Part 1

# Fundamentals

# 1

# General Systems Theory

## 1.1. Introduction

What do a nerve cell, the mathematical field of complex numbers and the Rosetta stone have in common? Nothing much, apparently. However, all three are systems, each in its own way. To grasp the unity behind this diversity of appearances, we must resort to general systems theory (GST), a theory that does not concern a specific type of systems in particular, but instead what makes a system a system. In the following, we will refer to GST, developed by Mario A. Bunge, in particular in volume 4 of his *Treatise on Basic Philosophy* [BUN 79]. We consider that Bunge's theory develops that of L. von Bertalanffy [BER 69], as well as renews it.

In this chapter, we define a system as a composite object characterized by (1) its composition, (2) its environment and (3) its structure. We will differentiate two types of systems: abstract or concrete depending on whether the objects composing the system are abstract or concrete. We will examine the relationships between the components and the environment according to whether the systems are abstract or concrete. We will also introduce the concepts of a subsystem and a level. More detailed analysis of the objects and properties will be done depending on whether the objects are material or abstract. We will introduce different classifications of properties: accidental and essential properties with the related concept of a type, structural and behavioral properties with the related concept of a dispositional property and, finally for systems, the resulting and emerging properties. We will also define the concepts of state, event, process, behavior and fact. The chapter will conclude with the three types of systems of interest for systems engineering: technological systems, systems of knowledge and systems of signs (or semiotic systems).

## 1.2. What is a system?

Following on from Bunge, a system $\Sigma$ is an object composed of several parts (its components). These components have relationships between each other. We call endo-structure $S_{int}$ of a system the network of these relationships between components, whereas the system components may have relationships with objects that do not form part of the system and what we call the environment E. The network of relationships between system components and the environment is called the exo-structure $S_{ext}$ of this system. The structure S of a system is, therefore, the union of both its endo-structure and exo-structure: $S = S_{int} \cup S_{ext}$.

In summary, a system $\Sigma$ is an object denoted by a triplet (C, E and S) such that:

– card(C) > 1, which expresses the fact that $\Sigma$ is composed of several parts (composite object);

– $S = S_{int} \cup S_{ext}$ with $S_{int} \neq \emptyset$, which expresses the fact that the endo-structure of $\Sigma$ is not empty.

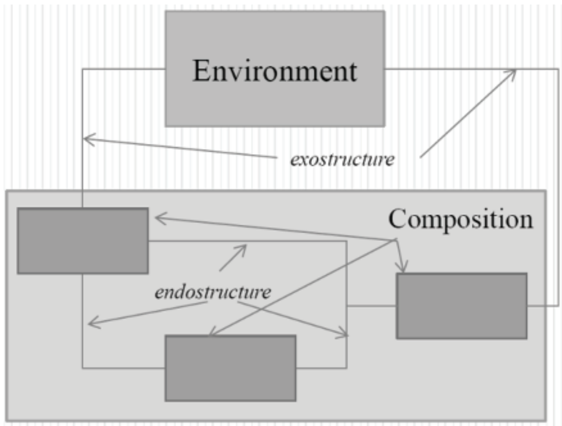


**Figure 1.1.** *System composition, structure and environment*

When E is empty, we say that the system Σ is a closed system. In the opposite case, we would say that this is an open system.

When its endo-structure $S_{int}$ is empty, the object Σ is not a system; this is the case for fictitious stellar objects such as constellations. Ursa Major, unlike the galaxy M31 or the galaxy of Andromeda, is not a stellar system, whereas the stars that form it are themselves systems.

The definition of a system that we state deviates from the one proposed by von Bertalanffy and by many authors later on, beginning with the definition given in [SEB 13], namely "a system is a set of elements in interaction". In fact, in the case of the definition by Bunge, a system is an object whereas in the second case, it is a set. This may appear to be a negligible difference, two slightly different ways of designing the same reality. However, we claim at the opposite that the definition by Bunge provides us with a particularly fruitful characterization of a system, whereas its definition as a set prevents this characterization. In fact, a set is a particular type of object, i.e. an abstraction, resulting from a movement of mind, which allows different individual elements to be taken as a whole, whatever they are, (Ursa Major, for example). If all systems (concrete or abstract) are considered as sets (i.e. are mathematical beings), they are fictions resulting from movements of mind (brain processes), then systems could not exist independent of human beings who think of them. This is exactly the point of view held by constructivists[1].

