure of the next supersystem, and so on. This notion is elucidated by

DEFINITION 1.7. Let σ be a system and call Σ the totality of systems, and

$$N_\sigma = \{\sigma_i \in \Sigma \mid \sigma \prec \sigma_i \;\&\; 1 \leq i \leq n\}$$

a collection of supersystems of σ partially ordered by the subsystem relation $\prec$. Then

(i) N_σ is a system of *nested* systems with core σ;

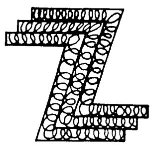


Fig. 1.3. An imaginary system of Chinese boxes or hierarchy of systems. The primary structure, i.e. the amino acid sequence, is not shown. The secondary structure is the helix, the tertiary the Z shape. And the quaternary structure is the way the individual Z's are assembled together, i.e. the double staircase.

(ii) the *primary structure* of σ is the structure of σ itself; the *secondary structure* of σ is the structure of the smallest supersystem of σ in N_σ, i.e. σ_1; in general, the *n-ary structure* of σ is the structure of σ_{n-1}.

1.5. *Level*

Talk of levels of organization (or complexity, integration, or evolution) and of a hierarchy of such has been rampant in science, particularly in biology, for the last half century or so. Unfortunately there is no consensus on the significance of the terms 'level' and 'hierarchy', which are used in a variety of ways and seldom if ever defined (Bunge, 1959b, 1959c). This fuzziness must be blamed not only on scientists but also on philosophers – on the inexact philosophers who despise clarity and on the exact ones who are not aware of the philosophical problems raised by scientific research. Let us attempt to remedy this situation by clarifying one concept of level, and the corresponding one of hierarchy, that are widely used in contemporary science.

The intuitive idea is simple: the things at any given level are composed of things belonging to preceding levels. Thus biospheres are composed of ecosystems, which are composed of populations, which are composed of organisms, which are composed of organs, which are composed of cells, which are composed of organelles, which are composed of molecules, which are composed of atoms, which are composed of so-called elementary particles. One way of exactifying this notion is by means of

DEFINITION 1.8 Let $L = \{L_i \mid 1 \leq i \leq n\}$ be a family of n nonempty sets of concrete things. Then

(i) one level *precedes* another iff all the things in the latter are composed of things in (some or all of) the latter. I.e. for any L_i and L_j in L,

$$L_i < L_j =_{df} (\forall x)[x \in L_j \Rightarrow (\exists y)\,(y \in L_i \;\&\; y \in \mathscr{C}(x))]\,;$$

(ii) a thing *belongs to a given level* iff it is composed of things in (some or all of) the precedings levels. I.e. for any $L_i \in L$:

For any x in L_i: $x \in L_i =_{df} \mathscr{C}(x) \subset \bigcup_{k=1}^{i-1} L_k$;

(iii) $\mathscr{L} = \langle L, < \rangle$ is a *level structure*.

Note the following points. First, a level is not a thing but a set and therefore a concept, though not an idle one. Hence levels cannot act upon one another. In particular the higher levels cannot command or even obey the lower ones. All talk of interlevel action is elliptical or metaphorical, not literal. Second, the relation between levels is neither the part–whole relation nor the set inclusion relation but a *sui generis* relation definable in terms of the former. Third, there is nothing obscure about the notion of level precedence as long as one sticks to the above definition instead of construing '$L_i < L_j$' as "the L_i's are inferior to the L_j's" or in similar guise. Fourth, it is mistaken to call a level structure $\mathscr{L} = \langle L, < \rangle$ a *hierarchy*, because the level order $<$ is not a dominance relation (Bunge, 1973a). Fifth, our concept is so far static: we are not assuming anything about the origin or mode of composition of systems in terms of evolution.

1.6. *Systems Association*

Whether or not two things form a system, they can be assumed to associate (or add physically) to form a third thing. Thus thing a and thing b, no matter how distant and indifferent, may be assumed to form thing $c = a \dotplus b$. In other words, the set of things is closed under the operation $\dotplus$ of *association*, physical addition, or juxtaposition (Vol. 3, Ch. 1, Sec. 1).

