# Organizations

Social Systems Conducting Experiments

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# Chapter 2

# The Experimental Arche: Ashby's Cybernetics

## 2.1 Introduction

In this chapter we introduce Ashby's cybernetics – a theory about the regulation of all kinds of systems. Ashby's cybernetic theory is fundamental to our perspective on organizations as "social systems conducting experiments" because it provides us with the conceptual tools to describe the "experimental arche" of organizations (see Chap. 1). In particular, Ashby's theory on regulation enables us to arrive at a first description of organizations conducting experiments, making apparent (1) that the objects organizations experiment with – goals, transformation processes, infrastructural parts or operational regulatory activities – are related to three types of (organizational) regulation, and (2) how conducting such experiments should be regulated itself. Moreover, because Ashby's notion of regulation is intimately tied to the survival of systems, his theory can be used to make explicit how conducting organizational experiments is linked to the survival of organizations.

In his work, Ashby formulates the regulatory principles and methods that underpin organizing as an experiment and many currently popular devices supporting this experiment. In his books "An Introduction to Cybernetics" (1958) and "Design for a Brain" (1960) and in many articles, Ashby systematically unfolds basic principles and methods of cybernetics that are still at the core of organizing and all kinds of fashionable management techniques advanced as "new" in contemporary textbooks and journals. Particularly in "An Introduction to Cybernetics" Ashby strives to develop these principles and methods in a way that is as insightful as possible. For this reason, we focus on this book in this chapter (some excursions granted).

In his introduction to cybernetics, Ashby provides a conceptual articulation – rather than an empirical description – of regulation. It is not his aim to empirically describe instances of regulation that are tied to a particular embodiment, a particular place or time. The principles and methods he lays down are truly general and certain. They provide a rigorous treatment of all instances of regulation whether it is regulation in mechanisms, organisms (to which most of his examples refer), organizations, or societies.

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To explain the organization of this chapter, it is helpful to understand that regulating a system is, in essence, trying to influence its behavior. That is, every "concrete system" we encounter – be it a car, a dog, some transformation process, or an organization – shows particular behavior, and regulating it, in essence, means trying to influence it in such a way that it behaves "properly."

Based on this idea of regulation, at least two requirements can be given: (1) a description of the (proper) behavior of a system, and (2) based on this description, notions about how to influence the system's behavior. These two requirements fit Ashby's description of the aim of cybernetics. He writes that cybernetics hopes to provide "effective methods for the study, and control, of systems that are intrinsically extremely complex" (Ashby 1958, p. 6). The *study* of complex systems (such as organizations) entails arriving at a description of their behavior (in terms of what is labeled a "transformation") and *control* has to do with influencing their (own) behavior – it has to do with regulation (Fig. 2.1).

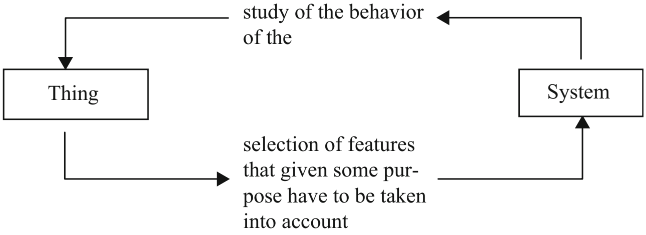

**Fig. 2.1** Things and systems

Accordingly, we discuss, in this chapter Ashby's method for the *study* of complex systems (in Sect. 2.2) and effective methods to control (regulate) the behavior of complex systems (in Sect. 2.3). Finally, we show (in Sect. 2.4) the relevance of the presented cybernetic concepts for understanding organizations as "social systems conducting *experiments*."

## 2.2 Cybernetics: Effective Methods for the Study of Complex Systems

In this section we discuss Ashby's method for the study of complex systems. Above, we gave a first description of regulation as influencing the behavior of some "concrete entity." This entails that we should "model" the behavior of this entity in such a way that we can understand *how* it behaves in the first place, and how this behavior *reacts* to "influences." One could say that (at least) two kinds of influences on behavior (input) can be discerned: "disturbances" – causing the concrete entity to behave "improperly," and "regulatory actions" – causing "proper" behavior (by preventing or dealing with disturbances). A description of the behavior of a system should take such influences (input) into account.

Moreover, in order to regulate a system, a regulator needs to find regularities in the behavior of a system given disturbances and regulatory actions. If no regularities can be found, influencing the system with the hope of making it behave properly is impossible. Accordingly, a description of the behavior of some concrete entity needs to show these regularities.

In all, the description of the behavior of some concrete system we want to study (and regulate) should make apparent how a system behaves, how this behavior "reacts" to disturbances and regulatory actions, and it should show regularity.

In this section, we start with the conceptual devices, needed to describe the behavior of any concrete entity (Ashby's notions of "system" and "transformation"). Next, we move on to regularity and input. Finally we describe Ashby's famous "black box" method – a procedure to describe the behavior of some concrete entity and to determine whether this behavior meets the criteria for regularity.

### *2.2.1 Describing Behavior: "Systems" and "Transformations"*

In its study of complex systems, cybernetics stresses their behavior. As Ashby puts it, "Cybernetics treats, not things but ways of behaving. It does not ask "what is this thing?" but "what does it do?" (Ashby 1958, p. 1).

To study behavior, observers need to model it. To this purpose, Ashby introduces the concept of *system*. He defines a system as a set of variables. "Variables" are features of things that, given some purpose, have to be taken into account (Ashby 1958, p. 40; 1960, p. 15).[1] The system is Ashby's basic conceptual device to study behavior.

For instance, a manager may be interested in the "growth behavior" of her organization. To study this behavior, she may select "net profit" and "number of employees" as features that have to be taken into account. Thus, a system with two variables is defined: "net profit of organization X" and "number of employees of organization X." Given this system, the value of its variables at different moments in time can be determined. Ashby calls the set of values of the variables at a given moment in time, the *state* of the system. So, for instance, the state ($10.000, – , 40) here means that, at a particular moment in time, the variable "net profit" has the value "$10.000" and the variable "number of employees" has the value "40."

By measuring the values of the variables (the states) at different moments in time, it becomes possible to study the behavior of a system. Behavior can be defined as the sequence of states of a system in the course of time.

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[1] "Things" are the "concrete entities" or "processes" of which we select variables to describe their behavior. In the remainder of this chapter we will use the term "system" to refer to the set of variables. The "thing" to which these variables refer is indicated with several other terms (e.g. "concrete system," "concrete entities," "real system" or "real machine").

A basic element in the description of behavior is the "*transition*." A transition "is specified by two states and the indication of which changed to which" (1958, p. 10). Ashby calls the *operand* the state that changes to another. For instance, at time $= t$, an organization's inventory may contain 100 items: 60 items of product X and 40 of product Y. If we define the system to study the behavior of the organization's inventory as "number of items of product X" and "number of items of product Y" then the state of the system at time $= t$ is (60,40). Let this be state A.

All kinds of influences, Ashby calls them "operators" (e.g., client behavior, deliveries of suppliers), act upon this state and may cause it to change. The state into which the operand changes, is called the *transform*. If, for instance, due to all kinds of influences, the inventory at the next moment in time (say, one day later)[2] changes to 50 items of product X and 40 of product Y – i.e., the new state (transform) is (50, 40). Let us call this state, state B.

The transition describes the change from operand to transform. In the example (see Table 2.1), a transition called T1 describes the change from state A at time $= t$ to state B at time $= t + 1$. The arrow indicates which state changes to which.

**Table 2.1** Notation of a transition

| | |
|---|---|
| T1↓ | A (operand, state at time = t) |
| | B (transform, state at time = t + 1) |

In the inventory example, the (vector) notation would be as in Table 2.2

**Table 2.2** Notation of transition using vectors

| | |
|---|---|
| T1↓ | (60,40) |
| | (50,40) |

Given these definitions, we can start to study the *behavior* of the system. At time $=$ $t + 2$ (two days later), the state of the inventory system may become (40, 40) – i.e., 40 items of both products. We call this state C. Now, transition T2 can be written as Table 2.3.

**Table 2.3** Example of transition

| | |
|---|---|
| T2↓ | B |
| | C |

At time $= t + 3$, the state may become (60, 40) – for instance because of the delivery of items of product X. This is exactly the state we called A above, so we can write Table 2.4.

**Table 2.4** Transition example (continued)

| | |
|---|---|
| T3↓ | C |
| | A |

---

[2] For reasons of simplicity and clarity, we abstract (like Ashby) from continuous change and assume $\Delta t$ to be of constant value.

These results can also be written in the form of a *series* of transitions (see Table 2.5).

**Table 2.5** A series of transitions

| T1 | T2 | T3 |
|---|---|---|
| A | B | C |
| B | C | A |

Now, suppose that an observer studies the behavior of the system for a considerable period of time. After a while he stops his observations and writes down the following series of transitions (Table 2.6).

**Table 2.6** A series of transitons (continued)

| T1 | T2 | T3 | T4 | T5 | T6 | T7 | T8 | T9 | T10 |
|---|---|---|---|---|---|---|---|---|---|
| A | B | C | A | D | B | C | A | D | E |
| B | C | A | D | B | C | A | D | E | A |

If the observer supposes that this series adequately describes the behavior of the system, he can abstract from the particular moments in time at which the transitions occurred and rewrite Table 2.6 in a *conditional* form (see Table 2.7).

**Table 2.7** A transformation

| T↓ | A | B | C | D | E |
|---|---|---|---|---|---|
| | B or D | C | A | B or E | A |

Table 2.7 states that *if* the system at any moment in time is in a particular operand state in the top row (e.g., state A), *then* it will be in a transform state indicated below this operand the next moment in time (e.g., state B or state D). So, A transforms into B or D, B transforms into C, etc. We refer to a description of a system's behavior in terms of a conditional set of transitions by the term *transformation* (cf. Ashby 1958, p. 10).

It appears from the table, that operands A and D have two transforms, B and D, and B and E respectively. Operands B, C and E have only one transform, C, A, and A respectively. From this description, the observer can, for instance, infer that if the system at any moment in time (say, t) starts in state B it will be in state C at the next moment in time (t + 1). If it starts in state C, it will move to state A, and starting from state A it will move to either state B or state D.

It should be noted that it is a decision of the observer or regulator to suppose that some series of transitions describes the behavior "adequately" and can be taken as a point of departure for deriving a conditional transformation. Such decisions are based on experience with or knowledge about the concrete system and always contain uncertainty. This means that the resulting transformation is always a *hypothesis* about how the concrete entity will behave.

To study the behavior of concrete entities, then, observers may define systems. Systems consist of selections of variables that, given the purpose of the observer, have to be taken into account. Using the system as a device, the observer can describe behavior as it occurs over time in terms of transitions. By rewriting these transitions in a (conditional) transformation, the observer can start looking for regular behavior. However, to be able to judge whether regular behavior actually occurs, criteria for regularity are needed.

### 2.2.2 Regular Behavior and Input

Using a set of variables (a system), an observer can describe behavior in terms of a transformation. However, describing behavior is not an end in itself. Behavior is described to enable control. For regulatory purposes, the observer needs to know whether the described behavior is regular or not. In Ashby's words, "Cybernetics deals with all forms of behavior in so far as they are regular, or determinate, or reproducible" (Ashby 1958, p. 1). So, the observer needs criteria to determine the regularity of the described behavior or, as Ashby calls it, whether the behavior is "machine-like" or not. Ashby derives these criteria from two distinctions regarding transformations: open versus closed and single-valued versus multi-valued transformations.

In an open transformation, there is at least one state in the transformation that cannot act as an operand because no transform has been specified for that state. In this case, at least one element in the set of transforms is not an element in the set of operands. Transformation "O" (Table 2.8) is an example of an open transformation.