Bunge provides an opposing realist vision to these constructivist theories: the objects exist according to two very different modalities: only concrete objects really exist objectively, whereas abstract objects only exist as fictions (which we will discuss later on in Chapter 3). So, a system may be either a concrete object (i.e. a material object) or an abstract object (i.e. a fiction) with all components of a material system being material objects, whereas in an abstract system it is only composed of abstract parts.

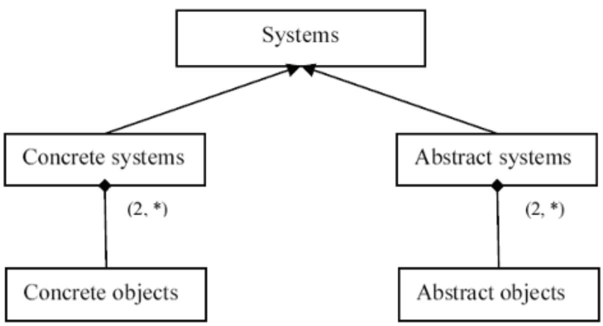


**Figure 1.2.** *Concrete and abstract systems composition*

1 Thus, Jean-Louis Le Moigne in his "General System Theory, Modeling Theory" (Dunod, 1984) recruits the physiologist Claude Bernard to support the constructivist theories (into the context of Claude Bernard's sentence: "systems are not in the nature, but in the mind of men", the word "systems" designates, unambiguously, intellectual constructs, theoretical and philosophical systems, while the existence of concrete systems is neither considered nor settled).

The following are examples of concrete (material) systems: the solar system, a macromolecule, the central nervous system of *Homo sapiens*, a family unit. Similarly, a project team, a book, a hospital, a factory and an airplane are also concrete systems, as well as a country's airspace, an energy production and distribution system at a continental scale. We are able to talk about the latter as systems of systems [LUZ 10]. To conclude with Bunge on this point, we hold the view that "the world is a world of systems" and that any concrete object is a system, a part of a system or both.

The following are examples of abstract systems: the mathematical theory of complex numbers field, the analytical mechanics of J.L. Lagrange, and the system of gods and goddesses of Olympus.

If, by definition, a concrete system is composed of concrete objects, however, it may have abstract systems in its environment; in this case, the concrete system is said to be capable of designating objects of abstract systems using concrete objects. Just as an example, languages, such as English and French (which are concrete systems), allow us to designate the same abstract concept of "system" in GST (which is an abstract system, more specifically a theory) using the different concrete words: "system" in English, "système" in French, "Система" in Russian, and so on'.

Similarly, if an abstract system is inevitably composed of abstract objects it may, however, have concrete systems in its environment; in this case, the abstract system is said to be capable of representing objects of concrete systems using abstract objects. Therefore, a theory such as GST (which is an abstract system) allows us to represent any type of concrete or abstract system and to point out the essential characteristics.

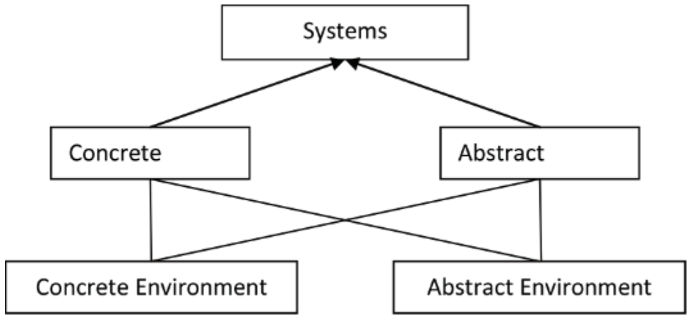


**Figure 1.3.** *Concrete and abstract systems environment*

The type of relationships, among the components of a system (endo-structure), on the one hand, and those connecting components with the elements in the environment (exo-structure), on the other hand, depends on the nature of the systems considered.

For the endo-structure, (1) with concrete systems, the relationships are material binding relationships (links) or non-binding material relationships; whereas with abstract systems, the relationships are formal relationships. We are concerned with links between concrete components when a change of state in some induces a change in state of others; this is typical in a mechanical system whose degrees of freedom are reduced by the links between parts. However, the links in question are not limited to mechanical links; they may be multiphysical (electrical, magnetic, nuclear etc.), chemical, biological or psychosocial. In addition to these links, the endo-structure may include non-binding material links such as topological, metric and temporal relationships. For example, "to be before, after, above, below, aligned with, centered, previous to, simultaneous, subsequent" are non-binding relationships. (2) For abstract systems, the relationships forming their endo-structure are formal relationships including logical operators (e.g. negation, conjunction and disjunction), relational operators (e.g.

equality, comparisons, belonging and inclusion), as well as assessment functions (e.g. "being well formed", "having the following meaning" and "being approximately true").