Not so with systems: two systems may or may not associate to form a third. Thus two molecules may not combine to form a system, and two social systems may not merge to form a third. In general the physical addition or association of two things will be a thing but not a system: *systemicity is not conserved.* The environment, the structure and perhaps even the composition of the resulting thing are different from the mere union of the partial compositions, environments, and structures. See Figure 1.4. In short, the set of all systems has no algebraic structure – not even the rather modest one of a semigroup. But, of course, since systems are things, they do comply with the algebra of things. In particular they associate to form further things.

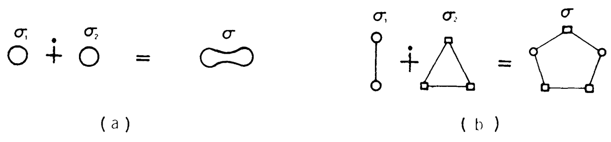


Fig. 1.4. (*a*) Before fusion, $\mathscr{E}(\sigma_1) = \{\sigma_2\}$, $\mathscr{E}(\sigma_2) = \{\sigma_1\}$. After fusion, $\mathscr{E}(\sigma_1 + \sigma_2) = \emptyset$. (*b*) Before merger, $\mathscr{S}(\sigma_1) = \{\text{Linear link}\}$ and $\mathscr{S}(\sigma_2) = \{\text{Triangular link}\}$. After merger, $\mathscr{S}(\sigma_1 + \sigma_2) = \{\text{Pentagonal link}\}$.

1.7. *Other Kinds of System: Property and Functional*

We are interested not only in concrete systems but also in property systems, or sets of interrelated properties, as well as in functional systems, or sets of coupled processes. For example, most of the properties of a thing that is either simple (basic) or a system hang together, i.e. a change in one of them is accompanied by changes in others. As a consequence most of the changes occurring in either a simple thing or a system are coupled, so that if one of them starts or stops, others change. (The cautious prefix 'most' is intended to exclude superficial properties, such as position and color, which can often change considerably, within bounds, without dragging changes in other properties.) Although every thing other than an aggregate or conglomerate has properties and undergoes processes that constitute systems, property systems and functional systems are particularly conspicuous among organisms. In particular the mental abilities of an animal form a system.

We shall use the following conventions:

DEFINITION 1.9 Let $p(x)$ be the set of properties of a thing x, and $\pi(x)$ the set of processes occurring in x. Then

(i) the subset $p_0(x) \subset p(x)$ is a *property system* of x iff every property in $p_0(x)$ is lawfully related to at least one other property in $p_0(x)$;

(ii) the subset $\pi_0(x) \subset \pi(x)$ is a *functional system* of x iff every process in $\pi_0(x)$ is lawfully related to at least one other process in $\pi_0(x)$.

Because in a system all properties and processes are lawfully interrelated we conclude that, for every x, x is a concrete system iff $p(x)$ is a property system or $\pi(x)$ a functional system.

1.8. *Concluding Remarks*

The literature on systems is vast, rapidly growing, and somewhat bewildering. (Cf. Klir and Rogers, 1977.) However, the field is still immature and its reputation is jeopardized by a fringe of charlatans. Suffice it to mention three indicators of immaturity.

Firstly, the very definition of the concept of a system is still in doubt, so that many a paper starts by spending time defining or redefining the concept. Yet, so much effort spent on definitions has yielded only three which are as popular as they are incorrect. According to the first definition, a system is a set of interrelated elements – which is fine for conceptual systems but not for concrete ones since sets, no matter how structured, are sets, hence concepts not things. The second definition equates a system with a black box equipped with inputs and outputs, which is fine in a few cases but useless when the internal structure of the system is relevant. And the third widely used definition is a generalization of the preceding, namely this: a system is a binary relation – again a conceptual object.

