ior of this system for a sufficiently long time and, if required, by exerting actions on its inputs, one can achieve a level of knowledge about the properties of the system such that it is possible to predict the motion of its output coordinates for any given change in inputs.

However, no matter in what detail we study the behavior of a black box, we cannot deduce basic inferences about its internal structure: different systems can have the same behavior.

Systems characterized by identical sets of input and output quantities and identical reactions to external actions are called *isomorphic*. Isomorphic systems are obviously indistinguishable from each other from the perspective of an observer to whom only their input and output coordinates are accessible. An example of an isomorphism is the indistinguishability of gas and thermoelectric thermometers from the viewpoint of an experimenter, no matter what experiment he or she conducts on them before resorting to opening the black box.

The study of systems by the black box method cannot lead to a unique deduction about their internal structure, for the behavior of a given system (considered as a black box) does not differ from the behavior of all systems isomorphic to it. In this connection one should consider that for any concrete system, it is possible to select an infinite set of concrete systems isomorphic to it. However, the black box concept is widely used in science, although not always in a clear manner. In essence, a black box is any object under observation for which all of the conclusions about its properties are based on an investigation of its external properties, without resorting to an investigation of its structure and the properties of the elements of the object. The black box method is especially important for investigation of the behavior of a system, and because behavior is almost always of interest in the analysis of systems, the black box method is one of the basic instruments in the investigation of systems.

For any set of isomorphic systems, there exists an original-model relation in the sense that any system in this set can be considered as the original or as a model of the rest. *However, the isomorphism conditions are not the necessary conditions for correspondence of a model to the original.*

Among the coordinates of a system that determine its state, some can be more essential or less essential in relation to the problem being solved by the investigator. If we exclude inessential coordinates from consideration, then instead of the original system $X$ with dimension of state space $n$, we obtain a simpler system $Y$ with dimension of state space $n' < n$. Then each given state of $X$ will have a corresponding state of system $Y$ (because assigning values to inessential coordinates does not keep us from determining the state of $Y$ with respect to the essential coordinates of system $X$). But to each specific state of system $Y$, there will not exist a unique value of the state of system $X$, this is because in assigning a state of system $Y$, we do not fix the values of inessential coordinates.

System $Y$ obtained from original system $X$ by means of its simplification (at the expense of lowering the number of coordinates considered or more



coarse estimates of their values) is called a *homomorphic* or simplified model of system $X$. Relations between the original $X$ and its homomorphic model $Y$ are unequal, for $X$ cannot be considered as a homomorphic model of $Y$.

In the plan of what has been mentioned, mathematical models are of interest. *A mathematical model of a system is a description in some formal language that permits us to deduce inferences about some characteristics of behavior of this system with the help of formal procedures on its description.* Because a mathematical description cannot be comprehensive and ideally precise, mathematical models do not describe real systems but instead describe their simplified (homomorphic) models. In this connection, types of mathematical models are completely different; they can be characteristics of systems given by functional dependencies or graphs, equations describing the motion of systems, tables or graphs of transformations of systems from particular states to other states, and so on. One should remember that *a model is always a simplification of the original and is usually some distortion of it.*

## 1.7 Control

In the systems approach, questions associated with control are rather important and are even separated into an independent scientific specialty that Wiener named *cybernetics*. Cybernetics, as the science of control, studies not all systems in general but only *controlled systems*, which frequently are called *cybernetic systems*. On the other hand, the region of applications of cybernetics extends to the most varied systems—technical, biological, and social among them—in which control is carried out. More than that, in practice we deal with controlled systems as a rule. In other words, the class of cybernetic systems is dominating.

One of the characteristic features of a controlled system is the ability to change its motion, to make a transition to different states under the influence of various controlling actions. Thus, an automobile can occupy different positions in space and can move in different directions and with different speeds depending on how it is controlled.

As noted earlier, the desired behavior of a controlled system is achieved with the help of controlling actions, under whose influence the system acquires a better (in a specific sense) state than it would have acquired in the absence of the controlling actions.

To clarify our sense of the word "better" as used here, imagine an artificially controlled system created by humans and used for our purposes. The behavior of the system is evaluated by its creator, and the word "better" means better in relation to the goals of the subject-creator of the system. On the other hand, biologically controlled systems were created in the evolutionary process