For the exo-structure, we find the same type of relationships as for the endo-structure; to these we must add relationships including those between concrete and abstract objects such as representation and designation relationships that will be discussed in Chapters 3 and 4.

| | Concrete systems | Abstract systems |
|---|---|---|
| Endo-structure | Links<br>Non-binding material relationships | Formal relationships |
| Exo-structure | *Concrete environment*<br>Links<br>Non-binding material relationships<br>*Abstract environment*<br>Designation | *Abstract environment*<br>Formal relationships<br>*Concrete environment*<br>Representation |

**Table 1.1.** *Endo and exo-structure for concrete and abstract systems*

## 1.3. Systems, subsystems and levels

The fact that a system is a composite object makes it possible for the components of a system to be considered separately. We can then ask the question: can the parts of a system be considered as systems for themselves?

We have an immediate answer to this question if we consider, for example, an atom of helium. This is definitely a system, composed of two electrons and a nucleus whose cohesion is assured by electromagnetic bonds (photons). Electrons are not systems since they belong to the set of elementary particles. The helium nucleus is also a system composed of two protons and two neutrons whose confinement is assured by strong nuclear bonds (gluons).

However, neutrons and protons are not considered as systems.

A system can therefore be composed of objects that are themselves systems. We can say that any systems composing a system Σ are subsystems of Σ.

If σ $\stackrel{\wedge}{=}(c,e,s)$ is a subsystem of Σ$\stackrel{\wedge}{=}(C,E,S)$, we obtain $c \subset C$, $E \subset e$ and $s \subset S$, which means that components of σ are components of Σ, the environment of Σ is included in that of σ and the structure of σ is included in that of Σ.

This possibility for a system to be composed of subsystems can obviously be repeated and this allows us to understand a system as being a hierarchy of subsystems with successive levels with the required decomposition depth.

For example, Dillinger [DIL 90] described a language as a system of signs (concrete system) that is composed of sentences, which are subsystems composed of clauses. These clauses are, in turn, subsystems composed of phrases. Phrases are subsystems composed of words, which are composed of morphemes, which, to finish, are systems of phonemes.

In other words, Dillinger provides us with a language description (true or not, this is another topic) as a system hierarchically organized into six levels (true or not, this is another topic):

1) sentences;

2) clauses;

3) phrases;

4) words;

5) morphemes;

6) phonemes.

## 1.4. Concrete and abstract objects

Starting from Aristotle's statement, from his *Metaphysics*, being (*ousia*) is a compound of matter and form (hylomorphism)[2]. It follows two complimentary ontological clauses: the world is exclusively made of concrete objects, and a concrete object is made of matter with material properties.

For example, according to the standard model of elementary particles, an electron is an elementary particle, characterized particularly by the following properties: a mass of $9.109 \times 10^{-31}$ kg, an electric charge of $-1.602 \times 10^{-19}$ C, a radius less than $10^{-22}$ m and a spin of 1/2. Moreover, a photon is a stable particle with a spin of 1, and its electric charge and mass are zero. Assumed by G. Stoney, its existence was then proved by J. Thomson.

For Bunge, the hallmark of material objects would be to have energy [BUN 10]. In other words, energy would be a universal property of matter, whereas this would be lacking in immaterial objects, which is quite understandable given the incongruity of a phrase such as "the internal energy of the number π". As a corollary, the hallmark of concrete objects would be their aptitude for change, that is to say, they are capable of moving in a space of states. Briefly told, an object is concrete or material if and only if it possesses an energy or iff it is capable of being changed. Therefore, material objects have a real mode of existence, and according to both Bunge and Heraclitus "to be is to become".

According to this ontological assumption, concrete systems have energy and are able to change. This means that the composition C (t), environment E (t) and structure S

2 "By the matter I mean, for instance, the bronze, by the shape the pattern of its form, and by the compound of these the statue, the concrete whole" Aristotle, *Metaphysics Book Z*, Chapter III, translated by W.D. Ross.

(t) a specific system may change during the lifecycle of the system. Denotation of a concrete system Å (t) ) by the triplet (C (t), E (t), S (t)) allows us to highlight its evolution over time.