**Table 2.8** An open transformation

| O↓ | A | B | C | D |
|---|---|---|---|---|
| | C | D | E | A |

In the case of transformation "O," transform "E" is not an element of the set of operands {A, B, C, D} and so, after the occurrence of transform "E" the next transform cannot be determined. Open transformations are unsuited for describing regular behavior, because for some known states, the next state cannot be determined.

A transformation is closed if it is not open. In this case, all its transforms also appear as operands in the transformation. All elements in the set of transforms are an element of the set of operands. Transformation "C" (Table 2.9) is an example of a closed transformation.

**Table 2.9** A closed transformation

| C↓ | A | B | C | D |
|---|---|---|---|---|
| | A | C | B | A |

Closed transformations can be used to determine the next state for all the states that (are known to) occur. According to Ashby, the behavior of a system is regular if it can be described as a closed transformation.

The distinction between single-valued and multi-valued transformations enables Ashby to specify *types* of regularity.

A transformation is single-valued if, “it converts each operand to only one transform” (Ashby 1958, p. 14). See Table 2.10 for an example of a single-valued transformation.

**Table 2.10** A Single valued transformation

| S↓ | A | B | C | D |
|---|---|---|---|---|
| | A | B | D | A |

A transformation is multi-valued if an operand does not always change to the same transform. In the example (see Table 2.11), D may change into A or into C.

**Table 2.11** A multi-valued transformation

| M↓ | A | B | C | D |
|---|---|---|---|---|
| | A or B | C or D | A | A or C |

If the behavior of some system can be described as a closed and single-valued transformation, it is labeled a *determinate machine*. Given the operands of a closed and single-valued transformation, its transforms can be predicted with certainty. Hence, the behavior of a determinate machine can be predicted with certainty.

If the behavior of a system can be described as a closed and multi-valued transformation, it can be modeled as a *Markovian machine*. The behavior of the Markovian machine is described by a “matrix of transition probabilities” (Ashby 1958, p. 225). For a Markovian machine, the occurrence of a transform can only be predicted with a probability. For instance: state A may change into B with a probability of 0.9 and into C with probability 0.1.

Until now, we only paid attention to changes in the values of the variables of the system, defined to describe the behavior of some thing. Using these variables, we can describe change in behavior, but we cannot yet account for the reasons of this change. One of these reasons is that a system is susceptible to “input.” That is, there may be variables (that are *no* part of the system that is used to describe the behavior of some thing) influencing the system’s behavior. Ashby calls these variables *parameters*. He defines input as the specific value of a parameter at a specific moment in time. Dependent on the input, i.e., the value of a parameter, a system behaves in a particular way.

To describe the influence of parameter-value changes, Ashby introduces the “determinate machine with input.” A determinate machine with input is a collection of determinate machines (sharing a set of operands). The value of the parameter is the input. The input specifies which one of the determinate machines determines the behavior (Ashby 1958, p. 44). Table 2.12 is an example of a determinate machine with input.

**Table 2.12** A determinate machine with input

| $I_p$↓ | 80 | 70 | 60 | 50 | 40 |
|---|---|---|---|---|---|
| $P = 20$ | 70 | 60 | 50 | 40 | 60 |
| $P = 40$ | 70 | 60 | 50 | 40 | 80 |

In the example, the operands and transforms represent the number of products in stock at some moment in time. The parameter P represents the order quantity. It can have two states: 20 or 40. Dependent on the state of P, the behavior of the stock differs. If $P = 20$, then the transformation consisting of the first and second row of the table results. The behavior it represents can be interpreted as follows: starting with a stock of 80 items, every time period 10 are sold and when it reaches 40, 20 items are added to the stock. If $P = 40$, then the transformation consists of rows 1 and 3 – with a comparable interpretation.

Normally, a machine with input is given a name containing an index representing its parameter(s) ($I_p$ in the example). In this example, the machine with input contained one parameter with only two values. It is, of course, possible to have many parameters with many different values as input.[3]

In sum, to be considered regular, the behavior of a system must be describable as a closed transformation either with or without parameters (input). An observer searching for regularity first determines whether the behavior of the system meets the criteria of the determinate machine or the machine with input. If the behavior of the system does not meet these criteria, one has to be content with the statistical predictability of the Markovian machine.

To study (and regulate) the behavior of complex concrete entities, a regulator should define a system (a set of variables) and should try to arrive at a transformation, describing its behavior. To account for input, a transformation should contain parameters. Moreover, two criteria have been given to determine whether the behavior, described by the transformation, is regular. Given a system, parameters and criteria, it is, in theory, possible to describe the behavior of systems in terms of a transformation and establish whether they show regularity. However, one may ask how an observer should go about to describe in practice the behavior of a concrete system. What is needed, then, is a *procedure* prescribing the steps an observer has to take to describe the behavior of a system, to assess whether this transformation is regular or not, and to determine the type of regularity.

### 2.2.3 A Procedure to Describe Behavior and Identify Regularity

At the heart of the procedure for the identification of regular behavior is Ashby's famous "Black Box." According to Ashby everything that can be the object of study and manipulation is a Black Box. The things we experience, manipulate, or study in everyday life, are all Black Boxes. We experience their behavior in terms of relations between input and output without reference to the "inner mechanism" producing their behavior.

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[3] In addition to determinate machines with input, there are also Markovian machines with input. These are composed of a set of Markovian machines (sharing the same operands). The state(s) of the parameter(s) determines which one of the Markovian machines determines the behavior of the Markovian machine with input.

As we said before, whenever we encounter something we want to deal with, Ashby proposes that we "model" the behavior of this thing using "a system and a transformation." That is, we (implicitly) define variables to describe the behavior and we describe behavior in terms of changes in the values of these variables. Moreover, if we want to manipulate (or understand) its behavior we also have to define parameters that may influence it. In this way, we describe the "thing's" susceptibility to input (among which "disturbances" and our "regulatory actions"). We may proceed by studying the behavior, given various changes in the parameter values – a study that may lead to conjectures about regularities between input and output. This study results in a final description of both the behavior of some thing and the effect of input on this behavior: the transformation. Based on this transformation, we may try to actually manipulate the behavior by (re) setting the parameter values.

Ashby stresses that while we try to establish conjectures and try to derive the transformation of the thing (the black box) we cannot open it to inspect its inner "mechanism." The only things we can do are manipulating its input (parameter states), observing its behavior (the output – the change of the state(s) of variables of the system). Because the inner mechanism of the Box remains hidden (it stays in the dark, so to speak) it is called black.

To give an example, suppose an observer wants to study and manipulate (regulate) the behavior of company X (some black box). To this purpose, the observer defines a system, say, the annual economic result of company X, to describe its behavior (its output). He also defines as a parameter (input) the particular CEO in charge. After some observation, the observer writes down Table 2.13.

**Table 2.13** Example of a machine with input (see text)

| $R_p\downarrow$ | Result $> 0$ | result $\leq 0$ |
|---|---|---|
| $P =$ CEO 1 | Result $> 0$ | result $> 0$ |
| $P =$ CEO 2 | Result $\leq 0$ | result $\leq 0$ |

Table 2.13 specifies the relation between the parameter (input – i.c. the CEO in charge) and the behavior (output) of the system (the result of the company). This relation meets the requirements of the determinate machine with input. If the observer is able to determine who is in charge of company X (the input), and if the observer has enough "authority" to change the parameter value, (s)he can manipulate its annual economic result (the organization's behavior – the output).

One may ask how the observer has arrived at this transformation, showing regularity in the relation between input and output of the black box. What is the procedure one has to follow? The procedure for finding transformations describing behavior can be summarized as an iteration of five steps.

### Step 1. Select a Purpose

To study the behavior of Black Boxes, Ashby suggests that we work from some "main interest that is already given" (Ashby 1958, p. 40). In other words, what is needed is that we work from some purpose. In the example, for instance, the observer may want to understand and manipulate the organization's profitability.

### Step 2. Define the System, the Parameters, and the Measurement Interval

Given the purpose, an observer has to select variables that define the system. The values of the variables of the system (its states) are the output of the black box. In the example, the observer chooses to select the annual economic result of company X as the variable describing its output. At the same time, given the purpose, the observer can select relevant parameters. The states of the parameters are the input to the black box. In the example, the observer believes that the CEO in charge influences the annual economic result – hence the parameter "CEO in charge" is selected. This parameter can be in either of two states "CEO 1 is in charge" or "CEO 2 is in charge." Finally, the observer needs to define the points in time at which the behavior is recorded. Suppose that in the example, the point in time at which measurement takes place is December 31 at 24.00 h of each year, beginning in 1980.

Given the specification of the variables to measure the output of the Black Box, the parameters to measure its input, and the points in time measurement takes place, it is possible to record, "at each of a sequence of times the states of the Box's various parts, input and output" (Ashby 1958, p. 88).

### Step 3. Record the Behavior of the Black Box in Terms of Input and Output

Given the selection of the variables, parameters, and measurement points, the observer can "manipulate" the input and observe the output of the Black Box. These manipulations and observations are recorded in a protocol. In the protocol, the observer records the values of the input and the output at each of the selected points in time. Thus, the Black Box, "is investigated by the collection of a long protocol, drawn out in time, showing the sequence of input and output states" (Ashby 1958, p. 88).

To illustrate how recording behavior works, we code, in our example, the parameter values "CEO 1 is in charge" as 1 and "CEO 2 is in charge" as 2. The output states, company X's results, are coded in millions of dollars as follows:

A: outcome $< -5$
B: $-5 \leq$ outcome $< 0$
C: $0 \leq$ outcome $< 5$
D: outcome $\geq 5$

On the basis of observation, the following protocol is recorded (see Table 2.14).

**Table 2.14** Protocol of observed behavior

| | ‘80 | ‘81 | ‘82 | ‘83 | ‘84 | ‘85 | ‘86 | ‘87 | ‘88 | ‘89 | ‘90 | ‘91 | ‘92 | ‘93 | ‘94 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| CEO | 2 | 1 | 1 | 2 | 2 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 2 | 2 | 2 |
| Output | B | C | D | B | A | C | C | B | C | B | D | D | B | B | A |
| | ‘95 | ‘96 | ‘97 | ‘98 | ‘99 | ‘00 | ‘01 | ‘02 | ‘03 | ‘04 | ‘05 | ‘06 | ‘07 | ‘08 | ‘09 |
| CEO | 1 | 1 | 1 | 2 | 2 | 1 | 1 | 2 | 1 | 2 | 1 | 1 | 2 | 2 | 2 |
| Output | C | D | D | B | A | C | D | B | C | B | D | D | B | A | A |

**Table 2.15** List of states following a particular state (see text)

| | | |
|---|---|---|
| 1,C | → | 1,D; 1,C; 2,B; 2,B; 1,D; 1,D; 2,B |
| 1,D | → | 2,B,1,D; 2,B; 1,D |
| | | 2,B; 2,B; 1,D; 2,B |
| 2,A | → | 1,C; 1,C; 1,C; 2,A |
| 2,B | → | 1,C; 2,A; 1,C; 1,D |
| | | 2,B; 2,A; 2A; 1,C; 1,D; 2,A |

**Table 2.16** Matrix of transitions describing behavior

| $R_p$↓ | A | B | C | D |
|---|---|---|---|---|
| P = CEO 1 | C, C, C | C, C, D, C, D | D, C, D, D | D, D, D |
| P = CEO 2 | A | A, B, A, A, A | B, B, B | B, B, B, B, B |

**Table 2.17** Matrix of transitions describing behavior (simplified)

| $R_p$↓ | A | B | C | D |
|---|---|---|---|---|
| P = CEO 1 | C | C or D | C or D | D |
| P = CEO 2 | A | A or B | B | B |

### Step 4: Construct a Conditional Transformation

To construct a conditional transformation, the observer needs to re-code the protocol resulting from step 3, and, if possible, simplify it. To do so, the observer collects, for each occurring combination of input and output state, all the combinations that immediately follow it. This results in Table 2.15.