Secondly, some writers claim that everything imaginable is a system, and that a general theory of systems should deal with every possible thing (without thereby becoming part of philosophy) and every possible problem, theoretical or practical, concerning the behavior of systems of all kinds. Some have even asserted that such a theory should cover not only concrete systems but also conceptual ones, so that it would be a thoroughly unified science of everything.

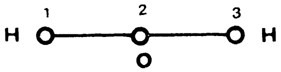
Thirdly, some enthusiasts of general theories of systems have seen in these a vindication of holistic philosophies, hence a condemnation of the analytic method characteristic of science. However, most of those who approve of general systems theories for their alleged holistic virtues either misuse the term 'holistic' to designate "systemic", or are interested in instant wisdom rather than painstaking scientific or philosophical research.

Such confusions and wild claims, which linger because of insufficient foundational research in the field of systemics, have elicited some entirely negative reactions to it (e.g. Berlinski, 1976). While there is some legitimacy in such reactions, there is no denying that systemics abounds in good theories – such as automata theory and general lagrangian dynamics – serviceable in a number of fields, and that it provides an inspiring framework for posing problems and building models. Rather than throw out the baby together with the bath water we ought to change the latter once in a while.

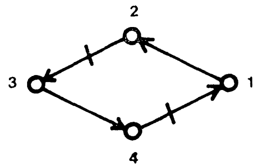
2. System Representations

2.1. *Coupling Graphs and Matrices*

We shall presently review two standard and equivalent ways of representing a system with a denumerable composition, be it a molecule or an industrial plant. They are the graph and the matrix representations. (See Klir and Valach (1967).) The following examples show how to proceed.

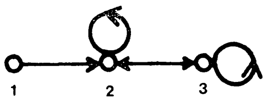


$$\sigma_1 = \begin{Vmatrix} 0 & 1 & 0 \\ 1 & 0 & 1 \\ 0 & 1 & 0 \end{Vmatrix}$$



$$\sigma_2 = \begin{Vmatrix} 0 & 1 & 0 & 0 \\ 0 & 0 & -1 & 0 \\ 0 & 0 & 0 & 1 \\ -1 & 0 & 0 & 0 \end{Vmatrix}$$

The arrows indicate excitation, the crossed arrows inhibition.



$$\sigma_3 = \begin{Vmatrix} 0 & 1 & 0 \\ 0 & 1 & 1 \\ 0 & 1 & 1 \end{Vmatrix}$$

The loops indicate self action or feedback.

We generalize the foregoing into the following semantic assumptions. Let σ be a system with m components and n different kinds of connection among them (e.g. mechanical, chemical, informational, social, etc.). Then σ is representable by

(i) a set of n directed graphs over the composition of σ, one for each kind of connection, with a total of m nodes (vertices), in such a way that (*a*) the nodes represent the components and (*b*) the edges represent the connections; or

(ii) a set of n $m \times m$ matrices ${}^pM$, where $1 \leq p \leq n$, such that (*a*) the matrix element ${}^pM_{rs}$ of the pth matrix represents the strength of the action of component r, in the pth respect, upon component s, and (*b*) the matrix element ${}^pM_{rr}$ stands for the action of kind p of the rth component on itself (feedback).

The off-diagonal elements ${}^pM_{rs}$, with $r \neq s$, represent connections other than self connections. There are $m^2 - m = m(m - 1)$ such elements per matrix, and a total of $nm(m - 1)$ per system with n different kinds of connection. This number is called the *coupling capacity* of the system.

So far we have represented the composition and the internal structure of a system while neglecting its environment, hence its external structure. An open system, i.e. one connected with its environment, can be represented as follows. Instead of building an $m \times m$ matrix for an m component system, as directed by the previous semantic postulate, we form an $(m + 1) \times (m + 1)$ matrix for each kind of connection, letting 0 stand for the environment *en bloc*. Any system component r for which $M_{0r} \neq 0$ is an input or receiver component, whereas s is an output or donor component of the system if $M_{s0} \neq 0$. For example, a two component open system with a single kind of connection can be represented by the matrix

$$M = \begin{Vmatrix} 0 & M_{01} & M_{02} \\ M_{10} & M_{11} & M_{12} \\ M_{20} & M_{21} & M_{22} \end{Vmatrix}.$$

The elements M_{01} and M_{02} are the inputs (to the first and second components respectively) and the entries M_{10} and M_{20} the outputs (of the first and second components respectively). The other entries represent the internal (or internuncial) connections among the system's components.