On the contrary, an abstract object lacks energy and is immutable. It only exists as a fiction produced and reproduced by those who know it. The modes of existence of immaterial and material objects are, therefore, distinct. The transcendental number $\pi$, like a unicorn or a chimera, is an "eternal" object whose mode of being is that of fiction imagined by those who invented it or have knowledge of it, whereas the mode of being of the sun, galaxies and elements composing it down to the elementary particles is that of material reality, independently of any informed or non-informed individual.

**Figure 1.4.** *Representation of fictions (Arezzo Chimera and pi number)*

## 1.5. Properties

### 1.5.1. *Material and formal properties*

Just like the modes of existence of immaterial and material objects differ, their properties are also distinct. The properties of concrete objects are material or factual properties such as "having a position", "having a speed", "having an energy", etc. Properties would be considered as absurd if we tried to associate them with a concept or a proposition.


**Figure 1.5.** *Concrete and abstract objects*

Just like material objects, abstractions, such as a concept or a proposition, have properties called abstract or formal properties. Properties of abstract objects include the meaning of a concept or the truth of a proposition. Meaning and truth are properties associated with abstract objects, and it would be equally absurd if we want to relate them to concrete objects such as a stone or an airplane (signs, despite the fact that they are concrete objects, have a particular status).

### 1.5.2. *Accidental and essential properties, laws and types*

In this section, we are going to describe briefly the main assumptions and results from the theory of properties [BUN 77a, BUN 77b] designed by Bunge. Our theory of property-based requirements (PBRs) is based on these results, which will be discussed in Chapters 6, 7, 9 and 10.

When we consider objects and properties, there are two possible entries: an entry by the properties and an entry by the objects.

Using the first entry, the following definition is proposed: for a property P, the set of individual objects owning this property makes up the class C(P) of P. The class C(P) defines the extension of property P. For example, property E: "having an energy" for class C(E) represents the collection of material objects.

Bunge defines a precedence relation "≤" between the properties P and Q of material objects in the following manner: P ≤ Q if and only if C(Q) ⊆C(P); in other words, P precedes Q if and only if all objects owning the property Q also possess the property P. Thus, "to be a mammal" ≤ "to use a double articulation communication system" or even "to be an aircraft" ≤ "to be a helicopter" in the sense that humans who use double articulation communication systems are mammals, or even, helicopters are aircraft with rotating wings. According to the mathematical theory of sets, the relation "≤" defines a transitive and reflexive preorder [BOU 56]. However, this precedence relation is not antisymmetric since P ≤ Q and Q ≤ P do not imply that P and Q are identical, but only that P and Q are coextensive or concomitant, that is to say, the objects with P also possess Q and *vice versa*.

Bunge assumes that for two material properties P and Q, there is always a third material property R such that C(R)=C(P)∩C(Q), except if they are incompatible. He then defines the conjunction P∧Q of two material properties P and Q by posing C(P∧Q)=C(P)∩C(Q), as well as the incompatibility of P and Q by posing C(P)∩C(Q)=∅.

If we now consider the second entry mentioned above, the entry by the objects, we can define all the properties an object possesses and then can distinguish the essential properties of this object, on the one hand, and its accidental properties, on the other hand:

1) A property P of an object O is said to be essential if it is materially linked to other properties of O. For example, this is the case for the mass of Saturn's satellite called Pollux, which is linked not only to other static characteristics of its orbit (foci, apogee and perigee) but also to dynamic properties such as its period of revolution. Along with Bunge, we find that all material objects have essential

properties and each essential property of a material object has at least one link with one of its other essential properties.

We name a material law any relation L materially linking together essential properties $\{P_1, P_2, ..,P_n\}$ of a material object O. When two or several essential properties $\{P_1, P_2, ..,P_n\}$ of a material object O are linked by a material law L, the evolution of one of these properties will induce a change in one or several properties that are linked to the first, according to law L. We also note that the material law L is also a property of the material object O.

It is on this assumption that science and technology are based, depending on which essential properties of objects are linked together by material laws. If we remove this assumption, the project of science and technology becomes insane.

Taking essential properties of an object O into consideration will allow us, as we will see below, to define a space of states that is the same for all objects sharing the same essential properties.