Using Table 2.15, the observer can arrive at a transition-matrix presented in Table 2.16 and its simplified form given in Table 2.17.

According to Ashby, “all knowledge obtainable from a Black Box (of given input and output) is such as can be obtained by re-coding the protocol; all that, and nothing more” (Ashby 1958, p. 89). So, the protocol, and “nothing more,” is the point of departure for step 5.

### Step 5. Establish Regularities in the Behavior of the Black Box (and Iterate)

The conditional transformation, resulting from step 4 can now be used to establish the regularities in the behavior, described by the transformation. To do this, the observer compares the resulting transformation to the criteria for regular behavior.

**Table 2.18** Description of behavior from example (abstracted version)

| $R_p$ (abstracted)↓ | result > 0 | result ≤ 0 |
|---|---|---|
| P = CEO 1 | result > 0 | result > 0 |
| P = CEO 2 | result ≤ 0 | result ≤ 0 |

**Table 2.19** Description of behavior from example using probabilities

| $R_p$↓ | A | B | C | D |
|---|---|---|---|---|
| P = CEO 1 | C (p = 1) | C (p = 0,6) or D (p = 0,4) | C (p = 0,25) or D (p = 0,75) | D (p = 1) |
| P = CEO 2 | A (p = 1) | A (p = 0,8) B (p = 0,2) | B (p = 1) | B (p = 1) |

From Table 2.16, it appears that transformation $R_p$ is a closed and multi-valued transformation.

Depending on the kind of regularity found, the observer can take further action. If the transformation is closed and single-valued, the observer can stop: based on this transformation the behavior is perfectly predictable. If the transformation does not meet these criteria, the observer may now follow four different strategies.

*Strategy A*. Given the protocol, the observer may redefine its results by means of abstraction. For instance, using the protocol, the observer abstracts from the particular state of the result and only takes into account whether it is greater than zero or smaller than or equal to zero (Table 2.18).

The abstracted representation of transformation $R_p$ has the advantage that it meets the criterion of the determinate machine with input. The observer can predict that if CEO 1 is in charge, the result of company X will always become positive and if CEO 2 is in charge, it will always become negative. It has the disadvantage that specificity regarding the values of the output states is lost.

*Strategy B*. Given the protocol, the observer may also be content with statistical determinacy (i.e. a Markovian machine with input). In this case, the observer uses the protocol to determine the probabilities of the occurrence of a particular outcome (Table 2.19 shows these probabilities which are based on Table 2.16). Using Table 2.19, it is impossible to predict the output of the black box with certainty – but it can be predicted with a particular probability.

*Strategy C*. It may be that the observer is both unable to find determinacy after applying strategy A and discontent with the statistical determinacy resulting from applying strategy B. In this case, it is possible to go back to step 2 of the procedure. Given the main interest, the observer can add parameters to the selected ones, select new parameters, select new measurement intervals, and/or select new variables. Then the observer proceeds by drawing up a new protocol (step 3), deriving a new conditional transformation (step 4), and analyzing whether this meets the criteria for the determinate or the Markovian machine with input (step 5).

*Strategy D*. Finally, the observer may go back to step 1 of the procedure and select another "main interest." For instance, the observer shifts his main interest from the organization's performance to the satisfaction of the organization's employees. Now, the observer has to work his way down from step 1 to step 4.

Strategy C and D turn the procedure for finding regular behavior into a *cycle* that can be used to redirect the observer's search for regularity. This cycle allows observers to explore the world by looking for regularities that can be used for the purpose of the regulation of the behavior of black boxes.

In this section we have discussed how an observer can try to arrive at a description of the behavior of some "thing" or black box, capturing the regularities between input and output: the transformation. Before we continue with a discussion about how these transformations can be used to regulate complex systems in the next section, we want to comment on the use of them.

In our daily lives we encounter all kind of "things" we try to deal with. Yet, we seldom explicitly construct a conditional transformation according to Ashby's prescriptions, let alone that we explicitly check whether it passes the criteria for regularity. However, in dealing with the black boxes of our daily lives we always *implicitly* have or build some model of how they behave. Without such a model, interaction with them would simply be impossible. We use such models to predict and understand their behavior and think about ways to interact with them. However, we also know from experience that many black boxes behave unexpectedly – they behave in ways we cannot predict (in fact, we will argue that our models of most black boxes *cannot* be perfect – see Chap. 3). To deal with this we can change our model of a black box – and see if it allows for better prediction and interaction with it.

The use of Ashby's theory, then, is that it (1) describes the necessary elements of these models (variables, parameters, and their relation) – even though these models remain implicit and are in practice imperfect, (2) makes explicit which steps are needed to build and rebuild models of behavior, and (3) gives criteria for "optimal models." This knowledge may be used to diagnose problems in our interaction with systems and it may help us to anticipate problems and prevent them. In all, Ashby's theory provides normative guidelines for the description of behavior that can be used in dealing with problematic situations in our daily lives – for instance in regulating organizations.

To illustrate the importance of Ashby's notions about describing behavior for regulating organizations, imagine some organizational process that is to be managed. Managing a process implies knowledge about its desired result – often given in terms of output of the process (i.e., in terms of variables like "number of products," or "quality of products"). It also implies knowledge about what negatively affects the output (disturbances like unmotivated personnel; machines breaking down, etc.) and about how to prevent or deal with such disturbances (regulatory actions like installing a reward system; or intensifying machine maintenance). In fact, all these situations imply a model containing (1) variables describing the behavior of the process, (2) notions about desired behavior, and (3) parameters (disturbances and regulatory actions) affecting the behavior. In the course of managing organizational processes, then, every manager always constructs and uses (and reconstructs) models of their behavior – more or less explicitly. In other words, building and using models of behavior using variables and parameters is at the heart of management (Conant and Ashby 1970).

## 2.3 Cybernetics: Effective Methods for the Control of Complex Systems

Ashby's ideas about the *study* of complex systems are a first step to what is the central theme of cybernetics: the "control" of complex systems (Ashby 1958, p. 195). Given the main theme of cybernetics, the concept of "control" should be thoroughly explained. However, it appears that control can be seen in at least two different ways. The first is to define control as some kind of "dealing with" as we did above. In this case both setting targets and realizing them is part of control. This interpretation of control is more or less equal to most common-sense ideas about regulation.

Another way to define control is to equate it with "setting the targets" when dealing with complex systems. Ashby seems to do both. In introducing the topic of cybernetics (1958, pp. 1–4) his idea of control seems to refer to "dealing with" or "regulating" complex systems – while in Chap. 11 of his introduction he reserves control for setting targets. In this chapter he also introduces the term regulation – referring to *realizing* the targets set by control. He explains: Once a controller sets the target, the regulator has to take care of realizing it. A controller is in complete control if, whatever the target, the regulator is always able to realize it. So, the completeness of control depends on the effectiveness of the regulator. Regulation and control are, in this sense, intimately related: they are both necessary components of "dealing with complex systems."

To explain Ashby's ideas about methods for effective "control" (i.e., for "dealing with complex systems") we divide this section into three parts. In the first part we explain Ashby's views on regulation by defining it, presenting different types of regulation, and by discussing how the effectiveness of a regulator can be increased.

Given our discussion of regulation, we introduce and explain three instances of regulation – control, design, and operational regulation – in the second part of this section. These instances of regulation are Ashby's counterparts of "strategic regulation," "regulation by design" and "operational regulation," which we discussed in Chap. 1.

Finally, we discuss the notion of adaptive behavior – which can be seen as a form of "self-regulation."

### *2.3.1 Ashby's Views on Regulation: Definition, Types of Regulation and Requisite Variety*

#### 2.3.1.1 Regulation: Ashby's Definition

A good starting point for discussing regulation is Ashby's description of a (good) regulator: "an essential feature of the good regulator is that *it blocks the flow of variety from disturbances to essential variables*" (Ashby 1958, p. 201).

**Table 2.20** The regulation table

| | | R | |
|---|---|---|---|
| | | α | ß |
| D | A | a | b |
| | B | b | a |

Before explaining this description, it is important to notice that Ashby provides a functional description, i.e., he specifies what a good regulator *should do*. The advantage of a functional description is that it abstains from the specific manifestation of a regulator. It states the function of a regulator, regardless of its physical, chemical, psychical, or social appearance.

To explain Ashby's functional description of the regulator, examine Table 2.20. This table describes the behavior of a machine with input. The system, defined to describe the behavior, consists of one variable which can have two states: a and b. Moreover, two parameters can be discerned: D (with states A and B) and R (with states α and ß). The states of the system, given the values of both parameter D and R, are given in the cells of the table. So, the table indicates, for instance, that, whatever its previous value, if $D = A$ and $R = \alpha$ then the next state of the system is a.[4]

In the table, a and b are possible states of a so-called essential variable. Ashby defines an *essential variable* as a variable that has to be "kept within assigned ("physiological") limits" if an organism is to survive in its environment (Ashby 1958, p. 197). The symbol for the essential variable(s) is: E. Although Ashby's definition stems from biology, it can be extended to other domains, for instance, to the domain of organizations. A more general definition of an essential variable, which also suits the organizational situation, would be that it is a variable that has to be kept within assigned limits to achieve a particular goal (e.g., survival).

From this definition we can see that essential variables always involve an element of selection that is related to a purpose. From the indefinitely many features of some concrete entity, some are selected as "essential" given a particular purpose. In some cases, the selection of essential variables is not subject to choice. For most biological systems, essential variables are fixed. For instance, for human beings both the variables "body temperature" and "blood pressure" are fixed. That is, we

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[4] Using the previous transformation-notation, the notation for this system would be:

| $T_{D,R}$ | | $a$ | $b$ |
|---|---|---|---|
| $D = A$ | $R = \alpha$ | $a$ | $a$ |
| $D = B$ | $R = \alpha$ | $b$ | $b$ |
| $D = A$ | $R = \beta$ | $b$ | $b$ |
| $D = B$ | $R = \beta$ | $b$ | $a$ |

In the case of the particular system we use to explain regulation (i.e. the one appearing in Table 2.20, with two parameters, one essential variable, and system states being independent of earlier system states) the notation in the text is more convenient.

cannot choose to leave them out of the set of essential variables, for our survival depends on them. In other cases, the selected essential variables may be subject to deliberate choice. For instance, a firm specializing in information and communication technology may deliberately select the capacity to innovate as a variable essential for its survival.

In the table we also find a D, standing for disturbances. Ashby defines a disturbance as "that which displaces, that which moves a system from one state to another" (Ashby 1958, p. 77). In the example, this means, that D can move the value of the essential variable either from a to b or form b to a. D is, therefore, a parameter of the essential variable. In the table, its possible states are A and B.

The R in the table stands for regulator. The states (or moves) available to regulator R are α and ß. It is the task of the regulator to block the flow of variety from the disturbances to the essential variables by means of acts of *regulation*. R, too, is a parameter of the essential variable.

Now, in order to regulate the behavior of some "thing," a transformation similar to the one described in Table 2.20 has to be available. That is, needed for regulation is a transformation describing the behavior of a system of essential variables associated with the "thing," given the states of D and R.

