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To Nil and Mert for their support and patience all the way through.

Foreword

What started as merely writing lecture notes became a journey through literature available on systems theories and a quest for developing a coherent set of principles and concepts on this matter. During my study at the Section Industrial Organisation and Management, Faculty of Mechanical Engineering, Delft University of Technology, I had already experienced the benefits of systems thinking in terms of analysing organisational problems and also understanding problems from a variety of disciplines. And it proved to be very helpful for solving the complex problems in industry. When I returned to Delft University of Technology as academic, I had to teach it to students at all levels, which created a new dimension, and, in addition, I started to use it for undertaking research, particularly for modelling of business processes and organisations.

However, at a certain moment, it looked like systems theories had arrived at a dead end, despite the concepts being very useful for both theory and practice. A turning point was the doctoral study. Also driven by curiosity, it encouraged me to look beyond systems thinking as it had been taught for a long while at Delft University of Technology. Particularly, new emerging theories in the science of complexity and complex adaptive systems had fuelled advances and applications in other domains than the traditional ones of engineering, biology and organisational studies – though this last topic seemed to concentrate more on information technology. That led to the inclusion of these theories in the current text.

In addition, students (and managers) seemed at times confused by some aspects of the theory behind systems thinking. This motivated me to take the development to a next stage with more precise elaborations of concepts and definitions as well as keeping it practical. At the same time, that meant looking beyond the obvious. The current writing is a reflection of that journey and making system theories accessible for a wide range of audiences, which includes now also doctoral students and fellow researchers.

That also means that many have already seen parts of this writing by discussions, readings, lectures and seminars, among them colleagues and students. In some cases, the need to explain also initiated improvements and further searches. Where concepts go beyond the generic knowledge, sources have been acknowledged in the text; where concepts are in the public domain or based on generic knowledge, sources have been omitted. For having the opportunity to explain and to expand, during teaching and research, I am grateful. The long time it took, I have shared with many my thoughts.

Scotland, July 2014.

Contents

Synopsis

Systems theories aim at describing objects to undertake studies. This synopsis introduces the most important concepts and models of Applied Systems Theory, a specific systems theory, to describe and to analyse objects with the intent of understanding, modifying or predicting their structure and their behaviour; more detailed and expanded descriptions are found in the chapters of this book.

I Systems, Entities as Part of a Whole

Machinery, houses, companies, computers, organisms and ecological networks as examples receive the label of systems when we want to isolate these objects of study from their environment. Whether it concerns organisational systems, such as companies and value chains, or technical systems, for example, ships and control systems, or ecological systems, we look at the object of study separated from its environment, perform an analysis and search for solutions to enhance its performance. This search is driven by unique problem definitions as a leading theme. Consequently, systems are essentially never the same; they depend on the problem and sometimes on the person performing the analysis. When we aim at improving the real-time response from an industrial robot or when the study focuses on designing the mechanical structure, each of these models of the robot as a system will differ according to its meaningful purpose denoted by the one who executes the study. Hence, the identification of a system is entirely dependent on the perspective (or problem definition) chosen.

Within a system, the elements do have mutual relationships between each other and with its environment (see Figure S.1). For instance, the quality system of a company might exist out of quality procedures, policies and guidelines, and at the same time it will link to the environment through relations with stakeholders, customers and suppliers. These structures describe the relationships elements do have within the system, which is called the internal structure, as well as with elements outside the system, which is named the external structure. For the case of the external structure, the external elements should be directly connected to elements within the system. For example, a manufacturing system might consist of pieces of equipment performing processes and it is coupled with the environment by the materials and parts delivered to it by suppliers and through the products it distributes to customers. Although a study attempts to isolate a system from its environment, the relationships with its environment, called the external structure, which defines its purpose within the whole or universe, remains visible nevertheless.

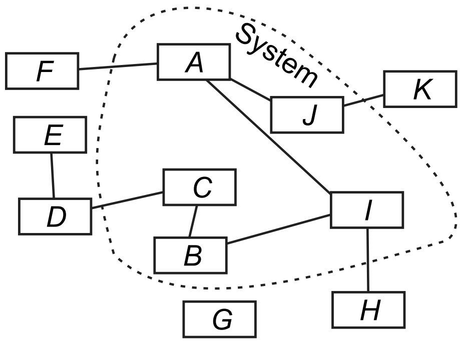

Figure S.1 *System with its elements and relationships. Each of the internal elements has at least one internal relationship to other elements within the boundary (A, B, C, I, J). The environment consists of those external elements that have direct relationships with internal elements (D, F, H, K). Some elements outside the system boundary have no or no direct relationship with internal elements (E and G) and should not be considered as part of the system's environment.*

Systems as Objects of Study

The aspects of the study will determine which relationships to explore and attribute values to the features of the aspect and the underlying parameters, see Figure S.2. An example is height; it is one of the parameters for dimensions as part of geometrical aspects, such as volume and position of objects of study. However, a specific aspect is always part of the larger set of system properties and relationships. Take for example a building; next to geometrical aspects, there are the aesthetic aspects (how the building looks) and the functional aspects (how it can be used). So, eventually we describe systems through specifying the particular relationships – aspects – they have with other elements, within the systems and their environments.

That distinction of aspects means also that when a search or an analysis extends to the properties of a system, there are two options for exploring it. Either an investigator concentrates on certain elements of the system (subsystem) or focuses on certain types of relationships within the system (aspectsystem), see Figure S.3. Look at the financial system of a company, being the filing of transactions and mutations, and the generating of

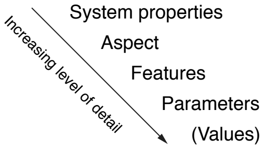

Figure S.2 *Interrelation between properties, aspects, features and parameters. The system properties may be broken down into aspects, which reflects the type of relationships investigated. When decomposing aspects, the investigator of a systems at features and parameters (to which values can be attributed).*

overviews about the current financial position. The overviews in the financial administration related to deliveries by suppliers represent a subsystem while the cash flow is an aspectsystem. Both a subsystem and an aspectsystem should fulfil the condition that they are a system in their own right. Note that concentrating on certain relationships by means of an aspectsystem also implies discarding elements that have no mutual relationships of the specific type with other elements. A case in point would be a study that originally included the elements related to quality as part of a company's system, but when focusing on logistic relationships in a later stage it left these elements out. The progress and results of the analysis and search determines which options for a closer look at a system, as a subsystem or an aspectsystem, will be taken.

Behaviour of Systems

Most studies of systems without doubt look at how properties of systems, elements and relationships change over time. Biologists wish to understand the emergence and the extinction of species, psychologists are seeking for the correct interventions in family units, managers want to improve performance of an organisational system and engineers want to know under which conditions a technological system will still perform its tasks. In the case of static systems merely describing and denoting the elements and their relationships will fulfil the needs of a study. Differently, when a study concerns a dynamic system, the state of elements and relationships vary over time and the interests of the investigation will turn to the causes of variation and perhaps to how to deal with those variations. For instance, vehicles are exposed to different road and weather conditions, companies face the challenges of competitive forces and the biodiversity of species on earth evolves over time. Studies for these

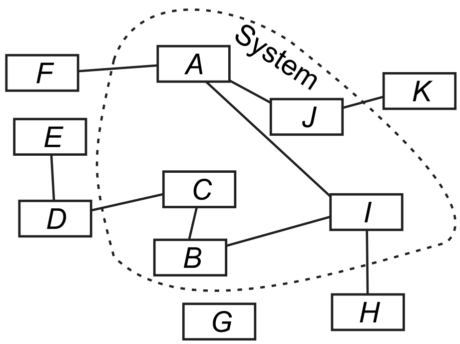

Figure S.3 *Two principles for investigating a system. Each of the internal elements has at least one internal relationship to other elements within the boundary (A, B, C, I, J). The environment consists of those external elements that have direct relationships with internal elements (D, F, H, K). Some elements outside the system boundary have no or no direct relationship with internal elements (E and G) and should not be considered as part of the system's environment.*

three examples might focus on the response of a vehicle to disturbance and maintaining direction of travel, the resilience of companies to changes in competitive forces and the sustainability of ecological systems.

The behaviour of a system as a whole, the changes in its relationships with the environment (the external structure), is triggered by events in the systems' boundaries. For the examples in the previous paragraph that might be: the road and weather conditions, the changing competition and the changes in the climate. Some of these changes lead to repetitive behaviour. Such is the case of the car; though the roads themselves might be very bumpy, the actual trajectory and position on the road are relatively predictable. In these cases, the behaviour is called static. Contrastingly, changes in the climate might cause extinction of species and adaptations by others. These systems will hardly ever return to a similar set of elements and relationships. This behaviour is called dynamic. Ultimately, the events that have an impact at the external structure of system often lead to changes in the (dynamic) behaviour of a system; these changes in external structure do not happen in the case of static behaviour.

When a study aims at improving the behaviour of a system, this is often the purpose of examining systems, there are two distinct directions for interventions. Either we optimise the values of the parameters and the features of aspects or we change the structure. The first option is mostly associated with optimisation requests and the results of such actions are very much limited by the existing possibilities of the system in terms of state and transition to another state, the behaviour. The overhaul and maintenance of a car shows these limitations; the car will perform better but not exceed its specifications. The second option means intervening into the structure of a system and leads to the ultimate question of the contribution of individual elements, subsystems, aspectsystems and their relationships to the overall behaviour. Improving the logistic performance of a company might lead to a total new approach to the underlying concepts introducing new points for holding inventory and different methods for planning and scheduling; this leads to a new internal and possibly external structure. Both organisational systems and technical systems then face design requirements, as set by the relationships with their environment, to evaluate existing and alternative structures.

II System Approaches

For analysing the structure and behaviour of a system, there are two points of departure for examining it in addition to the concepts of subsystems and aspectsystems:

- the whole (system);
- the elements and the relationships (mostly the internal ones).

When starting with the elements a study will encounter the fundamental problem that we can not clearly distinguish the relationship the system has with its environment; this might lead to considering the system as being closed and ignoring the interaction with the environment. However, that relationship with the environment determines strongly the requirements imposed on the subsystems and the elements in case of open systems (which are the majority of cases). For example, the cargo load and speed as design parameters of the ship driven by demand for this transport mode will determine to a large extent the selection and dimensions of its propulsion system. So, starting by examining systems and then moving to subsystems, aspectsystems and elements creates the opportunity to define the relationships an element (or subsystem) has to its environment and the requirements imposed by those relationships.

Blackbox Approach

As the first principle for examining systems, the blackbox approach focuses on the external relationships, starts from the system as a whole and does not look at the internal elements and relationships. By solely concentrating on the external relationships of the system with its environment it studies the interactions between these relationships to understand the behaviour of the system. One could say that the blackbox approach is equivalent to looking at a system as being a single element (see Figure S.4). For example, an organisation is viewed as a blackbox when making enquiries about the relationships between orders and delivery dates without examining the internal processes for order processing. This might appear as a simple relationship revealing that orders for standard products have a lead-time of 24 hours while the delivery of special products might mount up to 6 weeks, whereas generally these two product categories do not differ much. In general, it is not easy to obtain insight into the functioning of a blackbox since the possibilities of linking external relationships increase exponentially with the number of relationships. Nevertheless, this complexity of external

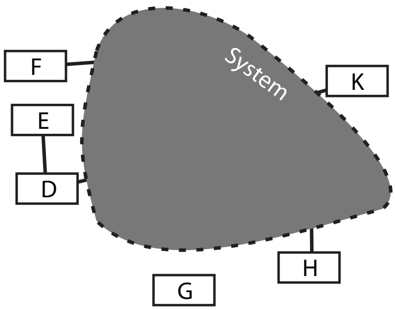

Figure S.4 *System as blackbox. The blackbox approach allows examining the external structure and behaviour of a system. The elements and the internal structure are not looked at. The blackbox approach for analysing systems supports deductive reasoning by examining the behaviour of the system in response to external stimuli.*

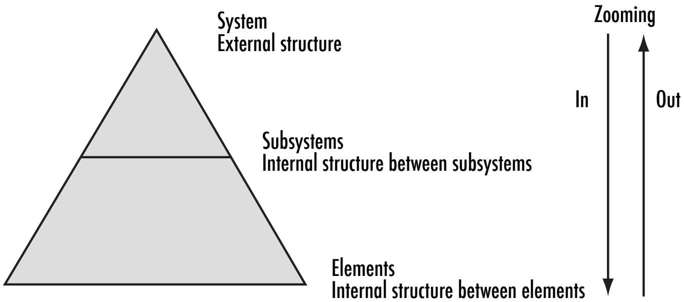

Figure S.5 *Aggregation strata and zooming in and out applied to systems. In this drawing the levels of system, subsystems and elements represent levels of detail for investigating a system. By zooming in more details (i.e. subsystems and elements of the system) become visible. Zooming out results in distinguishing (emergent) properties of the system as a whole and mostly makes it better possible to examine the external structure of a system.*

relationships, the advantage of the blackbox approach is found in the elimination of the internal details of the system, content and structure during analysis and design; this is based on rule of thumb that the principle solution should follow the requirements imposed by the external relationships. The delivery time of standard products can be acceptable in the example, the lead-time for special products well above competitive standards: to analyse the order processing we need only to examine the processing of orders for special products and might skip all what involves processes for standard products. Hence, the example demonstrates the advantage of the blackbox approach for investigating systems: the analysis of behaviour without being burdened with internal details.

Aggregation Strata

The second principle for examining systems as from a holistic perspective is by using aggregation strata. During an analysis the details might overwhelm and there is the need to create an overview by models and by arranging data, whether of qualitative or of quantitative nature. Particularly, when we examine the internal structure of systems, the distinction between systems, subsystems (or aspectsystems) and elements provides a model for allocating related observations to different levels of aggregation (aggregation strata); see Figure S.5. Naturally, we do so already by creating hierarchical organisational structures and the design of units or modules within technical systems. The use of aggregation strata for analysis and design aims at arranging data and information in such a way that the perception of the problem and the systems clarifies the causes for underlying poor performance, the deficiencies for improving behaviour to meeting newly set criteria and the possible options for structuring a system. That also means that when a system is analysed or a problem is resolved, going into more detail does not necessarily contribute to better understanding. For example, if the profit and loss statement of a company shows that the expenditures outstrip the revenues, then in the first instance going into more detail about the revenue generation, such as market segmentation, will not contribute to solving the problem of profitability; however, many are inclined to provide as much as detail as possible to solve a problem, relevant or irrelevant. Therefore, the distinction of aggregation strata assists in avoiding detail when not necessary. However, a higher level within the aggregation strata 'absorbs' the details of the lower level, resulting in loss of accuracy but at the same time gaining overview. Aggregation strata accommodate a better grip on the problem by defining levels of detail for searching and analysing data derived from a problem definition (for both analysis and design).

III Processes

Going back to the temporal aspect of looking at systems, often a study does not look at systems from a static point of view, as a snapshot, but how they evolved over time. For example, an oven for baking cakes and pastries, viewed as a system, has achieved a certain temperature at a given time. This temperature reflects the state of the system – the values of relevant parameters at a certain point of time (note that the problem definition prescribes which relationships are relevant). The change of temperature is an event, a change of relationship, caused by another event, e.g. the setting of the temperature by the cook or baker; an activity indicates an event induced by another event and activities generally consume time, that means that it takes a while before the changes in relationships take effect. For the given example it means that the oven will reach the set temperature after a certain time has lapsed. Therefore, in many cases the state of a system depends on previous events, the so-called memory.

Static and Dynamic Systems

For static systems this so-called memory constitutes of the creation of the systems, the elements and their relationships. A bridge as part of the (geographical) landscape does not change its position; its elements and relationships as part of a map remain the same. However, at a certain point in time, the bridge as a system has been created. In view of the problem, the position of the bridge in the geographical landscape, no changes take effect during the period of observation because of its purpose (nevertheless, one might come up with events that change the position of the bridge in the landscape). However, for organisations and increasingly for technical systems, responses to changes in external relationships (events) determine the potential behaviour under varying conditions. How do companies react to the dynamics of the markets? How does a computer network react to loads of request for web-sites? Dynamic systems might imply solely changes in the values of relationships, external changes in relationships leading to internal changes, or they might even affect the structure of the system. When restructurings companies that is mostly done by adapting the external structure and the internal structure. Whereas static systems are ‘created’ once and have a fixed state, dynamic systems go through different states (values of relationships and properties or changes in structure) induced by events.

Processes: Change of State

In the case of dynamic systems processes happen when events lead to activities that act on the system and eventually these activities might lead to changes in the external relationships or internal relationships of the systems. For example, a piece of equipment is assembled by putting components together that were initially not connected to each other; hence, the assembly process creates relationships between the components that did not exist before. In other words, the initial event – called the input – leads to output. To establish these changes we need elements within the process to interact with the flowing elements. In the case of assembly the process needs labour or equipment to establish changes in properties of the flowing elements; these are called resources, see Figure S.6. When analysing the processes of an organisation, it might also be necessary to consider how the resources are structures (in groups and departments). Generally speaking, for the analysis and design of dynamic systems, such as machines and organisations, we focus on processes rather than on the elements as such and we have interest in the processes for displaying behaviour that the environment ‘requires’; in addition to the analysis and design of processes, the structure of the resources might be subject of investigations.

Function

The execution of a process delivers output, a flowing element or flowing elements, to the environment that will fulfil a need, called the function. The function is an aggregate of the flowing element(s) allowing us to look for more principal solutions to fulfil the need. Take electricity, for example; the function of electricity is energy. However, energy can also be delivered by

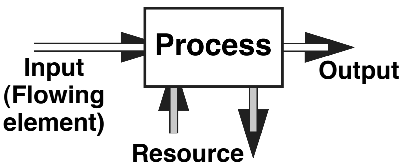

Figure S.6 *Process as interaction between flowing element and resource. The transformation of input into output requires the presence of resources. The changes of the state of the flowing element correspond the changes of state of the resource.*

mechanical processes, think about a watermill, or by radiation. For particular cases that means more sources of energy can be considered than just electricity for solving problems and for designs. The primary objective of denoting functions is not to get 'trapped' by particular solutions but increasing the scope by looking at the essence of the output.

IV Control of Processes

Processes, such as manufacturing and agriculture, do not always produce the same output when fulfilling their function within the environment. For example, during manufacturing irregularities in supply or production processes might cause disruptions. The same goes for the growth of agricultural products, when weather conditions determine the quantity and quality of the output of farms. Eventually, we often want to achieve predictable behaviour despite the irregularities that occur when conducting processes. That stresses the need for controlling the primary process, albeit that three conditions need to fulfilled to make that possible:

- The existence of a target state. If no target state exists, the control mechanisms will not exert effective interventions.
- The capability to measure a parameter relevant to the target state.
- The capability to influence the outcome of a process through an intervention.

The comparison of the target state with the measurement of relevant parameters represents monitoring, which in case of deviations will lead to an intervention. Control depends entirely on the integral capability to exert influence on the primary processes to achieve a pre-determined target state.

Directing

As the first of four principal control mechanisms, directing means only generating a one-time intervention for control of the system. Such an activity

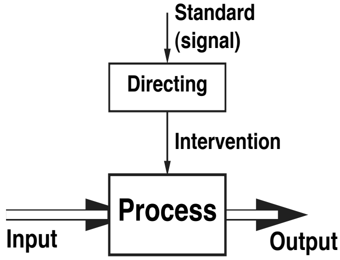

Figure S.7 *Directing. A control signal, the standard, is converted into interventions for the process (or input). Observe that no measurement takes place, the control process relies on the adequate translation of the standard into an one-time intervention (or directives).*

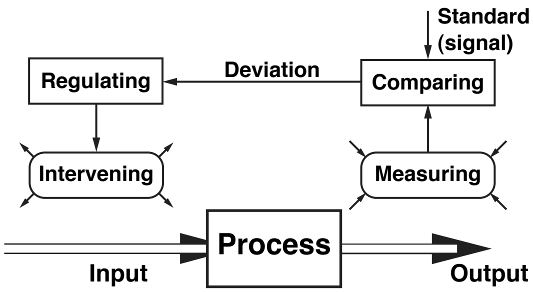

Figure S.8 *Feedback. Deviations in the measurement of parameters of the output's state lead to interventions in either the input or the process' parameters. The comparison might include calculations to make it possible to compare the standard with the measurement. The intervention depends on a model to convert deviations into interventions.*

might consist of setting the value of a parameter or introducing a structure. After this activity the system should produce the desired output without further intervention, e.g. setting the temperature of a house; in general, such an activity more or less generates 'norms' for processes seen as blackbox no matter their internal structure. Whatever behaviour of the primary process will occur after setting the signal or standard, no correction will take place (see Figure S.7). An example is setting the amount of electric power to be generated based on past patterns for demand, the day in the year and the actual time of the day. To that purpose, the controller must know exactly which specific intervention produces those results. The control of most processes does not comply with this prerequisite due to disturbances in input, resources and throughput.

Feedback

As the second principal control mechanism, feedback (see Figure S.8) measures parameters of the output or process parameters and intervenes upstream. The intervention upstream corrects the input, the process or the resources. An example of feedback is when the operations of a company fail to reach pre-determined output levels and then employing more workers increases the level of production. Or it might be that feedback is provided on coursework to a learner who then sources more suitable textbooks. Generically speaking, the feedback mechanisms respond to deviations no matter their cause.

Feedforward

Whereas feedback measures parameters of the transformation process or its outcome and intervenes in the process, resources or input, feedforward parameters are measured upstream of the intervention. The intervention by

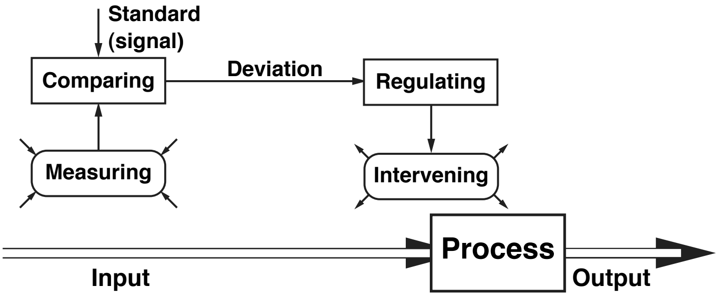

Figure S.9 *Feedforward. Generic representation showing that a measurement taken from the properties of the input results in an intervention downstream. The regulatory mechanism depends on a model connecting the deviation to the intervention.*

a feedforward control mechanism (see Figure S.9) could be directed at either the influx of flowing elements or parameters of the process. Feedforward happens when a company has to process unexpected rush orders and decides to increase its capacity to fulfil the overall demand. It might also be that there is leakage, for instance, in the case of water supply to the water purification plants, and the distribution to users by water utility providers are temporarily decreased or suspended; however, if the water purification plant decides to increase its influx of water to compensate for the leakage, then it might be that the intervention is upstream of the measurement and hence it could be considered feedback. The essential difference between feedback and feedforward is the relative position of the intervention in comparison to the measurement.

Completing Deficiencies

Sometimes it might be more practical to 'complete' the deficiencies in the output of flowing elements rather than intervening in the process, resources or input of flowing elements; to recover from the deficiencies in output, there are two fundamental mechanisms (see Figure S.10). The first one is

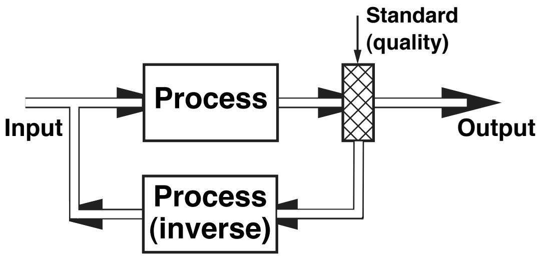

Figure S.10 *Completing deficiencies through a feedback loop in the primary process. After a check on the properties, the output of flowing elements (the defected ones) is returned to the input of the process. Please note that in practice this requires an additional process to convert the flowing elements to a state that processing becomes possible again (as indicated in the figure by the inverse process).*

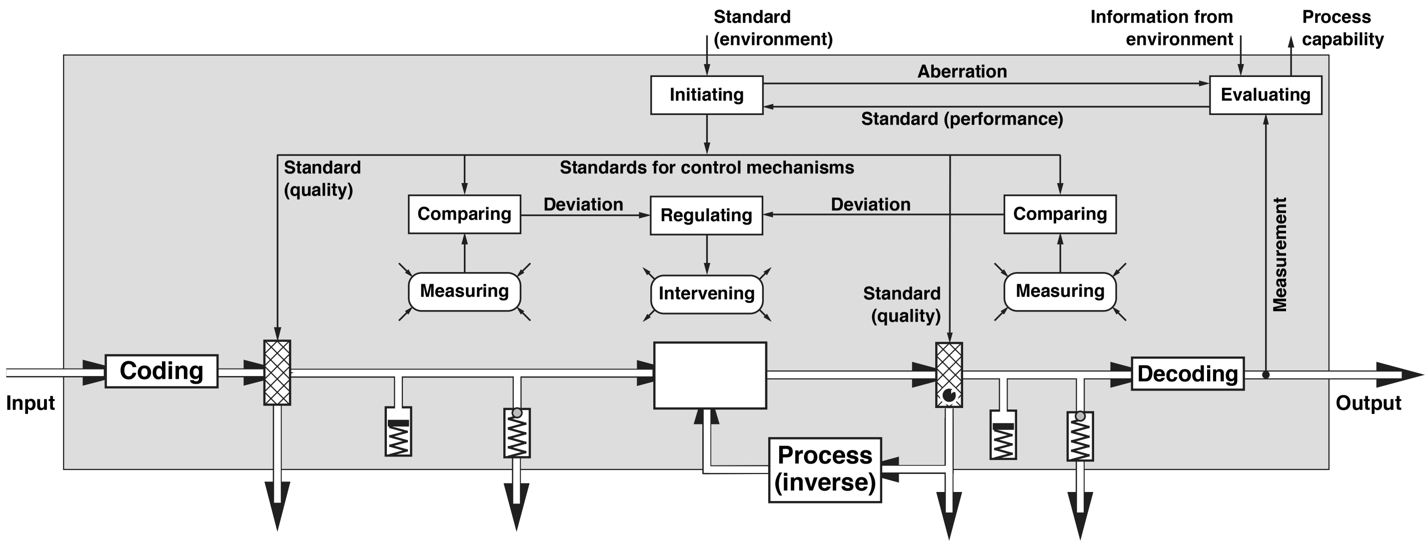

Figure S.11 *Steady-state model. This generic model provides a complete overview of all processes in the boundary zones, the regulatory activities and the control mechanisms. For reasons of simplification the resources needed for all processes (primary process and control processes) have been omitted.*

by adding missing elements in the output or by correcting the output (the symbol in the quality figure). Such might be the case when at the end of an assembly line, cars are checked and missing components added and faulty components replaced; a car manufacturer would do that because discarding the entire vehicle would be more expensive. Alternatively, after the quality check, the 'faulty' output might be fed back into the transformation process by a loop; sometimes that requires an additional process to dismantle the product partially or entirely to make it suitable for the transformation process again. An example of the latter mechanism for feedback is when kids are building a house from toy bricks and come to the conclusion that it does not look as good as they had in mind, take the bricks apart and have a go at it again. Therefore, completing deficiencies intervenes directly in the output of a process itself rather than adjusting the input of flowing elements, the input of resources or the process parameters.

V Steady-State Model

Processes and systems of resources only operate within certain boundaries of control and throughput. For example, a transaction process for banking only allows authorised users to enter the system and discards any other entities though an electronic signature or password. These so-called boundary control mechanisms act on the flowing elements of the primary process itself and on the internal control processes. It consists of three zones: the input boundary zone, the output boundary zone and the regulatory boundary zone, see Figure S.11. Because these zones are interrelated and have some common elements, the common features elements are explained in the next subsections as well as the specific features of each of the three boundary zones.

Coding and Decoding

Generically speaking the input of flowing elements needs to be made suitable for the primary process and the output of flowing elements for the environment; these processes are called coding and decoding. For the process itself the input needs to be coded before it can be used in the primary process. Take for example, the chewing of food as a coding process for the digestion in the human body; by chewing properly food is broken down in smaller pieces that allow more effective decomposition during the processes in the stomach and intestines. Whereas coding occurs before the primary process, decoding happens after the completion of the process and adopts the flowing elements to the environment. For example exhaust gasses of a car are processed through a catalyser before streaming into the environment, that way reducing the output of CO and NO_2. Coding and decoding ensure that the interaction with the environment through the flowing elements stays within the capabilities for the process and the capability of absorbing output by the environment.

Quality Filters

After coding and before decoding, the flowing elements pass through a filter that compares the quality of the flowing elements with pre-set standards. If these standards are not met, then principally the flowing elements are discarded. Using an example again, the coding of authorised users of the banking system for transactions happens through connecting to a (debit or credit) card, a signature, a fingerprint or username and password. The quality filter determines of a user appears on the authorised list of users. If not, then they are discarded by the system, but if they do they can conduct and authorise transactions as part of the actual banking process. On the output side, similar processes happen. However, if necessary, output that does not comply with standards is rejected, for example, incomplete details for a bank transfer, and recycled through the process for acquiring the required quality or deficiencies are added or replaced (see control mechanisms for completing deficiencies); if the user does not succeed in providing all correct details, the transaction is cancelled entirely (and exited from the primary process). The example also implies that the quality control in the output boundary zone has more options at its disposal than the quality filter in the input boundary zone.

Buffers and Valves

The synchronising of the influx of flowing elements with the capability of the process and the transfer of flowing elements into the environment means that buffers need to absorb the differences. For instance, companies do so by holding inventory of materials and parts they need for manufacturing products; sometimes this type of inventory is held for economic reasons (cost savings by ordering large batches) or for uncertainty (irregularity of supply). Conversely, at the output side they might store finished products in warehouses to be distributed according to actual demand by consumers. For example, that is the case for products for festive seasons, like Christmas puddings, which are made months before their actual purchase by consumers. Hence, buffers smooth irregularities between the primary process and input and output.

In actual situations, the capability to absorb the differences between process and input or output might be limited. Might the input exceed the capability or can the output not be distributed to the environment and can the buffers absorb no more flowing elements, then the flowing elements are discarded into the environment through valves as overflow. Take the case of a power plant based on traditional fossil fuel; generally, the level of production can only be limitedly altered on the very short term (it might take days before a power plant reaches its maximum capacity). For that reason, the excess energy needs to be discarded. But also the flow of water to a watermill might exceed the capacity of the watermill itself and might bypass the mill because it cannot be stored or used. Hence, the buffers and valves act to align the inflow and output with the capability of the process, albeit in different and complementary ways.

Initiation and Evaluation

In addition to the boundary zones for the input and output, the regulatory boundary zone interacts with the environment about the standards for the control mechanisms for the primary process. One of its mechanisms is converting standards of the environment into operational, normative standards within the system. This so-called initiating process might transform the deadline for an order into deadlines for individual steps in the production process and capacity requirements for sub-processes. As the second mechanism, the actual performance of a system might call for the need to adapt the standards. Such a situation occurs when the processing of orders in a firm does take structurally two weeks rather than the standard of one week. To perform the evaluation process, information from the environment helps to assess the standards or creates the need for adaptation. Also, market growth might end up in increasing the levels of inventory to allow the same service degree for delivery to customers. If the change of standards affects the performance to the environment, a signal will be generated to inform the environment about the changing capability of the transformation process. Hence, the regulatory boundary zone consists of (i) the conversion of external standards into operational standards for the control processes, (ii) the evaluation of the performance of the transformation process to revise standards, if necessary, and (iii) the transfer to the environment about the actual state of its capability to perform the primary process and maintain standards.