It also allows us to define a type of objects. We define a type of objects as the collection of objects that share the same essential properties or even have the same real space of states. So, we can define the satellite type as the type that collects all the actual and potential satellites, the human type as the type collecting all the human beings (dead, alive or to come), the aircraft type, etc. like this.

Here, the term "type" is also quite general and can be specialized by introducing the concepts of "gender", "species", "order", "kind", etc., as systematics specialists do. For example, in the field of aeronautics, we can introduce the aircraft gender, and within type we can distinguish at least two species: fixed-wing aircraft (or airplane) and rotary-wing aircraft (or helicopter). Within the helicopter species, we can distinguish category A and category B kinds, according to helicopter regulations. Finally, within these kinds, we can distinguish types of helicopters. One type of helicopters is a collection of helicopters that have been or will be produced, according to the same type design definition (TDD), which has gained approval (type certificate (TC)) from the competent airworthiness authority, attesting that this definition conforms to the airworthiness regulations.

2) A property P of an object O is said to be accidental if it is not materially linked to any other property of O. As an example, this is the case for the color of aircraft flight recorders, familiarly called “black boxes”, and which could be of any other color, if the regulation did not require, in a fairly conventional way, that flight recorders be orange.

If we then consider all individual objects with the name “Pollux”, we define a fiction, a heterogeneous set of individuals including a hero from Greek mythology, a satellite of Saturn, a grammarian of the Greek language of the 2nd Century AD, a character of a dog from a television series, an elephant from Jardin des Plantes, etc. Note that naming a satellite of Saturn or an elephant in Jardin des Plantes “Pollux” does not change much, or even anything about the existence of this natural satellite or elephant. “To have the name Pollux” is not a material property of this satellite or elephant. The name of object materials, when they have one, is a property of the object represented within a system of signs used to denote it whereas this denotation has an accidental character, if we refer to the theses of linguist F. de Saussure on “the arbitrary nature of the sign” [SAU 00].

### 1.5.3. *Dispositions, structural and behavioral properties*

If we consider, for example, the electric charge of an electron, it is a typical characteristic of this object, an intrinsic property, whereas its velocity is a relational property of this object with regard to other objects forming a framework (for example, the frame of an instrument, a building and three fixed stars). However, in both cases, a property is inevitably a property of an object or a group of objects.

Flying is a property of aircraft, for example. This does not mean that an aircraft permanently flies but only that it is capable of flying, it has a disposition to fly. An aircraft spends most of its time on the ground in parking lots or on runways. During the periods spent on the ground, the ability to fly is retained, without being used. In other words, flying is a potential property or a disposition of aircraft that is only used at certain times, when they fly effectively.

As Roozenburg [ROO 91] states, manifesting a disposition requires conditions of actualization. For example, whether an aircraft has fuel or not, and whether there is a pilot to perform the takeoff or not, forms parts of the conditions of actualization in order for an aircraft to fly.

*Conditions of use* $\wedge$ *structural properties* $\rightarrow$ *actualization of dispositions*

However, object dispositions do not come from the conditions of actualization that reveal them, but rather from inner and sometimes hidden characteristics (structural properties) of the object. The object can do what it does, in given circumstances, because it is structurally how it is.

Therefore, an aircraft obtains its ability to fly from its wing (fixed or rotary). Flying and possessing wings are two essential properties of aircraft, linked by a material law, which we know from a lift law statement such as: $F_Z = 1/2\,\rho V^2 S C_z$ .

The characteristics of a wing, such as its reference area S and its lift coefficient $C_z$, are structural properties of the wing while the lift effect of a wing (exerted with force $F_z$) is a behavioral property (or disposition) that is only actualized when there is a transfer to the surrounding atmosphere at a minimum velocity V.

### 1.5.4. *Resulting and emerging properties*

Classifying properties as resulting or, on the contrary, as emerging is typical with systems, unlike preceding classifications that were about concrete or abstract objects, without questioning whether they are systems or not.

For a property P of system Σ denoted by the triplet $(C, E, S)$, P is said to be a resulting property of Σ when parts of Σ already possess the property P.

For example, for the property “have a signification”: the words “system”, “is”, “object” and “composite” all have a signification, just like the statement “a system is a composite object” also has a signification. We can say that the signification of the statement above is a resulting property since its components already had one.

However, we can say that the statement “a system is a composite object” is true (or false), whereas saying that the word “system” is true sounds like an incongruity. This is due to the fact that a statement can have a value of truth, whereas a word cannot; “to be true”, “to be approximately true” and “to be false” are possible emerging properties of a statement because the words that form it do not possess this property.