Ashby uses the term *variety* to refer to the number of different states a variable can have. The symbol for variety is V. For instance, referring to the table, the variety of the essential variable is 2 (the essential variable has two different states, a and b). This can also be written as $V(E) = 2$. Similarly, in the table the varieties of the disturbances V(D) and of the regulator V(R) are 2.

Given these definitions we can explain what it means that a good regulator blocks the flow of variety from disturbances to essential variables. To this purpose, the table should be read as follows. If the disturbances take on a specific state, say A, the regulator selects a move, say α. The combination of A and α has as an outcome of regulation a state of the essential variable, *in casu* a. There are in total 4 combinations of D-R values that all have as an outcome a specific value of the essential variable. In general, a separate variable "outcome" (O) can be introduced to refer to the values of the essential variables that come about after the regulator has selected a move, given some value of D. The set of different states it can have is a subset of the set of possible states of the essential variables and, hence, it follows that $V(O) \leq V(E)$.

Now, let us see whether the regulator can keep the variety of the outcome (V(O)) as low as possible in the face of changing states of D.

First suppose that the regulator has only one move at its disposal, say α. Now, if D is in state A and R is in state α, the outcome of regulation will be that E is in state a. That is, $O = a$. And so, $V(O) = 1$ (we only have state a). If D changes to state B and R remains in state α, the result of regulation will be that E changes to state b. O will be b, and hence, the variety of the outcome increases from 1 to 2 (state a and state b).

In this case, the outcome is determined by the state of the disturbances. The variety of the essential variable after regulation – V(O) – is the same as the variety of the disturbances. The full variety of the disturbances "flows" to the essential variables. In other words: no variety is blocked. Thus, R, with only one move at its disposal, is not a good regulator. In fact, it is the worst possible regulator, for it blocks no variety flowing from the disturbances to the essential variables.

Now, let us suppose that the regulator has moves α *and* ß at its disposal. If D is in state A and R is in state α, the result of regulation will be that E is in state a. The variety of E after regulation – V(O) – is 1 (state a). If D changes to state B and if the regulator wants to keep the variety in the outcome as low as possible it should change the state of R into ß, producing outcome state a. The variety of E after regulation – V(O) –remains 1 (state a). By selecting its moves R can continuously produce outcome state a, whatever the state of D. In fact, whatever the state of D, R is always able to continuously produce either a or b as outcome. This means that the regulator can always keep the variety of the outcome at 1. Apparently, no variety is transmitted from the disturbances to the outcome, or, put differently, the value of the essential variable does not change due to a change in D. R is a good (even a perfect) regulator. R fully blocks the flow of variety from the disturbances to the essential variable.

Thus, we have found a general way to speak about regulators and their effectiveness. Regulators block variety flowing from disturbances to essential variables. The more variety they block, the more effective the regulator. The most effective regulator is the one that blocks all the variety flowing from disturbances to essential variables. In this case, the regulator can fully determine the state of the essential variable.

Given this description of a regulator, we can now also define regulation as the activity performed by the regulator. That is, regulation is "blocking the flow of variety from disturbances to essential variables." If the more general description of essential variables is used (i.e., those variables that must be kept within limits to achieve some goal) then the *purpose* of regulation is that it enables the realization of this goal. If the goal is the survival of some concrete system, then the purpose of regulation is trying to keep the values of its essential variables within the limits needed for survival, in spite of the values of disturbances.

Using the definitions and the table as a point of departure, we can now discuss different types of regulation. Moreover, we can discuss the law of Requisite Variety as the principle underpinning effective regulation.

#### 2.3.1.2 Types of Regulation

Above, we defined regulation as "blocking the flow of variety from disturbances to essential variables." According to Ashby, different types of regulation exist. Ashby distinguishes two of them: passive and active regulation. If we take Table 2.20 as a point of departure and call that which selects regulatory actions in the face of disturbances a regulator, we can explain the difference between passive and active regulation.

In the case of passive regulation there exists a passive block between the disturbances and the essential variables (Ashby 1958, p. 201). This passive block, for instance the shell of a turtle, separates the essential variables from a variety of disturbances. It is characteristic of passive regulation that it does not involve selection. A passive block is part of the regulation table and "does its job" – the regulator does not select a regulatory move dependent on the occurrence of a possibly disturbing event, for the block is given independent of disturbances. Because no selection is involved, the passive "regulator" does not need information about changes in the state of the essential variable or about disturbances causing such changes to perform its regulatory activity.

In the case of active regulation, the regulator needs to select a regulatory move. Dependent on either the occurrence of a change of the state of the essential variable or of a disturbance, the regulator selects the regulatory move to block the flow of variety to the essential variables. Because it has to select a regulatory move, the active regulator either needs information about changes in the state of the essential variable or about the disturbances causing such changes in order to perform its regulatory function. Ashby uses these two sources of information that trigger the selection of regulatory moves to make an additional distinction within the class of active regulation. (Ashby 1958, p. 219; Conant and Ashby 1970, p. 92): error-controlled and cause-controlled regulation

To explain the difference between error and cause-controlled regulation, we refer back to Table 2.20 (repeated in Table 2.21).

This table was to be interpreted as "Given some value of D and R, the essential variable will have some specific value." Ashby calls the mechanism producing the value of the essential variable (given the values of the parameters D and R): T (which stands for Table). Ashby now acknowledges two different ways in which the outcome is determined: error-controlled and cause-controlled regulation. Error-controlled regulation is characterized by the following sequence of events:

At $t = 1$ R has some value
At $t = 2$ D takes on a new value
At $t = 3$ the value of D (at $t = 2$) and the value of R (at $t = 1$) are input for T
At $t = 4$ T determines the value of the essential variables (O) given the values of D and R. This is an undesired value – E is outside its specified norm-values
At $t = 5$ Based on the fact that the changed value is undesired, R selects a new regulatory move. That is, R takes on a new value
At $t = 6$ Based on the new value of R and the value of D, T determines a new value of E, that lies within the specified norm-values

In error-controlled regulation, regulatory moves are selected only *after* the value of an essential variable is changed. As Ashby puts it: this type of regulation "reacts

**Table 2.21** The regulation table

| | | R | |
|---|---|---|---|
| | | α | ß |
| D | A | a | b |
| | B | b | a |

to disaster" (1958, p. 221). The selection of a regulatory move is triggered by a change in the value of the essential variable. Its main goal is to repair the damage.[5]

The sequence of events characterizing cause-controlled regulation is:

At t = 1 R has some value
At t = 2 D takes on a new value
At t = 3 the regulator recognizes the possible threat of D if R's state remains unchanged. R changes its state to one in which the new value of D cannot affect the essential variables
At t = 4 the value of D (at t = 2) and the value of R (at t = 3) are input for T
At t = 5 T determines the value of the essential variables (O) given the values of D and R. This is a desired value; E stays within its norm

In this sequence, R selects a regulatory move *before* the new value of D can change the value of the essential variable. Ashby: "R reacts to threat" (1958, p. 221). In the case of cause-controlled regulation, the selection of a regulatory move is triggered by information about disturbances threatening to displace the state of the essential variable. Before the state of the essential variable actually changes, the regulator selects a move that keeps the state of the essential variable constant. The main goal of cause-controlled regulation is to prevent disaster, given the occurrence of some potentially harmful event.

We now have two basic types of regulation: passive and active regulation. Furthermore, active regulation has been split up into error-controlled and cause-controlled regulation. These distinctions are used to draw regulation-Table 2.22. The table shows the three possible ways of dealing with disturbances discussed thus far: (1) by means of passive blocks, installed with the purpose of blocking one

**Table 2.22** Passive and active regulation

| Regulatory potential | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | | Passive regulation | | | Active regulation | | | | | |
| | | Passive Block 1 | … | Passive Block j | Error-controlled | | | Cause controlled | | |
| | | | | | $EC_1$ | … | $EC_k$ | $CC_1$ | … | $CC_m$ |
| | $D_1$ | ▨ | | | | | | | | |
| | $D_2$ | ▨ | | | | | | | | |
| | .. | | ▨ | | | | | | | |
| D | $D_i$ | | | ▨ | | | | | | |
| | $D_{i+1}$ | | | | X | | | | | |
| | … | | | | | | | … | | |
| | $D_n$ | | | | | | | | X | |

---

[5] It should be noted that if the essential variable is moved beyond its limits, the concrete system to which the essential variables refer should (by definition of the essential variables) cease to exits. If not, the variables are not essential. To deal with this, Ashby suggests that "the states of the essential variables lie on a scale of undesirability" (p. 224) – creating a non-lethal buffer-zone in which regulatory action is required.

or more disturbances (independent of the specific occurrence of some possibly disturbing event) more or less permanently (shaded areas), and (2) by means of several error- and cause-controlled regulatory actions, made available to deal with "residual" disturbances (i.e., the disturbances not blocked by the passive blocks: $D_{i+1}$ to $D_n$). These regulatory actions have to be selected in the face of actual damage or threat.

To illustrate these different modes of regulation, imagine a medieval knight on a battlefield. One of the essential variables might be "pain," with the norm value "none." In combat, the knight will encounter many opponents with different weapons all potentially threatening this essential variable. To deal with these disturbances, he might wear suitable armor: a passive block. If a sword hits him nevertheless (e.g., somewhere, not covered by the armor), he might withdraw from the fight, treat his wounds and try to recover: an error-controlled regulatory activity, directed at dealing with the pain. A cause-controlled regulatory activity might be to actively parry the attacks of an opponent, with the effect that these attacks cannot harm him.

It is important to note that, here, we only discuss passive and active regulation, as far as they appear in a table that has already been constructed and remains unaltered. *Given* the table, a regulatory activity is performed, and this activity is either selected by a regulator (active regulation) or not (passive regulation). It is, of course, also possible to deal with disturbances by *adding* regulatory potential, i.e., by adding passive blocks, error or cause-controlled regulatory actions to the table – thus altering it. For instance, if the knight picks up a shield, he adds a passive block to "the table." For now, the distinction between passive and active regulation as given suffices – we will discuss adding regulatory potential later in the text.

Cause-controlled and error-controlled regulation differ in three important respects: complexity, effectiveness, and logical dependence.

Firstly, relative to cause-controlled regulation, error-controlled regulation is simple. Unlike cause-controlled regulation, error-controlled regulation only needs the change of the state of the essential variables as a trigger for action. Cause-controlled regulation needs conjectures about more or less stable relations between the occurrence of particular disturbances and changes in the state of the essential variable. Given these conjectures and given a particular disturbance, the cause-controlled regulator can select a specific regulatory move.

Secondly, relative to error-controlled regulation, cause-controlled regulation can be perfect. In order to function, the error-controlled regulator is dependent on the actual occurrence of an error, a displacement from the state of the essential variable to another state. Unlike error-controlled regulation, cause-controlled regulation does not need a change of the state of the essential variable to function as an active block. It depends on a change of the state of the disturbances and is independent of the actual occurrence of an error.

Thirdly, cause-controlled regulation is logically dependent on the occurrence of disturbances and errors. In order to establish conjectures with respect to relations between the occurrence of disturbances and changes in the state of the essential variables, these relations somehow have to be observed. This means that error-controlled regulation can be used in the process of the design of cause-controlled regulation.

To sum up, Ashby distinguishes passive and active regulation. The need for selection of a regulatory move and the need for information to select this move are discriminatory for this distinction. Passive regulation does not require selection. No information is needed. Active regulation involves selection. It can be distinguished into cause and error-controlled regulation dependent on the source of information triggering the selection of the regulatory moves. This source of the information is either a change of the state of D (cause-controlled regulation) or a change of the state of E (error-controlled regulation).