Limitations of the Steady-State Model

The primary process, and possibly secondary processes, together with the control processes and the three boundary zones form the steady-state model; however, this steady-state model only applies to recurring processes. Through the control processes it will adapt to changes in its environment and the adaptation is limited to the scope of the primary process and the limitations embedded in the control processes. Does one want to go beyond the existing capabilities of a process than a new internal (and, if necessary, an external) structure should make that happen; that redesign is not covered by the steady-state model but by the breakthrough model (see Section VIII of this synopsis).

Note also that a steady-state model, consisting out of a primary process, control processes and boundary zones, applies to one aspect only. So far, there is no process model that captures multiple aspects, mostly because of the subjective weighting of individual aspects. Each person attributes different values to certain aspects, e.g. environmental impact versus financial results. If we want to apply the steady-state models for different aspects, we need to construct separate models for each aspect.

VI Autopoiesis

However, a steady-state model is a repetitive process that also occurs in so-called autopoietic systems. Autopoiesis is a process whereby a structure, i.e. a system of resources, reproduces itself. An autopoietic system is an autonomous and self-maintaining system that has processes in place for producing the elements and subsystems it consists of. By doing so, the elements and subsystems, through their interaction, generate recursively the same structure of processes which produced them. Cells and organisms are examples of autopoietic systems; generally speaking they produce their own offspring as a 'copy' of their own contents and structure. This principle has profound implications since the generation of contents and structure of offspring depends on the original state of the autopoietic system and therefore any mutation can be traced back to former states.

Structurally Closed and Self-Referential

That also means that an autopoietic system is operationally closed and it structural state is determined by the processes for generating offspring differing from its (internal) primary processes; this also called structurally closed. Take a human being as a simplified example of an autopoietic system. The primary processes of maintaining its steady-state – breathing in air, drinking water and consuming food – differ from the process of creating children, although the primary processes is needed to achieve that offspring is born. The intake for the primary process can be changed relatively quickly to the environment. However, the capabilities of the offspring are building on the capabilities of the parents. For instance, it takes people starting to live at the high altitude of the Andes mountain range a few generations before their respiratory system is fully adapted to the conditions of 'thin air', air with less oxygen. Therefore, the concept of autopoiesis explains processes of mutation.

The theory of autopoiesis adds further insight to the more cybernetic views that have dominated the previous sections in this synopsis. Principally, it tells that next generations of autopoietic systems build on the elements and structures of previous generations. Such is the case in evolutionary biology for offspring. Autopoiesis implies also that these systems are self-referential in their interaction with the environment; only that what can be perceived acts as stimulus for activities in the system and for the next generation. A case in point is the vision of human beings; generically speaking, the vision is limited to certain frequencies of light, and, therefore, the capability of observation is limited in comparison of that of birds and insects. Furthermore, the concept of autopoiesis is also a very difficult theory to apply to systems because the observers have cognitive limitations as well. Think about the observations of stars that use equipment that goes beyond the frequencies of the naked eye as an enhancement of the visual capabilities of human beings. Therefore, the principles of autopoietic theory serve as explanation for systems with a high degree of complexity but should applied with reservations.

Allopoietic Systems

A special class of autopoiesis systems are allopoietic systems. These systems do not self-produce through 'offspring' as autopoietic systems do but are 'created' or emerge from systems external to them. The dependency on the external systems for justifying its existence means also that it depends on the perceived need of the output or function by the external entities (or systems, sometimes also called actors or agents). Examples of allopoietic systems are organisational systems; these are created by some entities labelled as stakeholders (owners, shareholders, and, in case of cooperative arrangements, employees) for the sake of other stakeholders (customers, employees, society, etc.). Both internal and external actors drive mutations, i.e. changes, in organisational structures; a case in point is the implementation of safety and health regulations triggered by legislative requirements. Therefore, adaptations of an allopoietic system are driven by external enactment, while at the same time building on the self-referential aspects of cognition. A conversion of an allopoietic system relies on its extant subsystems and elements and in that sense follows autopoietic principles (many companies integrated the safety and health systems into the existing structures for quality systems). Only when further adaptations are not possible the allopoietic systems become extinct and, in the best case, elements or subsystems are re-used by external (perhaps, different) entities.

VII Complex Adaptive Systems

In addition to the concepts of autopoiesis, the theories about complex adaptive systems state that these have many autonomous entities, that they are able to respond to external changes and that they form self-maintaining systems with internal pathways for feedback. The concepts related to complex adaptive systems aim at explaining the behaviour of such systems, called non-linear behaviour, that cannot directly be explained as a result of the behaviour of individual entities of that system.

Simple Rules

One of the mechanisms to explain that non-linear behaviour is that simple rules for the interaction between entities in a complex adaptive system could lead to complex patterns. A famous example is flocking of birds; computerised simulations that use rules such as maintaining a certain distance to the nearest-by entity result in patterns that look very similar to the patterns of flight by a large group of birds. However, such patterns might only appear in homogeneous and regular environments.

Fitness Landscapes

Another mechanism for explaining the non-linear behaviour is the search by complex adaptive systems for optimal points on a fitness landscapes. These landscapes can be imagined as real-life landscapes with rugged areas, hilly areas and flats. Complex adaptive systems seek out peaks on these landscapes, which might be either local peaks or global peaks. Moving from one peak to an other (higher) one follows pathways that will lead to passing through sub-optimal points, such depressions and valleys in the landscape. These pathways can be circumvented if a complex adaptive system takes larger steps (for mutations), however these steps also increase the chance of missing out on reaching other peaks. Note that complex adaptive systems consist out of more entities and its thoughts need to be applied to groups of entities, for example, species, economics sectors and national systems rather than a single specimen or firm.

VIII Breakthrough Model

However, the changing environment and the changes induced by organisations themselves are often put into a coherent approach called a strategy. For for the formation of strategy organisations can deploy dynamic strategies, forecasting and scenario planning. Each of these strategies depends on how organisations perceive their environment, since organisations can be considered allopoietic systems.

The breakthrough model (Figure S.12) offers an overview of the necessary internal processes for the formation and generation of strategies. As part of the allopoietic principles, in the breakthrough model, an organisation by scanning the environment sets out a strategy; such a strategy might have new or adapted goals and also includes the capabilities of the resources that are accessible to the organisation as a system. Thus, the process of 'strategy formation' informs tactical and operational decisions and also forms the base for reviewing decisions. As a next step, the process of 'confrontation and resource allocation' leads to more specific decisions on the utilisation of resources in the context of achieving the objectives of the organisation.

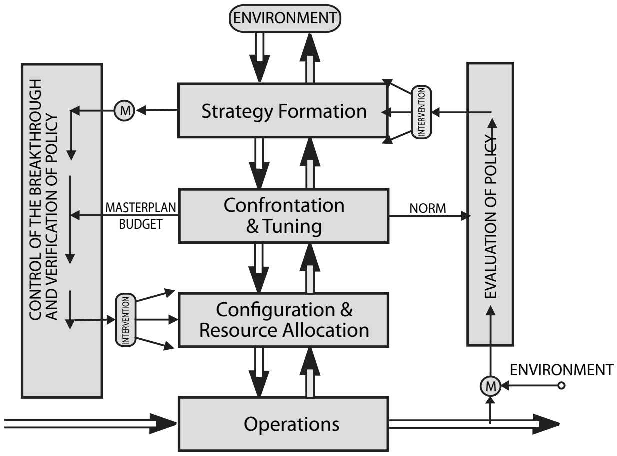

Figure S.12 *Breakthrough Model. By scanning the environment new or adapted goals are set and the derived policy acts as a reference for the review of tactical and operational decisions. The process of confrontation and resource allocation takes the possibilities into account leading to specific decisions on the utilisation of resources and structures for operations. Through the configuration and resource allocation process the actual implementation of the structural changes in operations takes place. The evaluation of strategies might create new input for the breakthrough processes. The verification enables companies to follow the progress of the breakthrough processes.*

Through the configuration and resource allocation process the actual implementation of the structural changes in operations takes place; that means that new subsystems and elements are introduced (or replacing previous ones) together with a new structure (that might cover both internal and external structures). The revised or new structure for operational processes is principally a steady-state model. Also, note that all these steps are iteratively linked. Hence, the breakthrough model is a reference model for the iterative (internal) processes that link the observations of change in the environment to actual structural changes in the operational (steady-state) processes.

In addition to the iterative process linking strategy formation to operational processes, there are two specific control mechanisms. Note that these control mechanisms might have similarities to the control processes in Section IV and V of this synopsis, but are also unique to the breakthrough model. The first mechanism is the evaluation of the strategies based on the actual performance of the primary (operational) processes; it is found in the right-hand side of the breakthrough model in Figure S.12. Note that the performance evaluation of the steady-state model only related to the capability of the primary process; the feedback mechanism for the achievement of strategy looks also at to what extent objectives are met. The evaluation of strategies might create new input for the breakthrough processes. As the second mechanism, the verification process enables companies to follow the progress of the implementation of strategies and resource allocation. This process differs substantially from the feedforward control process in Section IV; whereas feedforward focuses on the performance against set standards (and, therefore, a target state that was already achieved or the process has the capability of meeting it), the verification process measures against a future state that has not been reached, yet. Therefore, it does not only measure against the master plan derived from the strategy formation process but also reviews whether the capabilities of resources (and resource allocation) meet the 'requirements' of the future state for the primary process. Both verification and evaluation are essential parts of the breakthrough model to enable organisations to achieve future states.

1 Introduction

Thinking in systems goes back to both reasoning about physical objects and philosophising about the interrelationships between (scientific) disciplines. Over time, the thinking in systems has elevated systems theories from a theoretical framework to a practical methodology for application in a wide variety of disciplines, for example engineering, management and psychology. No matter their origins and applications, system theories have deepened our understanding of the complexity of real-life systems and also contributed to finding solutions for the challenges dealing with systems.

This book describes that particular way of looking at the world, thinking in wholes rather than thinking only in the properties of individual elements. Before elaborating the concepts of Applied Systems Theory in the chapters that follow, this introduction will briefly describe the origins of systems theories, a discipline of science that dates back to the 1940s. The next section indicates the areas of science, especially engineering and management, which use the theories. The origins of Applied Systems Theory, as recorded in this book, are elaborated in Section 1.3; this section will mention the main sources and how these were used. Over the course of time, systems theories have diverged in all kinds of strands. Section 1.4 will present the distinction between hard and soft systems methodologies, as two main strands of systems theories that have emerged. This section will also explain why this book about Applied Systems Theory represents a so-called hard systems theory with characteristics of soft systems theory. Finally, Section 1.5 outlines the scope of this book and how the book might be used.

1.1 Concise History of Systems Theories

Systems theories and their foundations are neither new nor recent. They are rooted in early scientific traditions. Peter Checkland, known as the founder of Soft Systems Methodology, mentions that Aristotle argued that a whole was more than the sum of its parts [Checkland, 1981, p. 75], one of the most fundamental principles underpinning systems theories. It was common that academics in ancient times would study multiple disciplines in science. From literature it is known that Faust [von Goethe, 1808, 1832] became the last single person to encompass all knowledge existing that time; although he embraced this thought of mastery at the expense of his soul in this play. That exemplifies that Aristotle's holistic view was overthrown by the Scientific Revolution of the 17th century. Since this revolution, a reductionist approach prevailed in which decomposition of problems into smaller ones constituted the main methodology, following principles outlined by Descartes [Wilson, 1998, p. 28]. This reductionist approach allowed individual sciences to progress and develop their own concepts, theories and

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methodologies. Sciences have developed in many different directions and displayed unawareness of each other's progress and insights into the nature of phenomena. Consequently, sciences turned into isolated communities of practice, which yielded tremendous progress in individual fields. Halfway through the 20th century, the need for integrative approaches appeared due to the increased complexity of engineering systems, particularly in control engineering and aerospace engineering (for example, airplanes and spacecraft), and because of advances in evolutionary biology that pointed to complex interactions in ecosystems. Cleland and King [1969, p. 3] trace the germ of the idea for integrative approaches back to a writing by Henry P. Kendall.

Originally, these integrative approaches – the system approaches – with their focus on the interaction between an entity and its environment, originated for a large part in biological perspectives on entities. The aim was twofold: to understand the complexity of reality for solving intricate, layered challenges and to stimulate multi-disciplinary thinking for enriching disciplines. Von Bertalanffy's drive to establish a discipline to enhance communication between experts, created ground for cross-fertilisation and initiated the search for the so-called General Systems Theory [von Bertalanffy, 1973; Kline, 1969], as universal language between sciences (see Box 1.1 for its founders). In the spirit of his thinking, the interaction between the many different fields did hold the promise of new perspectives. The communication and exchange between practitioners allows the emergence of new concepts through cross-fertilisation [Boulding, 1956, p. 201], much as the ancient cities of Cordoba, Spain, and Baghdad, Iraq, represent two historical sites at crossroads of cultures that boosted advances in science in their times of prosperity. That interaction between different disciplines and the search for cross-fertilisation inspired the series of Macy Conferences, where specialists from different areas of expertise met to discuss inter-disciplinary work and to lay the foundations for the General Systems Theory (see Box 1.2). Nowadays, the notion prevails that advances in theory and practice should be drafted from not only a specific field of research but also give way to the spirit of interdisciplinary thinking, much as the founders of systems theories envisioned.

In parallel to the development of science and the rise of systems theories, the view on systems has changed over the years. McCarthy [2004, pp. 125–126] points to the following perspectives that have influenced thinking in systems (note that the first four existed before systems thinking surfaced as a scientific discipline):

- the Aristotelian view (the perception of systems as organic, living and spiritual);
- the Cartesian view (the observation of systems as mechanistic and as resulting from reductionism);
- the Newtonian view (the examination of systems as obeying principles of mechanics);

Box 1.1: Founders of General Systems Theory

William Ross Ashby (1903 - 1972)

William Rosh Ashby was an English psychiatrist and a pioneer in the study of the organisation and control of complex systems. He created the concept of a ‘homeostatic machine’, which proved to be a fundamental concept for the development of mathematical models of cybernetics.

Gregory Bateson (1904 - 1980)

Gregory Bateson was a British anthropologist, social scientist, linguist and cyberneticist whose work intersected that of many other fields. He strongly opposed those scientists who attempted to ‘reduce’ everything to mere matter and was intent upon the task of re-introducing ‘Mind’ into the scientific equation. Gregory Bateson and his colleagues developed the Double Bind theory (about communicative situations where a person receives different or contradictory messages). He helped to elaborate the science of cybernetics with colleagues such as William Ross Ashby, Heinz von Foerster and Norbert Wiener.

Ludwig von Bertalanffy (1901-1972)

Karl Ludwig von Bertalanffy was a biologist. Already in the 1930s, Bertalanffy formulated the organismic system theory that later became the kernel of the General Systems Theory. His starting point was to deduce the phenomena of life from a spontaneous grouping of system forces, comparable to contemporary system developmental biology. Von Bertalanffy introduced the General Systems Theory as a new paradigm for model construction in all sciences. As opposed to the mathematical system theory, it describes its models in a qualitative and non-formalised language. Thus, its task was a very broad one, namely, to deduce universal principles that are valid for systems in general.

Kenneth E. Boulding (1910 - 1993)

Kenneth E. Boulding, also known as one of the founders of General Systems Theory, emphasised that human economic and other behaviour is embedded in a larger interconnected system: to understand the results of our behaviour, economic or otherwise, we must first research and develop a scientific understanding of the eco-dynamics of the general system, the global society in which we live. Boulding believed that in the absence of a strong commitment to the right kind of social science research and understanding, the human species might well be doomed to extinction. But he died optimistic, believing our evolutionary journey had just begun.

Box 1.1 (Continued)

Margaret Mead (1901 - 1978)

Margaret Mead was an American cultural anthropologist. It was through her work that many people learned about anthropology and its holistic vision of the human species.

Sources: Brauckmann [1999], Heylighen [2004], Wikipedia [2009]

- the romantic view (the concept of systems as self-organising wholes);
- the general systems science view (the notion of systems as consisting of elements and their relationships to the whole, and open versus closed systems);
- the cybernetic view (the examiniation of systems with feedback, and the capability for self-balancing, self-regulating and self-organisation);
- the soft systems view (the consideration of systems as mental constructs);
- the complex systems view (the perspective of systems as an expression of non-linearity, self-organisation and emergence).

Despite their differences in points of departure, among these perspectives a common and binding theme is the understanding of complicated entities in many fields by:

- determining the system boundary, the constituent elements, the relationships between elements, the attributes of elements and the input and output of the system;
- supporting the integration of views and knowledge to study the total system and how it interacts with its environment.

Consequently, systems theories essentially constitute a multi-disciplinary perspective for studying entities, or objects, as some call them (for example, Kline [1969, p. 36]), with the ultimate purpose of providing a better understanding of objects and constructs of the mind, paving the way for more adequate description, purposeful analysis and design.

1.2 Application of Systems Theories

As a result of the multi-disciplinary approach, systems theories for studying complicated entities have found their way back to many fields of science [Heylighen and Joslyn, 1992], such as theoretical development and conceptual foundations (e.g. the philosophies of Bahm [1981], Bunge [1979] and Laszlo [1972]), and applications ranging from mathematical modelling and information theory (e.g. the work of Mesarovic et al. [1970] and Klir [1969]) to practical applications for decision-making in organisations (e.g. Checkland [1981]). As one of two strands of applications, the mathematical systems

Box 1.2: Macy Conferences

The ten Macy Conferences between 1946 and 1953 were the first organised approach to interdisciplinarity, spawning breakthroughs in systems theory and leading to the foundation of what later was to be known as cybernetics. They were organised by the Josiah Macy, Jr. Foundation.
The participants were leading scientists from a wide range of fields. Casual recollections of several participants stress the communicative difficulties in the beginning, giving way to the gradual establishment of a common language powerful enough to communicate the intricacies of the various fields of expertise present. The scientists that participated in all or most of the conferences are known as the *core group*. They include:

- Gregory Bateson – anthropologist
- Julian Bigelow – electro technician
- Heinz von Foerster – biophysicist
- Lawrence K. Frank – social scientist
- Ralph W. Gerard – neuro physiologist
- Molly Harrower – psychologist
- Lawrence Kubie – psychiatrist
- Paul Lazarsfeld – sociologist
- Kurt Lewin – psychologist
- Warren McCulloch (chair) – psychiatrist
- Margaret Mead – anthropologist
- John von Neumann – mathematician
- Walter Pitts – mathematician
- Arturo Rosenblueth – physiologist
- Leonard J. Savage – mathematician
- Norbert Wiener – mathematician.

In addition to the core group several invited guests participated in the conferences; amongst many others: Claude Shannon (information theorist) and Max Delbrück (geneticist and biophysicist).

Source: Wikipedia [2007].

theories arose from the development of analogies between electrical circuits and other systems; this is often called hard systems thinking. Applications of this strand of systems theories include engineering, computing, ecology, management and, to a certain extent, family psychotherapy. The second strand of applications, that of systems analysis, which developed independently of systems theory, applies systems principles to aid a decision-maker with problems of identifying, reconstructing, optimising and controlling a system (usually a socio-technical organisation), while taking into account multiple objectives, constraints and resources. This strand combines systems theories as aid to decision-making and soft systems thinking (the latter viewing systems often as mental models). It aims to specify possible courses of action, together with their risks, costs and benefits. Systems theory is closely connected to cybernetics, and also to System Dynamics, which models changes in a network of coupled variables (e.g. the 'world dynamics' models of Forrester [1968] and the Club of Rome). Related ideas are used in the emerging 'sciences of complexity', studying self-organisation and heterogeneous networks of interacting actors, and associated domains such as far-from-equilibrium thermodynamics, chaotic dynamics, artificial life, artificial intelligence, neural networks and computer modelling and simulation. Systems analysis not only covers mathematical models for decision-making but also qualitative models for the study of information systems and organisational design; Applied Systems Theory constitutes one of the methods for this domain. These applications demonstrate the wide array of sciences that systems theories have boosted.

During the 1980s cybernetic approaches found their ways to many disciplines as basic approaches or methodologies. These approaches became so common that they seemed unique to many disciplines rather than presenting an interdisciplinary perspective. Wilson [1998] revived the discussion about interdisciplinary thinking by pointing to the concept of consilience as transferring knowledge from one domain to another, particularly the connection between biological phenomena and social sciences (akin the intent of the founders of General Systems Theory). He assumes that all phenomena are based on material processes that are causal and, however long and tortuous the sequences, ultimately reducible to the laws of physics [ibid, p. 266]. A consilience of knowledge about the management of organisations would demand a vision capable of sweeping from whole societies to an individual human brain. It would involve reduction – decomposition of events and phenomena – and synthesis – the integration of knowledge. To dissect something into its elements is consilience by reduction, and to reconstitute it is consilience by synthesis [ibid, p. 68]. Wilson offers an example of consilience in practice from his early research on ants [ibid., pp. 70–71]. To explain communication within an ant colony (e.g. an internal alarm alerting an entire colony to an attack by a predator), Wilson and his associates studied an ant colony across four levels of organisation, from the whole colony, then reductively to the organism (individual ants), to glands and sense organs, and finally to molecules (pheromones). He also worked in the opposite direction (synthesis) when he predicted the meanings of signals observed in the colony (for example, alarm, danger versus food, follow me) by linking various signals to matching changes in the molecular composition and concentration of individual ant pheromones; he used simulation models to compare theoretical findings with actual behaviour of ants. The result was a comprehensive or holistic study of ant communication [Peroff, 1999, p. 98].

The value of Wilson's thinking is that we have not reached yet the limits of interdisciplinary research and that at least some phenomena might be better explained by explicitly deploying principles of consilience to enhance cross-fertilisation among disciplines.

1.3 Foundations of Applied Systems Theory

The striving for cross-fertilisation implies that any systems theory is interdisciplinary in nature and constitutes a blend of concepts originating in the rise of systems theories and later developments. The text of this book has its origins in the rise of General Systems Theory and cybernetics during the 1950s, 1960s and 1970s; the book pays tribute to these by referencing to the early writings about systems thinking. A lot of interaction happened in the spirit of interdisciplinary exchange of thoughts (as also evident from Box 1.2), which makes it difficult at times to pinpoint the emergence of ideas and concepts and to trace it back to specific authors. Therefore, generally accepted terms and definitions in systems theories have not been traced back to specific literature; however, as much as possible, specific concepts and thoughts have been marked by reference to the originator as identified during the research for this book. That means that works of others are only cited when they are not considered part of the generic and interdisciplinary knowledge about systems theories.

The book also includes references to more recent developments, found in the science dealing with complex systems and the science of complexity (especially in Chapters 7–9). Inspired by the Zeitgeist of the late 1980s, the trend of decentralisation and the postulation of non-hierarchical, participative and distributed control in society and organisations also penetrated complexity science [Malik, 1992]. Starting with the works of the Santa Fe Institute in the early 1980s, the paradigm of self-organisation emerged and opened a new strand in the explanation and control of complexity [Jost, 2004]. With the increasing number of elements in artificial systems – turning them into networked entities – their control became increasingly complex [Tucker et al., 2003]. This made the deterministic, top-down approach to systems control inefficient, if not impossible, especially against the background of a highly dynamic environment. Henceforth, Applied Systems Theory as presented in this book has embraced the recent advances in the science of complexity.

For the actual text, many sources have been used. First of all, it builds on the systems theories that emerged during the 1950s, 1960s and 1970s and the General Systems Theory manifesting itself during the same period. Although homage is paid as much as possible to original authors, at the same time, that is hindered by the interdisciplinary approach (see the description of the Macy Conferences in Box 1.2). The theories from that period have found their way into other writings as well, such as the socio-technical approach of Miller and Rice [1967]. Secondly, Beer [1959; 1966; 1972] and Checkland [1981] have made major contributions to systems thinking and some of their ideas have been incorporated in this book. Thirdly, additional sources have been consulted, e.g. the web-sites from Principia Cybernetica and Wikipedia, to clarify terms and journal papers to obtain additional information. By using a wide range of sources, the text has moved away from its origins in General Systems Theory to a concise and consistent systems theory for practical use in engineering sciences and management science (and other sciences as demonstrated by the examples throughout).

Although widely accepted in the scientific and engineering community, the principles of systems theories have hardly reached the business community. Most theories developed for that domain constitute a generic approach, which hardly combines with the drive to arrive at specific solutions as necessary for adoption in business and managerial applications. Additionally, the search for optimal solutions that thrives application of systems theories but seems far off practical decision-making by managers; think about the principle of satisficing of Herbert Simon [1959, pp. 262–264]: accepting the first available solution that meets criteria, whether marginally or better than other solutions. This strand of Applied Systems Theory aims to offer a more applied approach than other systems theories; but it will take time before the systems theories catch on in managerial practice and management science sufficiently to turn it into a basic tool for resolving problems.

1.4 Hard Systems Approach vs. Soft Systems Approach

Using problem-solving applications of systems thinking to real-world problems is characteristic for Applied Systems Theory. According to Laszlo and Krippner [1998], this strand of the study of systems – problem solving – can be divided into three strands: (a) work in ‘hard systems’, e.g. the development and use of systems engineering methodology, (b) aid to decision-making, for example operations research and management science methodologies and (c) work in ‘soft systems’, such as the development and use of social systems design methodologies. Applied Systems Theory, as presented in this work, covers mostly (a) and (c), being a methodology for qualitative analysis and design. Its application resembles methods used in engineering for analysis and design, though these are not explicitly covered in the book, while at the same time it turns its attention to social organisations in later chapters. However, Applied Systems Theory is complementary to other methods and methodologies, as used in operations research and Soft Systems Methodology. Depending on the type of problem, one might choose the most appropriate methodology to resolve the problem (see Section 10.4). Applied Systems Theory is only one set of approaches and heuristics as methodology, may be a comprehensive one, to tackle real-world problems.

The combined hard systems and aid to decision-making approach of Applied Systems Theory contrasts with Soft Systems Methodology of Checkland [1981] – another popular method for social systems –, although both aim at resolving real-world problems. Both have their own domain of application within managerial science. The focus of Soft Systems Methodology is on the analysis of systems by a process of inquiry and involvement of stakeholders. This concerns mostly unstructured problems, which require iteration and questioning, whereas structured problems, especially in engineering, do not; during design stages, the latter calls for the understanding of structures and patterns. In this sense, Applied Systems Theory centres on a more formal way of modelling, which is complementary to Soft Systems Methodology.

1.5 Who Might Benefit from Applied Systems Theory and How?

In a more generic sense, system theories help to understand the complexity of the world we are in better; that can be used to describe real-world problems, to analyse these problems and to find solutions for them. Particularly for complex situations, interrelationships and understanding key mechanisms plays a key role during analysis and synthesis. System theories aim at identifying relevant interrelationships from the perspective of entities and processes. For those purposes, system theories are of interest to managers, consultants, engineers, students, researchers and stakeholders in processes of change.

For *managers* and *consultants*, the first generic group that will directly benefit, system theories help in multiple ways. First, by applying the concepts in this book, they will be able to develop a better holistic picture. That leads to decisions that are based on considering principle solutions rather than concentrating on optimisation of current structures and processes; too much emphasis on optimisation, when not appropriate, will result in sustaining solutions that are not feasible anymore, therefore reducing the productivity of an organisation. Moreover, Applied Systems Theory will aid in finding root causes and bottle-necks, and finding solutions for processes and structures for the domains of operations, new product and service development, logistics and supply chain management, quality management, health and safety systems, maintenance, etc. Furthermore, Applied Systems Theory can be used for designing or re-designing organisational structures (see Section 10.3). And, finally, the concepts can be applied to strategic renewal (see Chapter 9). Therefore, one might even conclude that a working knowledge of system theories should belong to the ‘basic toolbox’ of managers and consultants.

For *engineers*, including software engineers, system theories support analysing and designing technological systems. Building on the basic concepts of systems, Chapter 3 contains principles for analysis of those systems; some of these principles can also be used for design purposes. Chapter 4 concentrates on modelling of (business) processes. Furthermore, Chapter 5 presents the principle control mechanisms and Chapter 6 extends these to the steady-state model. Particularly, the distinction between primary processes, secondary processes and control processes in those chapters will be helpful for designing control and information systems. That is further supported by some basic principles of Systems Engineering that are found in Section 10.1. Since technological systems might have a huge impact on stakeholders, that perspective is part of Section 7.6 and critical systems thinking in Section 10.4. Hence, Applied Systems Theory offers a wide range of concepts and tools for engineers in a broad range of domains.

For *students*, not only restricted to those that are studying engineering and business and management, the concepts and the applications of Applied Systems Theory provide foundations for processes of analysis and design (artefacts or methods). Those foundations are an addition to the support it gives managers, consultants and engineers as described in the previous two paragraphs. By relating basic skills of analysis and synthesis to examples, some of these principles are highlighted. Furthermore, the concepts of system theories have found their way into biology, psychology, etc. That means that students can gain transferable skills from this book and have an entry to understanding multiple disciplines better.

For *researchers* in a broad scope of domains Applied Systems Theory offers some basic principles for analysis and synthesis. This is particularly the case for Chapter 3 that presents principles of modelling and reasoning that reach beyond the use of system theories. Furthermore, the descriptions of systems in Chapter 2, of processes in Chapter 4 and the cybernetic mechanisms might be of help for more specific strands of research, such as management and design of organisations. Furthermore, Chapters 7 and 8 provide a brief introduction into the principles of autopoiesis and complex adaptive systems. Those researchers that are interested in foresight and strategic renewal will find concepts in Chapter 9.

For *stakeholders in process of change* the book is of interest if they want to know more about some projects that use the principles of system theories. For those Chapter 2 offers some basic explanations, while in other chapters some features of so-called critical systems thinking are discussed. However, this is an addition to the text and not the mainstay of the book.

While the book discusses the wide-ranging concepts and applications of Applied Systems Theory, it does not go into detail of the methods and techniques used for analysis and synthesis. Even though the concepts are presented in a holistic way and always linked to a purpose, be it describing systems, analysis of systems and related processes or finding and detailing solutions, the specific methods and techniques are merely touched on. Readers that want to know more about problem solving are referred to other works.

1.6 Outline of Book

Given the focus on solving real-world problems, one might wonder why writing a book about Applied Systems Theory rather than focusing only on the practical applications might bring to the table. Indeed, without the application in any field this theory would become a framework without meaning, and lead to philosophical discussions on what systems represent or not (following the spirit of Hamlet's famous words). The analysis and design of systems are specific issues and vary for different fields of study, although present in the background and descriptions provided. Throughout the whole book, practical examples are given to relate the theory to the daily practice of engineering and organisations; from other fields than those two, some examples are given throughout in order not to restrict the application of the theory.

The writings on Applied Systems Theory originated in describing adequately both technical systems and organisations. In later chapters it will appear that the theory might also be applied to biological systems. In those sections of the text, it becomes apparent that concepts have been borrowed from evolutionary biology to explain phenomena of complex networks of technical systems and organisations. Furthermore, this writing focuses on general systems concepts, cybernetics and complex (adaptive) systems in an attempt to provide the reader with a coherent approach to analysis and design of systems. The book does not describe the design methodologies, these can be found in other books on engineering topics, information systems and management science.