We generalize the preceding into the following semantic assumption. Let σ be a system with m components and n different kinds of connections among them. Moreover, let the environment of σ be construed as a single entity labelled 0. Then σ is representable by $n\ (m + 1) \times (m + 1)$ matrices ${}^pM$, where $1 \leq p \leq n$, such that

(i) the *internal connectivity* of σ in the pth respect is representable by the matrix obtained from ${}^pM$ by striking off the M_{r0} and M_{0s} elements;

(ii) the *input* to σ in the respect p is represented by the row of input entries of ${}^pM$, i.e.

$${}^p\mathscr{I}(\sigma) = \left\| {}^pM_{01} \quad {}^pM_{02} \ldots {}^pM_{0m} \right\|;$$

(iii) the *output* of σ in the respect p is represented by the column of output entries of ${}^pM$, i.e.

$${}^p\mathscr{O}(\sigma) = \left\| {}^pM_{10} \quad {}^pM_{20} \ldots {}^pM_{m0} \right\|^t,$$

where t designates the transposition operation (conversion of row matrix into column matrix);

(iv) the *behavior* (or *observable performance*) of σ in the respect p is the ordered pair

$${}^p\beta(\sigma) = \langle {}^p\mathscr{I}(\sigma), {}^p\mathscr{O}(\sigma) \rangle;$$

(v) the (total) *behavior* of σ is the set of its partial behaviors:

$$\beta(\sigma) = \{{}^p\beta(\sigma) \mid 1 \leq p \leq n\}.$$

Example In the simplest case, of a two component system interacting with its environment in a single way, we have

$$\mathscr{I}(\sigma) = \|M_{01} \quad M_{02}\|, \qquad \mathscr{O}(\sigma) = \begin{Vmatrix} M_{10} \\ M_{20} \end{Vmatrix}.$$

In the absence of any data or hypotheses concerning the internal structure (i.e. the full coupling matrix) of such a system, we must restrict our attention to its behavior. The best we can do is to guess that the latter is linear, i.e. that there exists a matrix T transforming inputs into outputs: $\mathscr{O} = T\,\mathscr{I}^t$, where $\mathscr{I}^t$ is the transpose of $\mathscr{I}$. We set then

$$T = \begin{Vmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{Vmatrix}$$

with unknown T_{ij}'s and perform the indicated operations:

$$T\,\mathscr{I}^t = \begin{Vmatrix} T_{11} & T_{12} \\ T_{21} & T_{22} \end{Vmatrix} \cdot \begin{Vmatrix} M_{01} \\ M_{02} \end{Vmatrix} = \begin{Vmatrix} T_{11}M_{01} + T_{12}M_{02} \\ T_{21}M_{01} + T_{22}M_{02} \end{Vmatrix} = \begin{Vmatrix} M_{10} \\ M_{20} \end{Vmatrix},$$

thus obtaining the algebraic system

$$\begin{aligned} T_{11}M_{01} + T_{12}M_{02} &= M_{10} \\ T_{21}M_{01} + T_{22}M_{22} &= M_{20}. \end{aligned}$$

This system of equations has no unique solution when only the behavior of the concrete system (i.e. the M_{0i}'s and the M_{j0}'s) are given, for in this case there are only two conditions (equations) for four unknowns (the T_{ij}'s). Even hitting upon a solution by trial and error won't advance us a single step in the process of finding out the structure of the system, i.e. the complete coupling matrix M. The only procedure that could bring success is to guess and try out alternative assumptions about the system's structure and check whether they do yield the observed (or conjectured) behavior. That is, the way to theoretical knowedge is not from behavior to inferred structure but from hypothesized structure to behavior. This shows that behaviorism, phenomenalism, and inductivism are incapable, not just unwilling, to explain behavior.