This is true for language, as well as for any type of systems: a passenger airplane has the emerging property of transporting people from one airport to another through the air, a property that no component of this airplane possesses.

Some authors associate the concept of emergence with that of complexity. For them, the emergence of properties within systems is related to their complexity. We do not share this point of view. For us, any system, whatever it may be, whether simple or complex, always has emerging properties. We can see this by simply considering the properties of a water molecule compared to those of its constituent atoms or even observing the incredible diversity of shapes (geometric, rose, cardioid, nephroid, limacon of Pascal, lemniscates, epicycloid and conchoid) that can be obtained using basic mechanisms: rolling circle without sliding over a base circle, or segment and circle. Thus, emergence is a distinctive property of the structure of systems without any particular association with complexity: for an object, the phrase "be a system" is equivalent with the phrase "possess emerging properties".

As Bunge points out, the emergence [BUN 03] of properties at the level of a system is also accompanied by the submergence of the components' properties, i.e. the properties of the components also disappear at the level of the system. Thus, the explosive nature of the sodium atom is submerged in the molecule of salt.

The emergence of properties can be considered in another sense, related to the previous: in the evolution of a line of objects, new properties may arise in the descending objects that were not there before. It is in this sense that we can say that human language emerges in communities of hominids who did not have language before. We could also question whether properties emerge within a line of technological objects. Also, it is in this sense that the modern helicopter emerged into gyroplanes at the beginning of the 20th Century. This question is not answered here.

## 1.6. States, event, process, behavior and fact

In the previous section, we mentioned that abstract objects are immutable, and assigning them a state is no more relevant than wanting to assign them a material property.

However, material objects (and consequently concrete systems) are changing by nature, that is to say that different material properties may change value. This includes the fact that composition, structure and environment of a concrete system change over time. More basically, we assume that material properties can be split into two subcategories: qualitative and quantitative properties. Qualitative properties are characterized by finite domains of values, whereas quantitative properties are characterized by infinite (countable or uncountable) domains of values.

If we take object O, characterized by its essential properties $\{P_i\}_{i\in I}$, and if we assume that each property $P_i$ has a domain of values $D_i$ (finite or infinite), then at each moment, each property $P_i$ possesses a value $p_i$ within domain $D_i$ (for quantum properties, it is necessary to consider a distribution of values). Note that the value $p_i$ of $P_i$ may be constant (specific property) or variable (generic property).

We can then define the state e of an object O, at a given time t, as the set $\{p_i\}_{i\in I}$ of values of each of its essential properties, i.e. e= $\{p_i\}_{i\in I} \in \prod_{i=1}^{n} D_i$. Here, $\prod_{i=1}^{n} D_i$ that designates the space of theoretically possible states of O sets a reference framework. However, the material links between the essential properties of a material object determine the set of states $\{p_i\}_{i\in I}$ that are actually possible, whereas others are materially impossible. We call the actually possible space of states E of object O, or briefly, the space of states of O, the strict subset of $\prod_{i=1}^{n} D_i$ such that if $\{p_i\}_{i \in I} \in E$ then $\{p_i\}_{i \in I}$ is actually possible. Only, space E of the actually possible states is to be considered.

To illustrate the above problem, we can take the following example: a gaseous object G can be characterized by three generic properties: p pressure, v volume and T temperature, whose respective domains can be represented (in a system of units) by intervals $[p_{min}, p_{max}]$, $[v_{min}, v_{max}]$ and $[T_{min}, T_{max}]$ of the set of real numbers R. These three properties of object G are essential properties of G because they are linked to each other by a material law (whose effects can be observed using numerous experimental devices); in other words, the space of state $E_G$ of G is a strict subset of the Cartesian product $[p_{min}, p_{max}]x[v_{min}, v_{max}]x[T_{min}, T_{max}]$.

Note that this material law that links these properties of G is itself a property of G. It is an independent property of the object, irrespective of whether we (a knowing subject) know it or not.

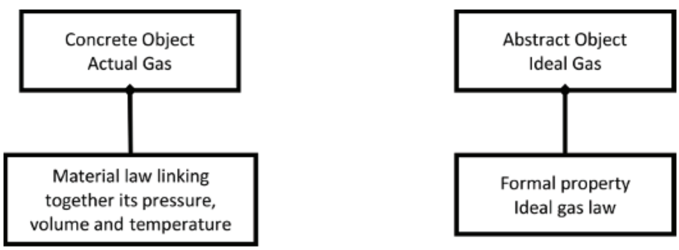


**Figure 1.6.** *Laws and law statements*

This material law must not be confused with law statements that are only approximately true representations of this material law: ideal gas law, van der Waals law, etc.