Right after this opening chapter, the second chapter of this book introduces the basic concepts of Applied Systems Theory. Through understanding these concepts it becomes possible to view systems and their relation to the environment. At the heart of studies into specific systems, we often aim at understanding their interaction with the environment and at inducement of internal changes caused by external events. The so-called design approach for systems, partly an engineering perspective, builds on that insight. To that purpose, how to study systems constitutes Chapter 3, especially paying attention why a system is more than its elements in the context of analysis and design. Additionally, the way to study systems in their environment becomes more defined. In the next chapter the concept of processes is worked out in more detail along with ways to look at systems and dynamic conditions. Chapter 4 also pays attention to alternative modelling of processes. Chapter 5 expands on the control of primary processes. It introduces the basic cybernetic concepts that link to primary processes and presents the mechanisms for exerting effective control. Extending the control mechanisms to the boundary zone for the primary process, Chapter 6 will introduce the steady-state model. Describing living systems and organisations requires the understanding of the principles of autopoiesis as outlined in Chapter 7. Further building on non-linear behaviour, the topic of complex adaptive systems constitutes Chapter 8. Thereafter, Chapter

9 describes the breakthrough model as a specific model for adaptation by organisations. Finally, Chapter 10 deals briefly with the application of the theories to engineering, biology and management science, even though other fields in social sciences have benefited from system theories as well.

References

Bahm, A. J. (1981). Five Types of Systems Philosophy. International Journal of General Systems, 6(4), 233–238.

Beer, S. (1959). Cybernetics and Management. New York: Wiley.

Beer, S. (1966). Decision and control; the meaning of operational research and management cybernetics. London: Wiley.

Beer, S. (1972). Brain of the Firm - the Managerial Cybernetics of Organization. Chichester: John Wiley & Sons.

Bertalanffy, L. v. (1973). General System Theory. New York: George Braziller.

Boulding, K. E. (1956). General Systems Theory. Management Science, 2(3), 197-208.

Brauckmann, S. (1999, January). Ludwig von Bertalanffy (1901–1972). Retrieved 29 December, 2006, from http://www.isss.org/lumLVB.htm

Bunge, M. A. (1979). A world of systems. Dordrecht: Reidel.

Checkland, P. (1981). Systems Thinking, Systems Practice. Chichester: John Wiley & Sons.

Cleland, D. I., & King, W. R. (1969). Systems, organizations, analysis, management: A book of readings. New York: McGraw-Hill.

Forrester, J. W. (1968). Principles of Systems. Boston, MA: MIT Press.

Goethe, J. W. von (1808). Faust: Eine Tragödie. Tübingen: Cotta.

Goethe, J. W. von (1832). Faust: Eine Tragödie, zweiter Teil. München: Wilhelm Goldman Verlag.

Heylighen, F. (2004). Cybernetics and Systems Thinkers. Principia Cybernetica Web Retrieved 23 August, 2009, from http://pespmc1.vub.ac.be/csthink.html

Heylighen, F., & Joslyn, C. (1992). What is Systems Theory? Principia Cybernetica Retrieved 30 August, 2004, from http://pespmc1.vub.ac.be/SYSTHEOR.html

Jost, J. (2004). External and internal complexity of complex adaptive systems. Theory in Biosciences, 123(1), 69-88.

Klir, G. J. (1969). An Approach To General Systems Theory. New York: Van Nostrand Reinhold.

Laszlo, A., & Krippner, S. (1998). Systems Theories: Their Origins, Foundations, and Development. In J. S. Jordan (Ed.), Systems Theories and A Priori Aspects of Perception (pp. 47-74). Amsterdam: Elsevier Science.

Laszlo, E. (1972). The Systems View of the World: The Natural Philosophy of the New Development in the Sciences. New York: George Braziller.

Malik, F. (1992). Strategie des Managements komplexer Systeme. Bern: Haupt.

McCarthy, I. P. (2004). Manufacturing strategy: understanding the fitness landscape. International Journal of Operations & Production Management, 24(2), 124-150.

Mesarovic, M. D., Macko, D., & Takahara, Y. (1970). Theory of hierarchical, multilevel systems. New York: Academic Press.

Miller, E. J., & Rice, A. K. (1967). Systems of Organization: The control of task and sentient boundaries. London: Tavistock.

Peroff, N. C. (1999). Is Management an Art or Science? A Clue in Consilience. Emergence, 1(1), 92–109.

Simon, H. (1959). Theories of Decision-Making in Economics and Behavioral Science. The American Economic Review, 49(3), 253–283.

Wikipedia. (2007, 2 February). Macy Conferences. Retrieved 11 February, 2007, from http://en.wikipedia.org/wiki/Macy_conferences

Wikipedia. (2009, 1 August). Margaret Mead. Retrieved 23 August, 2009, from http://en.wikipedia.org/wiki/Margaret_Mead

Wilson, E. O. (1998). Consilience: the unity of knowledge. New York: Alfred A. Knopf.

2 Basic Concepts

When defining what systems are, the first thing that comes to mind is how often people use the word: system. All kind of professions and knowledge domains denote different meanings to this concept used in daily language. Engineers frequently talk about systems when they review designs or analyse technical equipment, e.g. the propulsion system of a ship. Computer experts point to information and communication systems. Biologists see the oceans as ecological systems. In addition, many consider organisations as systems. Hence, the word systems refers to objects (discrete systems) as well as purposeful constructs of the mind that are abstract in exchange between people, like the concept of an organisation as a system. Distinguishing systems within reality helps to create, to describe and to analyse. To support the analysis of problems and to generate solutions, this chapter will define systems, discuss their properties and expand on their application in the domain of technical design, biology and organisations, but knowing that the principles are applicable to many (scientific) disciplines.

The use of systems theories as a methodology of description and analysis originates from the drive to simplify reality and to comprehend natural events. The reality us has fascinated mankind since long and many have tried to explain phenomena that we experience daily, to understand patterns and to predict what will happen. The complexity surrounding us has forced investigators to look at interrelationships between objects and events. How does a propulsion system of a ship react to changes in forces? How does an information and communication system react to a cyber attack? How does an ocean as a system react to pollution? And how does an ecological system react to human interventions? Putting it all together, we are looking for approaches and methodologies to understand what is going on and how to solve a wide range of problems presented to us. As mentioned in Section 1.2, systems theories attempt to bridge different disciplines by their range of applications and at the same time act as a platform for multi-disciplinary collaboration. Applied Systems Theory, as one of the systems theories (later, Chapter 10 will introduce briefly a few other theories), provides such an opportunity to describe and analyse problems, mainly due to its holistic approach.

This chapter starts by looking what the concept of systems means and by defining then in Section 2.1; some of the keywords will be elaborated on. The section thereafter discusses the properties of systems, needed for further analysis of a system. The chapter continues by looking at subsystems and aspectsystems appear in Section 2.3 and 2.4, as specific ways of examining systems, in more detail. The state of systems, related to their properties, is the topic of Section 2.5, and relates to events and activities that happen in the environment of a system. Since systems might react to changes in

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their environment, Section 2.6 introduces the various concepts of systems' behaviour. Finally, Section 2.7 addresses the system boundary.

2.1 Systems

Although incorporated in daily language, when we talk about systems, each of us might attribute total different meanings to this comprehensive word, the key to any systems theory (see examples of definitions in Box 2.1). What we intend telling is that we separate elements from a total reality to study the nature of the system driven by the purpose of a particular study. This will enable the investigator to analyse and to predict the behaviour of such a system, for example an organisation. Anybody wanting to describe or

Box 2.1: Definition of Systems

This box provides definitions of systems to show similarities and differences in what a system is according to different authors.

Applied Systems Theory

A system consists of elements discernible within the total reality (universe), defined by the aims of the investigator. All these elements have at least one relationship with another element within the system and may have relationships with other elements within total reality.

Alternative Definitions

... any entity, conceptual or physical, which consists of interdependent parts. *[Ackoff, 1969, p. 332]*

... sets of elements standing in interrelation ... *[von Bertalanffy, 1973, p. 38]*

... the word "system" has been defined in many ways, all definers will agree that a system is a set of parts coordinated to accomplish a set of goals. *[West Churchman, 1968, p. 29]*

... system is defined as a set of concepts and/or elements used to satisfy a need or requirement. *[Miles, 1973, p. 2]*

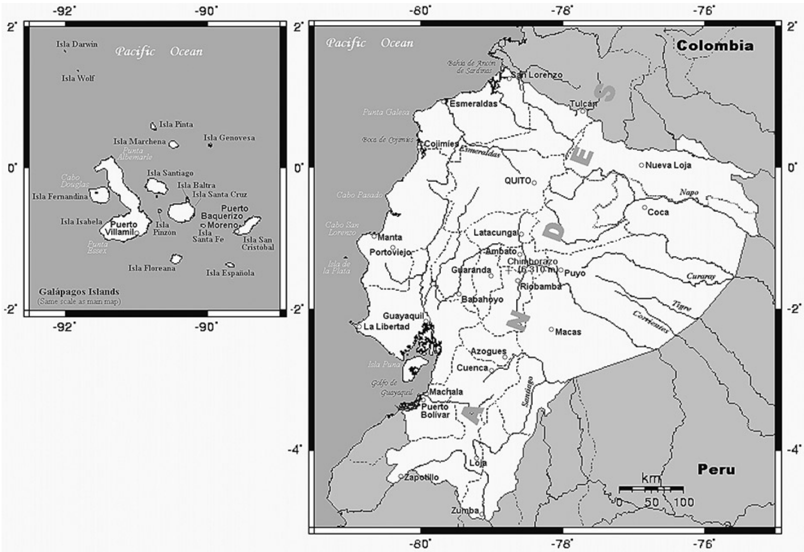
System ... is a set of entities, real or abstract, comprising a whole where each component interacts with or is related to at least one other component and they all serve a common objective. *[Wikipedia, 2007]* analyse an organisation does not start by enumerating everything outside the organisation or by defining all small objects within a company, for example individual employees and forms in use. The simplification starts by defining objects and entities of interest given the problem statement. That means that the elements of study might quite differ when we perform a analysis of a quality system or a logistics system even though it might concern the same company. Once we have defined the entities the investigator will examine the relationships enabling us to understand the behaviour of a system.

Defining Systems

Therefore, a system is more than just listing its elements. Think about a watch; all separate elements (parts) of a watch do not make it work and indicate the time; however, when it is put together and an energy source activated (hand-wound, automatic winding, battery, etc.) then the watch starts showing the time. For the purpose of analysis and design, the separation of a system from its surroundings helps understanding the relationship between the system and its environment, the relationships between its elements and elements in that environment and the interaction between elements within the system (see definition in Box 2.1). Cutting the relationships of the system, better those of its elements, from the environment will result in limiting any study to the optimisation of the system itself; it will not lead to embedding in its environment or to adapting the system to its environment from which it makes part. Which interaction to review, within the system and with the environment, depends entirely on the nature of the study and the analysis. As Checkland [1993, p. 101] notes: ‘the observer will, *for his own purposes*, use systems thinking as a means for arriving at his description’.

Some examples will illustrate this definition of systems. Box 2.A shows a map of the Galápagos Islands and demonstrates that the view on the system will differ when considering it from a geographical perspective, from a socio-economic view or from an evolutionary perspective (the Galápagos Islands appear in the work of Charles Darwin [1859]). Another example is the service and overhaul of airplanes by an airline that might serve as an element of the airline when exploring the adherence to flight schedules. When looking at the way that interaction takes place between workers within the Technical Service Department to optimise co-operation, people will serve as the elements of the study. However, if we want to observe the maintenance and overhaul of the airplanes themselves, only the steps necessary for this process constitute the elements of study. The interaction with the environment will differ as well. We might consider the propulsion of a car as a system. The propulsion system then includes all elements related to moving a car, e.g. engine, transmission and tyres, but other elements of the car, like the dashboard, will not be part of the system. The examples merely demonstrate the notion that the nature of a study entirely determines how to look at any system or even how to define a system (and therefore, it depends even on the perception of the observer).

Box 2.A: Introducing the Galápagos Islands



Source: Wikipedia [2009]

The Galápagos Islands have become famous through the work of Charles Darwin (1809–1882); they are an archipelago of volcanic islands distributed around the equator in the Pacific Ocean, 972 km west of continental Ecuador (South America), see figure above. The Galápagos islands and its surrounding waters form an Ecuadorian province, a national park and a biological marine reserve. The islands' population (ca. 23,000) lives mostly of tourism, farming and fishing.

When examining the geographical position of these islands, the only interest is into the shape and the position of islands relative to continents, countries or islands (for example, the relative position to the rest of Ecuador). But if an analysis would concentrate on the social-economic conditions, the elements and relationships to consider are social-economic entities, such as fisherman, fleets, food processing companies, traders, tourism agencies and their collaborations. Although the geographical location might be to the advantage of social-economic prosperity, it is not the prime concern. As a third case, Darwin's study focused on the fauna, particularly, the populations of finches that he studied and that allowed him to verify the theory of natural selection that was simultaneously proposed by Alfred Russel Wallace (1823–1913) [Darwin and Wallace, 1858]. Again, the geographical location might favour the study of natural selection but does not include it in the first instance. Hence, these three examples of investigations into a system show that the elements and relationships to consider might differ substantially from study to study.

Modelling systems by using Applied Systems Theory starts out with analysis of the elements and their relationships and the interaction of a system with its environment. Figure 2.1 shows also that you can distinguish a system within total reality but not separate it from that same total reality. This points to the need to consider organisations as open systems rather than closed systems. The definition, the one of Applied Systems Theory, mentions several key words (see Box 2.2) that need elaboration before moving on to discussing the properties of systems and closed versus open systems.

Elements

The elements constitute the smallest parts needed for the purposeful analysis of a system within a specific study. In Figure 2.1 all elements, except G, are part of the analysis undertaken; the systems itself consists of the elements A, B, C, I and J. To understand the purpose of any system, you need to look at the relationships between the external elements and the internal elements. For example, an element of the propulsion system of a car is the engine. The engine converts thermal energy (through the combustion of fuel) into mechanical energy and transfers that energy through the drive shaft to the gearbox, another element of the propulsion system, to the axles that are attached to the wheels; finally, it creates the driving force through the contact with the road surface (this contact constitutes the relationship with the environment). As another instance, within the logistics system of a factory, the department responsible for the supply of materials might be seen as an element of the system when analysing the flow of goods. Both the propulsion system and the logistics system have relations with the environment, which affect the performance of the system. For example, the propulsion system is linked to the driver as an element from the environment; actions generated by

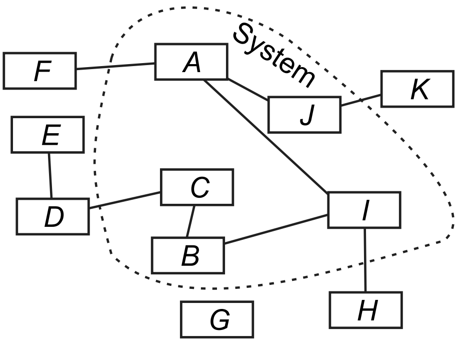


Figure 2.1 *System with its elements and relationships. Each of the internal elements has at least one internal relationship to other elements within the boundary (A, B, C, I and J). The environment consists of those external elements that have direct relationships with internal elements (D, F, H and K). Some elements outside the system boundary have no or no direct relationship with internal elements (E and G) and should not be considered as part of the system's environment.*

the driver influence the behaviour of the propulsion system. And conversely, the reaction of the propulsion system to external circumstances, think about slippery road conditions, determines how the driver might have to adjust speed. The department responsible for material supply within the logistics system of a company connects to suppliers as external elements. Therefore, the logistics performance of any company depends not only on the internal elements but on the performance of suppliers as well. Both examples show that the environment has a strong impact on the performance of systems. For that reason, the examination of the interaction of a system (through its elements) with the environment often constitutes the first step of analysis.

Elements might range from physical objects to constructs of the mind, depending on the study's objectives. When examining the material flow as such within a company, the flowing elements of the system consist of the materials and parts transformed into products. In the case of information systems, the elements also depend on the problem definition. The microprocessor within a computer or server handles bits or bytes, the elements that make up a system through batch-jobs or files that pass through that processor. But in the case that the investigator wants to analyse the infrastructure of the information system, the servers, computers and cabling are the elements of the system. In another case when we are examining the interaction between the organisation and the information system, the information is considered the element (information is then the combination of bytes into data with an attributed meaning; information is a construct of the mind). As might become clear, the problem definition has a strong influence on what to consider as

Box 2.2: Key Concepts of Systems

Elements

The elements constitute the smallest parts needed for the purposeful analysis of a system within a specific study.

Relationships

Relationships describe the dependencies amongst elements, whether it be a mono- or bi-directional influence.

Universe

The universe comprises of all elements and relationships, known and unknown.

Environment

The environment is that part of the universe that has any (known) direct relationships with elements of the system.

elements and whether these have a discrete, physical nature or have abstract meanings within a particular study.

Relationships

The elements in the environment and the internal elements have relationships that describe the dependencies amongst elements, whether it be a mono- or bi-directional influence. This influence reflects the change(s) in values of properties of systems. Between elements, different relationships might exist. For example, in the propulsion system of a car the engine and the gearbox share both an energetic relationship as well as a geometric relationship. Note that within a system interrelationships exist between elements, which implies that all elements are connected by relationships and no isolated elements are present. When examining the logistic relationship between a supplier and the customer aimed at the physical goods flow, the human interaction is of no interest for the study at that point of time; therefore the directors of the company are not part of the system being studied but part of total reality. Hence, the aims of a study determine the relationships both internal and external to be considered for analysis.

Universe

The total reality points to the universe comprising of all elements and their relationships, known and unknown. Depending on the nature of the study, we will consider only a partial set of elements and specific kinds of relationships within the total reality as identified by a problem definition. This implies that not all elements and relationships bear any weight for a specific study. Besides, no one can be aware of all elements and relationships; the regular discovery of stellar systems, planets, etc. demonstrate this notion. In most cases it is possible to distinguish the elements in the universe that have an impact on the system under investigation. For the propulsion system of a car, the universe consists of other systems from the car, e.g. the suspension system, as well as other systems, like the weather system, which do not directly influence the behaviour of its propulsion system. Even so, this applies as well to the human resource management when studying the optimisation of the logistics system of a personal computer manufacturer for deliveries to customers. The concept of the universe as a total reality beyond full comprehension points to the limitation of any study: taking only a partial reality into account.

Therefore, the view on a system might totally differ when considered from distinct disciplines and sciences each having their own objectives as well. Considering the definition of a system, each study requires emphasising specific elements and relationships within total reality. This notion indicates that each of the different disciplines working together in a context of solving a problem within a specific study should generate an unique focus on the elements and relationships within the universe. Take for example, the customer service department of a bank. A computer specialist might look at it from the perspective of hardware, integration with communication technologies and software applications that control workflow. However, a marketeer will approach the same department from the frame of reference for communication with customers, offering of products and resolving of complaints. In other words, no system will be the same for investigators from different backgrounds; it will even vary from study to study how a system is defined.

Environment

When analysing a system, in the first instance, we tend to restrict ourselves to that part of the universe that has any (known) direct relationships with the system. The environment consists of the elements that have any relationship with the system but are not part of the system and for that matter are part of total reality (universe). In Figure 2.1 element G is no part of the environment while at the same time the environment itself is part of the universe; even element E should not be considered part of the environment since it does not have a direct relationship with any internal element. West Churchman [1979, pp. 35–37] notes that those elements that are outside the system's control but relevant to its objectives constitute the environment. The examples as mentioned above identify the driver as part of the environment for the propulsion system of a car and the supplier as environment for the logistic system for deliveries to customers. Again, the objective of the study determines which elements outside the system make up the environment.

The environment exerts a strong influence on systems, even beyond what is visible by the eye. For example, the ancient Egyptians did cut trees and papyrus under the moonlight during the Full Moon, which was for a long time considered a superstitious act. As it later turned out, this timing for cutting papyrus would enhance its durability due the higher degree of saps present in the logs. Nowadays, we would not consider the timing of harvesting wood. From the point of view of the increasing importance of durability in our age, this superstition turns into expansion of our view on sustainable production of wood. The example shows that we need to consider carefully how the environment looks like and how it affects the behaviour of the system.

2.2 Properties of Systems

Once you have defined a system related to the scope of the specific study, the need to describe the system emerges for further analysis and possibly later also the necessity to generate solutions. The description of a system allows further analysis by pointing out which properties it possesses in relation to the problem definition. The generic properties of a system (see Box 2.3) allow doing so and are divided into the content, the structure and the attributes. In addition to content, structure and attributes, the emergent properties of systems demonstrate the principle of systems that they are more than their

Box 2.3: Generic Properties of Systems

Contents
The contents of a system represents all elements that constitute the smallest parts needed for the purposeful analysis of a system.

Structure
The structure consists of all interrelationships which describe the dependencies amongst elements, whether it be a mono- or bi-directional influence. The structure is consisting of both an internal structure and external structure.

Attributes
The attributes consist of the properties of the system or the properties of its constituent elements.

Emergence
Emergence refers to properties of the whole that cannot be solely explained by the properties of the constituent elements.

elements. And finally, the degree of interconnectedness between elements is expressed by the dimension of wholeness and independence. These five properties help to understand the behaviour of the system.

Content

The content refers to the listing of all internal elements of a system; for example, in Figure 2.1 the content of the system is: A, B, C, I and J. The concept of content compares to a list of parts on a technical drawing, the bill of materials used for logistics management and a directory of files on a computer. The content does not describe the relations between the elements and between the system and the environment as such. But it does separate those elements that belong to the system from those that do not within the universe. It is simply a list of elements and the level of detail for the elements might vary depending on the problem definition. For example, if somebody wants to know if all meetings have been documented a list of minutes of meetings (content of a file) will suffice. If somebody else wants to know whether a specific issue has been addressed, the contents of the minutes of the meeting will need to be examined (that means a lower level of detail). Henceforth, the distinction of the level of detail of elements depends on the aims of the investigator and the content merely lists the internal elements of a system.

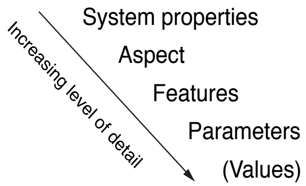


Figure 2.2 *Interrelation between properties, aspects, features and parameters. The system properties may be broken down into aspects, which reflect the types of relationships that are investigated. When decomposing aspects, the investigator of a systems at features and parameters (to which values can be attributed). That means that the figure shows that by going into more detail, sometimes the relationship with the original property of the system might become less clear.*

Structure

To understand the properties of a system, the investigator needs to examine the structure of the system, i.e. the listing of all interrelationships between elements; please note that it always concerns the relationships of interest to the study undertaken. Relationships imply that elements do have a mutual influence on each other that stretches beyond the fact that each of these elements just is present within the system. It approaches the concept of connectivity as described by Hitchins [1992, pp. 79–80]. He notes that only when elements have some influence on each other, an interrelationship exists, changing at least one of the properties under consideration. For example, when a user saves a document on the hard disk of a computer and the programme saves data and settings in separate files. For retrieving documents, the specific application will have to use the interrelationship between the data and settings to make an adequate representation of the document in the user interface (for example, the display of the computer or tablet). Hence, the examination of the structure clarifies the influence elements have on each other.

To distinguish the relationships within the system from the relationships with the environment, a division exists between its internal structure and its external structure. The internal structure records all the relationships between the elements within the system (internal relationships). For example, Wilson [1991, p. 70] mentions that physical layout, power hierarchy, formal and informal communications reflect the structure of the organisation as a system; most of these descriptions are internally oriented. The relationships with the environment, so-called external relationships, are the domain of the external structure, which means that exploring these requires crossing the system's boundary. For instance, the relationships with suppliers are part of an organisation's external structure. Generically speaking, the external structure has a strong affect on the internal structure.

Attributes

Elements do have attributes that we commonly describe by using features. The shape and performance represent attributes of a delivery van in general, the dimensions and transport capabilities features belonging to them (attributes carry similarity to aspects which Section 2.4 will introduce). A feature may be classified as either determinate or determinable. A determinable feature is one that can get more specific. For example, colour is a determinable property because it can be restricted to redness, blueness, etc. A determinate feature is one that cannot become more specific. These features might be described by parameters that in turn might have values. Features do not have necessarily a quantitative value, for example the colour is also a parameter which does not have directly a numerical value (although physicists use wavelengths of light and the painting industry a standardised coding). Instead you might describe features with meaningful adjectives, such as blue for the parameter colour. Figure 2.2 depicts the relations between the system properties, aspects, features and parameters.

Emergence

Especially, when describing complex systems, the whole may have properties that refer to the whole and are meaningless in terms of the parts that make up the whole [Checkland and Scholes, 1993, pp. 18–19]; these we call emergent properties of the whole system. This notion increasingly becomes important when systems consist of many elements and numerous types of relationships. That is apparent for a car: all individual parts cannot provide its transport function, however when put together it is capable of transporting passengers and goods. Conversely, when we strive for reducing systems by distinguishing elements, the emergent properties might be lost. Organisations often achieve performances that exceed the sum of the individual capabilities (often referred to as synergy). These performances elevate the organisation from being a collection of elements to a level of self-being. Therefore, the performance of an organisation cannot be traced back to an individual even though that person might have had a strong influence. In that respect, emergence is a property of the whole system more than of individual elements.

For organisations, biological as well as technological systems this points to an integration step when discussing the properties of a system. When looking at the whole system we might attribute different properties then when reviewing the elements themselves. For the purpose of analysis, we might loose perspective moving from the system level to the level of elements. Conversely, when shifting attention from elements to the system as a whole, we will discover properties that were not noticeable before. These phenomena might explain why ecosystems show resilience when a species (as an elements of it) becomes extinct because of self-regulating mechanisms at the level at the whole ecosystem; for example, the bird called dodo (Raphus cucullatus) died out at the Indian Ocean island of Mauritius during the mid-to-late 17th century, however, Mauritius' ecosystem has continued to flourish (until recently that is). At the same time, ecosystems can collapse because of changes at the level of the elements; that happened when the sea lamprey (Petromyzon marinus) – a marine invader from the Atlantic Ocean that entered the Great Lakes (between Canada and the U.S.A.) through the ship canals and locks built to bypass obstacles like Niagara Falls – outcompeted smaller, native lampreys and devastated the fish communities of the Great Lakes from the 1930s on. In that sense, these examples show that systems theories are by definition not reductionist in the sense of Descartes' view but provide a balancing insight between properties that can be attributed to the system as a whole and properties that are an extension of the properties of the elements.

Wholeness and Independence

This especially holds true when elements have many and strong interrelationships. Wholeness indicates that all elements have relationships with all other elements within the system whatever these might be. In such a case changes in any relationship will affect all its elements and in practice lead to instability within the system and towards the environment. Some extended operating systems for computers, such as versions of the Windows® operating systems, and large software applications tend to possess this

Box 2.4: Definition of Subsystems and Aspectsystems

Subsystems

A subsystem is a subset of elements within the system, while retaining all original relationships between these elements.

Aspectsystems

An aspect system is a subset of relationships within the system, while retaining the original elements on the condition that all remaining elements have mutual relationships within and outside the system.

In contrast to denotation of subsystems, there are many definitions on how to call a system with a subset of relationships under consideration. For example, aspectsystems are also known as partial systems. Calling them partial systems might cause confusion because some authors follow the definition of aspectsystem from Applied Systems Theory (e.g. de Leeuw, 1979, p. 97) and some use the mathematical sense where it means a subset of equations. Further adding to the confusion, some denote a partial system as a subsystem. And a subset of relationships has been called a functional system as well (Gershenson and Heylighen, 2003, p. 608). Finally, aspects are equated to subsystems (van der Zwaan, 1975, pp. 150, 153). In the definitions of Applied Systems, there is a strong separation between looking at specific elements (subsystem) and specific relationships (aspectsystem).

characteristic and within the community of information technology have a name that adaptations have unpredictable outcomes. At the other side of this spectrum is independence when elements within the system have no interrelations at all. In fact, we cannot call this a system since it does not comply with the definition in Box 2.1, which presumes the presence of relationships between elements. Hence, the degree of interconnectivity within the system also indicates how difficult it might be to intervene. For systems that are gravitating towards wholeness, there are possible ways to counter that; for example, modular design of products and services aims at achieving a higher degree of independence that way creating more flexibility and less dependence of production control to market demands. Practically, systems span a wide range of connectivity between elements ranging from wholeness to near independence, however, the higher the degree of interrelations between elements, the more complex the system to understand (note that Chapter 8 will expand on complex adaptive systems).

2.3 Subsystems

When conducting a study of a particular system, the need to examine specific parts of the system might emerge. In the case of evaluating the performance of an organisation we might need to analyse the purchasing system as part of the logistics system. While designing a windmill we might need to look at the energy conversion. Both examples show an expansion of details, while ignoring other elements or relationships. Since a system consists of elements and relationships, we might as well distinguish two ways of breaking down a system into 'partial' systems (that follows from Figure 2.1 that depicts the key elements of a system: elements and relationships). First, we might look at specific set of elements contained within the total system, then we speak about a subsystem (the purchasing system) and, second, we might examine certain types of relationships by distinguishing an aspectsystem (the energy conversion).

Looking at clusters of elements, subsystems, helps defining main parts within a system without describing endless lists of elements (see the definition in Box 2.4), especially when the original system contains a large number of elements. Imagine a listing of all the parts of an airplane, the individual organisms of an ecosystem (like the rainforest) or all the personnel working for a company like Shell or Philips through which the investigator has to find his way to find a certain type of parts, species or personnel, e.g. database specialists. Subsystems define sets of elements as purposeful entities within the system. Doing so, the relations within the system, with the environment and, therefore, the relations between the subsystem and the other elements remain the same. The original system becomes now part of the environment of the subsystem. In fact, an investigator might view a system as a set of interrelated subsystems.

The application of dividing systems into subsystems strongly relates to simplifying the structure of a system to purposeful entities without losing overview. During the study of these systems and their elements, subsystems serve as intermediates between the system as a whole and the elements. The airplane has different subsystems, e.g. the electrical system, the fuselage of the plane, the wings, etc. An organisation will have subsystems, too. When studying the logistic system, the purchasing system and the warehouse system are subsystems. Within the purchasing system, goods receipt is one of its subsystems. All these subsystems have interrelations. In a house, one might have subsystem for water supply and supply of electricity; these are interconnected by the geometrical position in the building. Hence, subsystems might have various levels, depending on the depth of the study, but the different type of subsystems also have interrelationships to each other.

The definition in Box 2.4 also reflects that a subsystem itself is a system (see Figure 2.3). Defining subsystems results in studying the smaller parts of a total system without isolating it from the total system and its properties. It implies as well that a specific study into a subsystem requires an adapted problem definition for the subsystem. The original objective of the study resulted in distinguishing that particular set of elements and relationships while the need for exploring a subsystem has narrowed down the focus caused by further analysis at system level. That further analysis told to limit the scope to these particular elements, i.e. the subsystem. Hence, the need for investigating a subsystem has a strong link to the progress of the analysis and detailing as part of the study.

2.4 Aspectsystems

The second principle for having a more detailed look at a system focuses on which relationships in particular draw interest in the perspective of the problem definition. An example in economics illustrates this. When conducting a cost-price analysis results in the quest to find data on prices of parts or on units of labour, the physical characteristics of the product are of no interest except for obtaining the proper data for the cost-price calculation.

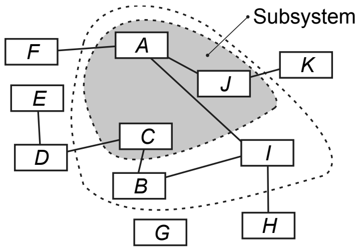


Figure 2.3 *A subsystem within a system. Some elements are not looked at as part of the particular subsystem (elements B and I in this example); they become part of the environment of the subsystem.*

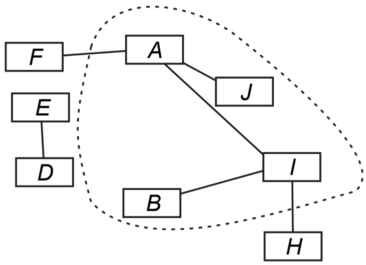


Figure 2.4 *Aspectsystem. While principally retaining all elements, the specific relationships studied, result in discarding some elements as being part of the system under review. A comparison with Figure 2.1 shows that element C is no longer part of the system and that elements D and K are no longer part of the environment.*

Other relationships than those related to the objectives of the study have no impact on the results, for example, the aesthetic aspect of the product. This way the number of relationships under examination is reduced to the necessary ones according to the nature of the study. The relationships subject to closer study are called the aspect or aspects and an aspect always concerns a subset of the relationships present in the system and its relationship with the environment.