Obviously neither the graph nor the matrix representation of a system suffices for all purposes. It represents only the composition, structure, and environment of a system with neglect of its dynamics. A more complete representation can only be obtained by setting up a full fledged dynamical theory incorporating and expanding the information contained in the graph or the matrix representation. We turn next to the common core of such dynamical representations, namely the state space representation. (See the Appendices for a number of particular, yet also cross-disciplinary, mathematical models of systems.)

2.2. *The State Space Representation*

Every system of a given kind K has a finite number n of general properties, such as age, number of components, connectivity among them, inputs, and outputs. And each such general property is representable by a function $F_i\colon A \to V_i$, where $1 \leq i \leq n$. Collecting all such property-representing functions into a single ordered n-tuple or list

$$\mathbb{F} = \langle F_1, F_2, \ldots, F_n \rangle : A \longrightarrow V_1 \times V_2 \times \ldots \times V_n,$$

we form the *state function* of systems of the given kind. Just as $\mathbb{F}$ represents the totality of general properties of the K's, so each value $\mathbb{F}(a) = \langle F_1(a), F_2(a), \ldots, F_n(a) \rangle$ represents the totality of individual properties of a particular system, such as its age and composition at a given time.

The domain A of the state function $\mathbb{F}$ of systems of kind K is the cartesian product of certain sets, such as K, the family 2^E of sets of environmental items with which the members of K are coupled, the set F of reference frames, the set T of time instants, and so on. (2^E is the power set of the set E of environmental things, so the environment e of a particular system is a member of that family, i.e. $e \in 2^E$.) And the codomain V_i of the ith component F_i of the state function is usually taken to be some subset of the real line $\mathbb{R}$. (If a property is represented by a complex valued function each component of the latter counts as a component of $\mathbb{F}$.) In short,

$$\mathbb{F} : K \times 2^E \times F \times T \times \cdots \longrightarrow \mathbb{R}^n.$$

The value $\mathbb{F}(k, e, f, t, \ldots) = \langle a, b, \ldots, n \rangle \in \mathbb{R}^n$ of the state function of system $k \in K$ interacting with environmental items $e \in 2^E$, relative to reference frame $f \in F$ at time $t \in T$, is the *state* of k at t. The collection of all such possible states, which is a subset of $\mathbb{R}^n$, is the (conceivable) *state space* of systems of kind K, or $S(K)$ for short. However, since the components of $\mathbb{F}$ are lawfully interrelated, and thus mutually restricted, not every n-tuple of real numbers represents a really (or nomologically) possible state of a system. I.e. the *lawful state space* of systems of kind K, or $S_{\mathrm{L}}(K)$ for short, is a proper subset of the conceivable state space $S(K)$.

In short, every really possible state of a K is a point in some region $S_{\mathbb{L}}(K)$ of the cartesian space $\mathbb{R}^n$. See Figure 1.5.

Example 1 In the elementary kinetic theory of gases, the state function is the triple consisting of the pressure, volume, and temperature functions. The corresponding state space is a cube contained in $(\mathbb{R}^+)^3$. *Example 2* In Hamiltonian dynamics the state (or phase) vector is $\langle q(k, f, t), p(k, f, t)\rangle$, where q is the canonical coordinate and p the corresponding momentum – neither of which need be mechanical properties. *Example 3* In chemical kinetics the instantaneous state of a chemical system is described by the values of the partial concentrations of reactants and reaction products. Therefore the state space of the system is a hypercube contained in $(\mathbb{R}^+)^n$, where n is the number of system components (reactants, catalyzers, and products). If there is diffusion, further axes must be added to the state space, in particular temperature and position coordinates. *Example 4* In the genetics of populations three commonly used state variables are the size of a population, the probability (incorrectly called "frequency') of some particular gene or gene constellation, and the latter's adaptive value. Hence for a system composed of two interacting populations, A and B, the state space is the region of $\mathbb{R}^6$ spanned by the sextuples $\langle N_A(t), N_B(t), P_A(t), P_B(t), v_A(t), v_B(t)\rangle$ in the course of time.