#### 2.3.1.3 Effective Regulation: The Law of Requisite Variety

Ashby’s famous Law of Requisite Variety defines the effectiveness of regulators in terms of the relation between the varieties of the disturbances D, the regulator R and the essential variables E. In his discussions of the Law of Requisite Variety, Ashby focuses on active regulation. Because he is only interested in the relation between the varieties of D, R, and E, it does not matter whether these (active) regulators are cause or error-controlled. To get started, we refer back to the regulator of regulation table from the previous section (see Table 2.21).

We already stated that this regulator can completely block the flow of variety from the disturbances to the essential variables. R is a perfect regulator by Ashby’s standards.

Of course, regulation is more complex than can be described by means of a simple dichotomy between “no regulation” and “perfect regulation.” In the majority of cases, a regulator blocks only a *part* of the flow of variety from the disturbances to the essential variable. In these cases, the regulator is “more or less good.” Given this situation, Ashby asks whether any “general statement can be made about R’s modes of play and prospects of success” (Ashby 1958, p. 204).

To understand Ashby’s answer to this question, it is helpful to examine Table 2.23.

**Table 2.23** Regulation table

| | | R’ | |
|---|---|---|---|
| | | α | ß |
| D | A | a | b |
| | B | b | c |
| | C | c | a |

In this table, we see an essential variable which, before regulation, can take on three values: a, b, and c. V(E) before regulation is 3. Moreover, we see a disturbance that has three possible states: A, B, and C. V(D) is 3. Finally, the regulator has two regulatory moves at its disposal, α and ß. V(R) is 2. In Table 2.23, it is easy to see that the minimal variety of E after regulation (V(O), as we labeled this variety) that can be achieved by R’ is 2. This means that R’ is a less than perfect regulator.

Given this performance of R’, the question becomes how R’ can be changed to improve its prospects of success. To answer this question, look at Table 2.24.

**Table 2.24** Regulation table with improved regulatory potential

| | | R’ improved | | |
|---|---|---|---|---|
| | | α | ß | γ |
| D | A | a | b | c |
| | B | b | c | a |
| | C | c | a | b |

In this table, regulatory move γ has been added to the repertoire of R’. By this increase in the variety of the regulatory moves, R’ is now able to force down the variety of the essential variable after regulation to 1, which is below the minimum that could be achieved by the old R’. By increasing the variety of the regulator, the variety of the essential variable after regulation (V(O)) is reduced from 2 to 1.

The example of R’ is an instance of the Law of Requisite Variety. Ashby formulates this Law as follows.

> “Thus the variety in the outcomes, if minimal, can be decreased further only by a corresponding increase in that of R. [. . .] This is the law of Requisite Variety. To put it more picturesquely: only variety in R can force down the variety due to D; only variety can destroy variety” (Ashby 1958, p. 207).

A more precise formulation of the Law of Requisite Variety is:
IF,

V(D) is given and fixed, and

V(E) before regulation is given and fixed, and

V(E) after regulation (V(O)) is minimal, but greater than one

THEN,

V(E) after regulation (= V(O), the “variety in the outcomes”) can only be decreased by increasing V(R).

In essence, this law means that in the given circumstances, only amplifying regulatory potential will help in dealing with disturbances. It specifies, in a general way, how to increase the effectiveness of regulators.

## *2.3.2 Control, Design and Operational Regulation*

Above, we defined regulation as “blocking the flow of variety from disturbances to essential variables.” Referring to essential variables as those variables that must be kept within limits to achieve some goal, the *purpose* of regulation is to realize this goal (survival can be seen as one of these goals). An even more general formulation is that the purpose of regulation is to ensure that some concrete system shows “desired behavior.”

At the heart of the discussion about regulation was the regulation table. Regulation means using the regulation table in a specific situation. That is, given essential variables and their desired states; given possible occurrences of disturbances, and given the availability of several regulatory actions, a passive block deals with disturbances and/or a regulator selects an error or cause-controlled regulatory action with the purpose of ensuring that the essential variables stay at or reach their desired states. For regulation, then, the regulation table is required.

However, implicit in the discussion thus far, is the question how this table is "constructed." With regard to Ashby's theory, two additional activities can be introduced to deal with this question: *control* and *design*. In this section we discuss these activities and use them to arrive at a method for dealing with complex systems.

#### 2.3.2.1 Control

The first activity is "control." If the purpose of regulation is to ensure that some concrete system reaches some target, then this target should be set. For instance, referring to Table 2.24, it may be that, to stay alive, states a and c are unwanted. If some organism remains in a or c too long, it eventually dies. To stay alive this organism has to maintain the value of the essential variable at b. This is the target set for survival. Ashby calls that which sets the target, the controller. Setting the target (control) entails selecting the essential variables and the desired values of the essential variables.

The controller is in *complete* control if it can select and realize whatever states of the essential variable as its target. To realize the selected targets, the controller needs the regulator. Dependent on the selection of the target by the controller, the regulator performs its task. It "obeys" the controller and attempts to keep the state of the essential variables within the margins of the target specified by the controller by selecting the "right" regulatory moves.

Now, if the controller wants to be in complete control over the outcomes of the essential variables, i.e., if it wants to be able to select and realize whatever of these states as its target, it needs a regulator that is able to produce the selected state irrespective the state of the disturbances. To this purpose, the regulator must be "perfectly" effective. To quote Ashby,

> "[. . .] the fact that R is a perfect regulator gives C complete control over the output in spite of the entrance of disturbing effects by way of D. Thus perfect **regulation** *of the outcome by R makes possible a complete* **control** *over the outcome by C*." (1958, p. 214).

Therefore, regulation and control are not only intimately related in the sense that the regulator "obeys" the controller. They are also related in the sense that the completeness of control over the outcome by the controller depends on the effectiveness of the regulator. The controller's potential to continually produce whatever state(s) of the essential variables as the target, depends on the regulator's potential for regulation. Perfect regulators allow for complete control, imperfect regulators admit only of incomplete control.

At this point it is useful to distinguish between two types of effectiveness of a regulator. A regulator can be said to be "generally effective" if it can realize whatever target the controller sets. A generally effective regulator is a perfect regulator. One can also evaluate the potential of the regulator to realize one or some of the goals a controller can set. The potential of a regulator to realize a specific goal can be labeled as its "specific effectiveness." Of course, general effectiveness entails specific effectiveness. In many (practical) situations, however, one can be content with the regulator's specific effectiveness.

What we have now, is a controller setting the target and a regulator attempting to produce the corresponding states of the essential variables. Dependent on the effectiveness of the regulator, control is more or less complete. If the completeness of control is at stake, it seems crucial to have a regulator that is as perfect as possible. If we are only interested in a specific target (or a set of targets) it seems crucial to have a regulator that is able to realize this (or these) targets. Therefore, the question becomes, How can we achieve this, how can we make a regulator as (generally or specifically) effective as possible? The answer to this question amounts to providing the regulator with the means to deal adequately with relevant disturbances, i.e., to providing the regulator with an effective "regulation table."

To this purpose we have to introduce another activity in addition to that of the controller and that of the regulator. We call this activity *design*. The purpose of design is to select out of the set of possible "mechanisms," a "mechanism" that maximizes the regulator's potential for blocking the flow of variety from the disturbances to the essential variables. That which performs the design activity is called the *designer*.

#### 2.3.2.2 Design

To explain what design entails, we need to underline that the relation between D, R, and E depends on all kinds of physical, chemical, organic, or social processes in the real world. Dependent on these processes (we call them the "mechanism") a particular relation between D, R, and E emerges that can be expressed by a table. When designing for effective regulation, the designer strives for setting the optimal relation between D, R, and E (and between V(D), V(R), and V(E)) as a goal, and selects out of all the possible "mechanisms," the "mechanism" with the highest prospect of success in realizing this goal. A mechanism can be described by a regulation table expressing the relation between possible disturbances, values of essential variables and regulatory activities. And, because we wish to abstract from the actual processes realizing this mechanism, we will, below, refer to the table as the "object" of design. In this way, it can be said that the designer "constructs" or "reconstructs" the regulatory table.

In "An Introduction to Cybernetics," Ashby focuses on explaining in cybernetic terms the *process* of the design of a regulator. In our text, we do not want to go into Ashby's technical discussion of this process. We just want to concentrate on the question how we can enhance the regulator's prospects of success by means of design.

To answer this question, it should be kept in mind that a *regulator* deals with a given set of disturbances in specific actual situations (by means of passive or active regulation) and that the task of a *designer* is to provide a "mechanism"/table by means of which actual regulation *vis-à-vis* a set of disturbances becomes possible. In other words, given some goal (a set of essential variables and their norm values), the designer thinks of disturbances possibly affecting these goals (in general) and constructs a table, enabling a regulator to make sure that these goals are met when confronted with specific disturbances. To construct an effective table, the designer can do two things:

1. Decrease the variety of disturbances (attenuation) and
2. Increase the regulatory potential of a regulator (amplification).

By constructing a table with a decreased variety of disturbances (attenuation), a designer makes the regulator's task less difficult. By amplifying regulatory potential – adding passive blocks, error-controlled or cause-controlled regulatory actions – a designer also increases the prospect of success of a regulator: for the table now includes more ways to deal with disturbances (amplification directly follows from the law of requisite variety: only an increase in R makes it possible to decrease the variety in O).

We now have two related criteria for selecting a "mechanism" to increase the regulator's prospect of success. The selected "mechanism" in the *first* place should decrease as much as possible the variety of the disturbances the regulator must face (attenuation) and in the *second* place it should increase as much as needed the regulatory variety of the regulator (amplification).

At this point it is important to note that design refers to *every* new selection of a mechanism. Phrased in terms of tables: it refers to constructing the table (for the first time) and to all reconstructions of it (i.e., by means of adding new passive blocks or active regulatory activities or by means of removing disturbances).

If we want to design "mechanisms" for effective and efficient regulation, it is relevant to emphasize the logical priority between these criteria. First, we should construct the "mechanism" in such a way that the variety of the disturbances is decreased as much as possible. Otherwise, the regulator would face a larger than necessary variety of disturbances, which is inefficient. Second, we should construct the "mechanism" in such a way that the variety of the regulator is increased as much as needed to block the variety flowing from D to E.

The resulting "mechanism" (expressed by the regulation table) is "generally effective" if it allows for perfect regulation and complete control; it is specifically effective if it allows for realizing a specific target given all the relevant disturbances. Moreover, it is efficient if it adds no regulatory moves beyond the point of either perfect regulation or specific effective regulation. In this way, we are able to design "mechanisms" realizing the functional requirement of effective and efficient regulation and providing (complete) control over the outcomes of the essential variables.

To summarize: based on an overview and understanding of disturbances that may threaten the essential variables (set by control), the designer (1) removes disturbances, as much as possible, and (2) selects passive blocks and error and cause-controlled regulatory activities to deal with them. The designer constructs the regulatory table, to be "used" by a regulator.

Given this explanation of design, we can understand that activities, performed with the purpose of constructing or reconstructing the mechanism (table) are activities of a designer. However, it can also be the case that some cause-controlled regulatory action has as an effect that some disturbance is removed or, even, that regulatory potential is increased. Or, to put it more generally, it can be that an activity has a cause-controlled "aspect" as well as a design "aspect." For instance, the knight from a previous example may kill his opponent in his cause-controlled efforts to prevent damage. The effect is that this opponent is removed from the table as a disturbance. In this case, an activity can be said to have a cause-controlled aspect (it is meant to prevent damage possibly coming from a specific disturbance to the essential variables) and a design aspect (it changes the table, for a specific disturbance is removed from it).