A material law, whether causal or stochastic, *actually* links the essential properties of an object with each other. This is what a law statement designates; for example, the ideal gas law designates the material law linking pressure, temperature and volume of the gas capsule.

The ideal gas law statement designates a nomological proposition, that is to say, an abstract object whose truth is only approximate in the sense that it imperfectly represents a material property of real gases, namely the interdependence of pressure, temperature and volume.

Given this, we can define an event as a transition from one state of an object to another (thus, a concrete object possesses at least two states, due to the fact that a concrete object is mutable). Moreover, a process is defined as a sequence or a continuum of events leading an object from an initial state to a final state.

Therefore, the emission or absorption of a photon is an event during which an electron "jumps" from one energy level to another, whereas the propagation of a nerve impulse is a process through a network of neurons. We must remember that an event, or a process, is inevitably an event or a process within an object, and that events or processes without a material support object are not real but abstractions.

Next, we can define *a* real behavior b (actually possible) of an object O as an actually possible trajectory in its actually possible space of states.

$b: t \in [t_0, t_1] \rightarrow s \in E$ where E is the actually possible space of states of object O.

In the same way, we can define *the* behavior[3] of object O as the set of actually possible behaviors of O.

To conclude, we introduce the concept of fact as follows: a fact is either a concrete object in a given state or an event (or a process) occurring in a concrete object.

For example, an aircraft flying in cruising level or a computer powered on are facts. The facts have to be distinguished from statements that denote them, “the aircraft is flying at cruise level” or “the computer is powered up”.

## 1.7. Systems of interest

We say that systems engineering is concerned with three types of systems. Figure 1.7. shows the types of systems that will be involved in the systems engineering, either as its purpose (technological systems) or as the means to be used (knowledge systems and signs systems

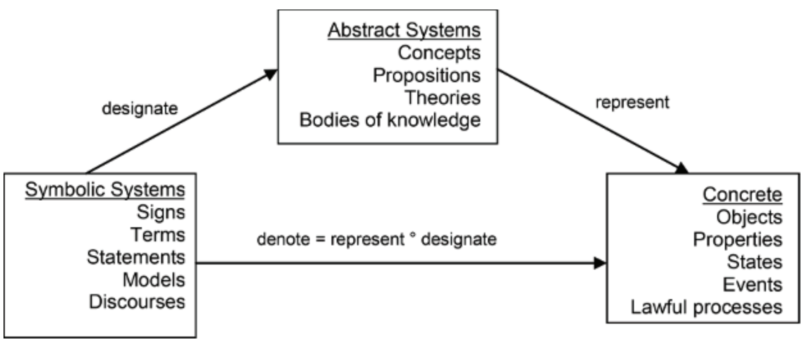


**Figure 1.7.** *Systems involved in the systems engineering processes*

3 Bunge calls it “mechanism”. The behavior does not necessarily have observable effects. This is the case for static systems that have no observable reactions, to some extent, under the action of external forces.

First, and rather obviously, technological systems form the first type of systems considered in systems engineering. For example, the standard ISO15288, page 52 [ISO 02], indicates that "systems considered in this International Standard are man-made, created and utilized to provide services in defined environments for the benefit of users and other stakeholders". We dedicate one chapter (Chapter 2) to the characterization of technological systems as a type of concrete systems.

However, technological systems are not the only systems considered in systems engineering. A second category includes systems of knowledge and, in particular, scientific and technological systems of knowledge. In fact, as we will see later on, technological systems are artificial systems that are designed, produced, operated, maintained and dismantled by taking into account the available scientific (basic and applied) and available technological knowledge. We dedicate one chapter (Chapter 3) to the characterization of these systems of knowledge that are abstract systems.

Finally, a third category of systems is also considered in systems engineering, to which belong all documents, frameworks and all models used to design, produce, operate, maintain and dismantle technological systems, that is semiotic systems. It includes a lot of systems of signs which, on the one hand, denote the technological systems of interest and, on the other hand, designate the systems of knowledge representing the technological systems of interest. We dedicate one chapter (Chapter 4) to characterizing systems of signs and models (that form a subcategory of sign systems).