The concept of state space can be used to clarify that of system. The state space of an aggregate or conglomerate of non-interacting things is uniquely determined by the partial states spaces. Moreover, since the

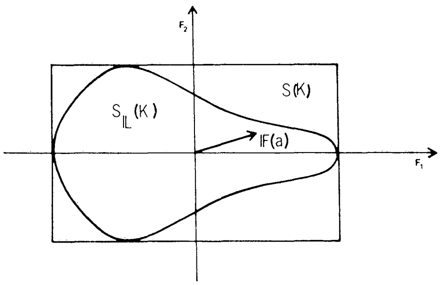


Fig. 1.5. The lawful state space $S_{\mathbb{L}}(K)$ of systems of kind K is a subset of the cartesian product of the ranges of the components of the state function. Only two such components, F_1 and F_2, are depicted here. $\mathbb{F}(a) = \langle F_1(a), F_2(a)\rangle$ is a (really) possible state of a particular system of the given kind. As time 'goes by', the tip of $\mathbb{F}(a)$ moves about within $S_{\mathbb{L}}(K)$.

contributions of the latter are all on the same footing, we may take the total state space to equal the union of the partial state spaces. In particular, let $S_{\mathbb{L}}(K)$ and $S_{\mathbb{L}}(M)$ be the lawful states spaces of things of kinds K and M respectively. Then the state space of the association $k + m$ of two non-interacting things of kinds K and M respectively, relative to the same reference frame, is $S_{\mathbb{L}}(K) \cup S_{\mathbb{L}}(M)$. Not so in the case of a system: here the state of every component is determined, at least partly, by the states other system components are in, so that the total state space is no longer the union of the partial state spaces. Thus in Example 4 above the state space of the two component system must be constructed *ab initio* rather than on the sole basis of the state spaces for the individual biopopulations. In sum, a thing is an *aggregate* if and only if its state space equals the union of the state spaces of its components – otherwise it is a (concrete) *system*. (Cf. Bunge, 1977a, 1977b.)

Every event occurs in or to some concrete thing and it consists in a change of state of the thing – the change being merely quantitative, as in the case of motion, or qualitative as well, as in the case of the coming into being or the metamorphosis of a thing. A light flash, the dissociation of a molecule, a storm, the growth of a bud, the learning of a trick, and the fall of a government are events – or rather processes, for they are complex and therefore analyzable into further events. Being changes in the states of things, events and processes are representable as trajectories in the state spaces of changing things. (An unchanging thing, if there were one, would have a state space consisting of a single point.) Different trajectories in a state space may have the same end points. That is, there are cases in which one and the same net change can be effected along alternative routes. See Figure 1.6.

The functions g and g' occurring in Figure 1.6 are not supposed to be arbitrary: they must be lawful if we are to allow only lawful events and discard lawless ones, i.e. miracles. In other words, the g occurring in the event representation $e = \langle s, s', g \rangle$ must be compatible with the laws of the system(s) concerned. Equivalently: a *lawful event or process* occurring in a system of kind K, with end points s and s', is representable by a triple $\langle s, s', g \rangle$, where $g : S_{\mathbb{L}}(K) \to S_{\mathbb{L}}(K)$ is compatible with the laws of the K's. If we disregard the intermediate states between the end points of the processes, we are left with arrows or ordered pairs $\langle s, s' \rangle \in S_{\mathbb{L}}(K) \times S_{\mathbb{L}}(K)$. The collection of all such pairs of states, i.e. the set of all net events (for a given g) constitutes the *event space* of the K's (for g). Symbol:

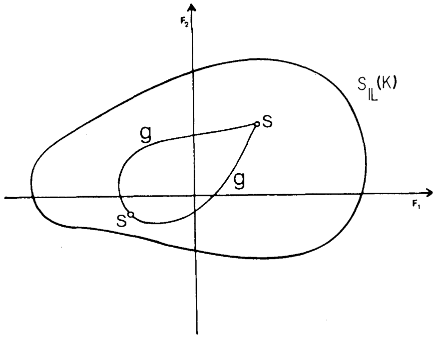


Fig. 1.6. Two different processes resulting in the same net change. The net change from state s to state s' can be represented as the ordered pair (or arrow) $\langle s, s'\rangle$. Since the change along curve g may be distinct from the change along curve $g' \neq g$, we must represent the full events (or processes) by $\langle s, s', g\rangle$ and $\langle s, s', g'\rangle$ respectively.

$E_{\mathbb{L}}(K) \subseteq S_{\mathbb{L}}(K) \times S_{\mathbb{L}}(K)$. In general the inclusion is proper: not all state transitions are lawful.

Since we shall make ample use of the state space representation in this work, we may as well compress the preceding into the following semantic assumption. For each kind K of system possessing n properties there is a property-representing function $\mathbb{F}: A \to V_1 \times V_2 \times \ldots \times V_n$ with n components, called a *state function* for systems of the kind. Furthermore

(i) the *totality of general properties* of systems of kind K is representable by the set of all the components (or coordinates) of $\mathbb{F}$, i.e. $p(K) = \{F_i \mid 1 \leq i \leq n\}$;

(ii) every *particular property* of a system of kind K is representable by a value of a component of $\mathbb{F}$, i.e. by $F_i(a)$ for $a \in A$ and some $1 \leq i \leq n$;

(iii) the *state* of systems of kind K at $a \in A$ is representable by the value of $\mathbb{F}$ at a, i.e. $s = \mathbb{F}(a) = \langle F_1(a), F_2(a), \ldots, F_n(a)\rangle$;

(iv) the collection of all such states of things of kind K, i.e. the range of $\mathbb{F}$, is the *lawful state space* of the K's, or $S_{\mathbb{L}}(K)$ for short;

(v) every *event* occurring in a system of kind K is representable by an ordered triple $\langle s, s', g\rangle$, where $s, s' \in S_{\mathbb{L}}(K)$ and g is a lawful map of $S_{\mathbb{L}}(K)$ into itself;

(vi) the collection of all really possible (lawful) events occurring in systems of kind K is the *event space* of K, or $E_{\mathbb{L}}(K)$ for short;

(vii) for a system in a given environment, and relative to a given reference frame, the state function takes often the form of a time-dependent function $\mathbb{F}: T \to \mathbb{R}^n$, where $T \subseteq \mathbb{R}$ is the set of instants relative to the given frame;

(viii) If $\mathbb{F}: T \to \mathbb{R}^n$, then the totality of *processes* occurring in a system x of kind K during the time interval $\tau \subseteq T$ is representable by the set of states x is in during τ:

$$\pi(x, \tau) = \{\mathbb{F}(t) \mid t \in \tau\};$$

(ix) the *history* of a system x of kind K representable by a state function $\mathbb{F} : T \to \mathbb{R}^n$, during the interval $\tau \subseteq T$, is representable by the trajectory

$$h(x) = \{\langle t, \mathbb{F}(t)\rangle \mid t \in \tau\};$$

(x) the *total action* (or *effect*) of a thing x on a thing y equals the difference between the forced trajectory and the free trajectory of the patient y:

$$A(x, y) = h(y \mid x) \cap \overline{h(y)}.$$

A detailed treatment of these concepts is given elsewhere (Vol. 3, Ch. 5). We shall presently use them to advance a handful of general principles concerning systems.