Therefore, it is important to note that the same activity can have a cause-controlled as well as a design "aspect." The cause-controlled aspect entails dealing with an actual threat by preventing it to do real damage. The design aspect entails that the activity changes the table. Given a particular table, it is easy to determine these aspects. In order to have a cause-controlled aspect, the activity should be contained in the table, and it should be selected in the face of a particular, actual threat. Cause-controlled regulation always acts with respect to an actual *specific* event, possibly disturbing the essential variables: it *reacts* to this event by preventing damage. The design aspect manifests itself whenever the table is changed – by removing a disturbance or by adding regulatory potential.

#### 2.3.2.3 A Method to Deal with Complex Systems

The design activity completes the listing of activities needed to formulate a method for the effective control of complex systems. This method consists of the three activities, control, design, and regulation.

The relation between these three activities is – in general – that without a target (essential variables and desired values) set by control, it is impossible to design a mechanism realizing these targets. In particular, it is impossible to (1) identify disturbances and reduce them and (2) device regulatory actions. Given a designed mechanism (expressed by the regulation table) a regulator selects and implements specific regulatory actions in specific circumstances to deal with specific disturbances. So, without the designed regulatory actions, a regulator cannot deal with disturbances. In other words: targets are needed for design, design is needed for regulation and actual regulatory actions are needed to deal with specific disturbances in specific circumstances to reach the targets set by control.

Using the specifics of and the relations between control, design, and regulation, we can now specify a method supporting the effective control of the behavior of complex systems. This method consists of the following three steps in order of priority.

Step 1: Control

Control sets the target, i.e., it specifies what the essential variables (E) are and which states of E are desired states. Control is a *sine qua non* for both design and regulation.

Step 2: Design

By means of design, the designer constructs a mechanism embodying a more or less effective and efficient relation between D, R and E that can be expressed in a regulation table. In constructing this mechanism, the designer should

1. First decrease the variety of disturbances as much as is possible (attenuation)
2. Second, increase the variety of the regulatory actions to the level needed to block the remaining variety of the disturbances (amplification – by installing passive blocks or providing active regulatory options).

Step 3: Regulation

In the case of passive regulation, disturbances are automatically blocked by the regulator. In the case of active regulation, the regulator *selects* the regulatory actions needed to block as much as possible the flow of variety from the disturbances to the essential variable(s) and *implements* them in order to keep the states of the essential variable within the limits specified by control. Given the design of the "mechanism," the regulator more or less effectively blocks the flow of variety from disturbances to essential variables.

Unfortunately, the term regulation has now become ambiguous – it can refer to "dealing with disturbances, given a regulation table" (this is the interpretation in step 3 of the method above), and it can refer to the more general notion of "influencing the behavior of something" – an interpretation of regulation we used earlier in Chap. 1 and in the introduction of this chapter. We resolve this ambiguity by sticking to the latter interpretation of regulation, and re-label the first as "operational regulation". So, step 3 should read "operational regulation."

The three-step method for regulating complex systems is at the heart of regulation in organizations. And, because organizational regulation and continuously conducting experiments are intimately related, the method also underpins the organizational experiment. In the sections below, we therefore want to explain how this method underlies regulation and "organizational experimentation."

However, to understand how it underlies regulation and experimentation, it may be useful to start with an illustration and elaboration of the method's three different steps. Below, we will first provide this illustration. In the sections that follow we discuss how the method underlies organizational regulation en experimentation.

#### 2.3.2.4 An Illustration of Ashby's Method: Problem-Solving as a Series of "Control," "Design" and "Operational Regulation" – Activities

To illustrate and elaborate Ashby's three-step method it may be useful to think of the method as a general model for solving problems. The association between Ashby's method and problem solving is quite natural. A problematic situation may be considered as a situation in which relevant variables do not meet their associated norm-values. Solving problems, then, is, essentially, ensuring that relevant variables regain their norm-values.

To be a bit more precise, the following steps offer a "cybernetic" (i.e., based on Ashby's method) model for dealing with problems. Given some (more or less articulated) problematic situation one should:

1. Define a system whose behavior is associated with the problematic situation
2. Define norms for the variables of the system
3. Redefine the problematic situation in terms of systemic variables being outside their norm-values
4. Determine disturbances – events having a negative impact on the systemic variables (That is: determine parameters, whose values have a negative influence on the variables)
5. Try to eliminate disturbances (attenuation) if possible
6. If the problematic situation is not resolved; define and install, for the remaining disturbances, regulatory potential passive blocks, error- and cause controlled regulation (amplification)
7. If the problem is not resolved by a passive block, perform error- or cause controlled regulatory activities
8. Evaluate the effect of the regulation on the variables of the system, and given the result either decide that the problem is solved or go back to previous steps.

This sequence of steps incorporates the three different steps from Ashby's method. Steps 1 and 2 cover the control activity; steps 4, 5, and 6 are design activities (they construct the regulation table by attenuation of disturbances and by amplification of regulation). Step 7 covers operational regulation: the designed table is used to select and implement active regulatory activities.

Let us see how this sequence works in practice. Suppose that someone owns a lawn and wants to keep it as smooth as possible. That is, the lawn should be without holes or bumps, and, so, every mole or dog is considered as a threat and may call for action. In this example, an *actual* problem occurs when the variables are outside their assigned limits (i.e., there are holes or bumps). A *virtual* problem exists when no holes or bumps are currently present, but may be expected (due to the possible entry of moles and dogs). To deal with a problem (actual or virtual) a system should be defined (step 1). The system in this case should contain variables by means of which "smoothness of the lawn" can be expressed. For instance, the variables "number of holes" and "number of bumps" can be selected. To represent smoothness, the norm for both variables can be set to "0" (step 2). A problematic situation can now be defined (step 3) as the situation in which the value of one of these variables exceeds 0. Possible disturbances (step 4) may be (in this case) moles or dogs. Forcing all dog-owners in the neighborhood to move to another city (and take their dogs with them) or killing dogs are (rather far-fetched) examples of attenuation, (step 5) for they remove the dogs as disturbances. One may also define and implement (step 6) passive blocks that automatically block the influence of disturbances on the essential variables – e.g., building a fence around the lawn is an example of a passive block automatically taking care of the dogs as disturbances. To actively deal with the (possible) effect of moles on the lawn, error- or cause-controlled activities can be defined (step 6). A cause-controlled action may be to place ultrasonic anti-mole equipment every time moles are noticed in neighboring lawns. An error-controlled action is to flatten the surface after a molehill was produced. Trying to kill the mole (already present in the garden) by placing a trap is also a cause-controlled activity – for it is meant to prevent (further) damage. Actually selecting and implementing one or more of these actions, given specific circumstances is step 7. For instance, it may be that molehills are spotted in the neighborhood. Given this information, it may be decided to implement the ultrasonic anti-mole equipment. Finally, the result of this action may be monitored and further action may be required (step 8). It may be, for instance, that the equipment does not work at all and that several molehills appear. In this case new actions are needed (step 7) or may even have to be designed (steps 6). The last step allows for iteration. Going back to previous steps can mean that other operational regulatory actions may be chosen (step 7) or defined (step 6). It can also mean that other disturbances; ways of attenuating them; different norms; or even different systems (sets of variables) may be selected. Of course, going back to earlier steps is also allowed in other steps of the sequence.[6]

The last step suggests that if a problem is solved (the desired values of the relevant variables are within their specified limits) – the sequence stops. This may not be true for all problems. Dealing with some problems may require a more continuous process of "problem-solving" in which (instead of being solved once and for all) periods of "stability" may be discerned. That is, periods of time in which the relevant variables have their desired values. These periods may, however, be disrupted, after which by means of the problem-solving activities a new period of stability is established.

As we said above, the sequence of steps, describing problem-solving incorporates control, design and operational regulation. And, so, given this "translation," we can refer to problem-solving as a (continuous) process involving control, design and operational regulation. In the course of dealing with problems, iterations between these three types of activities are possible. This is indicated in Fig. 2.2, in which a sequence of control, design and operational regulation activities regarding some problem is given.

On the vertical axis, the three types of activities are stated. A horizontal line in the graph at the level of some type of activity indicates that, for some period of time, only activities of that type are carried out. A vertical line indicates a shift to another type of activity. To deal with a problem one has to start (implicitly or explicitly) with a formulation of the problem (i.e., a definition of the problem in terms of essential variables being outside their desired values). This "control period" is indicated in the figure by the first horizontal line on the left-hand side (under 1).

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[6] Evaluation can be regarded as a continuous process, monitoring all the steps. It is also needed at as a separate last step.

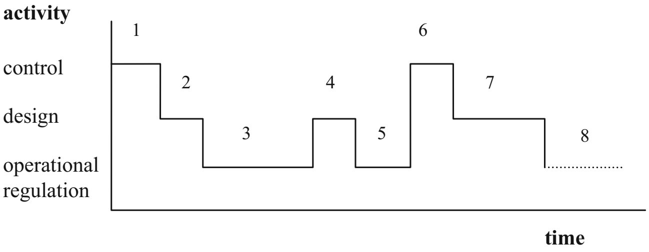

**Fig. 2.2** Control, design and regulation activities associated with problem-solving

After control, design takes over and by means of attenuation and/or amplification the regulation table is constructed (the horizontal line under 2). Next, during a "period of operational regulation" (the third horizontal line) one tries to deal with the problem – by means of implementing cause and error-controlled regulatory activities.

In dealing with most problems, these three activities will probably be performed in this sequence (although one may return to control after design to change variables and/or norms). In the rest of the process of dealing with a problem, the three types of activities may follow each other in many ways. One might say that each problem has its own specific history of control, design and operational regulation activities – in terms of how control, design and operational regulation will follow each other, and, of course, in terms of the specific control, design and operational regulation activities needed to deal with the problem.

#### 2.3.2.5 Ashby's Method Underlies Regulation in and of Organizations

To see how Ashby's method underlies "regulation in organizations," we may refer back to Chap. 1, where we introduced organizational regulation in terms of "making sure that organizational transformation processes are run correctly." To do so, goals have to be set for them; infrastructural conditions (from three classes: division of work; human resources and technology) have to be designed for them, so as to ensure that these processes realize their goals, and these processes have to be monitored in order to avoid and repair problems. It is not difficult to see that this interpretation of regulation in organizations is, in fact, a straightforward translation of Ashby's method: it describes dealing with organizational transformation processes in terms of control (setting goals), design (providing infrastructural conditions – from the three different classes) and operational regulation (monitoring of and intervening in organizational transformation processes). Figure 2.3 represents this translation.

In fact, many of the models available in management literature and practice are instantiations of this interpretation of Ashby's method. One well-known model (instantiating these ideas) is the management model of Anthony (1965), who acknowledges three levels of management: strategic; tactical and operational

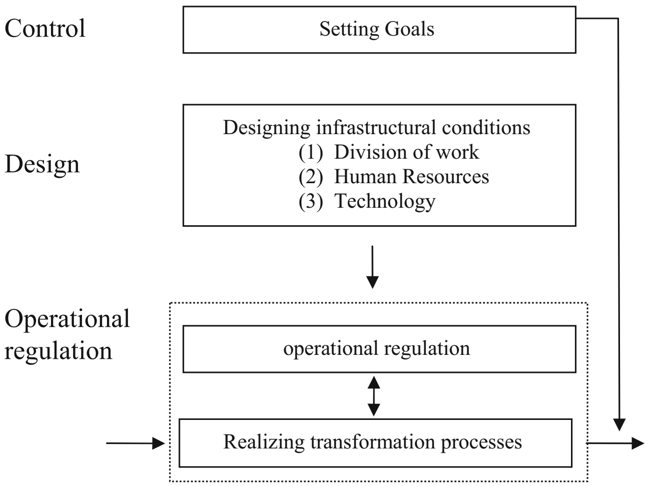

**Fig. 2.3** Regulation in organizations based on Ashby's theory

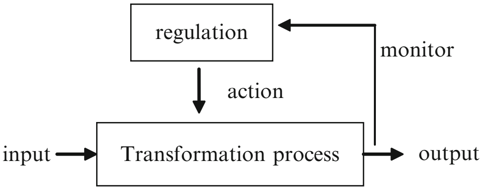

**Fig. 2.4** The "control cycle"

management – roughly corresponding with control, design and regulation. Another model, often used in management literature is the "control-cycle" (see Fig. 2.4). In this cycle goals are set for the output of the transformation process. Given these goals, the output is monitored (the current state of the output is compared to the desired state; the goal). If the gap between the two is problematic, actions are taken to intervene in the transformation process (or with regard to the input) in order to make sure that the output will, at some later moment, reach the goals set for it.