An aspectsystem reflects the choice for particular relationships as the area of interest. Basically, we eliminate all the relations except the ones we choose to explore (see definition in Box 2.4). If it occurs that some of the remaining elements do not have any more relationships with other elements in the system, these elements might be removed, leaving the aspectsystem always with elements that have mutual relationships within the system or with elements outside the system; see Figure 2.4 in relation to Figure 2.1, where elements D and E have a relationship of the aspect but no relation to elements within the system for which these should be discarded as part of the study). An example might illustrate this; the fuel consumption of a jet engine has no direct relationship to the use of lubricants for rolling parts within the total system of the airplane. Hence, the focus on a specific type of relationships not only reduces the number of relationships to consider but might also affect the number of elements in a more detailed study.

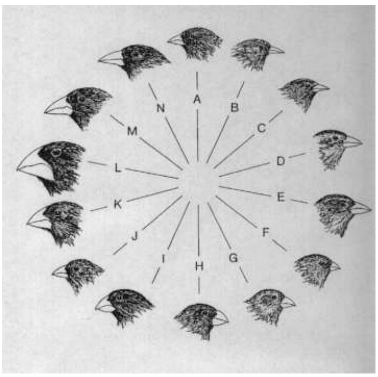
No predefined aspectsystems do exist since the aspect under review, a particular set of relationships, finds its origin in the specific problem definition. When communicating people often point to general classes of aspects that might have a common meaning for all, e.g. the energy system. Within companies, the quality system and the logistics system are mostly seen as separate entities. Though when quality is a must, improvement of the business processes might require investigating both these general aspects and integrating them into one aspect for the study at hand (and may be even skipping relationships of quality and logistics that do not relate to the focus of the study). This example underlines the necessity to articulate in each situation the aspect for evaluation.

For further illustration of the concept of aspects, two examples will follow with generic classifications of relationships. To describe an office building and an organisation an architect might distinguish several aspects:

- the geometrical aspect. This includes the dimensions of the structure of the building, the size of the offices, the lay-out, the position of the building in the environment, etc.;
- the functional aspect. The functional aspect describes the use of the building, the flow of people through the building, the goods entering the building, catering facilities and so on;
- the energetic aspect. In present times, the energy consumption plays an important role in the design and construction of buildings;
- the utilities aspect. This aspect consists of the power supply throughout the building, the information and communication infrastructure, the water supply and piping, the drainage system, the illumination and so forth;

Box 2.B: Galápagos Islands: Subsystems and Aspectsystems

The Galápagos Islands have become most famous through the work of Charles Darwin (1809–1882) when he studied populations of endemic species. From the perspective of systems theories, he has applied thinking in subsystems and aspectsystems. Consider all fauna in these islands as a system. By taking a specific species within the fauna, a subsystem is created. A specific population of one the species on one of the islands should then be called a subsystem of a subsystem. By comparing subsystems of subsystems, most notably the finches, Darwin did find the evidence for the theory of natural selection and adaptive radiation. However, by concentrating on the anatomical appearance of species, he has focused on only one aspect; for example, he did not consider predatory relationships. Nowadays, biologists would rely on a number of aspects before concluding on relationships between populations of species, DNA samples being one of them.



- the aesthetic aspect. Office buildings should be a pleasant place to work in and might have to leave an impression in people's mind;
- the structural aspect. Buildings have to withstand external influences, weather and earth movements, and display internal strength during the time of occupancy;
- the maintenance aspect. The building has to be kept in a working state due to the deterioration appearing in the course of time.

Each of these aspects describes particular sets of relationships of the building, which may have little or limited interrelations. Eventually, the problem definition will define which particular sets of relationships are of interest and this way what the aspect compromises. Generic classifications of aspects have little meaning for specific problems except that they might be helpful for generating theories for generic aspects, like in the case of an organisation:

- the logistic aspect. This aspect consists of the flow of materials and goods through the company and to the customers. It also includes planning of production, storage and movements;
- the quality aspect. This aspect entails meeting the customers' requirement sand maintaining the standards for products and processes;
- the technology aspect. The deployment of skills and knowledge to expand the product range and to improve primary processes are the domain of technology;
- the human aspect. It addresses the way people within the company communicate and co-operate either with other in the company or with persons outside the organisation;
- the information aspect. This entails the flow of information through the company and the processing of data;
- the financial-economic aspect which compromises the cash-flow, budgeting, decision-making, etc.

These aspects of an organisation follow more or less the division of (scientific) disciplines, neither one describing the system in its full extent. When choosing for a specific aspect, the study limits itself to a partial description of the object under review. However, such a description might go beyond a single aspect as a generic classification. For example, in the case of the firm, if a study is undertaken into handling of complaints, only a part of the quality aspectsystem and part of the logistics aspectsystem will be of interest. Hence, for specific problems the aspects under consideration might be unique and not following canonical divides and that means that what is considered a system and aspectsystem is contingent on the problem definition.

Describing a system in fuller detail requires the comprehension of interrelationships between aspects that might exist, though at a specific point in time little might be known about these. These interrelationships come into the picture during evaluation, appraisal and decision-making. Managers and engineers take decisions regarding trade-offs between quality and cost-price but each person attributes different values to the two aspects. Even persons fulfilling similar jobs will have different opinions. Therefore, the trade-off between aspects is subjective and might differ from one occasion to an other, mainly because little is known about the interrelationships between aspects.

2.5 State of Systems

At a certain moment in time, a system might have defined properties, the content, the structure and the attributes, the so-called state of a system (see definition in Box 2.5). For example, a company has a set of elements, an organisational structure and has certain values for the financial and logistic aspect, all representing the state of the system at a given moment. When the state of the system does not change in view of the problem definition, the entity is a static system, the properties remain the same within the given time-frame. The position of a bridge in a landscape on a map marks a static system. If at an event any of the system's properties changes, whether it concerns the content, the structure or attributes, then we call the system dynamic. A capital expansion of a firm represents such an event, some of the features concerning the financial aspect do change with the intent to strengthen the financial-economic position of the company. Activities, events leading to other events, take time in general, creating interdependencies between several states of a system. To summarise, when the state of a system remains unchanged, the

Box 2.5: Definitions of State and Behaviour of Systems

State

The state of a system describes its content, its structure and (the values of) its attributes at a given moment in time.

Behaviour

Behaviour is the capability of a system to respond to variations in external relationships and modifications of the external structure, either through changes in attributes, adjustments of the structure or adaptation of the external structure.

One could say that the state of a system is related to a specific point in time and behaviour is considered during a certain period of time.

Behaviour can be static or dynamic; behaviour is called dynamics when properties or relationships change. The properties can change deterministic or probabilistic. If the properties remain stable within a specific time-frame, the system is in a steady-state; however, when the outcomes depends on the memory of the system, the behaviour is transient.

system is called static; when activities cause any type of changes in the state, the system is regarded as dynamic.

The state of a system is therefore dependent on previous events and states; all these successive stages, the history of all previous states and events, correspond to the memory of the system. In the case of companies, the state of an organisation has roots in previous organisational structures, the intake from orders, the knowledge gained by people working in the organisation. If the elements and relationships remain unchanged over a period of time, only the attributes change limiting the scope of a system to its present capabilities. The memory will tell us about the adaptations taking place in response to changes in the environment because they are embedded in the current state of a system.

When modifications occur in the interrelations, within the system or those with the environment, or elements, this implies directly also alterations in relationships; the system has an altering structure. Such an altering structure might display a repeating pattern; in general it is assumed that these variations are irreversible due to the memory. Managers and engineers exert a similar characteristic in this view when both look for interventions to enhance performance of either organisations or technical objects through structural changes. These structural changes always concern changes in elements and relationships, e.g. the organisational structure or redesign of equipment. The observation that the structure does not change might entirely depend on the interval between the monitoring moments, pointing out the caution to drawing early inferences on the dynamic capabilities of a system.

To summarise, the dynamic capability of a system tells about the ability to undergo change in state while the changes in the structure reflect only on the elements and relationships and not the attributes. Examples of the various possibilities are:

- bridge on map (position in the landscape): static system;
- car engine (delivering power for propulsion): dynamic system, permanent structure;
- company (delivering products to customers): dynamic system, altering structure.

Generally speaking, systems either have a permanent structure that we intend to change in a revised or new permanent structure or have a changing structure that we influence as participants in the system.

2.6 Behaviour of Systems

A dynamic system will display specific behaviour during the time of the study depending on the nature of the objectives either through variation in attributes or by modifications of the internal structure. The time-frame might influence the outcomes of the study depending on its horizon: how did the system respond to changes in the external structure during different periods. Take a company, on the short-term substitutes for products from competitors might lead to direct changes in price and delivery time by a company, whereas on the long run it should develop a new product range to battle the threat of this unexpected event. Therefore, the events in the external structure always lead to an internal reaction of the system. Additionally, in many cases, the internal activities also result in changes towards the external relationships again causing a reaction by the environment, as seen from the example from the company. Behaviour denotes the capability of a system to respond to variations in external relationships and modifications of the external structure (see definition in Box 2.5).

During the studies, the investigator might encounter one of the two typical cases of a system's behaviour:

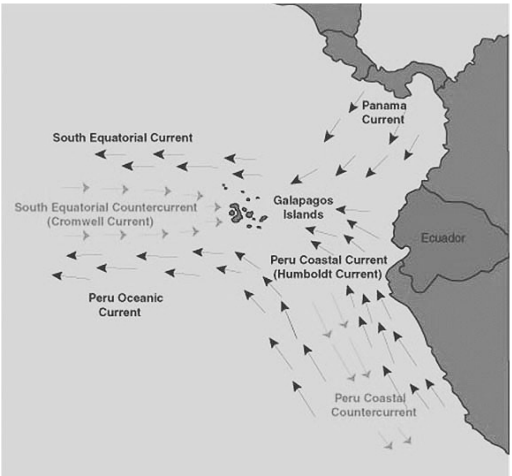
- static system behaviour. The properties of external relationships depend only on the specific values of events acting on the system and the timing of these values;
- dynamic system behaviour. The properties of external relationships depend also on the history of events over time.

For example, a company processes orders for standardised products from a wide variety of customers. If the lead-time remains the same no matter how many orders it accepts the company displays static behaviour in terms of the lead-time; to achieve this it should be possible to tune the capacity to the order flow and the company should have an infinite capacity. When the capacity has limitations, the actual lead-time of the company will also depend on the intake of orders during previous periods. Whether the behaviour of a system is static or dynamic does not only depend on the time-frame but also on constraints embedded in the system's properties.

When we can predict the behaviour of a system entirely, then the behaviour is deterministic whether the nature of the system behaviour is static or dynamic. The responses of control systems in petrochemical plants possess this characteristic by reacting on deviations in the chemical processes. In contrast to deterministic behaviour, the system might also display behaviour with a degree of probability, stochastic system behaviour. For example, fuzzy control systems coming about during the 1990s found their way in home appliances and not exerting a predefined action. Although capturing systems' behaviour becomes more difficult in case of stochastic changes in relationships, tuning of attributes and relationships belongs to the possibilities to alter the behaviour. In both cases, deterministic or stochastic behaviour, the outcomes of changes in the relationships are predictable, albeit to a varying degree.

In case of recurrent behaviour, either deterministic or stochastic, the system is in a steady-state. The system repeats the same changes in relationships and attributes, mostly related to the fact that similar events act on the elements which requires no adaptations in relationships and elements. When events cause changing the behaviour in course of time, the systems is called a transient system. The memory might prevent that particular behaviour appears again as happens during the growth stages of a human

Box 2.C: Galápagos Islands: Behaviour



The unique, relatively stable subtropical climate at the Galápagos Islands has contributed to the study of endemic species. The climate is determined almost exclusively by ocean currents, which are themselves influenced by the trade winds that push them. The marine biota are also affected by these currents. The Galapagos Islands are situated at a major intersection of several ocean currents, the cold Humboldt current (which predominantly influences the climate), the cold Cromwell current (also known as the Equatorial Countercurrent, which is responsible for much of the unique marine life around the Galapagos) and the warm Panama current, see figure above. The unique mixture of relatively cool waters, tropical latitudes and islands with different altitudes produces an ever changing environment; that has resulted in flora and fauna found nowhere else on Earth.

From a system's perspective, the climate is relatively constant but its behaviour is dynamic and stochastic when predicting the weather for a relatively short period of time, say from days to weeks; the weather can be predicted but there is uncertainty about the exact conditions. This caused by the memory (today's weather conditions depend on yesterday's ones). Taking a time horizon of years, the climate is fairly constant with predictable cycles, in systems theory's terms: the climate system of the islands is in a steady-state. Even the El Niño, occurring every four to seven years, has a fairly predictable impact on the climate of the islands. The recent trends in climate change can be labelled as causing a transition; for example, at least 45 Galápagos species have now disappeared or are facing extinction. For the study of endemic species at the Galápagos Islands, the climate constitutes the environment.

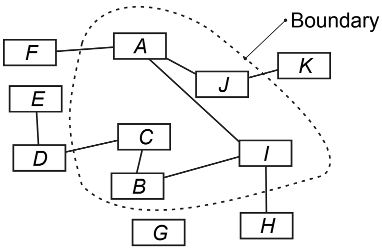


Figure 2.5 *Boundary of a system. The boundary separates the internal elements from the elements that constitute the environment. The relationships that cross this boundary, i.e. relationships between internal and external elements, are called the external structure.*

being. A steady-state becomes only possible when a homeostasis, a balance, occurs in the relation to the environment.

2.7 Systems Boundary

Around a system the investigator will draw a system boundary, separating the elements from the environment (see Figure 2.5). The purpose of study will determine this separation to examine these specific elements within the universe (system), and the external structure and internal structure. As a way of illustration might serve the study of whales in their habitat in New Zealand. Although this might help to study behaviour of local populations of sperm whales, some whales also follow migratory routes from the Antarctic to the tropics. If the study wants to understand, the behaviour of all whales, it might be necessary to include the migratory routes, resulting in an increase of geographical spread of the system studied. That means that the problem definition determines mostly the system boundary. Therefore, there are a few practical guidelines for setting the system boundary:

- the exchange with the environment concentrates on a few elements. The internal structure has in this case a more dominant role in determining the system behaviour than the external structure. This might result in the practical guideline that the number of internal relationships equals or exceeds the number of relationships in the external structure;
- the exchange with the environment might require more effort then maintaining the internal structure. This indicates the capability of the system to maintain itself within its environment;
- the capability of the system to serve a purpose within its environment. Again, this refers to the capability of the system to maintain itself within its environment but directed at its purposefulness.

Might a system experience difficulties in maintaining itself in the environment than the system has to adapt its behaviour to the events taking place in the external structure or has to dissolve itself. Such a situation might arise from the diffusion of the system boundary, a problem encountered by many companies through the increased capabilities of information and communication technology where customers have a stronger influence on the behaviour of a system. Whether static or dynamic systems, or whether they display static behaviour or dynamic behaviour, the internal structure should match with the performance requirements imposed on and through the external structure.

The interaction with the environment points to so-called open systems. In the case of closed systems, the interaction with the environment is not considered. It is hard to imagine that to be the case, any system has a position in the universe and is interrelated. Nevertheless, if that occurs, the only consideration is the internal structure; the system boundary merely serves as a separator of the internal structure and content from the universe (not just the environment, following the definition of Applied Systems Theory).

2.8 Summary

Looking at systems means purposeful distinction of elements and relationships within the universe (therefore, systems are always part of the universe). The separation should serve the nature of the study and an investigation will take only those elements and relationships within the system into account plus the relationships with its environment, i.e. those elements in the universe with which the internal elements have relationships. By describing a system by its contents, its structure and its attributes, it becomes possible to define the state of a system and its behaviour in view of the nature of the study undertaken.

Subsystems and aspectsystems represent two different ways of examining a system in more detail. Subsystems leave the relationships intact in favour of looking at a subset of elements while aspectsystems concentrate on certain type of relationships within the system. Defining an aspectsystem means eliminating elements that have no interrelations of a specific type anymore with any other element present in the system. Practically, it means that a study always considers an aspect or perhaps some, while at the same time the investigation concentrates at subsystems of a larger set.

Ultimately, most studies look for ways to modify the behaviour, the change of the state of a system by events happening in the external structure. The modification of behaviour of technical or organisational systems results either from optimisation of attributes (of elements) or from altering the structure of the system. When the behaviour repeats over time the system has achieved a steady-state. Especially organisational systems show transient behaviour due to the memory caused by earlier events that led to adjustments especially in the structure of the system and therefore will hardly reach a steady-state.

References

Ackoff, R. L. (1969). Systems, Organizations, and Interdisciplinary Research. In F. E. Emery (Ed.), Systems Thinking (pp. 330–347). Harmondsworth: Penguin Books.

Bertalanffy, L. v. (1973). General System Theory. New York: George Braziller.

Checkland, P. (1981). Systems Thinking, Systems Practice. Chichester: John Wiley & Sons.

Checkland, P., & Scholes, J. (1990). Soft Systems Methodology in Action. Chichester: John Wiley & Sons.

Darwin, C. (1859). On the Origin of Species by Means of Natural Selection or, The Preservation of Favoured Races in the Struggle for Life. London: John Murray.

Gershenson, C., & Heylighen, F. (2003, 14–17 Sept.). When Can we Call a System Self-organizing? Paper presented at the 7th European Conferene on Advances in Artificial Life, Dortmund.

Hitchins, D. K. (1993). Putting Systems to Work. New York: John Wiley & Sons.

Leeuw, d., A.C.J. (1979). The control paradigm as an aid for understanding and designing organizations Progress in cybernetics and systems research (Vol. 5, pp. 93–100). London: Hemisphere.

Miles Jr., R. F. (1973). Systems Concepts: Lectures on Contemporary Approaches to Systems. New York: John Wiley & Sons.

West Churchman, C. (1979). The Systems Approach: Revised and Updated. New York: Dell.

Wikipedia. (2007, 14 March). System. Retrieved 18 March, 2007, from http://en.wikipedia.org/wiki/System

Wilson, E. O. (1998). Consilience: the unity of knowledge. New York: Alfred A. Knopf.

Zwaan, v. d., A.H. (1975). The sociotechnical systems approach: A critical evaluation. International Journal of Production Research, 13(2), 149–163.

3 System Approaches

Suppose we have defined a problem and identified the system associated with it: how to start investigating this system? Take it apart, examine all individual parts (replacing faulty ones) and reassemble to see if it works? This carries the danger of drowning in too much information, too many details, forgetting about the relationships between the constituent elements, and ignoring the interactions between the system and its environment. Or should we look at the system from the outside, occasionally opening a suspect subsystem for closer investigation? Starting from the whole has the risk of not gaining enough depth to really identify the source of trouble. Either way might end up in addressing symptoms instead of finding the root causes; reason why this chapter looks into more detail about how to deploy systems theories for resolving problems.

In any case, an adequate problem definition constitutes the first step of investigation. For example, if a car does not move, the reason could be a mechanical fault somewhere inside the system *car*. The problem statement *the engine hums, the wheels spin, but it does not move* could lead to a wider systems boundary to include the mud pool that the car is actually in (or at least to take into account that the car has relationships with its environment). Therefore, the problem description should contain indicators for a system boundary and also point to the aspectsystem to be examined. In this particular example, the aspectsystem *motion* could quickly be narrowed down to traction, leaving out the need to examine other aspectsystems. This process of turning a problem description into a smart way of looking at the system and its relationship to the environment is called modelling.

This chapter explores modelling and associated system approaches while building on the concepts introduced in Chapter 2. Section 3.1 will discuss three methods of abstraction associated with modelling; abstraction constitutes one of the basic steps during the creation of a model needed for analysis and synthesis (design). Thereafter, Section 3.2 will describe the blackbox approach as a specific tool for system analysis. That leads to the distinction between inductive and deductive reasoning in Section 3.3, closely related to analysing a system from the perspective of elements or as a whole. Section 3.4 presents a classification of models, partially based on systems theories. Consecutively, Section 3.5 will pay attention to a hierarchy of systems, which helps to understand the validity of models for different types of systems.

3.1 Modelling and Abstraction

From the perspective of a given problem definition, a model is a simplified system to study another system. This goes back to Rosenblueth and Wiener

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[1945, p. 316] who state that abstraction consists in replacing the part of the universe under consideration by a model of similar but simpler structure. Rules, concepts, formulae, equations, drawings, graphs, etc. model reality by simplifying that reality into elements, relationships and properties or parameters that matter. They reflect on elements to study with specific relationships or aspects in mind (see Figure 3.1). Hence, a model is always an aspectsystem, pointing out the elements for closer observation. Beware; a model does not equal reality. For example, the social-economical reality of a country like the Netherlands has a higher complexity than even captured in the statistics of its Central Bureau of Statistics, even though the data are complex. Looking at the complexity of reality leaves often no choice but simplification. Additionally, de Rosnay [1979, p. 141] states that the building of a model implicitly includes an inventory of existing knowledge and knowledge not yet obtained. That means that modelling implies both the simplification of reality to understand systems and their behaviour, and the limitations of our contemporary knowledge.

In that sense, West Churchman [1979, p. 76] remarks: *More generally, it shows there is a fundamental limitation of any modelling of a system, that a system is always embedded in a larger system.* Again, this statement signifies the selection of the aspect(s) and subsystem(s) to consider for the investigation and that way defining the environment of the selected subsystem(s). For example, looking at the earth's ecosystem means understanding its connection to the solar system it is part of; changes in the radiation of the Sun influence temperatures and the position of the Moon influences tides. But the remark by West Churchman also means that aspectsystems and subsystems that do not contribute to the (solution of the) problem are best left out. Continuing with the Earth's ecosystem as part of the solar system, Jupiter does not have any effect on the radiation received on Earth and consequently variations in

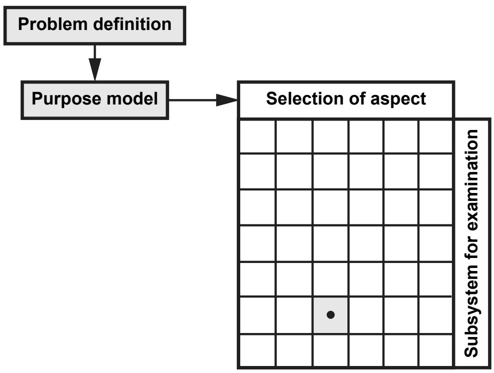


Figure 3.1 *Models as choice of aspects and subsystems. The purpose of the model, often captured by a problem definition, prescribes the primary areas of interest, both for the type of relationships to be examined and the particular subsystems as objects of study. The environment (as part of the universe) denotes an object as subsystem.*

temperatures; hence, it is best left out for the study of that particular aspect of the earth. That makes it all more important for any analysis to consider explicitly the boundaries of a system, which entails its environment, and the type of relationships the focus is on.

This search for understanding what to take into account and what not continues in the concept of abstraction. According to Timpf [1999, p. 126]:

An abstraction denotes the essential characteristics of an object that distinguishes it from all other kind of objects and thus provide crisply defined conceptual boundaries, relative to the perspective of the user.

Additionally, this statement by Timpf implies that modelling constitutes an abstraction process. She recognises three types of abstraction processes (although slightly modified to link these to Applied Systems Theory):

- Classification: a form of abstraction in which an object type is defined by a specific set of observed properties; please note that observation precedes classification. A famous example of classification is the practice of taxonomy by biologists for species, following the tradition set by Carl Linneaus (1707–1778). Such a classification makes it possible to compare objects and to relate them to each other; however, to classify, it is necessary to observe the individual elements first. At the same time, the classification decreases the number of elements, relationships and properties of elements to consider. Taking a viewing point from the elements, based on similar properties, grouping elements and relationships into subsystems and aspectsystems could be considered classification.
- Aggregation: a form of abstraction in which a relationship between similar or related objects is considered as a higher-level aggregate object for fulfilling an objective. An illustration of aggregation is to move from looking at an individual colouring pencil to considering a pencil set. Again, taking a viewing point from the elements, subsystems and aspectsystems could also be regarded as abstraction if they are related to fulfilling an objective.
- Generalisation: a form of abstraction in which similar objects are related based on having a limited range of similar elements and/or relationships. For example, in economics some scientists use selection models derived from evolutionary biological models to describe market mechanisms for companies, while understanding that organisms in evolutionary biology do not equal organisations as entities. As seen from the example, generalisation also occurs when transferring concepts (knowledge, theories, models) from one domain to another one.

These three types of abstraction have their own specific applications when modelling (see Box 3.1). Classification takes place when properties of systems or elements call for grouping with the explicit purpose of reducing the number of 'elements' considered. Aggregation acts as a measure of composition to decrease the relevant information known about a system. And generalisation helps us to transfer explore the validity of mental constructs to a larger set of entities (or domains of knowledge); mental constructs are

Box 3.1: Application of the Three Types of Abstraction

Classification

Classification takes place when properties of systems or elements call for grouping to decrease the number of variables. By way of illustration, houses, schools, industrial buildings could all belong to the generic class *building*, or local roads, city streets, highways could all belong to the generic class *roads*. By putting together similar entities, their differences are selectively ignored.

Aggregation

Aggregation is the putting together of different entities to form a coherent whole (in terms of Applied Systems Theory: either relationships or elements). For example, houses, apartment buildings, offices and amenities could form a community area; in that case, the focus is not only on the individual buildings but the total offering that community area provides. Aggregation purposefully leads to loss of detail (the perspective of the investigation determines whether that loss of detail leads to ignoring relevant properties of the system).

Generalisation

Generalisation is the application of behaviour derived from one set of entities to another set of entities, by the existence of similar relationships and elements but not necessarily all. For instance, after investigating the application of solar energy in houses, an inference is drawn for potential savings in offices, purely based on the fact that both consume energy; however, their energy consumption patterns might differ substantially. Therefore, a key question is not whether to generalise at all, but to what extent.

ideas, theories, models, frameworks, methods, etc. All these three abstraction mechanisms assist an investigator in gaining a better overview to resolve problems.

Classification

The use of classification as principle for abstraction typically arises during the early stages of observation, particularly when little is known about patterns of behaviour. For example, the biological taxonomy describing species, especially in the Linnaean sense of the word, was more than once performed as comparative anatomy of animals and plants, without necessarily an understanding of the underlying concepts and mechanisms that directed biological evolution. Sometimes, if little knowledge exists of certain objects, Box 3.2: Application of the Opposite Principles of Abstraction

Instantination

Instantination, as being the opposite of classification, defines properties of either elements or relationships, that makes these observably different from other elements or relationships in relation to the problem statement. In the case of a generic class of buildings, offices are a distinct instance of buildings when examining energy consumption. Instantination only contributes to understanding when the observably different properties have an impact on solving problems.

Decomposition

When applying decomposition, the opposite of aggregation, to a system, it is seperated into subsystems or aspectsystems of a single kind. When applied to a house, it could be split into living quarters, areas for food preparation and consumption, relaxing spaces and so forth. Or alternatively, the relationships of the house could be divided into geometry of the house, aesthetics, use of utlities, interaction of users with environment, etc. By nature, decomposition leads to distinguishing more detail driven by uncovering relevant subsystems and aspectsystems.

Specialisation

When using specialisation, as the opposite of generalisation, the emphasis is on those relationships and elements that distinguish systems from each other. For example, a meeting room is not commonly found in houses but in offices. Therefore, the design of an office building includes the integration of meeting rooms, or better meeting spaces. Specialisation is also an important way to generate more specific knowledge by applying general knowledge to specific instances.

comparison might lead to understanding the nature and behaviour of objects. It can be seen as a start to gain knowledge; so it happened in biology when Wallace's and Darwin's notion of natural selection [1858] made it possible to reach beyond classification and to understand evolution as a pattern of behaviour (in the sense of Applied Systems Theory, see Section 2.6). At the end, through classification and successive stages of observation governing principles should be detected to expose laws and the nature of change.

Classification has also limitations to its application as a mechanism for abstraction, especially when the initial set of properties used might prove irrelevant during later stages. For example, the single-celled organism *euglena* has properties from both plants and animals: it is green and processes sunlight for energy, as plants do, and it has a tail like structure to propel itself, akin animals have. For many years, it has been classified as a plant. Later, a new classification was created, called *Protista*, which is neither plant nor animal. This example demonstrates that classification resides in the potential of the investigator to differentiate between observable characteristics to those that matter and those that do not contribute to understanding a specific phenomenon; it also indicates that a classification is subject to knowledge.

Instantiation (see Box. 3.2), the opposite of classification, is describing an event, activity, element or system by looking at an individual specimen or phenomenon and setting it apart from the other entities in a class. Hence, enumerating the elements of a class is instantiation, which means that the class is not considered a sufficient description for problems at hand. Through listing and specifying elements (or subsystems) the search starts either for a more accurate description of the class to suit the objectives of the study or for an adequate distinction between subsystems. Listing more details does not always succeed in the resolution of a problem; particularly in management (studies), more details are often sought than necessary by lack of understanding of the governing principles. In these cases, a check proves to be necessary whether the newly introduced properties relate to the problem, and whether these properties indeed resolve the problem; on hindsight it might turn out that the identified properties do not at all address the symptoms found in the problem definition. By applying instantiation, an investigator could identify if properties of individual elements will contribute to comprehending a problem statement better.

The same dilemma exists in Applied Systems Theory when deciding which elements or (sub)systems and aspects will classify as pertaining to the problem statement. At the beginning of an analysis, we often simply do not have enough understanding of the problem to make a sensible choice. Unfortunately, no methodology (yet) exists that enables to draw the system boundary in predefined steps (the strand of Critical Systems Thinking, see Section 10.4, tries to address that). But aggregation, as discussed in the next subsection, gives the opportunity to the review the sensibility of the first choice and to adapt the problem definition. In this way of thinking, classification precedes aggregation. Timpf [1999, p. 131] explicitly states that classification is a prerequisite for all other abstraction mechanisms, even though it might be less useful during later stages of an investigation.