3. Basic assumptions

3.1. *Structural Matters*

So far we have made only a few definitions and semantic assumptions but no substantive hypotheses on the nature of systems. (Theorem 1.1 on the existence of systems and the nonexistence of stray things, as well as Corollary 1.1 on the openness of systems, followed from our definition of a concrete system in conjunction with certain general postulates, about the nature of things, laid down in Volume 3.) We shall presently wager a handful of basic assumptions concerning systems of all kinds, the first being certain postulates of a structural kind. Since these assumptions will concern the transactions of a system with its environment, we may as well define the concepts of input and of output in more general terms than we did in Sec. 2.1. We start then with

DEFINITION 1.10 Let σ be a system with an (immediate) environment $\mathscr{E}(\sigma)$. Then

(i) the totality of *inputs* of σ is the set of all the environmental actions on σ:

$$U(\sigma) = \bigcup_{x \in \mathscr{E}(\sigma)} A(x, \sigma);$$

(ii) the totality of *outputs* of σ is the set of all the actions of the system on its environment:

$$V(\sigma) = \bigcup_{y \in \mathscr{E}(\sigma)} A(\sigma, y);$$

(iii) the *activity of the environment* of σ is

$$E(\sigma) = \bigcup_{x, y \in \mathscr{E}(\sigma)} A(x, y) \cup U(\sigma) \cup V(\sigma).$$

Our first hypothesis is that all systems receive inputs and are selective, i.e. accept only a (small) subset of the totality of environmental actions impinging on them. More precisely, we lay down

POSTULATE 1.1. Let σ be a system with total input $U(\sigma)$. Then
(i) $U(\sigma) \neq \varnothing$;
(ii) $U(\sigma) \subset E(\sigma)$ or, equivalently, the (in-selection) function

$$\mu\colon U(\sigma) \longrightarrow E(\sigma)$$

is the inclusion (or embedding) map of $U(\sigma)$ into $E(\sigma)$.

Example Talking to plants is ineffectual – except insofar as it nourishes them with water and carbon dioxyde.

A second, equally pervasive, feature of concrete systems is that they react on their environment, i.e. that their output is never nil. (The so-called machines without output, studied in automata theory, are of course fictions.) Moreover, in every system there is spontaneous activity, i.e. not elicited by any inputs. Thus we make

POSTULATE 1.2. Let $V(\sigma)$ be the total output of a system σ. Then
(i) $V(\sigma) \neq \varnothing$;
(ii) the (out-selection) function

$$\nu\colon V(\sigma) \longrightarrow E(\sigma)$$

assigns each system output an environmental action but not conversely.

Example In every neuron there is spontaneous activity that is superposed on the activity elicited by afferent stimulation.

The previous hypotheses are typical metaphysical principles in as much as they can be confirmed but not refuted, for they hinge on an item that is only partially knowable, namely the set E of environmental actions. Any evidence unfavorable to our postulates may be blamed on our ignorance of most of E.

The in-selection function μ and the out-selection function ν are joined in

DEFINITION 1.11 The function f that composes with the out-selection function ν of a system to yield its in-selection function μ, i.e. such that $\mu = f \circ \nu$, is called the *transfer* (or *transducer*) function f: $U(\sigma) \to V(\sigma)$ of σ:

$$\begin{tikzcd} U(\sigma) \arrow[r, "\mu"] \arrow[dr, "f"'] & E(\sigma) \\ & V(\sigma) \arrow[u, "\nu"'] \end{tikzcd}$$

Example The retina transforms (or maps or codes) light stimuli into nervous signals.

We close this subsection with a batch of general principles that will be stated in an informal way:

POSTULATE 1.3 Let σ be an arbitrary system other than the universe. Then

(i) every input to σ is an output of some other system (i.e. there are no inputs out of the blue);

(ii) σ receives inputs of several kinds (i.e. at some time or other every one of the components of the state function of σ is bound to be affected by environmental changes);

(iii) for every action upon σ there is a threshold below which σ does not respond;

(iv) the total input of σ has a nonvanishing random component;

(v) there is a delay, however small, between every input and the corresponding output if any.

So much for our general structural assumptions. Let us now look at systems from an evolutionary perspective.