Many versions of this model exist in management literature. One might argue that it is not difficult to find examples of Ashby's ideas with regard to what we would call management. It is rather the other way round, it is difficult to imagine something we call management and *not* to find something in it that has been discussed by Ashby in a general and comprehensive way.

Therefore, instead of adding more examples, we would like to stress that underlying all these different models and interpretations of management in organizations is a perfectly general model which can be described in cybernetic terms. This general model describes regulation as the *function* in organizations performing control, design and operational regulation activities with regard to some transformation process.

In mapping Ashby's method onto organizational regulation, the translation of control and operational regulation seems relatively straightforward. However, the translation of design – particularly its result (a "mechanism") - needs some further elaboration: what is it that is designed in the context of organizational regulation?

In Ashby's method, design is said to "construct a mechanism that can be expressed by a regulation table." And, in our explanation of design, we abstracted from the possible physical and social embodiment of this mechanism. However, if we translate Ashby's design to dealing with organizational transformation processes, it becomes relevant to discuss this mechanism in more detail.

As we discussed in Chap. 1, designing "infrastructural conditions" for some transformation process should result in "an organizational structure (i.e., a network of tasks and responsibilities), relating human resources and technological means in such a way that (1) the transformation process can be realized and (2) the transformation process can be regulated operationally – i.e., monitored and intervened in."

To give an example, if a goal of a particular transformation process is to produce a wooden table, design should think of different tasks, relevant for producing a wooden table and relate them into a "network of tasks." Such tasks may be "sawing"; "drilling," "assembling," or "painting." These tasks may be defined and related in sequence and/or in parallel in such a way that, if performed, wooden tables are actually produced. Once tasks are defined, they should be assigned to human resources. For instance, each task may be performed by a different person. Moreover, these human resources should know how to perform their tasks and they should be motivated to do so. At the same time different tools and machines are needed to realize these tasks. In this simple example, a description is given of "a mechanism" needed to *realize* transformation processes: a network of tasks relating knowledgeable and motivated human resources and technological means.

To deal with disturbances influencing the realization of a transformation process, a similar mechanism is needed. That is, to regulate organizational transformation processes, regulatory tasks should be defined and related – e.g., "process-monitoring" or "maintenance and repair." And, similarly, such tasks should be assigned to knowledgeable and motivated personnel and they should be provided with the proper technological means (e.g., tools to maintain or repair the equipment needed for sawing, drilling, etc.).

In short, the "mechanism" that is designed in the context of realizing and (operationally) regulating organizational transformation processes consists of (1) a particular division of work (organizational structure) relating (2) competent and motivated human resources, and (3) technological means (including tools and machinery). This type of mechanism was referred to as an *organizational infrastructure* (with respect to realizing and operationally regulating a transformation process).

Just like Ashby prescribes in his method, designing an organizational infrastructure should start with attenuating disturbances as much as possible, and proceed by amplifying regulatory activities (i.e., installing passive blocks as well as error and cause controlled regulatory actions). Both attenuation and amplification can come about by (changing) a particular division of work; a particular way to manage human resources and a particular configuration of technological means.

## 2.3.3 Adaptive Behavior

In the previous sections, we discussed Ashby's regulatory method and translated it into a description of organizational regulation. In this discussion we introduced control, design, and operational regulation with respect to some operational transformation. Although this treatment already suggested a tight relation between the regulatory activities themselves, and between the regulatory activities and the operational transformation, we have not yet discussed them as functional parts of one concrete system – i.e., one concrete system embodying a transformation process and capable of performing all three regulatory activities *itself*.

However, if one is interested in the question how concrete systems manage of regulating their own behavior in order to survive (like organisms or many organizations), one *should* relate the regulatory and operational functions into a concrete system. Ashby's theory provides several concepts such as self-regulation, adaptation, and ultra-stability to deal with this issue. In fact, one could say that it is by means of these concepts that Ashby's cybernetics delivers its most relevant contribution: it shows how adaptive behavior depends on a particular relation of regulatory and operational functions. Or, phrased in more technical terms: it shows how a concrete ("ultra-stable") system is able to adapt (and survive) due to its "circular organization." In this section, we explain how these cybernetic notions can be used to describe organizations as concrete systems, capable of regulating their own behavior in order to adapt and survive. We treat this topic in two parts: (1) adaptation and self-regulation, and (2) organizations as adaptive self-regulatory systems.

### 2.3.3.1 Adaptation and Self-Regulation

To explain both adaptation and self-regulation, it is useful to consider a concrete entity consisting of an operational part (producing behavior related to its survival) and a regulatory part aimed at regulating the operational part.

Now, any concrete system, producing operational behavior and capable of regulating its own behavior by means of one or more regulatory activities (control, design, operational regulation) *by itself* is capable of self-regulation. Given this description of self-regulation, it is possible to distinguish several forms of self-regulation based on the kind of regulatory activity the system persforms itself. A concrete system might, for instance, be capable of performing only operational regulatory activities and "regulate" its behavior, given particular goals and some "mechanism" – e.g., a thermostat. At the other end of this self-regulatory dimension are concrete systems performing all three regulatory activities by themselves – such as organizations. One might call these latter concrete systems capable of "complete" self-regulation. Below, we will discuss adaptation based on "complete" self-regulation.

Complete self-regulatory concrete systems can deal with environmental changes that may threaten their essential variables (i.e., with disturbances) in two general ways: they can employ their *existing* regulatory potential or they can *change* their regulatory potential and use it to counter disturbances. Usually, dealing with disturbances by means of changing regulatory potential (and using it) is associated with the concept of adaptation.

In line with the regulatory method discussed in the previous section, the required changes for adaptation can come about in two ways: it is possible to adapt by means of control or by means of design. Adaptation by means of control entails changing goals (i.e., altering the set of essential variables and/or changing their associated norm-values). Adaptation by means of design implies altering the "mechanism" in such a way that it includes:

1. Improved ways to perform the operational transformation. The goal of these changes is to attenuate, i.e., to reduce the probability of errors due to the operational transformation.
2. Improved ways to regulate (either by means of control, design or operational regulation). These may include:
3. Improved ways to control (i.e., change the set of goals)
4. Improved ways to attenuate environmental disturbances. Equipped with these new means to attenuate, the probability of the occurrence of disturbances in the environment of the concrete system may be reduced;
5. Improved ways to amplify operational regulatory potential

Suppose that this concrete system is able to perform by itself control, design and operational regulatory activities *successfully* and *continuously*. Performing these activities *successfully* means that goals are realized (essential variables stay within their limits; or regain acceptable values). Performing them *continuously* implies that it is possible to keep on (1) realizing the goals that are set, and/or (2) adjusting these goals. Successfully and continuously performing all regulatory activities, then, implies the possibility to adapt. It entails being able to set and realize goals effectively, over and over again.

Ashby discusses adaptive behavior and self-regulation, using the concept of "ultra-stability." In essence, an ultra-stable system is a self-regulatory concrete system that, due to its "circular" organization displays adaptive behavior (cf. Ashby 1960). In this text, we will not treat Ashby's ultra-stable system, but, instead, present our own interpretation of it. Our version deviates in that it (1) has a "circular organization" based on the relation between control, design and operational regulation, and (2) is directly tied to (adaptation and self-regulation of) organizations. This is the topic of the next section.

#### 2.3.3.2 Organizations as Adaptive Self-Regulatory Systems

Successful, continuous self-regulation in organizations means that an organization is able to select and reselect relevant goals, "proper" transformation processes and infrastructural conditions to realize these goals. Moreover, it can perform adequate operational regulatory activities vis-à-vis the selected transformation processes. An organization's self-regulatory capacity enables it to adapt and survive.

In Chap. 1, we stated that regulation in organizations is faced with a fundamental uncertainty – it is impossible to be sure about the contribution of the regulatory selections to survival. At the same time, it is impossible to foresee all environmental changes and, hence, regulation in organizations entails, fundamentally, the possibility to *revise* selections. Or, put in the terminology of Chap. 1, it must be possible to perform the (regulatory) experiment continuously. In fact, one may describe regulation in organizations as a particular (ongoing) sequence of control, design and operational regulation activities – just as we described in the section tying Ashby's method to solving problems.

Based on Ashby's notions, experimenting in organizations can now be described as continuous self-regulation (in terms of control, design and operational regulation), aimed at organizational survival. Now, *actual* organizational control, design and operational regulatory activities are realized by a particular organizational infrastructure; i.e., by human resources operating in a network of tasks and responsibilities, using a particular set of technological tools. So, a requirement for continuous self-regulation is a particular set of infrastructural conditions – see also Chap. 1. In Fig. 2.5 the relation between a particular set of infrastructural conditions and self-regulation is given. This particular infrastructure should be part of the concrete organizational system – for without it C, D, and OR-activities are impossible. In fact: adaptive behavior crucially depends on this infrastructure.

On closer inspection, it appears that self-regulation based adaptation in organizations involves five feedback-loops – each tied to a particular type of regulation (see also figs 2.6 and 2.7).

Figure 2.6 depicts the three feedback-loops directly related to realizing operational transformation processes. The first feedback-loop involves operational regulation

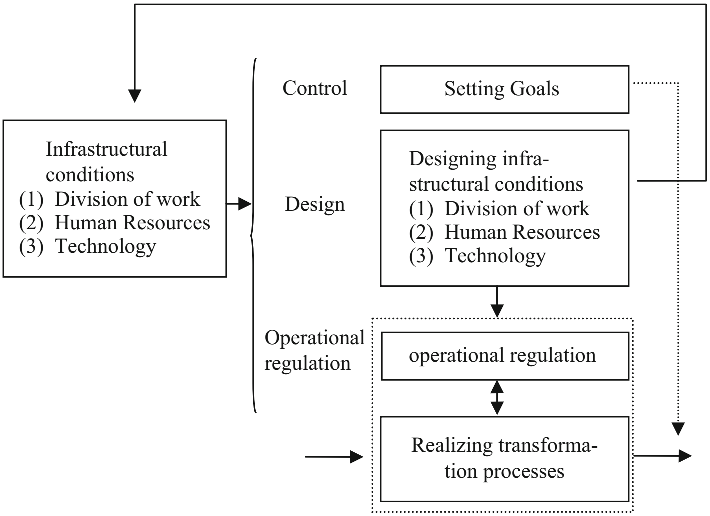

**Fig. 2.5** Self-regulation (in terms of a concrete organization performing C, D, and OR-activities) requires a particular set of infrastructural conditions

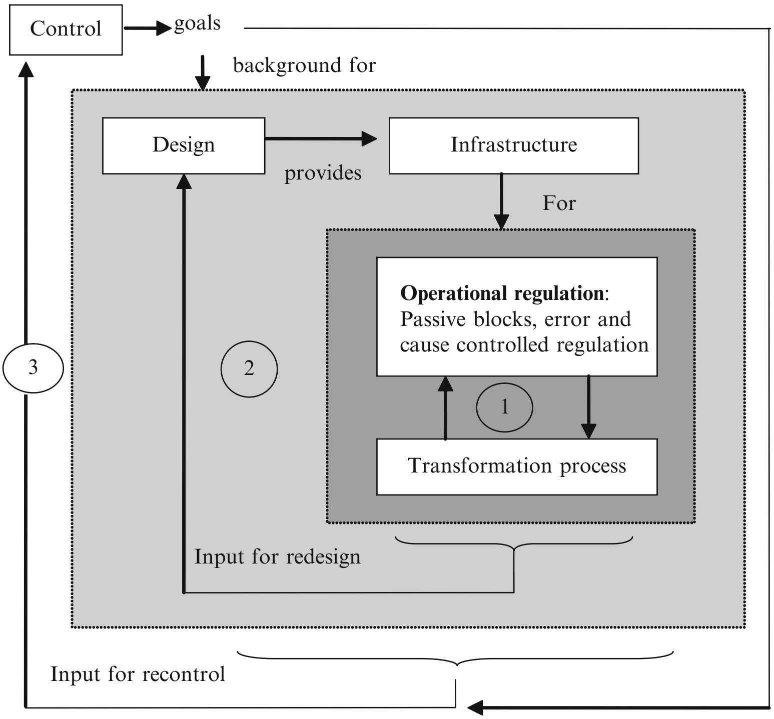

**Fig. 2.6** Feedback-loops in adaptive, self-regulatory organizations

vis-à-vis a transformation process. Given goals and infrastructure, this loop involves continuous reacting to disturbances by applying different kinds of operational regulation. In this loop disturbances are blocked by passive blocks; or dealt with in a more active fashion by means of error or cause controlled regulation.