Aggregation

Once a classification has been made, aggregation becomes possible; aggregation as the combination of different items, amounts, etc. into a single group or whole. For example, regarding all storage, transportation and distribution as parts of a (total) delivery system for a company. Timpf [1999, p. 131] notes that only members of the same class can be aggregated, because classification precedes aggregation. In practice, that means that elements or subsystems with similar relevant properties are aggregated into a single group or whole. In the case of a logistic system the resources used for

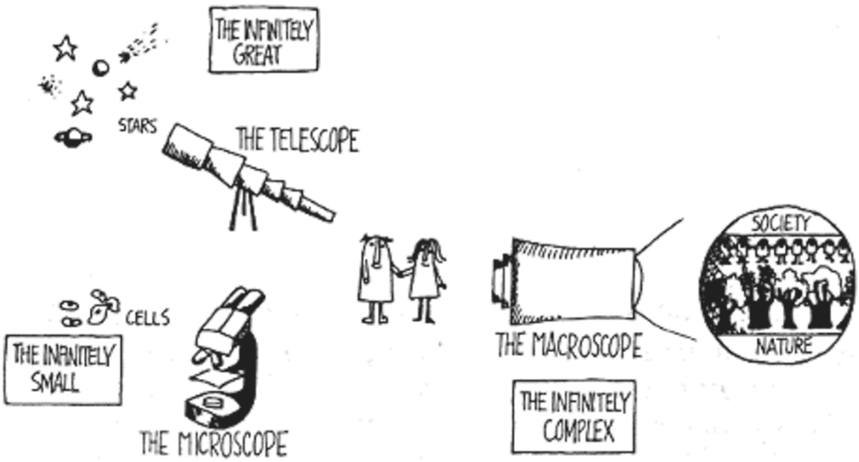


Figure 3.2: *Methods for exploring the unknown [de Rosnay, 1975, p. 10]. The microscope has permitted a dizzying plunge into the depths of the living matter, the discovery of the cell, microbes, and viruses. The telescope has opened the mind to the immensity of the cosmos, tracing the path of the planets and the stars. The macroscope symbolises the study of the infinitely complex, especially the interdependence and the dynamism of systems, transforming at the moment we study them.*

storage (for instance, warehouses), transportations (trucks) and distribution (vans) are quite different in their appearance and even use; however, they all hold products and, therefore, constitute the delivery system. Aggregation is justifiable whenever units are sufficiently independent and similar, e.g. in expressing political opinions through voting or market preferences through individual purchases. Aggregation leads to misleading indicators and theories whenever the whole collection exhibits a behaviour not expressed in a mere summation. Aggregation should not lead to loss of erratic detail but consider purposefully the relevant properties at the level of the grouping or whole.

This implies that aggregation describes at which level of detail a system will be investigated. For taking a close look at something, we can use a microscope; thus, we get a lot more detail, but only from a small piece of the original. Moving the microscope means another detailed view, but losing the previous one. Looking at a big, complex system would require a different device; something that reduces unnecessary details and clutter, but amplifies the essential relationships and relevant (sub)systems or elements. That is why de Rosnay [1979, Introduction] presents the concept of the macroscope, see Figure 3.2: *The roles are reversed: it is no longer the biologist who observes a living cell through a microscope; it is the cell itself that observes in the macroscope the organism that shelters it.* Note that this macroscope represents a symbolic instrument, a way of viewing and understanding; it is not a piece of hardware. Symbolically or not, the microscope and the

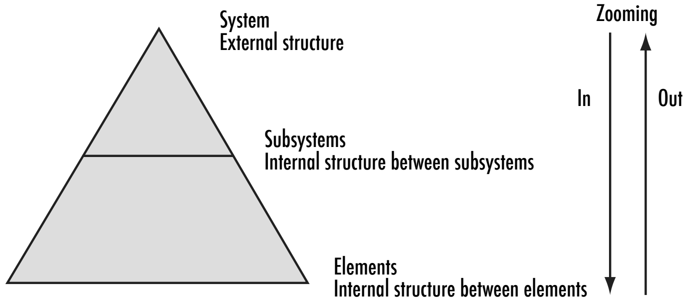


Figure 3.3: *Aggregation strata and zooming in and out applied to systems. In this drawing the levels of system, subsystems and elements represent levels of detail for investigating a system. By zooming in more details become visible (i.e. elements of the system). Zooming out results in distinguishing properties and mostly makes it better possible to examine the external structure of a system.*

macroscope represent two ways of viewing, either in more detail or from an overview.

Obviously, we need to be able to shift to different levels of detail and overview, depending on the state of the analysis. These different levels of detail are mentioned as levels of aggregation or aggregation strata by Mesarovic [1970, p. 37]. The process of going to a level of more detail, thus losing overview, is called zooming in or moving to a lower aggregation stratum (see Figure 3.3). The reverse is called zooming out means gaining overview, but loosing detail. Looking on a map when lost in a city is an example of zooming out. When planning a trip you will first examine a general map to find the way from one city to another; later you will inspect a detailed city map to find out how to arrive at the destination. Looking in more detail and zooming out helps solving problems at different stages of the problem analysis.

Many people might have experienced the following example of implicit use of aggregation strata. Suppose you come home and switch on the lights; but, no light. Fortunately, you have a spare light bulb at hand, so you change it. Considered from the perspective of Applied Systems Theory when you have a problem with your lighting system, based on knowledge and experience, you zoom in on the most probable cause: the light bulb, and take action. When there is still no light, you notice that the digital clock of your music player does not light up either. Maybe a fuse blew? After further analysis, you zoom out to the system level of which your first lighting system is a subsystem. With all fuses intact and still no light, you decide to check with the neighbours. They answer the door carrying a candle. Another step of zooming out tells you that the problem is beyond your control, and that the utility company providing electricity should be notified. This example shows that a careful use of aggregation strata can prevent a search in the wrong direction for too long. Without stating it explicitly, the system boundary has shifted along with the aggregation stratum from light bulb via the electrical system of the house to the electrical system of the area. Because of the possible changes in external relationships it is important to monitor the (changes of the) system boundary during the resolution of problems.

When problems become more complex, it is important to remain aware of the aggregation stratum. If, for example, society is faced with an ever-increasing consumption of electric energy, the choice for environmentally friendly energy sources, like solar or wind energy, could be made. At another aggregation stratum however, one could say that the only green energy is the energy neither produced nor consumed. It is up to the reader to argue whether this is an example of zooming in or out. This example demonstrates that the aggregation stratum at which reasoning takes place also influences which inferences will be drawn.

The opposite of aggregation is decomposition (see Box 3.2). Particularly, decomposition becomes necessary when behaviour of a system cannot be explained any more or no further inferences drawn at the current level of observation. For example, decomposing a personal audio system into a data-reading subsystem, an amplifying subsystem and a sound rendering subsystem to identify the subsystem at fault when the quality of music heard does not match expectations. However, decomposition does not help when examining emergent properties that cannot be clarified by looking at a lower level of abstraction. A case in point is an airplane; its potential to fly is difficultly understood by just looking at the 'nuts and bolts' it is made of. When designing or creating a system, decomposition might assist in enumerating or specifying elements at a lower level of detail so that it becomes possible to produce or buy these elements. Hence, the need for decomposition is associated with lower levels of abstraction if that helps to understand better the problem at hand.

Generalisation

Generalisation is another abstraction mechanism through which we realise that an element, subsystems or even systems has a limited number of characteristics in common with other elements, subsystem and systems, and which permits that these common characteristics lead to a higher level, more generic object or knowledge (also theory) that has a wider validity than the original application. However, generalisation does not require all properties of the elements to be (sufficiently) similar. An example of generalisation of is the application of theories and models from evolutionary biology to companies and market mechanisms; when talking about the functioning of markets, people often refer to competitive forces between companies as being selective for the fitter (please note that for the sake of argumentation, natural selection aims at weeding the least fit rather than selecting the fittest). However, companies and organisms or species appear quite distinct and share only few properties from the perspective of an observer as relevant for applying this analogy (or metaphor) of natural selection. As another example, recognising that both a gearbox and a watermill exploit the aspect rotation is generalisation for transferring one form of potential energy into another one. But a gearbox and a watermill do so in a quite different fashion and to a very different purpose. Hence, generalisation might mean that a phenomenon that is studied can be taken easily out of context and that generalisation has a limited application defined only by what it examines.

In everyday language, the difference between generalisation and aggregation may be blurred. However, modelling requires a clear understanding that generalisation focuses on a common (well known and understood) aspect of (entirely) different entities. Aggregation is merely a method for composing similar elements that constitute part of the same system. Again, this depends on the problem definition. For generalisation, no direct connection between systems considered is necessary. By way of illustration, cybernetics applied to management is generalisation (as happened during the 1950s and the 1960s); cybernetic theories arrived from control theories for technical systems and were used to advance control of production but also to introduce objective-oriented management. Principles of cybernetics could be applied to management of organisations because some aspects are similar (the control of primary processes, see Section 4.3 for its definition) but not all. It were these similarities that allowed this generalisation, while for differences this generalisation did not work out, a case in point being the interaction between employees in an organisation. However, for both generalisation and aggregation, classification that deals with combining entities at the researcher's choice, building a system (named *class*) from elements and subsystems is necessary. The difference between generalisation and abstraction resides in the problem definition. Abstraction is based on the same types of elements and similar properties; generalisation is about one aspect or some aspects at best.

Specialisation (see Box 3.2) is the opposite of generalisation as abstraction mechanism in the context of system approaches. Please note that specialisation might refer to quite different concepts in daily communication. Specialisation occurs when a generic phenomenon or knowledge insufficiently explains necessary details. Again, using the metaphor for natural selection for companies, the survival of the fitter might include systems, elements, relationships (or aspects) that are hardly relevant to organisms; take financial contracts, transactions and instruments (loans, shares) that have no direct equivalent in evolutionary biology. For the other case, *transforming energy* could be a gearbox, an electric transformer, a hydraulic torque converter, a watermill, etc. But for understanding these, quite different expertise is needed although at a generic level they achieve the same: converting a energy source into another type of energy. Specialisation leads to inclusion of elements and relationships that have not been considered in the generalisation of knowledge or the generic object.

3.2 Blackbox Approach

Very different from the three abstraction mechanisms, a convenient way of examining a system is by looking at its external relationships. That means momentarily forgetting about what is inside the system and only observing the changes in external relationships; this is called the *blackbox approach* (see Figure 3.4). When all is normal, there is no need to look into the details of a particular system. Only when there seems to be a problem, the blackbox should be opened (decomposition). For example: when a car does not start when turning the ignition key, you can open the hood, and check all kind of parts, connections, and other intricacies. A simple examination of the external relationship might have revealed the absence of fuel (refilling taken as supplying fuel being an external relationship to the car as a system). Hence, the blackbox approach supports the examination of a system as a whole and avoids getting lost in (unnecessary) details.

The blackbox approach, typical for systems theories, investigates the external structure of a system without identifying any of the internal elements. This approach supports a study by not looking at the elements of the system and the internal relationships and so creating space to focus on the behaviour of the system as if it was one element. In that sense, a blackbox is equivalent to a system [see Beer, 1959, p. 49]; for example, the human body or a house. At this level, the need arises to identify the relevant properties and the relevant (external) relationships for the problem definition. A remark should be made: to a certain extent considering the blackbox as one element eliminates the notion of external relationships, it strengthens the inevitability of linking a system to its environment. When at a later stage of the study it becomes necessary to open the blackbox, subsystems and elements might serve again as blackbox, akin the description of aggregation strata.

When applying the blackbox approach a study will aim at relating changes in one or more external relationships to other relationships in the external

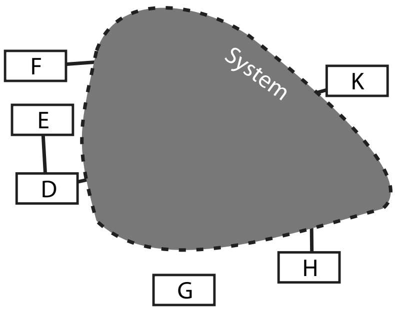


Figure 3.4: *System as blackbox. The blackbox approach allows examining the external structure and behaviour of a system. The elements and the internal structure are not looked at. The blackbox approach for analysing systems supports deductive reasoning by examining the behaviour of the system in response to external stimuli.*

Box 3.A: Building as Blackbox

Imagine that a building is blackbox. Everyday, an analyst observes which people are going in and out of the building and at what hour. That way the observer could find out what type of building it is without knowing the shape, the size and more details.

For example, when people arrive and they are all adults, dressed in formal outfits, carrying briefcases and heading straightforward into the building as a blackbox, an inference could be that it is an office building. What type of an office building would depend on a closer inspection of those entering.

Alternatively, a blackbox where every day two middle-aged people are entering and leaving five days a week at regular times the building wearing formal clothing, going in and out infrequently during the weekend dressed in casual clothes, five days a week, two kids with schoolbags are leaving and entering the house, in weekends accompanied by the two elder persons carrying sports gear, etc., it would be reasonable to assume a family was living there.

If these recordings of entrances and departures in the blackbox were combined with consumption levels of utilities, like electricity, that would even increase the probability of the inferences. An office building will utilise more energy during office hours, while a house would most likely consume more energy during the early morning, evening and early night.

structure. A change in a specific relationship might cause changes in another relationship. It might also occur that multiple relationships become affected. Or that multiple changes in relationships produce changes in one relationship. Consequently, observing a system as a blackbox requires an understanding of the mutual influence of the external relationships. For example, practising physicians deploy this method by deducting from the behaviour of the human being as a system, e.g. temperature, pain, coughs, what internal causes bear relevance to the well-being. Through purposeful dosing of medicine and assessing their efficacy for a particular case, doctors draw conclusions about their earlier findings (or rather their presumptions). Therefore, the response to medicines generates indications about the internal structure of the system (see Box 3.A for an other case of applying this method). More generically speaking, there is a strong relation between the exertion of stimuli and the externally oriented behaviour (and response) of a system.

However, the higher the number of external relationships and the related possibilities for exerting stimuli, the harder its gets arriving at inferences. Even to the extent, that it might become impossible to determine with certainty how the system responds to these changes in external relationships. Consider a system with only two external relationships. Even when the behaviour of the system is stochastic it becomes possible to describe the influence of one on the other. Increase the number of relationships to four, eight and so on. Then you will notice that it becomes harder to detect changes in relationships in comparison to the variation in only two relationships. The complexity of such an exercise increases certainly when multiple relationships affect multiple others. It seems reasonable that the blackbox approach becomes most effective when the modelling has reduced the external relationships that are considered to an acceptable number.

3.3 Inductive and Deductive Reasoning

In addition to the blackbox approach, the behaviour of a system might be analysed by two different ways of reasoning: inductive and deductive reasoning. These two types of reasoning have different starting points, inductive reasoning starts by looking at the internal elements and relationships and their influence on the behaviour of a system and deductive reasoning works the other way around, from the outside to the inside of a system. Each of these two ways has its specific applications.

Deductive Reasoning

Deductive reasoning looks at the behaviour of a system and tries to arrive at underlying causes. To apply deductive reasoning to a system, one needs a description of the expected state of a system. An example of deductive reasoning might be the case when you run out of cash unexpectedly; there are reasons why which expenditures did lead to the current deficit, esp. by comparing these with a budget. The deficit might have been triggered by factors within your control; for example, you might have spent more on entertainment than planned or have bought more exclusive food items to prepare a meal for your partner. Or alternatively, the deficit resulted from a rise in food prices, fuel, etc. Only by this comparison between what 'ought-to-be' and 'what-is' conclusions become possible. In quite of number of cases this type of reasoning involves a number of these steps for analysis before underlying causes appear. The application of deductive reasoning is found in the analysis of current systems and the evaluation of performance during 'design and engineering' activities.

Deductive reasoning has a close connection with the blackbox approach. When applying the blackbox approach, the investigator tries to understand the system without considering the internal structure. The performance evaluation of the external relationships (those ones that change after an event induced externally) determines how the system will behave as response to external stimuli and what possible weak spots in the internal structure exist. Hackers use this technique amongst others for understanding how computer systems operate before entering them. For this reason, the blackbox approach uses the principles of deductive reasoning for evaluating the behaviour of a system by comparing its performance against 'objectives'.

Equifinality, Homeostasis and Deductive Reasoning.

The principle of equifinality presents another challenge to determine, or for that matter predict, a system's behaviour. Equifinality refers to achieving set objectives through a dynamic balance during changing circumstances [Baker, 1973, p. 9]. Von Bertalanffy [1968, p. 40] writes about equifinality, when introducing the concept as part of the General Systems Theory:

> *In any closed system, the final state is unequivocally determined by the initial conditions... If either the initial conditions or the process is altered, the final state will also be changed. This is not so in open systems. Here, the final state may be reached from different initial conditions and in different ways. This is what is called equifinality, and it has a significant meaning for the phenomena of biological regulation... It can be shown, however, that open systems, insofar as they attain a steady state, must show equifinality, ...*

An example of equifinality is provided by Feiring and Lewis [1987]: a sample of children was observed on interactions with their mothers during 3 and 24 months after birth; initially, at 3 months the group differed on several social behaviours and after 24 months only on one. This example shows that different initial conditions might lead to the same outcome.

If a system reaches a final state – the state describes the properties of elements and relationships (see Section 2.5) – that might be robust to exactly how it has reached that state and therefore for disruptions by the environment, henceforth it will tend to maintain a homeostasis with the environment. The concept of homeostasis was formulated by Cannon [1932, p. 22] for processes of interaction or mechanisms that balance various influences and effects such that a stable state or a stable behaviour is maintained; in turn, his writings on this matter were based on the thoughts of Claude Bernard, a French physiologist living in the 19^{th} century, on *milieu intérieur*. Because of reaching a final state, in a sense independent from the initial state, equifinality directly connects to homeostasis [von Bertalanffy, 1968, p. 46]:

> *... equifinality, the tendency towards a characteristic final state from different initial states and in different ways, based on dynamic interactions in an open system attaining a steady state; the second, feedback, the homeostatic maintenance of a characteristic state or the seeking of a goal, based upon circular causal chains and mechanisms monitoring back information on deviations from the state to be maintained or the goal to be reached.*

Later scientists further developing the General Systems Theory confirmed this principle [Kast and Rozenzweig, 1970, p. 467; Hagen, 1973, p. 79]. As a trivial example, the human body maintains itself at a certain temperature, about 37° C. Disruptions by viral infections and other diseases will be counteracted by perspirations. Note that the principle of homeostasis applies to a wide range of domains, not only biological but also self-stabilising mechanical systems and organisations.

Furthermore, Hagen [1973, pp. 79–80] denotes that in case of homeostasis one property could return to its old value only if another one changed permanently in magnitude. When standing still, humans use muscles to maintain the standing position; imagine to be without muscles and to hold a standing position (relying only a skeleton). Hence the movements of muscles, though minute and hardly visible, make humans stand upright, seemingly without effort. This indicates sometimes as a signal of weakness for the effect of one-time interventions for systems; these interventions must draw on the resources at the disposal of a system before it can reach its equilibrium again.

Another overlooked phenomenon, called heterostasis, makes it possible that systems operate at multiple point of equilibrium, even though a limited number exist in practice [Selye, 1973]. For example, when having fever, patients are at equilibrium with their environment, even though they are maintaining a higher body temperature. This temporary equilibrium is less stable and requires the consumption of additional resources to maintain it in comparison the normative homeostatic state. Hence, the concepts of equifinality, homeostasis and heterostasis imply a link between the variable kept at a constant level and the resources needed for achieving that (this comes together in the concepts of processes in Chapter 4).

In addition, there should be processes for innovative decisions (adaptive systems), which move an entity along its life-cycle in response to external and internal stimuli [Kast and Rozenzweig, 1970, p. 467] for which maintaining the homeostasis does not suffice. Rather, in such cases, the system moves or searches for a new equilibrium. Later chapters about autopoietic systems and complex adaptive systems will elaborate on these adaptive processes for mostly biological systems and organisations. Also, the model for breakthrough processes, as part of Applied Systems Theory (see Chapter 9), demonstrates the related steps to identify new needs and changed requirements and to transfer these into a new structure for steady-state process, particularly for the case of organisations. Although the principle of equifinality assumes that different internal structures might produce the same or similar results and performance levels of systems and processes, the growth of biological systems and social organisations might require the evaluation of internal structures for future fits.

Multifinality is the opposite developmental principle to equifinality, whereby similar initial conditions lead to dissimilar outcomes. This indicates that for the investigator either the mechanisms are not understood or the relevant aspects have been left out; the first explanation is also related to the phenomenon of the impact of tiny variations on the behaviour of complex systems and that will appear in Chapter 8. An example of multifinality is given by Feiring and Lewis [1987] again. They demonstrate the principle of multifinality by referring to the study of children assessed for attachment classifications at the age of 1 and for emotional functioning at the age of 6.

The study revealed that 6-year old boys who were securely attached to their mothers exhibited fewer behavioural problems, but that female behaviour at the age of 6 did not significantly differ among attachment groups. Hence, multifinality indicates that similar starting conditions do not always result in similar outcomes. This implies that by applying deductive reasoning seemingly different phenomena or outcomes might be traced back to similar root causes when multifinality comes into play.

The principles of equifinality, multifinality, homeostasis and heterostasis have far-stretching implications for the application of deductive reasoning. The paradox of equifinality and multifinality means that when observing the behaviour of a system, it might be moving towards a final state irrespective of the initial state or moving away from an initial state without being able to predict the final outcome. That implies that the observer should select the appropriate period for observation of a system to know whether the system moves to a stable state. Also, variations in initial state and the response of the system might indicate whether the entity is subject to equifinality and multifinality. Equally well, for homeostasis and heterostasis, the period

Box 3.B: Equifinality, Homeostasis and Heterostasis

When looking at a house, it might be maintaining a stable temperature (this can be measured externally), certainly if there is a thermostat in the house for the heating or a temperature control for the air-conditioning). At the same time, the observer might notice that on hotter days the house consumes more electric energy; colder days result in the use of more gas for the heater. According to the principles of homeostasis, maintaining the stable temperature, one variable, requires variations in the usage of energy, in the form of electricity and gas, the other variable(s).

Also, after the house has been empty for a while, the temperature of the house will return to its set temperature. That final state will be reached, no matter the original external temperature, which the house has reached after being inhabited for a while. This is the principle of equifinality; the stable state of the house will be reached from any initial external temperature.

When for some reason or another, the temperature of the house will be maintained at an extreme high temperature during harsh winter conditions that will come along with a higher consumption of gas. The internal system for converting the gas in heat will be used longer and more intense, not only increasing the fuel consumption but also reducing the life span of the heater. This is called heterostasis, maintaining an extra-ordinary state during a brief period of time, albeit at the expense of durability of the system.

of observation might inform the observer about the behaviour. Generally speaking, the poised state of heterostasis is more difficult to maintain over longer periods of time and has side effects by straining the system, for example the use of resources. Therefore, the state of heterostasis will be punctuated by longer intervals of homeostasis. That means in all cases that dynamic of behaviour interpreted through deductive reasoning should be interpreted with care; however, as shown in Box 3.B, the understanding of equifinality, homeostasis and equifinality is very helpful for solving practical problems in conjunction with deductive reasoning.

Inductive Reasoning

As opposed to deductive reasoning, inductive reasoning looks at elements or subsystems rather than the performance of the whole in the context of systems thinking. In the case of Applied Systems Theory, inductive reasoning refers to understanding the impact of changes in properties of elements (or even discarding, replacing or adding elements) on the whole. An illustration of this is the replacement of handwritten documents by electronics ones. Although many of the steps for the procedures might remain the same or are similar, the implementation of that electronic documentation system will affect the performance of an organisation and how people work with it. Within the domain of synthesis as integrating components into a whole (covering a wide range of applications from engineering itself to design of organisations), inductive reasoning entails if another one replaces one element or subsystem, how the system will modify its behaviour. The foremost application in engineering and design constitutes the introduction of novel solutions as part of a total system, for example a new type of storage device in a computer (think about the use of flash drives instead of hard-disks in laptop computers). Hence, inductive reasoning takes the elements or subsystems as starting point for studying their effects on the whole.

Inductive reasoning as such is applied to situations that are complicated or ill-defined, when we look for patterns and simplify the problem or situation by constructing temporarily hypotheses or schemata to work with. This often called the hypothetico-deductive method and became later better known as ‘induction logic’ (made popular by Popper [1966, pp. 98-99]; his thoughts seem to be rooted in the research of Selz [1913, p. 97]). An example of this are chess players who form hypotheses or schemata about the opponents’ intentions by studying their moves; note that in the case of chess the ultimate objective is known: defeating the other player. Based on those hypotheses or schemata, localised deductions serve as specific conjecture for observations. In the case of chess, the player assumes a certain attack and deducts from that pattern which move the opponent most likely will make. The cycle becomes complete when feedback from the environment comes in that might strengthen or weaken beliefs in current hypotheses, discarding some when they cease to perform, and replacing them as needed with new ones [Arthur, 1994, p. 407]. In the case of chess, not only the moves but also the facial expressions might serve as indicator about the match develops. In other words, where we cannot fully reason or lack a full definition of the problem, we use simply models that bridge cause and effect for filling the gaps in the understanding of reality.

One of the most paramount constraints for applying inductive reasoning is caused by limitations in knowledge and experience. In most situations, it is presumed that decision-makers or those that analyse problems gather information and act based on full rationality. But that is hardly the case. In terms of Applied Systems Theory, any observer of a system has limited knowledge of the universe (see Section 2.1 for the definition of the universe); those elements and relationships known to the observer are called the *Real-Life System*. That implies that for each observer the Real-Life System might differ; in terms of Applied Systems Theory, the environment of each observer is different from all other observers (this theme will return in Chapter 7). Building on this the concept of bounded rationality states that rationality of individuals is restrained by the Real-Life System, cognitive limitations and finite amount of time for decision-making [Simon, 1947, 1959]. The cognitive limitations indicate that not only the Real-Life System influences thinking but also the capability of processing information and deriving useful hypotheses or schemata. Hence, bounded rationality embedded in the Real-Life System of the observer or decision-maker restricts in practice the application of inductive reasoning.

However, inductive reasoning should not be confused with 'trial-and-error'. By using trial-and-error, an investigator changes randomly any relationship or element to find out whether the intended effect will be achieved (in its most extreme form). This is particularly useful when no apparent hypotheses or schemata apply to the problem; the search for new drugs is often characterised by this trial-and-error method. This does not mean that the approach needs to be careless; for an individual, it can be methodical in manipulating the variables in an attempt to sort through possibilities that may result in success. It is possible to use trial-and-error to find all solutions or the best solution, when a finite number of possible and testable solutions exist. To find all solutions, one simply makes notes about observations and continues, rather than ending the process, when a solution is found, until all solutions have been tried. To find the best solution, one finds all solutions by the method just described and then comparatively evaluates them based upon some predefined set of criteria, the existence of which is a condition for the possibility of finding a best solution. Nevertheless, people who have little knowledge about a problem domain often use this method. Hence, trial-and-error has many characteristics of the search processes related to inductive reasoning but lacks the formulation of hypotheses or schemata in advance.

Even though inductive reasoning might be limited by bounded rationality and by search processes akin the trial-and-error method, it has its advantages as a complementary mechanism for the complexity of reality and those problem situations that are ill-defined. Particularly, it enables dealing with complexity of reality through constructing plausible, simpler models that we can cope with. An example of simplification by modelling is the drawing of a house by architects showing the four faces without going into much detail about how the actual construction should take place. That drawing is sufficient for a customer to understand how the house will look like once being built. Additionally, inductive reasoning makes it possible coping with situations that ill-defined: where we have insufficient definition of a problem definition, the working models or hypotheses fill the gap. That is similar to the stance taken by the Soft Systems Methodology of Checkland [1981, pp. 169–177] when talking about constructing conceptual models (to be seen as hypotheses); although his approach is more a means to involve stakeholders rather than a formal modelling technique (for more on Soft Systems Methodology, see Section 10.4). Modelling in his view is seen as understanding reality so that meaningful actions can be undertaken that lead to improving a ‘problem situation’; the extent of resolution determines whether another iterative cycle of problem solving should be evoked. This only indicates that inductive reasoning might imply going through a number of cycles before a plausible model is found, particularly in ill-defined and complex problem situations.

That premise of iteration is quite similar to scientific approaches but that comparison introduces further limitations to inductive reasoning. For scientific research inductive reasoning requires the following steps: the observation of all relevant facts (or properties), the classification of these facts, the generalisation and the testing of assumptions. The four-stage model of scientific discovery or inductive logic [Popper, 1999, p. 14], as an example of inductive reasoning, not only follows the principle of inductive reasoning but should also lead to caution with respect to hasty conclusions. The four stages of inductive logic consist of: (a) the definition of the old problem, (b) the formation of tentative theories about the phenomenon, (c) the attempts at elimination of at least some of these tentative theories, (d) the uncovering of new problems that gives reasons to repeat this cycle again. According to Popper [1999, p. 10], tentative theories (or hypotheses) should be falsifiable. Further investigation of theory and empirical data should reveal whether a refinement becomes possible such that testing will allow the assessment of theories [Popper, 1966, pp. 52-55]. For testing of hypotheses, it is necessary that the class of opportunities to falsify the theories should not be empty on beforehand. The generic character of theories allows no verification, but they could be open to falsification [Nola and Sankey, 2000, p. 18]. The second point of Popper’s philosophy towards scientific discovery, induction logic, warns for drawing generalisations where possibly inappropriate [Popper, 1966, pp. 98-99]. It shows that inductive reasoning is open to interpretation whereas deductive reasoning is closed and more directed at fact-finding within a given framework.

3.4 Types of Models

Since any type of reasoning deploys models of any kind as a tool to solve a problem, it is important to understand the relation between the models and the system to be studied. *'The best material model of a cat is another, or preferably the same, cat'*, said Norbert Wiener, one of the founders of cybernetics, together with Rosenblueth [1945, p. 320]; see Box 3.C for other famous statements about models and modelling. Such a statement does not help very much to reduce the complexity of the system to gain overview. Rephrasing the notion of a model we might say: a model is an aspectsystem of a (sub)system on a higher level of abstraction – any of the three types in Section 3.2 – for the purpose of studying an other system. That introduces the concepts of isomorphism and homomorphism that will be elaborated in the next subsections, followed by analogies and metaphors. After that, a

Box 3.C: Famous Statements about Models and Modelling

Essentially, all models are wrong, but some are useful. [Box and Draper, 1987, p. 4]

A theory has only the alternative of being right or wrong. A model has a third possibility: it may be right, but irrelevant. [Eigen, 1973, p. 618]

The purpose of models is not to fit the data but to sharpen the questions. [Samual Karlin, at the Eleventh R. A. Fisher Memorial Lecture, Royal Society (20 April 1983)]

There are many specific techniques that modellers use, which enable us to discover aspects of reality that may not be obvious to everyone ... [Silvert, 2001, p. 261]

Models are of central importance in many scientific contexts. The centrality of models such as the billiard ball model of a gas, the Bohr model of the atom, the MIT bag model of the nucleon, the Gaussian-chain model of a polymer, the Lorenz model of the atmosphere, the Lotka-Volterra model of predator-prey interaction, the double helix model of DNA, agent-based and evolutionary models in the social sciences, or general equilibrium models of markets in their respective domains are cases in point. Scientists spend a great deal of time building, testing, comparing and revising models, and much journal space is dedicated to introducing, applying and interpreting these valuable tools. In short, models are one of the principal instruments of modern science. [Frigg and Hartmann, 2006]

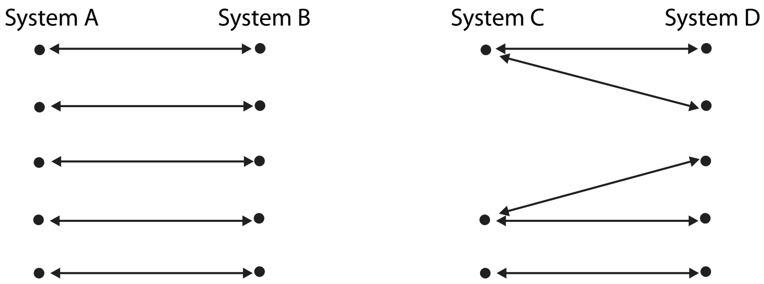


Figure 3.5: *Isomorphism and homomorphism for systems. Isomorphism means a one-on-one relationship between the two systems studied (left picture with System A and System B). When distinguishing one system in reality and one artificial one to be studied as an abstraction of reality, it becomes hard to achieve isomorphism; System C and D are homomorphic (depending on the problem definition).*

classification of models is presented that should aid in selecting models and understanding their limitations.