The second feedback-loop may be called the "design-loop." Given the goals, set by control design provides an organizational infrastructure, by means of which disturbances are attenuated, and which is the basis for performing transformation processes and their operational regulation. Monitoring this infrastructure, that is, its potential for attenuation, performing processes and their regulation, may result in redesign. Redesign simply means changing the infrastructure so that its potential for attenuation, performing transformation processes, and their regulation improves. In the figure, an arrow is drawn from operational regulation to design – because some operational regulatory activities may have design-consequences (see earlier).

In the third feedback-loop (the control-loop) goals for the transformation process are set, serving as a background for designing an organizational infrastructure. Monitoring goals (their environmental appropriateness, as well as whether they can be realized by means of a particular infrastructure) can result in resetting goals ("re-" control).

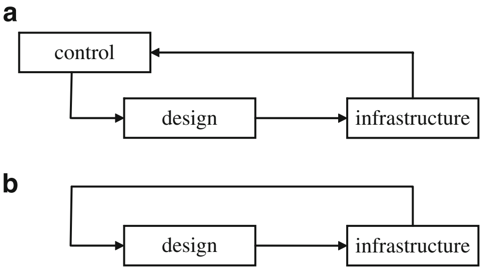

**Fig. 2.7** Feedback-loops in adaptive, self-regulatory organizations

With respect to these three loops, two remarks can be made. The first is that all three loops contain a more or less continuous 'monitoring aspect' (implicit in the explanation thus far). This means for the control and design loop that (regardless of actual disturbances) goals may be reset or the infrastructure may be redesigned. For the operational feedback loop this means that one is continuously monitoring events and evaluating their disturbing character, so that cause controlled regulatory actions may be taken.

A second remark concerns the 'nested' relation between the loops, representing a kind of default (but not fixed) loop-sequence with respect to dealing with actual disturbances. That is, if problems occur – they are usually first dealt with within the operational feedback loop. Only if these disturbances persist (and one lacks the prospect of successfully dealing with them within the operational loop), redesign may take place; and if this does not resolve the problem, resetting goals may be seen as a last resort.

In Fig. 2.7 two additional feedback-loops are given that are not directly tied to realizing the operational transformation processes, but to the appropriateness of the infrastructure with respect to supporting control and design activities. In the fourth feedback-loop (Fig. 2.7 a), the adequacy of the infrastructure in supporting control-activities is monitored which may result in a redesign of the infrastructure. In the fifth feedback-loop (Fig. 2.7 b) the adequacy of the infrastructure for performing design-activities is at stake: it monitors whether the division of work, human resources (and HR systems) or technology to design an infrastructure may be improved and redesigns it, if necessary.

## 2.4 Organizations as Systems Conducting Experiments

After an introduction to Ashby's ideas about effective methods for studying and controlling complex systems, we apply these notions to the main theme of this book: organizations as systems conducting experiments. In this section, we explain that, viewed from Ashby's cybernetic perspective, organizations necessarily conduct experiments. In this way, we use all that was said in the previous sections to describe organizations and explain how cybernetics can be used to study them.

To explain what this experiment entails, it is helpful to repeat the nature of the cybernetic view of regulating organizations we discussed in the previous sections. In short, it means that, in order to deal with problems in/of organizations, one has to:

1. Control: define the relevant variables and their desired values (set the goals)
2. Design: provide a mechanism, which can be expressed by a "regulation table." By means of this mechanism disturbances are attenuated and operational regulatory potential is amplified. In organizations, this mechanism harbors an infrastructure aimed at
   - Realizing transformation processes and
   - Regulating these transformation processes operationally
   - Design
   - Control
3. Regulate operationally: use the designed mechanism / regulation table, to "block the variety of disturbances to the relevant variables" – i.e., to select error or cause-controlled regulatory actions and implement them in order to deal with specific disturbances in specific circumstances.

Moreover, dealing with problems in organizations is a continuous process in which (1) goals are set and reset; (2) disturbances can be attenuated and regulatory activities can be added more than once; and (3) more than one regulatory activity can be selected and implemented. The goal of this continuous process is meaningful survival.

For organizations this process is fundamental. In organizations one continuously adopts goals, creates conditions and actions to realize them, and performs these actions so that the goals are actually met. Moreover, in the course of setting goals and realizing them it may turn out that (due to changing circumstances and/or insights) goals, conditions and actions may have to be adjusted. And, because the ultimate goal of this process is survival, it may be said that organizations continuously translate and realize survival by means of control, design and operational regulation activities – see Fig. 2.8.

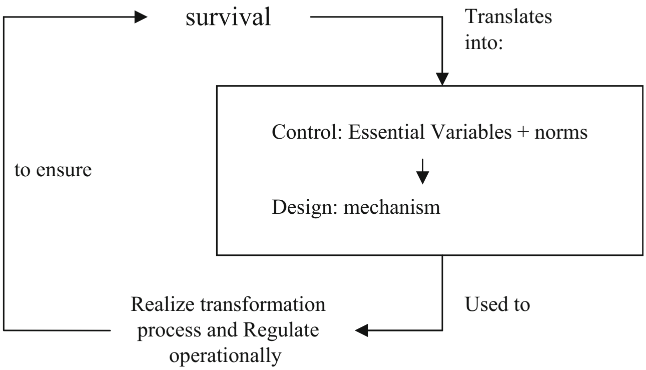

**Fig. 2.8** The continuous process of translating and ensuring survival by control, design and operational regulation

By referring to the control, design and regulation activities, organizations can be described as adaptive self-regulatory systems – systems that, by themselves, by means of these activities continuously aim at meaningful survival.

In the course of surviving, organizations face particular difficulties. First, the translation of the "overall idea of meaningful survival" into (a constellation of) specific variables and norms for a particular organization is not straightforward. And, second, the same holds for the design of an infrastructure and the success of its implementation. We will briefly discuss both related problems.

For living organisms many of the essential variables are fixed. A human being cannot "ignore," for instance, its body temperature or blood pressure as essential variables for survival. In a similar vein, the range of desired values is also more or less fixed for many of these variables. These variables and their desired values have stabilized in the process of the organism's evolution and can not be altered freely. For organizations, something similar can be said. For them it is essential that they can adapt and realize their goals. However, what these goals are, and how they are to be realized is not fixed and, therefore, subject to choice. For instance, a company producing information and communication technology may choose its innovative capacity as a variable essential for its survival. It does so, relative to its understanding of the specific current and projected environmental circumstances and its own competencies. For other organizations, this capacity may not be relevant at all – again based on an understanding of the specific circumstances. Given a selection of some essential variable(s), the desired values also are subject to choice. In the example of the capacity for innovation the variable first needs to be "specified" – e.g., in terms of number of relevant patents or the time-to-market of an innovation. Given the specification of variables at such a level that values can be attached to them, one has to choose desired values. This, again, depends on an understanding of the specific current and projected environmental circumstances of an organization and its own competencies. What is the desired "number of patents" and "what are relevant patents"? To determine the relevance of patents, one needs to develop an understanding of the effect of such patents for the meaningful survival of the organization (e.g., in terms of its future market position or profitability, or societal contribution).

A similar argument can be given for design and operational regulation, with respect to the contingency of the elements appearing in it. In fact, the main argument is that in the course of adapting to its environment (by means of control, design and operational regulation) organizations continuously face uncertainty. The relevant variables, parameters and their values entering this process can neither be known *a priori* nor *a posteriori* with certainty. They are contingent and there is no procedure for determining the "most" successful ones. To be more precise: this fundamental uncertainty manifests itself at three levels:

1. At the level of control, the essential variables and their desired values are not a priori known. A selection depends on an understanding of the current and projected environmental circumstances and the organizational competencies.

2. At the level of design, the parameters and their values are contingent
   a. That is, the current set of disturbances can not be known with certainty, for it depends on our knowledge of the environment – which can never be complete.
   b. The projected set of disturbances is contingent – many different futures can be projected, giving rise to many different possible disturbances.
   c. The set of attenuating and amplifying measures and their effect is also not a priori known.
3. At the level of operational regulation, the selection and implementation of a specific regulatory action is also not a priori fixed. It depends, among other things, on the regulator's understanding of the specific disturbance and the projected effect of a regulatory measure in the specific circumstances for a specific disturbance.

To sum up: if we follow Ashby's cybernetic perspective, we see that in their effort to survive, organizations face an inescapable contingency. They are forced to select from the sets of possible variables, desired values, parameters, their values, etc., while the outcomes of these selections (their contribution to the meaningful survival of the organization) is not a priori known. In this sense, one could say that organizations are continuously (forced to) conduct experiments. In this experiment, essential variables, their desired values, parameters etc., can be viewed as "hypotheses." That is, in the experiment organizations hypothesize that if the organization selects *these* variables with *these* desired values it can survive and if the organization selects *these* disturbances, *these* regulatory actions, *these* conditions for selecting and implementing them, and if regulators in the organization are able to select the "right" regulatory actions, given their understanding of disturbances, then, the organization will actually survive (as specified by the essential variables and their desired values).

Moreover, experimenting with the organization's meaningful survival is a continuous process. It is a process in which the organization can select new variables, desired values, other disturbances, other ways to attenuate and/or amplify them, select other conditions, etc. It is, in fact, a continuous process of "cybernetic problem-solving" as we described earlier in this chapter: a continuous process in which control, design and operational regulation activities are performed iteratively.

As we stated, this experiment is central in our cybernetic perspective on organizing in the rest of this book. In this chapter we treated the basic cybernetic elements for understanding the experiment. In the coming chapters we elaborate on the nature of this experiment (the rest of Part I of this book) and discuss the necessary conditions for conducting it (in Part II). The nature of the experiment is elaborated in the next chapter (in which the central issue is the process of *selecting* variables, desired values, parameters, etc. and the role of knowledge in this process). In Chap. 4 we relate the "experimental arche" of organizations to their "social arche." In Part II we discuss the conditions, necessary for conducting organizational experiments in terms of required *functions* (Chap. 6) and *structures* (Chap. 7).

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