Isomorphism

When there are as many elements and relationships in the model as in the original system, we speak about isomorphism (see Figure 3.5). 'Isomorphic' (in Greek ισοσ = equal and μορπηε = shape) means 'having a similar form' and one system is said to be isomorphic with another when, in formal terms at least, they could be interchanged [Beer, 1959, p. 42]. The terms goes back to Eilhard Mitscherlich (1974-1863), who introduced the law of isomorphism, which states that compounds crystallising together probably have similar structures and compositions. In mathematics, the word *isomorphism* applies when two complex objects can be mapped onto each other, in such a way that to each part there is a corresponding part in the other object. Hofstadter [1999, p. 49] expands this definition:

> *The word 'isomorphism' applies when two complex structures can be mapped onto each other, in such a way that to each part of one structure there is a corresponding part in the other structure, where 'corresponding' means that the two parts play similar roles in their respective structures.*

Isomorphic structures are 'the same' at some level of abstraction; that implies ignoring the specific elements and relationships at lower level of detail. Here are some everyday examples of isomorphic structures:

- A solid cube made of wood and a solid cube made of lead are both solid cubes from a geometric perspective, although their materials differ entirely;
- The Clock Tower in London (that contains the Big Ben) and a mechanical wristwatch when looking at their mechanisms for reckoning time are similar, even though both devices vary greatly in size;

- A six-sided die and a bag, from which a number 1 through 6 is chosen, have random number generating abilities that are isomorphic, despite the method of obtaining a number being completely different.

From these examples, it becomes also clear that isomorphic model building includes always a perspective for observation. Consequently, the building of models for complex systems is unlikely to result in perfect isomorphism (even cats differ from specimen to specimen); in the case of exceedingly complex systems, that result will be by definition impossible to verify, if not to achieve [Beer, 1959, p. 42]. Ultimately, the extent to which a model is isomorphic with the real system at a given aggregation stratum will determine its usefulness for predictions given a problem definition.

Homomorphism

The imperfection of model building expresses itself in homomorphism. This occurs when the model has fewer elements than the original, but with all relevant relations intact from a given perspective; or homomorphism from one object to another of the same kind, is a mapping that is compatible with all relevant structures. When structuring systems for a given problem definition we are looking for a homomorphic model, a model is always a simplification, with isomorphism for the aspect under consideration; and if not, as much isomorphic as possible. Homomorphism is important in establishing whether one system is a model of another and which properties of the original the model retains for the specific purpose of investigation. Some examples are:

- The comparison of the English language and the Sami language (the Sami are Europe's most northern indigenous people living in Finland, Norway, Russia and Sweden) when using the word snow. The Sami language has hundred words for snow while in English language that is limited to a few words, such as pack, powder, sleet and snow.
- The similarity between natural ecosystems and economic ecosystems for interactions among its constituent actors. A natural ecosystem might have a wider variety than an economic ecosystem and an economic system is a construct of the human mind. These differences will make it difficult to make a direct comparison.

For each system one can construct a lattice of homomorphic simplifications. In that sense, the three abstraction mechanisms – classification, aggregation and generalisation – are forms of homomorphism.

Analogies and Metaphors

In addition to isomorphism and homomorphism, analogies and metaphors are distinguished as archetypes for how similar distinct systems might be. In that sense, an analogy is a comparison between two different things, in order to highlight some form of similarity. Analogies are often used to explain new or complex concepts by showing the similarities between these and familiar concepts. Some types of analogies can have a precise mathematical formulation through the concept of isomorphism. A famous example, in engineering is the mathematical description of a simple mechanical oscillating system and a simple electronic oscillating system. While their materials are entirely different, the behaviour of these two systems expressed in equations is exactly identical. Within the domain of logic reasoning, an analogy focuses on similarities in known respects to similarities in other respects. Ultimately, an analogy is a kind of generalisation. Very differently, metaphors address a figure of speech, which is not literally applicable to the object of comparison. For instance, an organisation and a human body are compared with each other, leading to the proposition that an organisation needs a head (note that this concept has even penetrated daily language). But there is no way that an organisation functions like a human body; the metaphor acts symbolically to underline the importance of somebody in charge of an organisation. In this perspective, an analogy might be considered a kind of extended metaphor or long simile in which an explicit comparison is made between two things (events, ideas, people, etc.) for the purpose of furthering a line of reasoning or drawing an inference; it is a form of reasoning that employs comparative or parallel cases.

For applying analogies or metaphors in the context of systems theories, a few words are in order. First, the application of concepts in use in other disciplines does not deny the reality or concreteness of phenomena in the domain of application. By way of illustration, the process of creation within

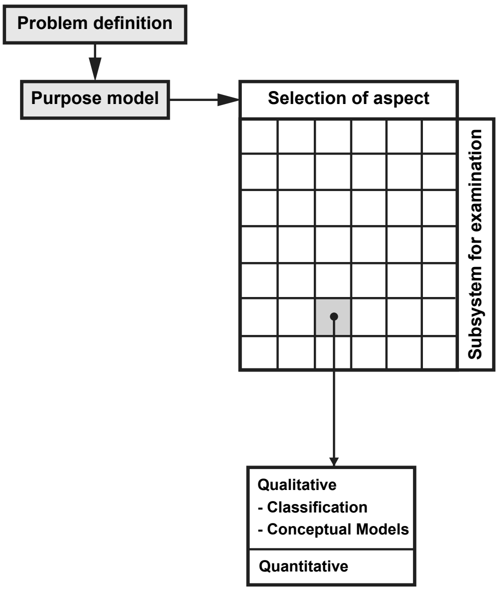


Figure 3.6: *Expansion of models (building on Figure 2). The problem definition points to the aspects and subsystems to be considered. Additionally, models have the dimension of either being qualitative or quantitative. Qualitative models are further divided into classifications and conceptual models.*

the arts might be compared with the process of design in engineering-based sciences, albeit that the context of creation is very different for both of them. Second, if some fields of science are further along in their understanding of reality, related fields should make sure that their explanations are consistent with the latest discoveries and insights – which is the notion of consilience [Wilson, 1998, p. 8]. Current crossovers of biological concepts to all other kinds of sciences, such as information and communication technologies, urban planning, material sciences, etc. serve as an example. Third, using metaphors and analogies is sometimes judged negatively. However, any conceptual or formal model can be said to involve metaphors and analogies to some extent; the systems theories themselves are a case in point. According to Hodgson [1993, pp. 18-19], analogies and metaphors should not be regarded just as literary ornaments that hide the core of a theory or model. Playing with metaphors means approaching reality from various perspectives, and recognising that concepts have subjective interpretations, as well as inevitably a social and academic history and context.

Of course, one needs at all times to be conscious that analogies and metaphors can be misleading, because they are incomplete or inaccurate, or inappropriate in the worst case [Morgan, 1997, p. 5]. Kickert [1993, p. 262] asserts that caution is appropriate when applying theories derived from natural sciences to social sciences. The same holds of course for formal models, which can be considered a particular type (subcategory) of metaphor. Many models in economics can be traced back to modelling traditions in natural sciences, such as biology, physics and engineering. For example, an analogy that is persistent in economic theory is that firms, industries or even countries as a whole behave like individuals (at the level of firms enforced by the acknowledgement of a corporation as a legal entity [Bakan, 2004]). This may be an appropriate analogy for some elements of decision-making but it is doubtful as a generic approach. Hence, analogies and metaphors, as a specific form of homomorphism, have strong limitations in their applications.

Qualitative Models

Metaphors or analogies could be considered mostly as so-called qualitative models, although also sometimes quantification is possible; whether models are qualitative or quantitative constitutes one dimension of models (see Figure 3.6). Qualitative models describe reality with aspects and features (see Section 2.2) and can be divided into two types: classification and conceptual models; note that metaphors and analogies are principally conceptual models. Newton's Third Law of Motions states that for every action there is an equal and opposite reaction and is in essence a qualitative model (in this case a conceptual model). Once qualitative models become enriched with parameters and their values, quantitative approaches become possible; Newton's law has been transferred later into formulae, which did allow calculations and further studying of phenomena. Sometimes qualitative models suffice, especially for descriptions and explanations, and sometimes we need quantitative models, for predicting possible future events, for example, estimating the time of arrival of flights. In most cases, qualitative models precede quantitative models.

As already discussed in Section 3.1 (taxonomic) classification, as one of the two types of qualitative models, is the act of placing an object, system, element or concept into a set or sets of categories (such as a taxonomy or a subject index), based on its properties. That assumes that all objects, systems, elements or concepts in that specific set (or class) have similar properties from a certain perspective, whether at the level of the objects, systems, elements or concepts themselves or at an aggregated level. That means that a person may classify the object or concept according to an ontology, which as a fundamental branch of metaphysics seeks to describe and categorise entities or posit basic categories within an overarching framework. Ontology has strong implications for the perceptions of reality and therefore may be linked to philosophical thinking. In that context, some philosophers, notably those of the Platonic school, argue that all nouns refer to entities. In that view, ontology covers objects as well as constructs of the mind and events. Other philosophers contend that some nouns do not name entities but provide a kind of shorthand way of referring to a collection (of either objects, systems and elements or constructs of the mind or events). This way of thinking has strong parallels with distinguishing aggregation strata. In this latter view, a society refers to a collection of persons with some shared characteristics (or properties in terms of system theories) and geometry refers to a collection of specific kinds of output resulting from intellectual activity. Any ontology must give an account of which words refer to entities, which do not, why, and what categories result. When one applies this process to nouns such as electrons, energy, contract, happiness, time, truth, causality and god, ontology becomes fundamental not only to philosophy but also to many branches of science and activities of creation (like design and engineering). Examples of taxonomic classifications include library classifications, scientific classifications of organisms, medical classifications, such as ICD, and security classifications. Hence, classification limits itself to describing properties as a (quasi-)static approach.

Where classification aims at describing (common) properties, conceptual models explain phenomena and, in that sense, emphasise studying relationships between elements or systems. This type of models might tell us what will happen next (whether it is based on empirical observations or heuristic laws). Derived from Engelbart [1962, pp. 128-129], developing conceptual models means specifying the following:

- The essential objects or components of the system to be studied.
- The relationships of the elements that are recognised.
- The kinds of changes in the elements or their relationships affect the functioning of the system – and in what ways.
- The objectives and methods of research (or investigation).

Some will take it that conceptual models are broader and more fundamental than scientific theories in the sense that they set the preconditions for theory formulation. In fact, they might provide the conceptual and methodological tools for formulating hypotheses and theories, the process of inductive logic as pointed out by Popper [1966, pp. 52-55; 1999, p. 14], see Section 3.3. Once, a conceptual model has been proven through empirical studies, it becomes a theory, and if that happens under repeatable and 'objective' conditions, we call it a scientific theory. If they are also seen to represent schools of thought, chronological continuity, or principles, beliefs and values of the research community, they become paradigms. A famous example of a paradigm is the Austrian School of Economics. Economists belonging to this school of economic thought advocate strict adherence to the principle that social-economic phenomena can only be accurately explained by showing how they result from the intentional states that motivate the individual actors and they emphasise the spontaneous organising power of the price mechanism. This paradigm then strongly influences research undertaken by those adhering to this school. Consequently, the conceptual model is always constructed – it does not simply lie somewhere waiting around for somebody to pick it up.

For purposes of scientific research, a conceptual model provides a working strategy, a scheme containing general, major concepts and their interrelations. The model orients studies into phenomena towards specific sets of research questions aiming at formulating (substantial) theories. A conceptual model cannot be assessed directly empirically, because it forms the basis of formulating empirically testable questions and hypotheses. Ultimately, it can only be assessed in terms of its instrumental and heuristic value. If substantial theories prove to be useful in many circumstances, the underpinning conceptual model might be so too; however, waiting for conceptual models or substantial theories to prove to their validity may take some time.

Even before embarking on some line of inquiry, whether scientific or practical, it may be important to argue about the merits of various conceptual models. The following are general (scientific) principles that can be used to judge the merits of a conceptual model:

- The scope of the conceptual model for situations to study. Mostly, a conceptual model is more useful when it covers a wide range of situations as possible (this is called the principle of fecundity). Taking it further, when studying some phenomena, ideally they should be studied in all situations, and also under extreme conditions; for example, most economic behaviour is assumed to be rational but what about people that emotional behaviour. That implies that the boundaries of the application of the conceptual model should be sought; it also denotes that a broader scope is better because it subsumes narrower ones, other things being equal.
- The conceptual model should be limited in a meaningful way as a system (systematic power). For example, understanding information seeking

by human actors, the proper system is not the provision of some service (like a library and its clients) but rather an information actor immersed in his or her situation and information environment (for example, all information access systems). Hence, this principle explores whether the conceptual model is fit for purpose and has the ability to organise concepts, relationships and data in meaningful systematic ways.

- The conceptual model should be at a sufficient level of detail to study the phenomenon or provide an explanation (accuracy). This argument is akin to aggregation strata. It means that a conceptual model should not be so abstract that it hardly describes the situation. For instance, modelling a car solely from how many people it can transport will hardly indicate its fuel consumption. However, if the model is extremely detailed, it might lead to the inclusion of irrelevant details. Using the example of the car again, the colour of the clothing of seats will not have any impact on the fuel consumption. It might well be that the development of a conceptual model will go through iterations before the right level of aggregation is established.

In addition to these three principles (scope, systematic power and accuracy), whether the conceptual model has been developed to study practical events or its aims at scientific discovery, when two competing conceptual models are compared the following criteria may be applied to judge their merits:

- Simplicity. This indicates that a conceptual model that is simpler tends to be better, assuming all other things being equal (this principle is commonly known as Ockham's razor).
- Explanatory power. This criterion indicates the ability of a model to effectively explain the subject matter it pertains. Particularly useful is to look at the details of what might be observed (but with greater detail, greater inaccuracy might be introduced).
- Reliability. This measure points to the ability, within the range of the model, to provide valid representations across the full range of possible situations (and is strongly related to the scope of the model).
- Fecundity. This demonstrates the ability of the model to suggest problems for solving and hypotheses for testing; in other words, it represents the ability of a model to open new lines of inquiry.

To meet all these criteria, theoretical development or the construction of new conceptual models in any research area or investigation often requires conceptual and terminological development. Conceptual development may mean fulfilling, perhaps in a better way than before, the basic requirements for scientific concepts – precision, accuracy, simplicity, generality, and suitability for expressing propositions. Moreover, effective conceptual models represent essential features (objects, relationships, events) of the domain investigated.

Quantitative Models

Many times a model is required to provide answers in the form of hard numbers. Such quantitative models mostly are the result of the evolution of qualitative models via mathematical abstraction. Because of the required accuracy, these models often have a rather narrow scope of relationships and variables they might consider. In the domain of quantitative models, four kinds of models are distinguished (three of these are derived from Ackoff [1962, p. 109]), see also Figure 3.7:

(1) Sampling models consist of a mere subset of mutually exclusive objects taken from a larger set of objects. The representation is based on the assurance that each object of the universe had the same probability to be included in the sample. A sampling model resembles classification but differs in the sense that not all relevant properties have been identified, yet. However, sampling might also consider other criteria for selection. Flyvjberg [2006, p. 230] sets out that these might include extreme or deviant instances, cases with maximum variation or critical examples.

(2) Iconic models are linear transformations of a configuration of objects in the universe based on a single aspect, mostly. The representation is based on the assurance that an iconic model retains that universe's topological characteristics. Iconic models look like the real thing but sometimes

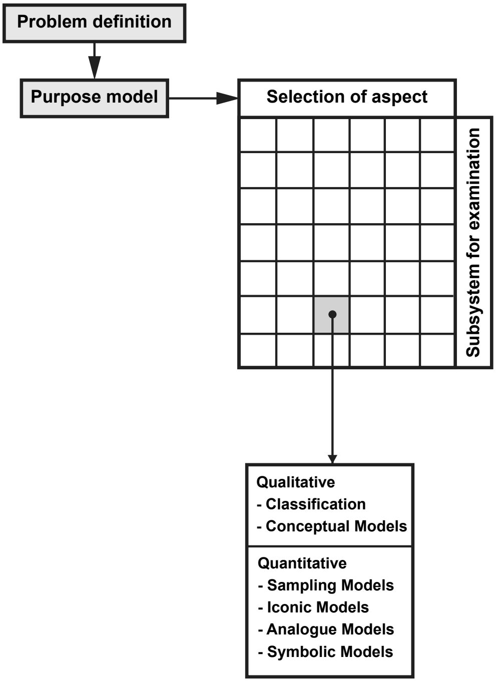


Figure 3.7: *Overview of qualitative and quantitative models. This expansion of Figure 3.6 shows the four basic quantitative models: sampling models, iconic models, analogue models and symbolic models.*

employ a change of scale or materials. They are used principally to communicate (design) ideas – for example, to the designer, to a client (e.g. sketches, 3D prototypes) or to users. Iconic models represent reality, for example, scale models, photographs and graphical representation of networks.

(3) Analogue models explore particular features of an idea by stripping away detail and focusing, via a suitable analogous representation, on just a few key elements (e.g. flow diagrams and circuit diagrams). They have no pretence at looking like the real thing and are intended primarily to examine functions rather than communicate appearances. Analogue models like all other models are a simplification of reality. Some call these behavioural models, the relations are transformations, equations or operating rules and the representation is based on the assurance that the behaviour of the model corresponds to the behaviour of the system modelled. This is established either by identifying the model's parameters and equations, or showing that the principle of homomorphism is not contradicted, for example, the computer simulation of an economy and the model of a plane built into an automatic pilot.

(4) Symbolic models represent ideas by means of a code (for instance, numbers, mathematical formulae, words and musical notation). These models are very useful at analysing performance and predicting events. Symbolic models are an abstraction of reality. In symbolic models the set of objects are represented by symbols and the relations are expressed in the form of algebraic, computational or algorithmic statements exhibiting no behaviour of their own. Symbolic models must be realised in or coupled with a machine in order to become a behavioural model of something else. For example, a formal statement about a social process must be translated into the algorithmic form of a programme acceptable to a computer.

Even though these four types of quantitative representation differ quite substantially, all build on conceptual qualitative models (whether implicitly and explicitly) and have greater detail that might lead to loss of accuracy compared to the original qualitative model.

Overview of Models

The combined overview for the selection or development of qualitative and quantitative models is presented in Figure 3.8. The search for a model starts with the problem definition, which should lead to the distinction of a subsystem and specific relationships of interest to the objectives of the study. The use of a model is prescriptive, descriptive, explanatory or predictive. A prescriptive theory gives directions or rules as to how something should work or be carried out. For example, a model may suggest how a menu of software should be laid out. A descriptive theory seeks to support the process of thought, by providing consistent and appropriate terminology (it relates very closely to classification). An explanatory theory seeks to explain

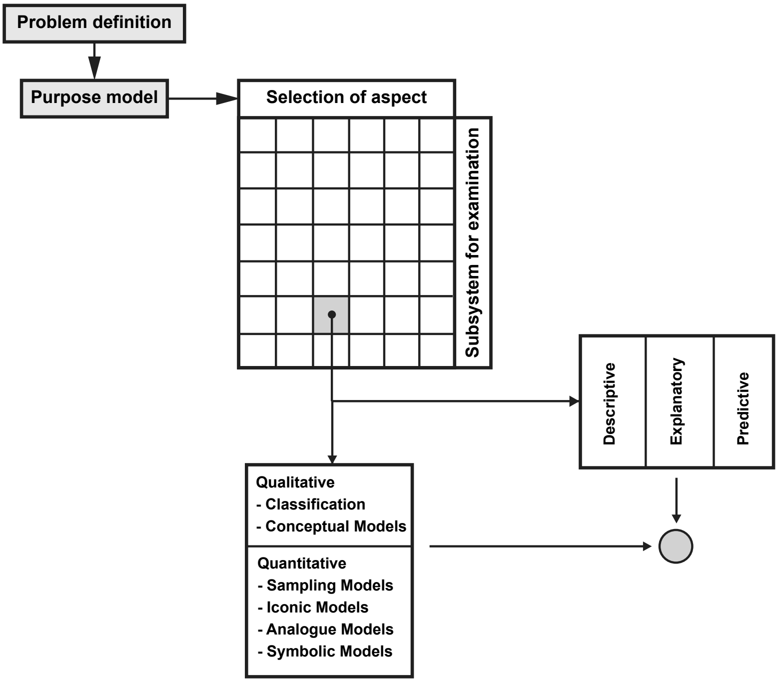


Figure 3.8: *Classification of models. The problem definition points to the aspects and subsystems to be considered. Models have two dimensions: (1) being descriptive, explanatory or prescriptive and (2) being qualitative or quantitative. On the second dimension, a further refinement leads to specific purposes of models.*

how on hindsight how a phenomenon occurred. Predictive theories allow researchers to predict the outcomes of a system's behaviour. If designers propose a new system, predictive theory indicates what the outcomes might or should be. Hence, the dimension of the use of a model complements the dimension of qualitative and qualitative models.

Note that models move through successive stages of modification during the use for analysing and solving problems. With predictive models it becomes possible to forecast the future. These models are necessary to design solutions and can be either deterministic or stochastic models. An explanatory theory precedes a predictive one. The understanding of why it happens leads to explanatory models. The underlying mechanisms become clear, most of these models have an analytical character. In turn, a descriptive theory comes before an explanatory one. A descriptive model simple describes what happens or states properties. The taxonomy used by biologists can be considered as a descriptive model: it describes but has almost no impact on the understanding of why and how. The addition later of evolutionary mechanism made it possible to develop explanatory models, followed by predictive models. Hence, the development of models for a certain should never be viewed from a static perspective but will be modified from refined from descriptive to explanatory to predictive models.

Given that models take centre-stage in many investigations, that also means that over the years quite a number of people have made statements about them. Wiener's statement of the model of a cat has already been mentioned. A few others have been added in Box 3.C and indicate both the necessity and the difficulty in developing any type of model (and theory). The statements underline that a model only fits with a certain problem or purpose. Figure 3.6 shows this notion undoubtedly: first a model limits itself to certain elements (from the universe) and aspects, and then on the two dimensions (qualitative and quantitative, and use). In all stages, higher accuracy comes along with a reduction in scope and fecundity. This dilemma of building and using models has been well-recognised but indicates both the necessity of working with models and its inherent weaknesses; the on-going development of insight and knowledge only adds to the temporal value of models.

3.5 Systems Hierarchy of Boulding

The systems hierarchy of Boulding presents another way of looking at modelling. Boulding [1956] has introduced a systems hierarchy to distinguish systems according their complexity. He remarks that lower levels of his systems hierarchy are a prerequisite for higher levels but do not per se suffice for describing systems of a higher order (note the parallel with emergent properties and behaviour – concepts mentioned in Sections 2.2 and 2,6). Boulding [1956, pp. 202–205] distinguishes nine levels in this hierarchy. However, later he reworked these nine levels and presented eleven levels in the systems hierarchy [Boulding, 1985], see Figure 3.9:

- level of mechanical systems. Systems at this level are controlled by simple connections and few parameters. A case in point is the Copernican revolution that introduced a new framework for the solar system (the Sun being a the centre rather then Earth) and later permitted a simpler description of the planetary movements. In mathematical terms, the connections or relationships are seldom more complex than equations of the third degree. Examples are the laws of gravitation, Ohm's law (the relationship between voltage, current and resistance in electric circuits) and Boyle's law (the relationship between pressure and volume of a gas);
- level of cybernetic systems. The processes that determine the moves of the system to maintain any given equilibrium, within its limits. Most physical and chemical reactions and most social systems do in fact exhibit a tendency to equilibrium by using negative feedback. The homeostatic system is an example of a cybernetic system and such systems exist throughout the empirical world of the biologist and the social scientist, according to Boulding [1956, p. 203];
- level of positive feedback systems. A system exhibiting positive feedback, in response acts to increase the magnitude of the perturbation until a limitation is reached. After accelerating to that point of limitation, either breakdown or breakthrough happens. Examples are fires that getter

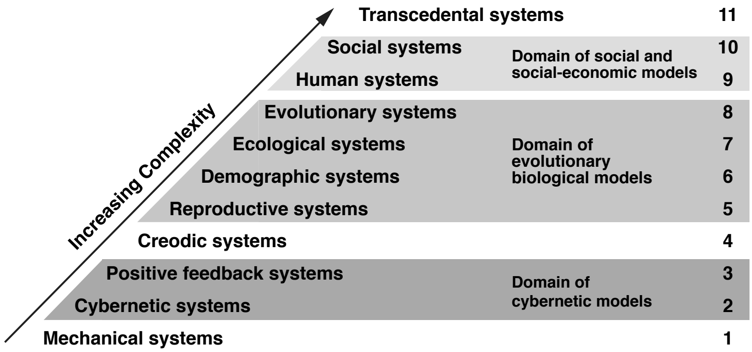


Figure 3.9: *The eleven levels of Boulding (1985). The domain of organisations and social systems moves at the ninth and tenth level, which indicates the importance of meaning, value systems, and symbolisation (levels also indicated by numbers). Models from evolutionary biology mostly dominate the fifth to the eight' level. The domain of systems theory and some other approaches in management science (e.g. information technology) find themselves at the second and third level. For example, that indicates that models from evolutionary biology might bridge the gap between some of the approaches management science based on cybernetics and the actual organisational domain. The fourth level in this figure moves between cybernetic and evolutionary models; for example, autocatalytic systems can be positioned here but have both teleological and cybernetic traits in their behaviour (for autocatalytic systems, see Chapter 8).*

hotter as it burns and eventually extinguish themselves after all available resources are consumed or learning, when the more one learns, the easier it gets.

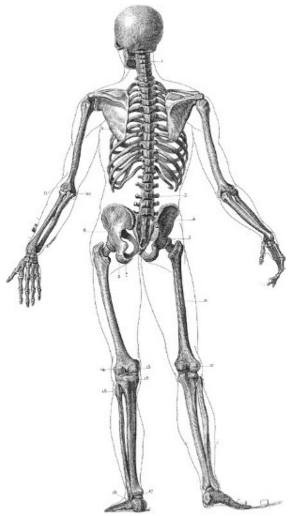
- level of creodic systems. This fourth level in the systems hierarchy includes all systems that are teleological in nature and which may be called planned in a wide sense as they are guided by some kind of initial plan. An examples is genetics, with the work of Dawkins [1989] showing the point;
- level of reproductive systems. At this fifth level genetic mechanisms guide both reproduction and growth, whether these are biological or social. While in biological studies genes constitutes the basis for reproduction, Dawkins [1989, p. 192] has proposed memes, as unit for recombination in social systems. Memes constitute elements of a culture or system of behaviour that may be considered passing from one individual to another. Dawkins extends this concept to a wide variety of topics like ideas, artefacts, including people, products, books, behaviours, routines, knowledge, science, religion, art, rituals, institutions, and politics. In organisational studies memes enjoy a high degree of popularity;
- level of demographic systems. Demographic systems, at the sixth level of the systems hierarchy, consist of populations of reproductive systems; a population is to be understood as a defined collection of

Box 3.F: Human Body and Systems Hierarchy of Boulding

Modelling and viewing the human body serves as an example for the systems hierarchy. Below are some descriptions for the different levels.

Level 2: Mechanical Systems

The skeleton of the human body is an example of this level of simple, dynamic systems. Even though, some might consider the skeletal system complex, the bones can only move relatively to each other. Note that all muscular tissue and conjunctional tissue has been left out of the picture on the right.



Level 3: Cybernetic Systems

Maintaining balance and posture could be seen as a cybernetic system. Muscles and sensors act on tiny deviations to prevent humans from falling down. Another, more famous example is maintaining a constant body temperature.

Level 4: Positive Feedback Systems

If the body moves to a new position, then it is not only homeostasis it tries to achieve (a stable position) but also a new point in the three dimensional space. Positive feedback features also in Chapter 5.

Level 5: Creodic Systems

For example, many of the basic reactions in our body concern autocatalytic sets. These are a collection of entities, each of which can be created by other entities within the set. Autocatalytic sets were originally and most concretely defined in terms of molecular entities. Chapter 7 will pay more attention to this phenomenon.

Level 6–8: Evolutionary Biological Systems

At these three levels, we could consider the genetic evolution of human bodies: how they developed in the many different people and tribes with their own characteristics as well as the development of human kind (homo sapiens).

Level 9–10: Societal Systems

An example at this level, how human beings interact in organisations. Not only do people learn from interaction but they also form collaborations to undertake ventures that would not have possible on their own.

comparable entities, not necessarily identical but similar enough to create a classification;

- level of ecological systems. These systems at the seventh level are formed out of interacting populations of different species. Dynamic processes include not only population dynamics but also symbiosis (both beneficial and detrimental) and chain effects (for instance, the food chain). The Great Barrier Reef off the coast of north-east Australia serves as an example. But also management scientists have introduced the term ecosystem for pointing to interdependencies between firms, suppliers and customers;
- level of evolutionary systems. Such systems can be both ecological, changing under the influence of mutation and selection, and artificial, obeying the same patterns but in the transferred sense of new ideas. These systems tend to evolve towards greater complexity.
- level of human systems. According to Boulding [1985], the systems at the ninth level of his newer hierarchy, differ from other living systems because of the information processing capability of the brain; in that context he mentions that advance pattern recognition and communication abilities with speech, writing and use of sophisticated artefacts are distinctive marks.
- level of social systems. These systems result from interaction between human beings and/or their artefacts; the social activity itself may be classified as belonging to economic, political, communicative and integrative systems. The interaction thrives on learning processes where evaluations and experiences are communicated throughout the system. At this tenth level, it concerns the content and meaning of messages, the nature and dimension of value systems, the transcriptions of images into a historical record, the subtle symbolisation of art, music, poetry and the complex gamut of human emotion;
- level of transcendental systems. These philosophical systems are the ultimates and absolutes and the inescapable unknowables and they must also exhibit systematic structure and relationship, even though they contain a component of speculation.

From a biological evolutionary perspective and contemporary insight, the differentiation between the fifth to the tenth level might be blurred. Hence, Boulding's first hierarchy of systems [1956] and new ones should be interpreted for part in the Zeitgeist of their creation. In addition, if these levels underpin an investigation, they should be treated with care. Skyttner [2005, p. 110] gives an overview of other hierarchies of systems, like the hierarchical levels of Miller. Each hierarchy has its own purpose and applications.

Nevertheless, the models based on lower levels and used for higher levels in any hierarchy might be powerful to fuel understanding but they will also show deficiencies because of the differences between systems' levels. Again, models simplify the reality to serve a specific domain of research. Hence, we, as observers and researchers, will never be able to develop profound, comprehensive models that reflect reality, rather we have to make choices how to represent the problem domain in understandable pictures [Checkland, 1981, pp. 162-183]. The systems hierarchy serves a starting point for inspiring investigations at higher levels while at the same indicating their limitations.

So far, the concepts of Applied Systems Theory have covered all levels of the systems hierarchy of Boulding. Section 2.1 has generated definitions that are principally valid for all levels. From Section 2.2 on and throughout this chapter, the focus has been more on dynamics of systems (emergent properties should be considered as dynamic). In subsequent chapters, the focal point will move to the higher levels of this hierarchy.

3.6 Summary

Examining systems can start by looking at the whole (even before looking at the constituent elements) or by investigating the individual elements without considering the whole. Looking at the whole has the advantage that interrelationships are taken into account, which allows deductive reasoning (evaluating outcomes and performance of the whole to arrive at [root] causes situated at specific subsystems or elements and distinct aspects). Within this perspective, the blackbox approach is a particular way of looking at the system, by considering it as consisting of one element only. When investigating or hypothesising about the impact of subsystems or elements on the whole for selected aspects (inductive reasoning), one might forget about the interrelationships or the focus of the problem at hand. The choice for looking at the whole and deductive reasoning or examining parts and inductive reasoning is also influenced by the level of understanding of the behaviour of a system.

Whenever studying a system, the step of abstraction aims at avoiding unnecessary details by classification, aggregation or generalisation. Generalisation is a relation between class types, and classification is a relation between a class type and the objects belonging to this class. By using aggregation several connected elements are combined into one single element, this represents a typical feature of systems theories. When talking about aggregation for systems, people use the words zooming in and zooming at. Abstraction requires observation and understanding of reality. All three modes for abstraction can be used in combination.

The distinction of a system within total reality is a step towards modelling and aims at understanding reality; hence, models simplify reality for the purpose of studying and, therefore, a model is never reality. A closer examination will always result in the choice of a subsystem and aspect for further investigation. Different types of models, ranging from descriptive to predictive, and either qualitative or quantitative, could be chosen or developed to fit with the system studied and the level of understanding. Because models are always a simplification, the systems hierarchy of Boulding offers another way of looking at the validity of models from lower levels in this hierarchy for higher levels. Since models represent a lower level of complexity than the original object of study, the lower levels in the system hierarchy offer models for studying higher levels, if the investigator accounts for the differences and limitations (e.g. cybernetics to study management of social organisations). Hence, modelling reality comes along with a deliberate choice of subsystems and aspects, and with models that reflect the interpretations of reality.

References

Ackoff, R. L. (1962). Scientific Method: optimizing applied research decisions. New York: Wiley.

Arthur, W. B. (1994). Inductive Reasoning and Bounded Rationality. The American Economic Review, 84(2), 406–411.

Baker, F. (1973). Introduction: Organizations as Open Systems. In F. Baker (Ed.), Organizational Systems, General Systems Approaches to Complex Organizations (pp. 1–25). Homewood, IL: Richard D. Irwin.

Beer, S. (1959). Cybernetics and Management. New York: Wiley.

Bertalanffy, L. v. (1973). General System Theory. New York: George Braziller.

Boulding, K. E. (1956). General Systems Theory. Management Science, 2(3), 197–208.

Boulding, K. E. (1985). The World as a Total System. Beverly Hills: Sage.

Box, G. E. P., & Draper, N. R. (1987). Empirical Model-Building and Response Surfaces. Oxford: John Wiley & Sons.

Cannon, W. B. (1932). The Wisdom of the Body.

Checkland, P. (1981). Systems Thinking, Systems Practice. Chichester: John Wiley & Sons.

Darwin, C., & Wallace, A. R. (1858). On the Tendency of Species to form Varieties; and on the Perpetuation of Varieties and Species by Natural Means of Selection. Journal of the Proceedings of the Linnean Society of London. Zoology, 3, 46–50.

Dawkins, R. (1989). The Selfish Gene. Oxford: Oxford University Press.

de Rosnay, J. (1975). Le Macroscope: Vers une vision globale. Paris: Éditions du Seuil.

Eigen, M. (1973). The Origin of Biological Information. In J. Mehra (Ed.), The Physicists's Conception of Nature (pp. 594–632). Dordrecht: Reidel.

Engelbart, D. C. (1962). Augmenting Human Intellect: A Conceptual Framework (No. AFOSR-3223). Menlo Park: Stanford Research Institute.

Feiring, C., & Lewis, M. (1987). Equifinality and Multifinality: Diversity in Development from Infancy to Childhood. Paper presented at the Biennial Meeting of the Society for Research in Child Development, Baltimore, MD.

Flyvbjerg, B. (2006). Five Misunderstandings About Case-Study Research. Qualitative Inquiry, 12(2), 219–245.

Frigg, R., & Hartmann, S. (2006, 27th February, 2006). Models in Science. Stanford Encyclopedia of Philosophy Retrieved 27th May, 2012, from http://stanford.library.usyd.edu.au/entries/models-science/

Hagen, E. E. (1973). Analytical Models in the Study of Social Systems. In F. Baker (Ed.), Organizational Systems, General Systems Approaches to Complex Organizations (pp. 73–84). Homewood, IL: Richard D. Irwin.

Kast, F. E., & Rosenzweig, J. E. (1974). Organization and Management, a Systems Approach. Tokyo: McGraw-Hill.

Nola, R., & Howard, S. (2001). After Popper, Kuhn and Feyerabend: Recent Issues in Theories of Scientific Method. Dordrecht: Kluwer Academic Publishers.

Popper, K. (1999). All Life is Problem Solving. London: Routledge.

Popper, K. R. (1966). Logik der Forschung. Tübingen: J.C.B. Mohr.

Selye, H. (1973). Homeosatis and Heterostasis. Perspectives in Biology and Medicine, 16(3), 441–445.

Selz, O. (1913). Über die Gesetze des geordneten Denkverlaufs, erster Teil. Stuttgart: Spemann.

Silvert, W. (2001). Modelling as a Discipline. International Journal of General Systems, 30(3), 261–282.

Simon, H. (1959). Theories of Decision-Making in Economics and Behavioral Science. The American Economic Review, 49(3), 253–283.

Simon, H. A. (1947). Administrative behavior. A study of decision-making processes in administrative organization.

Skyttner, L. (2005). General Systems Theory: Problems, Perspectives, Practice. Danvers, MA: World Scientific Publishing.

Timpf, S. (1999). Abstraction, levels of details, and hierarchies in map series. In C. Freksa & D. M. Mark (Eds.), Spatial Information Theory - cognitive and computational foundations of geographic information science (Vol. 1661, pp. 125–140). London: Springer.

West Churchman, C. (1979). The Systems Approach: Revised and Updated. New York: Dell.

4 Processes

After the approaches to describe and to examine systems, this chapter explores the mechanisms of change for systems. This constitutes the realm of processes. For example, the growth of trees, an engine burning fuel in order to drive your car or printing a document. But also falling in love or studying this book and learning from it are processes. Getting acquainted with processes helps coping with many problems that appear since most concern a change that has taken place, whether it concerns recurrent processes or those for establishing new structures. This chapter means also that we are moving away from the inclusion of static, descriptive concepts found in Chapter 2 and 3 to dynamic notions only.

Many processes serve a purpose: they contribute something to the environment or they aim at preserving the state of a system. Especially, engineers and designers or humans, creating any environment for living, usually want to optimise or improve processes to achieve objectives whether that concerns the output of a process (for example, durable consumer goods) or how process are conducted (think about environmental pollution). Therefore, the creators of systems need to be aware of the systems' objectives, functions and behaviour in order to purposefully optimise or improve. Hence, this chapter focuses on processes in the widest sense possible.

To that purpose, this chapter covers the basic concepts related to processes and relates these to the behaviour and the analysis of systems. First, this chapter will explore the interaction between flowing elements and resources, the interaction being called processes. Section 4.2 will address the differences between homeostatic processes and adaptive processes. The topic of Section 4.3 is the distinction between primary and secondary processes. Then it will continue with discussing the concept of function and its relationship to processes. Section 4.5 is dedicated to systems of resources. Section 4.6 will elaborate on the behaviour of processes. Furthermore, Section 4.7 will link the blackbox approach to the analysis of processes. The final section of this chapter contains an overview of alternative methods for mapping processes, esp. for mapping business processes.

4.1 Processes as Interaction

Systems tend to change over time (static systems hardly exist although that also depends on the period of observation). This may happen without human intervention, like the growth of a tree or the corrosion of a steel structure; but the building of a steel structure from raw material is definitely a human activity. No matter the source or cause of changes, the transformation of a system from one state into another is called a process (see Figure 4.1). That means that the original state of elements and their relationships have

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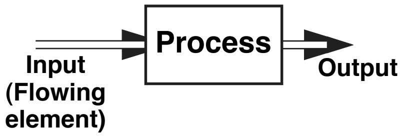


Figure 4.1 *Process as change of state. The initial state of the flowing element (input) is transformed to the final state (output). The difference between the input and the output defines the transformation (process).*

converted into a new state of elements and relationships. Even stapling of sheets of paper is a process; before the execution of the process, there were loose sheets, after stapling there is a pack. The input, consisting out of flowing elements, has state A with certain properties and the output state B with any of these properties changed. The difference between state A and state B of the flowing elements defines the process, or more precisely, the effects of the process on the flowing elements.

This means also that if no change of state for the flowing elements has taken place, then no process was executed. The following example might demonstrate that this has a powerful meaning in what is examined. Consider the checking of the quality of a product at a workstation in a production line (assuming that the product is not transported to conduct the quality check). If the problem definition covers the analysis of recurring quality problems then the quality check should be considered a process; the state has changed that some properties of the product comply with requirements while before that check that was not assured yet. Another problem definition focusing purely on logistics questions, transport and handling of goods in that factory, would consider that no change has taken place; hence, the quality check is not a process in the sense of the logistic problems to be solved. This indicates that what is considered as a process is also affected by the problem's perspective.

To achieve a target state of output, the execution of any process requires resources to bring about the changes in state of the flowing elements. The stapling of sheets of paper can only be done with a kind of stapling device. Hence, in its most basic form a process is modelled as a flowing element interacting with a resource (Figure 4.2). For example, if the flowing element is a tree trunk, changing into logs for the fireplace, the resource consists of a saw, axe and human labour. Note that the box depicting the process is not a system but merely an abstraction of a place and time for the interaction between flowing element and resource. In some cases, when the resources are trivial to the problem, they may be left out then. When modelling the reduction rate of a gearbox, resources like lubricants would be omitted (but not when modelling the heat transfer processes of that very same system). The change of the state of the flowing element relates to the change of state of the resource; thus processes represent resources as a system and flowing elements as a system having an effect on each other.

Also the question which system should be regarded as the flowing element and which system as the resource depends entirely on the problem definition and the chosen aspect. If the process consists of drilling a hole in a metal

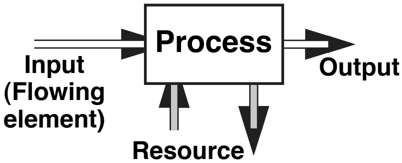


Figure 4.2 *Process as interaction between flowing element and resource. The transformation of input into output requires the presence of resources. The changes of the state of the flowing element correspond the changes of state of the resource.*

part, assembly workers might view the process as the transformation of a metal part without a hole into one with a hole, whereas the tooling department might look at the metal parts merely as resources to wear out their drill bits. That implies also that what is an 'end' to one process, might be a 'means' for another process; this is commonly known as the means-end hierarchy. Extensive applications of this hierarchy can be found in consumer research but it also links to processes and the purpose of systems. Particularly, by looking at what the purpose of the output is will derive meaning for the process (Section 4.4 discusses this more extensively). The definition of systems guided by a problem definition determines how to look at processes.

4.2 Types of Processes

In addition to the generic processes mentioned in Section 4.1, two more categories of processes deserve attention: adaptive processes and homeostatic processes. The generic processes exert every time the same interaction between the flowing elements and resources, ideally resulting in recurrent output. However, it might also be that through the execution of a process the state of flowing elements and resources changes more permanently, for which there are two basic ways to respond:

(a) through the changes in parameters that affect the capability of a system to interact. That leads to interventions within the current structure to maintain the state;

(b) through the alterations in the structure (which introduces sometimes new elements, removes existing ones and affects also the properties and parameters of relationships).

The first are called homeostatic processes and the second ones adaptive processes (see Box 4.A).

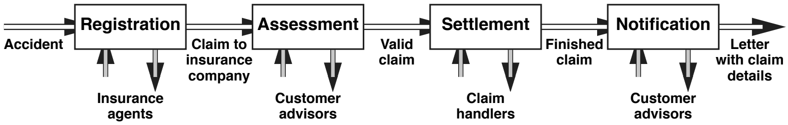
For systems at the lower levels of the systems hierarchy of Boulding (see Section 3.5), the second option only becomes possible through external intervention: the designer of the system intervenes. Systems at higher levels of the systems hierarchy have the capability to exert an intervention themselves and change their structure, although the mechanisms to establish these interventions might differ substantially at the different levels. But already at the second level, the design of the system allows an interaction with the environment, which can be viewed as regular interactions – with

Box 4.A: Example of the Three Types of Processes

Suppose that we take an administrative process as example for these three processes: a simplified process for handling insurance claims with respect to car insurance.

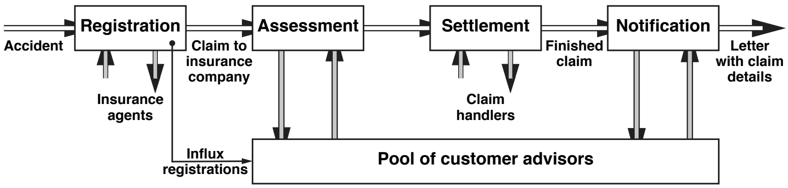
Generic Processes

The generic process consists of a claim registration followed by a claim assessment, settlement and notification (see figure below). Each of these processes necessary for processing the claim related to a car accident call on different resources. Only the second and fourth steps require a customer advisor (not automatically the same advisor, though; that depends on the practices in a specific insurance company).



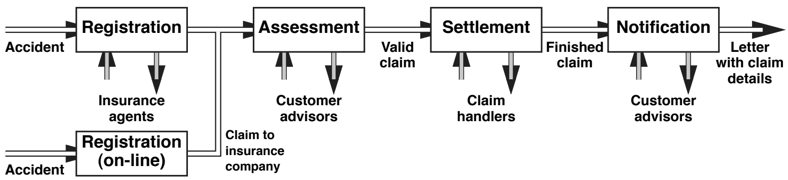
Homeostatic Processes

A homeostatic process would involve maintaining equilibrium with the environment. That could be managing the available capacity of customer advisors in response to the influx of “accidents” (not claims themselves, since they only appear as output from the first process), see figure below.



Adaptive Processes

For the insurance claim process an adaptation would be allowing the customers to fill out their own claims on-line (see figure below); for this step no resources in terms of advisors or agents are needed from the perspective of the company as an entity. Please note that the addition of a parallel process is the adaptive process and not the process of “claiming online” itself.



regard to the processes – and as perturbation – with regard to the conditions under which systems operate.

Homeostatic Processes

Characteristic for the processes of systems at the second and higher levels are homeostatic processes to deal with perturbation. Homeostatic processes occur when a system has to regain equilibrium after exposure to effects caused by stimuli or perturbations from the environment of the system (see Section 3.3 on homeostasis). In this sense, homeostatic processes point to dynamic self-regulation or in other words, to the condition of a system when it is able to maintain its essential variables within limits acceptable to its own structure in the face of unexpected disturbances. Examples of homeostatic processes are the cruise control of a car, the human body keeping its body temperature constant, the generation of human offspring as part of the demographic system to maintain an equal divide between man and woman and the assurance of the quality of products and services by companies. Maintaining a homeostatic state not only requires returning to a defined state but it also determines the interaction of a system with its environment. For any of the previous examples, an external influence exists that might lead to perturbations of the system, on which it has to act. Hence, homeostatic processes for maintaining an internal, constant state are triggered by stimuli external to the system.

Moreover, the influence of these stimuli has to be corrected if necessary, pointing out to the various concepts of control, which will be elaborated in Chapter 5. These corrective processes are internally oriented. For example, homeostasis occurs when the temperature of the human body rises in case of exposure to the sun. One of the processes, which bring the body temperature back to its normal value, is perspiring. An important resource enabling this process consists of the liquids in the human body. Consequently, homeostatic processes aim at maintaining a given state of a system within a defined range on beforehand.

Often that stable state or that stable behaviour is essential to assume structural stability of a system; this is also known as morphostasis: the process in complex system-environment exchanges that tends to serve or maintain a system's structure or state. For example, the size of the pupil of the human eye is negatively correlated with the intensity of light entering the retina thus keeping the amount of light within the limits of optimal processing of visual information. Too much light will destroy the light sensitive cones of the retina. Similarly, the blood sugar content and many other chemical quantities are balanced within the human body. Homeostatic processes never exceed striving for a current state (including the related structure to maintain the balance). The implication of morphostasis might also be that systems tend to 'repair' the perturbations in structure rather than neutralising the external influence. Examples are tissues in the human body, family structures and technological developments in society. But also, the 'balance of power' idea in the international political system denotes a homeostatic mechanism whose outcome presumably neither country desires by itself. Also in families, homeostasis may become pathological when family members no longer prefer that state yet cannot escape it as a consequence of the way they interact with one another. All these indicate that interventions take place in the context of a structure to maintain the structure. Homeostasis, in these cases of morphostasis, depends on the structure between elements as a continuous process, which make it impossible to move away from that given 'point of equilibrium'.

Adaptive Processes

Whereas homeostasis concerns states or behaviours of systems and processes, adaptive processes relate to structure and organisation of these systems. One of the biological adaptive processes is morphogenesis, the shaping of an organism by embryological processes of differentiation of cells, tissues and organs, and the development of organ systems according to the genetic 'blueprint' of the potential organism and environmental conditions. In evolutionary biology, it is believed that these processes, sometimes happening in the early stages of growth of an individual are responsible for the variation in species. A famous example of these processes is the 'placement' of limbs, etc. that are guided by so-called Hox genes; these Hox genes can cause human beings to have five or six toes (although, the latter is rare). Adaptation in technical systems, the lower levels of the systems' hierarchy, becomes only possible through external interventions; hence, it makes more sense to speak about interventions than about adaptive processes. For instance, by adding applications in a computer or tablet, its capabilities for providing or processing information changes, but this can only be done if a human being signals the installation of such an application. Whether as a result of external interventions or as an outcome of internal processes, generically speaking, adaptive processes aim at changing the structure of the systems as internal processes.

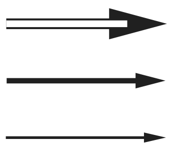
Adaptive processes occur in case that adaptation to the need from the environment of the system is necessary, and, therefore, they are externally oriented. Simplifying this statement: the structure of the system follows the requirements set by the environment. This is most common in new product and service development, engineering and some approaches in management sciences. For example, the design of organisational structures and information systems follow this pattern. To a certain extent, biological processes follow this pattern, too; ultimately, species adapt to the environment. In this way of viewing, the analysis opens up for deterministic approaches, which allows comparing one state of the system with another or one system with another. One of the underlying thoughts of this way of thinking is that it becomes possible to achieve equilibrium with the environment; that can be considered as balancing the internal structure and external structure of a system.

In short, to distinguish between these types of processes we state that adaptive processes in a system occur when the values from relevant aspects from the system environment are being considered as normative but at the same time are outside the remit of the boundaries for the homeostatic processes. For adaptive processes to occur that means mostly that these values from relevant aspects change beyond control, so to say. However, in biological processes there is a phenomenon called neutral or random genetic drift; it denotes the idea that some random mutations come at a quite regular, almost constant rate over time, and that the type of mutation is random and remain untouched by selection (Kimura, 1983). In other words, these mutations do not serve any function or do not change any function of the already existing genes in a population. As a result they do not disappear through selection. As the opposite of adaptive processes, homeostatic processes arise when values of relevant aspects within a system are being regarded as normative but within reach of the boundaries of these homeostatic processes. The internal processes of the system aim at maintaining that steady-state and in a way resist changing. Adapting occurs at the thin borderline between adaptive and homeostatic processes, but that will be discussed in Chapter 8.

Depicting Processes

Not only did this section introduce two specific instances of processes, as seen in Box 4.A, it also introduced different flowing elements. The three types of flowing elements that will be used from now on are shown in Box 4.1. The depiction of the primary process does not have to be materialistic

Box 4.1: Symbols for Processes (Applied Systems Theory)



Flowing elements (primary process)

Energy

Information

In Applied Systems Theory, three distinct symbols are used for processes. The symbol for flowing elements is different from the other two; note that the symbol can be used also for indicating information as the primary process when it concerns the ‘core” process of entity (Example 4.1 demonstrates this for the claims). The energy flow is distinguished from a regular primary process due to its different characteristics. Finally, the symbol for “information” differs from the other two, because it is related to information about the primary process, mostly used for control of primary processes (flowing elements and energy); the use of this symbol appears mostly in Chapters 5 and 6.

(products). It can also be either flowing elements in the form of essential information or energy flowing throughout a system; since energy cannot be captured directly as flowing element, it has a different symbol but is still used for the primary process. In that sense, the primary process serves as an abstraction of reality. When the process comprises the transformation of information about the primary process, it has a different symbol again. This is the case for control processes; information is then not directly the primary process but about a characteristic of the flowing elements or energy. The use of three different symbols makes it easier to distinguish the different purposes of processes.

4.3 Primary and Secondary Processes

Since processes aim at changing a state of a system (i.e. the flowing elements), this chapter has focused on the transformation of input into output. This transformation, when we talk about the primary process, means changing the state of the flowing elements from an initial condition (input) to a final condition (output) observed at a given aggregation stratum. However, resources are necessary to sustain this primary process. Secondary processes are those that recuperate the resources that have been deployed for the primary processes. Therefore, the primary and secondary process are linked to each other through the use of resources.

Primary Process

The primary process is the conversion of flowing element from one state into another for which is needs resources. The primary process is often linked to the purpose or objective of the system. Let us consider a jet engine of an aircraft in which we define this engine as a system. The primary process of the system is providing the relevant part of its environment (the aircraft) with thrust and aims at accelerating air through the engine. As another example,

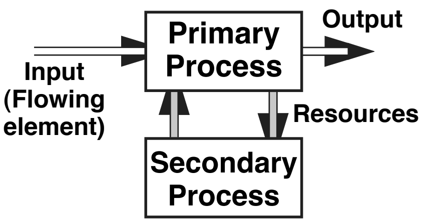
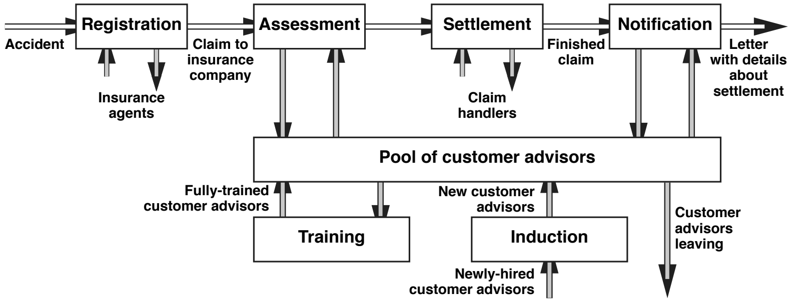


Figure 4.3 *Position of the secondary process in relation to the primary process. Similarly to the primary process, the secondary process transforms its flowing elements, the resources, needed for the primary process, from one state to another. When deployed by the primary process the initial state of the resource should potentially allow the interaction with the flowing element. Please note that the secondary process itself is also a process and requires in turn resources for its execution; for reasons of simplification that has been omitted in this figure.*

Box 4.B: Processes for Insurance Claims

The example of the simplified process for handling insurance claims continues. From Example 4.1 the homeostatic process is taken.



Primary Processes

The primary process in this case is the processing of 'accidents', into notification to the customer about the settlement of the claim. The pool of customer advisors is to be seen as a reservoir of available customer advisors that are assigned to assessment and notification depending on the number of claims to be handled.

Secondary Processes

In this case, the secondary process is the training of customer advisors to keep them up-to-date. Also the induction of newly-hired advisors constitutes a secondary process.

the primary process of a petrochemical plant is the conversion of crude oil into intermediaries or consumables, like car fuel. But none of these processes exists without a resource inducing this transformation, the engine or the plant, for the examples given. That makes it sometimes hard to distinguish what the system is when trying to identify it. In the case of an organisation, is it necessary to look at the organisation as a system of resources that produces output or to look at the primary process and the resources of the organisation as ensuring the output. Though by some considered pencil-licking, they represent very different views result in different modelling of the organisation. Therefore, the specific view on the primary process as interaction between flowing elements and resources has a profound impact on analysing and resolving problems.

The principle of processes as interaction between flowing elements and resources requires that in order to change a property or parameter of the flowing element a property or parameter of the resources should change too. By following a lecture, a student will acquire knowledge but that demands a lecturer to prepare a presentation; for that presentation the lecturer had to gain knowledge in the past or present. For both examples in the previous paragraphs, the execution of the primary process causes the jet engine and the equipment of the petrochemical plant to wear off. That means that the interaction between resources and flowing elements results in changes properties of the resources, which are also considered as a system.

Secondary Processes

Therefore, secondary processes act on resources to recondition the state of resources so that they can be used for the primary process again (see Figure 4.3). For example, maintenance processes aim at restoring the state of the jet engine and the petrochemical plant so that the continuation of the primary process is ensured. As another illustration, when we would discuss the process of pumping fuel to the jet engine during flight, this would be a secondary process. After all, the process of pumping fuel delivers the resource to ensure the continuation of the primary process, and, therefore, enables it to deliver the thrust. Box 4.B illustrates the application of secondary processes to the example of Box 4.A; in this case the secondary process consists of the training of advisors, which allows these to process claims appropriately. Hence, the primary and secondary process are linked through the flows of the resources.

A secondary process can become a primary process on another aggregation stratum; this is the means-end hierarchy. In another case in which we would be interested in the process of pumping fuel from one of the fuel tanks to the combustion chamber we would characterise this fuel pumping process as the primary process. A secondary process, and, therefore, the supplier of the resource, would be for example driving this pump by a hydraulic motor. This way, each secondary process enables the primary process it is related to fulfilling its function.

4.4 Process and Function

But what exactly is a function? Usually, a process satisfies a need (whether created by a designer or naturally evolved), to contribute something towards its greater entity (usually its environment); an abstraction of that contribution is called the function. West Churchman [1979, p. 13] demonstrates this for the automobile:

> *If you begin by thinking about the function of the automobile, that is, what it is for, then you won't describe the automobile by talking about the four wheels, its engine, size and so on. You will begin by thinking that an automobile is a mechanical means of transporting a few people from one place to another, ...*

For example, if somewhere in a process a reduction of the rotational speed is needed, the function of this part of the process would be reducing rotational

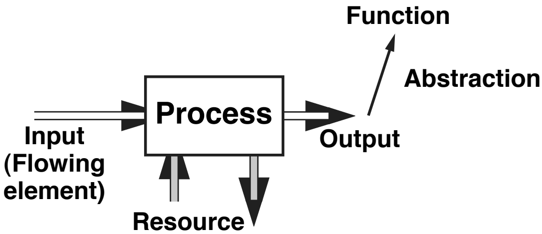


Figure 4.4 *Function as an abstraction of the output of a process. The function comprises of the contribution of the system to its environment, in particular for processes, the meaning of the output produced by the resources by the transformation of flowing elements.*

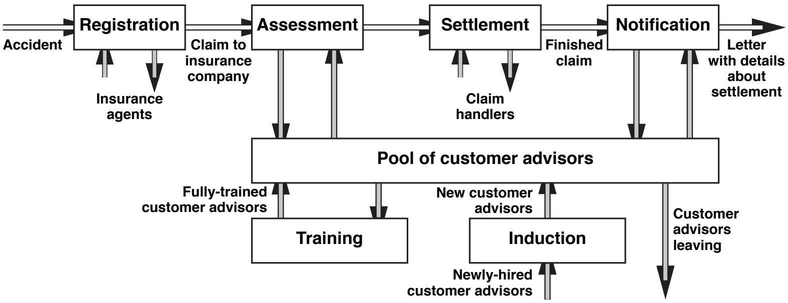
speed (note that in most cases a function can be described with a verb and a noun); note the link to ontology as mentioned in Section 3.4. Generally speaking, a function is always a rather abstract description of the output of a process; by not no talking about specific hardware for technical systems, specific organisms in biological systems or specific departments of an organisation system, the options how that function can be fulfilled remain open and allow further decision-making or evolutionary options.

Eventually, an output has to be produced through the execution of the process, that is the transformation of the input into the output. This is a specialisation of the function (Figure 4.4), the translation of the function into an activity (making the output available to the environment constitutes an event, see Sections 2.5–2.7; in the case that the output is made available internal the system it will be called an activity). The function of reducing rotational speed can be translated into employing a gearbox. It is important to notice that this is a choice out of (probably) many possibilities, based on more or less well-defined criteria. Instead of a gearbox, we could have chosen a belt drive or a chain drive to realise the same function. As soon as the process is formulated, the necessary resources become apparent, which are different for gearbox, belt drive or chain drive. A similar example could be given for the administration of a company; it is irrelevant to a certain extent whether financial statements are generated manually or automatically, albeit that the resources differ substantially in both instances. In that sense, it is the process that relates the function to the resources. Thus, the function describes merely the effect of the process, not the way the output is actually manufactured as a process.

Usually, for design the need of the environment is known (or created) through interaction with the environment. This means that the freedom of the designer lies in defining a suitable function and deciding on the most efficient way to implement it. Analysing a process involves looking at the existing process and the output. Generalising the intended function of the process is one of the hardest skills to master. But having formulated the function, most of the time it becomes possible to formulate alternative processes for the

Box 4.C: Function and Teleology for Insurance Claims

The example of the simplified process for handling insurance claims continues. From Box 4.B the primary and secondary processes are taken.



Function

The primary process delivers settlement as outcomes. For customers, these financial settlements have the purpose of reducing the risk of peaks in expenditures due to 'unexpected' events.

Extrinsic Finality

In this case, the extrinsic finality is found in the settlement being a 'means to an end'. The settlement is used by the customers to cover unexpected expenditures related to car accidents or to smooth expenditures over a longer period of time; different customers might have different perspectives on this. Insurance might also be necessary for legal reasons, for the purpose of simplification not dealt with here.

Intrinsic Finality

But also for this example, the continued existence of the entity 'insurance company' provides employment and thus livelihood for the employees. Training of employees, being better in handling insurance claims, contributes to the sustainability of the systems of resources (employees).

same function. This way the behaviour of the process can be influenced, thus enabling optimisation.

The purpose of systems can be found in the thinking about teleology. This concerns the supposition that there is design and purpose – a directive principle –, or finality in the works and processes of nature, and the philosophical study of that purpose. In this perspective, teleology depends on the concept of a final cause or purpose inherent in all beings. There are two types of such causes, intrinsic finality and extrinsic finality:

- Extrinsic finality consists of a being realising its purpose outside the being for the utility and welfare of other beings. For instance, minerals are ‘designed’ to be used by plants, which are in turn ‘designed’ to be consumed by animals.
- Intrinsic finality consists of a being realising its purpose by means of a natural tendency directed toward the perfection of its own nature. In essence, it is what is ‘good for’ a being. For example, physical masses obey universal gravitational tendencies that did not evolve, but are simply a cosmic ‘given’. Similarly, life is intended to behave in certain ways so as to preserve itself from death, disease and pain.

The concept of extrinsic finality from teleology resembles that of function, the purpose of the realisation of a process (or in abstracted form function) is found in its environment; see Box 4.C. The intrinsic finality is somewhat related to purpose of the systems resources, which will be discussed next.

4.5 Systems of Resources

Because a process is an interaction between flowing elements and resources, these resources can be considered as elements or systems. That means they can be grouped together as a system, creating an environment and external structure for the system of resources. Again, the problem definition sets out what to include or exclude as part of a system. For example, take suppliers delivering to a manufacturer. When considering the supply chain from raw materials suppliers to products to customers, the suppliers constitute part of the resources and are part of the system of resources under review. But when examining the control of deliveries to the company, than the problem’s perspective leads to the exclusion of suppliers and they become part of the environment of the system of resources. Reasoning in this way demonstrates that systems of resources follow the definition of systems.

Resources provide, or facilitate, the activities through which intakes are converted into outputs [Miller and Rice, 1967, pp. 28–29]. The resources required for any execution of processes are physical entities, in the case of technical and biological systems, or are artificial constructs of the human mind, like for organisational systems. The extent to which resources exist or do not exist constitutes the major internal constraint on process definitions and performance. Hence, the performance of a process links univocally to the system of resources deployed and will not exceed its capability.

Therefore, constraints arising either from the environment or from within the system of resources itself need to be reviewed to determine whether they are in fact inviolable. Whether that concerns technical, biological or organisational processes. A relaxation of constraints could lead to new processes or better performance of old ones; but there is no corresponding defined process for the evaluation and also for criteria to judge the performance to know what was standard has become substandard. The resources necessary for a process facilitate the transformation of input into output, while at the same time they inhibit the conversion through their constraints. Hence, to change the conversion as a process, a designer can either alter the span of the resources (i.e. include more or less resources) or replace the resources.

In systems of resources with more than one process and no adequate determination of priorities, the performance of one process acts as a constraint on the performance of another. Large systems are differentiated into constituent systems, each of which has its discrete primary process. Furthermore, the environment of any constituent system is comprised of other constituent systems and the whole, and the constraints on definition and performance in constituent systems include, therefore, those imposed by other constituent systems. The greater the differentiation of a large, complex system, the more numerous the constraints imposed.

Events at the boundaries of systems of resources cause activities within the system, sometimes exceeding the constraints. That can be the input of the flowing elements or that the output does not fulfil its function any more. For example, orders cause activities within an organisational system. Or the events might be changes in the environment of the system, the external resources, the way they interact with internal resources. In any case, events activate internal processes of maintaining homeostasis or they lead to adaptive processes, which require changes in the structure of the system, to cope with these events.

4.6 Behaviour and Processes

Hence, processes display behaviour taken as reacting to events. When talking about behaviour it is quite common to use it in the context of the behaviour of a person. We might say: 'He behaved rather annoying last night', expressing discontent in this case, indefinitely it refers to activities and effects of these. The concept of behaviour applies also the other objects, for example, the behaviour of a car subject to certain road conditions, like slippery surfaces. Apart from these examples, why take interest in behaviour of systems and the processes they are subjected to? The fact that we experience and recognise behaviour apparently holds that we are able to observe a change in at least one of the aspects of a system. The change of this state is called behaviour of the system. As stated before, a process might also display behaviour. This is nothing more than the change of the behaviour of the system, for example, originating from disruptions of resources.

Furthermore, behaviour can only occur within dynamic systems, this automatically being the case for processes: the system of flowing elements interacts with the system of resources. This is simply because only dynamic systems show interaction with the environment (see Sections 2.5 and 2.6). Having said so, we come to the distinction between static and dynamic behaviour. Static behaviour occurs when the output of a dynamic system depends on the value of the relevant aspect of the input. Of course, the value of the output at a certain point in time has to be matched with the corresponding input and the duration of the process to make a correct comparison possible. In case of static behaviour there should be a linear relation between the value of the relevant aspect and time of the input and output.

In case of dynamic behaviour the output of a system not only depends on the point of time and the input value of the considered aspect. The output also depends on, for example, buffering actions inside the process ('memory') or disturbing influences. When we assume that the output of the process has to be of constant quality, dynamic behaviour might jeopardise that goal. If still the goal stands to reach a constant quality of output, that raises the issue to what extent processes are capable to maintain that quality of the output; Chapter 5 will deal with mechanisms control.

We have to keep in mind that behaviour caused by one or more processes within a dynamic system might be static for one aspect but dynamic for another aspect. Therefore, in order to prevent deviations to arise in the actual problem resolution, the problem definitions should make what aspect(s) to focus on. The level of aggregation might also influence the characterisation of behaviour, in terms of being static or dynamic. The observation that the human body is in a stable condition is underpinned by the dynamics of the internal processes whether it is constant temperature or is stable motion. Henceforth, behaviour depends on the aspects chosen for the investigation of a system and on which aggregation stratum the analysis takes place.

4.7 Processes and Blackbox Approach

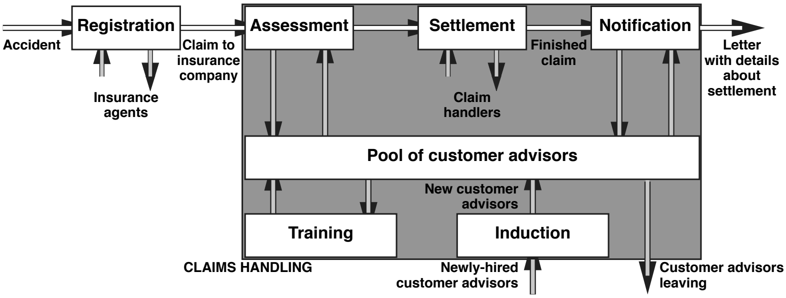
Similarly as in Section 3.2, we can apply the blackbox approach to processes, too. The blackbox approach examines the external structure of a system without identifying any of the internal elements. This approach supports a study by not looking at the elements of the system and the internal relationships creating space to focus on the behaviour of the system as if it was one element. Hence, at one level of aggregation we might consider a process as a blackbox, too, the inputs and outputs of the process serve as the external structure (see Figure 4.5).

By using the blackbox approach a study will aim at relating changes in one or more inputs of a process to alterations in one or more outputs. Used as an example before, practising physicians deploy this method by deducting

Figure 4.5 *Process as blackbox. Inputs are transferred into output without knowing any further details about the internal process. The investigator aims to relate variations in the input of flowing elements to the variations of the properties of the output.*

Box 4.D: Blackbox Approach, Behaviour for Insurance Claims

The example of the simplified process for handling insurance claims continues. From Box 4.B the primary and secondary process is taken. For ease of depiction, the original processes are depicted in the blackbox; normally, like in Figure 4.5 the blackbox does not reveal the more detailed 'internal' processes.



Claims Handling as Blackbox

Without going into detail, the blackbox allows examining the process at an aggregate level. In this case, the input of the blackbox is a claim to the insurance company and the output a letter with a settlement. Similarly, newly-hired insurance advisors enter the blackbox and some customer advisors are leaving.

Studying Behaviour

By looking at the input and output, the observer will learn whether claims are processed within a certain lead-time. Additionally, that can be linked to customer advisors entering and leaving the blackbox. That could lead to inferences about the available capacity of customer advisors for handling insurance claims. However, for example, if productivity improves, which is an adaptive process, the throughput of handling insurance claims improves, in which case there are more customer advisors leaving the blackbox than entering. Conversely, the observation of input, output and resources might lead to preliminary indications about the performance of internal processes.

from the behaviour of the human being as a process, e.g. temperature, pain and coughs, what internal causes bear relevance to the well-being. Through purposeful dosing of medicine and assessing their efficacy, doctors draw conclusions about their earlier findings. The reaction to medicines generates indications about the internal processes of the system of resources, the human body. There is a strong relationship between the exertion of stimuli in the form of input and the behaviour of a system as observed in its output, though the identification link requires observations.

Similarly, to the use of the blackbox approach for systems, the higher the number of inputs and outputs, the harder its gets to arrive at conclusions. Even to the extent, that it might become impossible to determine with certainty how the process responds to these changes in external relationships. Although capturing systems behaviour becomes more difficult in case of stochastic changes in relationships, tuning of attributes and relationships belongs to the possibilities to alter the behaviour. In terms of processes, a study has to relate the variances in the input to the variances in the output. Through inductive and deductive reasoning, the behaviour of the process might be revealed as reaction to changes in external stimuli (events).

When at a later stage of the study, the behaviour of the system has revealed itself, the necessity might arise to open the blackbox; by doing so, the subsystems and elements at the lower aggregation stratum might serve again as blackboxes. This zooming in allows first defining more precisely what parts to investigate based on the actual behaviour of the system. When the behaviour corresponds with the constraints imposed by the function and requirements of the output, then no further investigation is necessary, except for curiosity. When optimisation is required or possibly an intervention in structure, then zooming in and considering subsystems and elements as blackboxes again, might reduce the overload on information. Hence, stepwise process mapping, assisted by the blackbox approach and zooming in, provides a powerful tool for analysing the performance of systems.

4.8 Business Process Mapping

This section pays attention to process mapping as used in organisations and business environments. Some authors draw our attention to the importance of process mapping. Biazzo [2000, pp. 103–104, 111] classifies alternative approaches to business process analysis along two dimensions, strategy and focus. When the analysis looks at the behaviour of actors, the approach for a pragmatic construction is action analysis, and for a rational construction strategy coordination analysis. And when the analysis concerns systems, the approach is either social grammar analysis (pragmatic) or process mapping (rational). Biazzo sees process mapping exclusively as a rational approach focused on systems, comprising of defining boundaries, inputs and outputs of processes, workflow, conducting interviews with those responsible for the various activities, studying available documentation, creating a model and step-by-step revising this model for purposes of analysis. He stresses the importance of selection the proper approach and remarks that practitioners pay insufficient attention to the social context of work. With a different take, Bond [1999] reasons that business process modelling should precede the design of an information system, that way aligning the information system with the organisational requirements. In that respect, Lee and Dale [1998, p.

215] indicate that Business Process Management intends to align the business processes with strategic objectives and customers' needs but requires a change in a company's emphasis from functional to process orientation. Preiss [1999, pp. 42–45] pays explicit attention to the role of process improvement in the context of extended enterprises by modelling. He concludes that sufficient tools are available for analysis. The statements of the authors underline the importance of business process modelling. Process maps are intended to represent a process in such a way that is easy to read and understand for interconnecting process, linking resources, analysis and interventions.

Given that modelling of process is important, there are a number of different methods of process mapping in addition to the modelling approach of Applied Systems Theory. Five proven methods that reside mostly in development of information and communication technology are described in the rest of this section although many other formal and ad hoc methods exist.

Structured Systems Analysis and Design Methodology

The first one of those five methods, Structured Systems Analysis and Design Methodology, is used for the analysis and design of information systems. It is an open standard, which means it is freely available for use by organisations; many companies offer support, training and case tools for this design method. Organisations use this method because they expect that the use of a disciplined approach will eventually improve the quality and the reliability of the systems they produce. Because of the this expectation, many organisations have been willing to incur the considerable expense and effort coming along with the implementation of the Structured Systems Analysis and Design Methodology, for example, training of staff.

The Structured Systems Analysis and Design Methodology combines project management and modelling of information processes. For the purpose of managing the development of a project for information systems, it provides a framework for allocating modules, stages and steps. For the modelling of information processes it has three key techniques, which are described by David [1992] as being:

- Logical Data Modelling. This technique is used for identifying, modelling and documenting the data requirements of a business information system. This technique should identify a Logical Data Structure and should

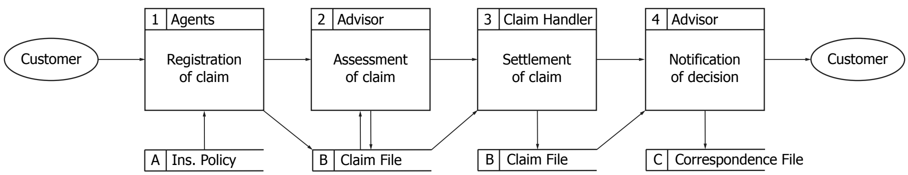


Figure 4.6 *Data Flow Modelling used for mapping process of insurance claims, based on generic process of Box 4.A. Note that the example has been greatly simplified to demonstrate its basic principles. This data flow model should be used in conjunction with Logical Data Modelling and Entity Event Modelling.*

generate the associated documentation. The Logical Data Structure represents the entities of an information system (objects in their widest sense about which a business needs to record information) and their relationships (necessary associations between entities). Please note that in terms of Applied Systems Theory, this Logical Data Structure covers both the contents and the structure (see Section 2.2).

- Data Flow Modelling. This method is used for identifying, modelling and documenting how data flows around in a business information system. This step results in Data Flow Diagrams supported by appropriate documentation. Data Flow Diagrams represent processes, data storage, external entities (which send data into a system or receive data from a system) and data flows (routes by which data flow in, through and out of the system).
- Entity Event Modelling. This is the procedure for identifying, modelling and documenting the business events, which affect each entity and the sequence in which these events occur. An Entity Event Model consists of a set of Entity Life Histories (one for each entity) and appropriate supporting documentation.

The widespread acceptance of the Structured Systems Analysis and Design Methodology may lie in the fact that it does not rely on a single technique. Each of the three system models provides a different viewpoint of the same system, each of which are required to form a complete model of the system (see Figure 4.6 for the example of Data Flow Modelling). Within the method each of the three techniques are cross-referenced against each other to ensure the completeness and accuracy of the model. This creates a number of advantages according to its advocates:

- Its structured analysis provides a clear picture of requirements that those that are involved will understand.
- It can be used by both experienced and inexperienced staff because of depicting sequence of activities.
- It support the planning and control of projects for information systems.
- Its structured approaches lead to comprehensive specifications that results in higher quality of the information systems being built.

However, the Structured Systems Analysis and Design Methodology also has some disadvantages, for example:

- It can be considered 'generic', because it describes the details that need to be considered in physical design, without describing in detail what needs to be produced.
- It can also be 'theoretical', because it describes an ideal approach that may not be relevant for most developments.

The Structured Systems Analysis & Design Method is a widely used method for the development of computer applications and has been adopted across private and public organisations since its origins in the 1980s.

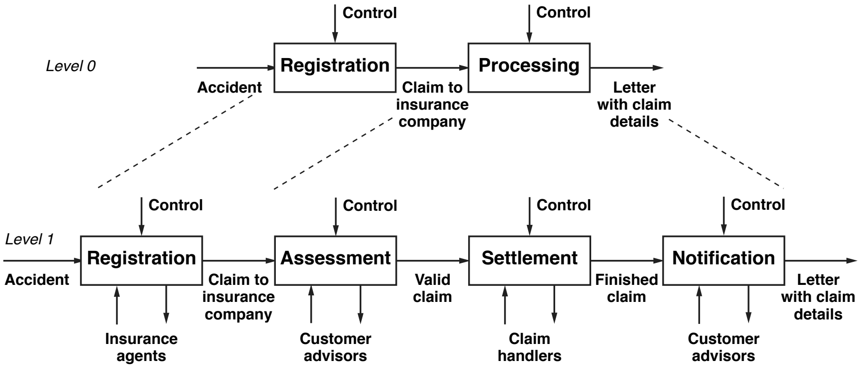


Figure 4.7 *Hierarchical view of IDEF0 for process of insurance claims, based on the generic process of Box 4.A. Processes are decomposed in activities at lower levels, akin aggregation strata in Applied Systems Theory. The diagrams provide an overview of input and output for processes, their resources and their control (control mechanisms will appear in more detail in Chapter 5).*

International DEFinition Method

The second method that this section looks at is the International DEFinition Method. This method was developed during the 1970s by the US Department of Defence, particularly for the US Air Force, before the Structured Systems Analysis and Design Methodology. It is mostly known by its abbreviation: IDEF. The method is designed to model the decisions, actions and activities of an organisation or system. Although developed over thirty years before, it was not until 1993 that the Computer Systems Laboratory of the National Institute of Standards and Technology released IDEF0 as a standard for function modelling. Peppard et al. [1995: 173] describe as it having started life as a software development tool, although it is now an accepted tool for process mapping within manufacturing and service organisations.

The IDEF0 diagrams are used for process mapping and visualisation of information in the form of inputs, controls, outputs and mechanisms; note the parallel with primary processes in this chapter and control processes in Chapter 5. Even though the method supports the hierarchical decomposition of activities (see Figure 4.7 for use in the example), it cannot express process execution sequence, iteration runs, selection of paths, parallel execution and conditional process flow, all necessary for designing computer and information systems; the use of hierarchical decomposition has similarities with the distinction of aggregation strata (Section 3.1). The IDEF3 diagrams, as a further development of IDEF0, overcome the above mentioned weaknesses, by capturing all temporal information, such as precedence and causality relationships associated with the enterprise processes and thus providing a basis for constructing analytical design models.

As seen from Figure 4.7, mapping using this standard generally involves two or more levels. The first level, the high level map, identifies the major processes – read primary process – by which the company operates [Peppard et al., 1995]; for example, direction setting, winning the customer, delivery to the customer, support to the customer, support to the organisation. The second level map breaks each of these processes into a sequence of steps, and then breaks those steps down again until the appropriate level is reached. This distinction of levels aims at keeping an overview while each diagram does not present overwhelming detail.

There are a number of strengths and weaknesses associated with IDEF0. Many would say that the main strength is that it is an effective method detailing the system activities. The descriptive activities of a system can be easily refined into increasing detail until the model is as descriptive as necessary for the task at hand. However, IDEF0 diagrams can be so concise that they are only understandable if the user is an expert on the process being mapped. The models also tend to be interpreted as a sequence of activities. The models may have embedded sequencing, however if this is not originally intended, hence, the user may need to interpret this. These weaknesses make that the method should be used with care and also might need sufficient explanation so that all involved can understand it.

ASME Mapping Standard

The third method, the mapping standard of the ASME (American Society of Mechanical Engineers), dates even further back than the methods of

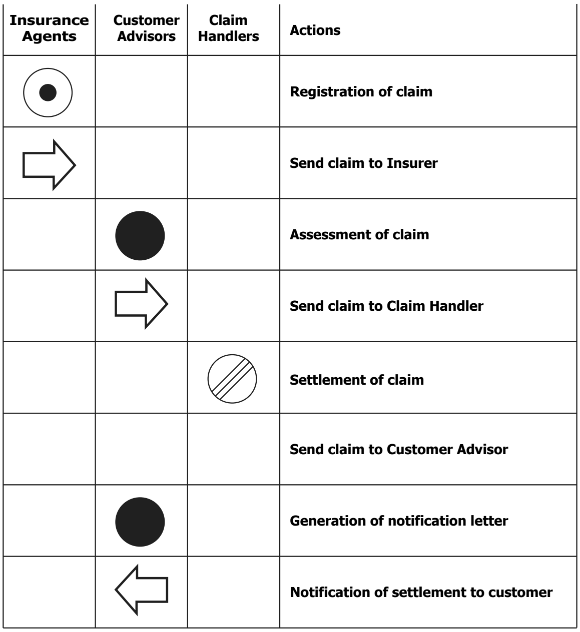


Figure 4.8 *Mapping of process for insurance claims according to ASME Mapping Standard, based on the generic process of Box 4.A. The depicted process is a simplification to demonstrate the application of the standard.*

IDEF0. It roots in the work of Frank Gilbreth, an early advocate of scientific management and pioneer of motion study, who presented to members of the ASME in 1921 on 'Process Charts–First Steps in Finding the One Best Way'. Later, in 1947, the ASME adopted a symbol set as the ASME Standard for Process Charts derived from Gilbreth's original work.

Now, this mapping standard is widely used in manufacturing and increasingly popular in office and service environments. The official ASME mapping standard has eleven different symbols in process diagrams; for example, it has symbols for 'do' operations, handling operations, inspection and storage. An example of its use is shown in Figure 4.8. It is suited for detailed level mapping and has the distinct advantage that 'inherent in its use is an evaluation of whether a step is value adding. Only one of the columns contains value adding steps and thus the areas of waste or non-value-adding activity are clear' [Peppard et al., 1995].

Unified Modelling Language

The Unified Modelling Language is a standardised, general-purpose modelling language in the domain of software engineering, which includes modelling of business processes. It combines data modelling (which are entity relationship diagrams), modelling of workflow (business modelling), object modelling (objects are variable, functions and data structures) and component modelling for the purpose of developing and building computer applications. Those developing software see the Unified Modelling Language as a language and not a methodology, because its use is independent from programming language. Although the Unified Modelling Language is generally used to model computer applications, it is not limited within this boundary; it is also used to model other processes, such as process flows in manufacturing units.

Within the fundamental notation of the Unified Modelling Language, concepts are depicted as symbols and relationships among concepts are depicted as paths (lines) connecting symbols. Diagrams are graphical projections of sets of model elements and are used to depict knowledge (syntax) about problems and solutions; these diagrams entail:

- Class diagrams.
- Object diagrams.
- Use case diagrams.

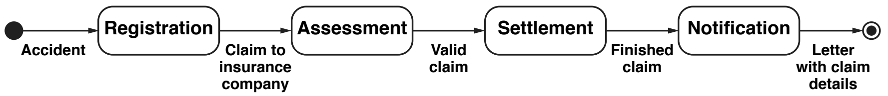


Figure 4.9 *Activity diagram for insurance claims according to Unified Modelling Language, based on the generic process of Box 4.A. The depicted process is a simplification to demonstrate the application of the standard; more symbols are used to create activity diagrams normally, such as symbols for decisions. In addition, the Unified Modelling Language uses eight more diagrams to depict processes and other related state changes in a computer application.*

- Sequence diagrams.
- Collaboration diagrams.
- State chart diagrams.
- Activity diagrams.
- Component diagrams.
- Deployment diagrams.

All these diagrams serve different purposes and depict different facets of a computer application; an example of an activity diagram is found in Figure 4.9. At the same time, they need to be collated to ensure that all are consistent; that is often done by using tools and developers' software that support the development of computer applications.

While the Unified Modelling Language has turned into an industry standard for computer applications, it carries also a number of disadvantages:

- The number of diagrams is complex and their interrelationships are difficult to interpret.
- The standard is not a standard for systems development (for example, the coding for programming is not included).
- The automatic generation of software systems is not possible.
- The method encourages an object connection architecture rather than interface connection architecture.

However, the Unified Modelling Language should be viewed as a software modelling language with an emphasis on graphics and motion that allows interacting with stakeholders.

Soft Systems Methodology

Although not primarily designed for business process mapping, or particularly, information technology, the Soft Systems Methodology as the fifth method in this section has found widespread use for improving business processes of organisations. In that respect, Checkland [1991] claims that this particular systems theory and its practice apply to many problem areas. However, the approach lends itself particularly well to dealing with complex situations, where those involved lack a common agreement on what constitutes the problem, and that needs to be addressed. To that purpose, in this approach stakeholders engage with each other guided by an analyst or facilitator; in that sense, this participatory stance has many parallels with action learning [for example, Raelin and Coughlan, 2006]. The Soft Systems Methodology and its related approaches have found widespread recognition and are taught at many academic institutions.

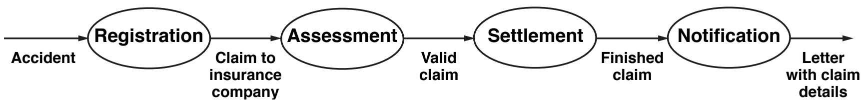


Figure 4.10 *Human Activity System for insurance claims according to Soft Systems Methodology, based on the generic process of Box 4.A. The depicted process is a simplification to demonstrate the application of the approach.*

The approach of Soft Systems Methodology has some similarities with Applied Systems Theory. It also looks at systems as being part of total reality; to that purpose, the so-called root definition describes the relationship of a system with its environment. And it recognises the function of a system (see Section 4.4), or better process, through what is called CATWOE:

- Clients (Who are the beneficiaries or stakeholders of this particular system?).
- Actors (Who are responsible for implementing this system?).
- Transformation (What are the inputs and what transformation do they go through to become the outputs?).
- Weltanschauung (What particular worldview justifies the existence of this system?).
- Owner (Who has the authority to abolish this system or change its measures of performance?).
- Environmental constraints (Which external constraints does this system take as a given?).

Many will see this mnemonic as a checklist for goal definition. However, it might be necessary to use the 'checklist' as appropriate. According to Checkland [1991], systems thinking is a way of modelling rather then a technique, see Figure 4.10 for an example, and it applies as a methodology to handle complex situations.

Furthermore, the most distinct difference with Applied Systems Theory is the Soft Systems Methodology uses seven stages for solving a problem:

- Entering the problem situation.
- Expressing the problem situation.
- Formulating root definitions of relevant systems (using CATWOE).
- Building conceptual models of Human Activity Systems (defined as an assembly of people and other resources organised into a whole in order to accomplish a purpose).
- Comparing the models with the real world.
- Defining changes that are desirable and feasible.
- Taking action to improve the real world situation.

Because of these seven stages and its participatory approach, Soft Systems Methodology serves well as a process for process evaluation and a modelling approach at the same time.

4.9 Summary

One the most common purpose of modelling by using Applied Systems is about changes of state of systems, also called processes. In that perspective, a process can be described as the transformation of the input(s) into the output(s), or as the interaction between the flowing element(s) and the resource(s). That means that a resource acts on flowing elements to achieve outputs. To that purpose, generically speaking, a system of flowing elements and a system of resources is needed to describe processes.

In that sense, on its own aggregation stratum, the resource can become the flowing element; this is the recursive scheme of primary and secondary processes. Secondary processes aim at maintaining the state of resources for primary processes. When they become themselves the focus of attention, that is called the means-end hierarchy.

Moreover, the function of a process, as an abstraction of the output, defines its contribution to the environment. Moreover, there might different principle solutions to achieving a specific function. Then, a designer of a system performs a specialisation of the function to define a process with its resources; that means that analysing an existing process includes generalising it into a function. Choosing and constructing a process to fulfil a certain function requires an understanding of the process' behaviour.

References

Biazzo, S. (2000). Approaches to business process analysis: a review. Business Process Management Journal, 6(2), 99–112.

Bond, T. C. (1999). Systems analysis and business process mapping: a symbiosis. Business Process Management Journal, 5(2), 164–177.

Cannon, W. B. (1932). The Wisdom of the Body.

Davis, W. S. (1992). Tools and Techniques for Structured Systems Analysis and Design. Reading, MA: Addison-Wesley.

Lee, R. G., & Dale, B. G. (1998). Business process management: a review and evaluation. Business Process Management Journal, 4(3), 214–225.

Peppard, J., & Rowland, P. (1995). The Essence of Business Process Re-engineering. Hemel Hempstead: Prentice Hall Europe.

Preiss, K. (1999). Modelling of knowledge flows and their impact. Journal of Knowledge Management, 3(1), 36–46.

Raelin, J. A., & Coghlan, D. (2006). Developing Managers as Learners and Researchers: Using Action Learning and Action Research. Journal of Management Education, 30(5), 670–689.

West Churchman, C. (1979). The Systems Approach: Revised and Updated. New York: Dell.

5 Control of Processes

It might well be that the output of the primary process, the topic of the previous chapter, does not match with pre-defined outcomes or expectations; that deviation evokes the need for control, the subject of this chapter. Consider the following example of driving a car, where the output is driving a car at a given speed. Would it suffice to push the gas pedal of a car into a certain position, await it to accelerate to a speed in mind and cruise? Most likely not, since all kinds of deviations might occur during travelling, such as other cars on the road, the state of the road, unexpected traffic jams, etc. The occurrence of these types of disturbances is why this chapter will focus on control processes. These processes connect directly to the state of systems and processes, which the previous chapter has dealt with the changing of the state of systems. Processes deliver an output, which fulfils a function, and that should not only be in accordance with the function but also meet requirements and constraints. When preparing and eating food we know that cooking does not always deliver the same result, even though we adhere to strict processes; some fast-food restaurants have battled this by submitting detailed instructions to workers how to prepare dishes they serve and meticulous control of ingredients used. But if there is variation in the ingredients, those controls might have limited reach and those that cook have to adapt recipes and instructions; that is also control. Note that in this chapter about basic concepts of control for processes the interest goes to activities in particular when talking about controlling.

Control processes, as we known today, are rooted in technological developments dating back to antiquity. An example of one of those early applications is how vertical windmills – as in the design of some of the famous Ducth windmills – are kept in the direction of the wind. However, a more formal analysis of the field started with an analysis of the dynamics of the flyball governor (James Watts' final step in the development of the steam engine), conducted by the famous physicist Maxwell in 1868 entitled 'On Governors'. This described and analysed the phenomenon of 'hunting' in which lags in the system can lead to overcompensation and unstable behaviour. This caused a flurry of interest in the topic. Another notable application of dynamic control was in the area of manned flight. The Wright brothers made their first successful test flights in 17th December, 1903; by 1904 they succeeded in controlling flights for substantial periods with their Flyer III (more so than the ability to produce lift from an aerofoil, which was known). Control of the airplane was necessary for its safe and economically successful use. By World War II, control theory was an important part of fire control, guidance and cybernetics as military applications. The Space Race to the moon depended on accurate control of the spacecraft. For that reason, the technological advances have relied on the development of adequate

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control theory. However, control theory is not only useful for technological applications, but also for fields like biology, economics, organisations and sociology.

To clarify the concept of control, Section 5.1 presents a few examples of control processes. Through these examples the chapter will arrive at a definition of control processes and outline the conditions for effective control. Subsequently, in Sections 5.2-5.5 the distinct four main types of control processes are described. And Section 5.6 focuses on when to apply which type of control. Section 5.7 will discuss echelons of control processes. Section 5.8 on Ashby's famous Law of Requisite Variety concludes this chapter.

5.1 Generic Concept of Control

Examples of control are found all throughout daily life. For example, the temperature of a room is measured and compared with the temperature as set by using a thermostat. The heating system responsible for heating a room is being activated when the actual temperature differs from the set temperature. Another application is a cruise control system in a car. The driver activates the cruise control system as soon as the desired speed has been reached so that the speed will be constant to this set value. In case of a slope in the road or a sudden head wind, the engine will adjust its power in order to annul the difference between the speed as set by the driver and the actual speed. Although more complex, this is also the basic concept of an autopilot in an aircraft controlling vertical and horizontal speed, altitude and heading. One of the differences in the latter context is that the pilot often sets the desired value of the parameter in question prior to this value has been reached. Another example is a manager telling an employee what to do right away to make the deadline for a specific order. But also manually adding some extra paint on a product after a robotic painting process took place, in order to accomplish the desired finish of the painted surface, is a matter of control. The result of the robotic painting process is being measured, compared with a desired result, and if necessary adjusted. These examples show that many applications of control exist.

Moreover, the examples show that an intervention exerted by a control process should always be accompanied by a transformation process other than the transformation of data necessary for the control process. That means that control processes intervene in on-going primary processes; for the examples in the previous paragraph, the primary processes are heating a room, driving a car, flying an aircraft and processing orders. Hence, these two, the primary process and the control process, are always interrelated, regardless of the fact that we can treat the processes for control separately from the primary process of the system. Or more precisely, the objective of a control process is controlling a transformation process, that way intervening

Box 5.1: Defining Control Processes

A control process is a process, whose purpose is solely to, if necessary, intervene in a transformation process in terms of adjusting the values of the relevant aspects to the desired values. It might consist of measuring, comparing, assigning (allocation) and intervening. Intervention takes place to adhere to standards.

either on the execution of the primary process or on the flowing elements or on the system of resources.

Essentially, control processes themselves constitute processes as defined in Section 4.1. Control processes also have their own resources and their own flowing elements; they cause a change of state of their flowing element (data) and therefore they, at least partly, determine the behaviour of the flowing element in terms of changes of values of the relevant aspects related to the primary process in consideration. That change can be induced in two ways. Either the system itself generates the target state for the primary process, as is the case for an organisation. Or the environment determines that target state; technological systems like cars and planes do not set their own objectives, like reaching a destination but a human being external to that system does. But once the target state has been set, the control processes generate interventions to reach that defined target state; hence, control processes are transformation processes as we have dealt with so far.

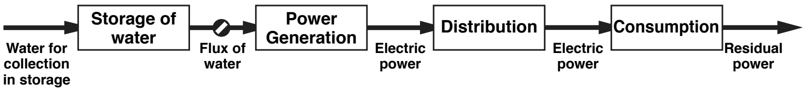
After denoting the purpose of control processes and their characteristics, it becomes possible to formulate a definition for a control process as written down in Box 5.1. This definition also entails that control processes rely on three conditions:

- a normative state of the flowing system, resource system, process properties should be given;
- the possibilities to measure that normative state should be present;
- the possibilities to influence the behaviour of the process should be present.

Only when these three conditions are met, it becomes possible to exert control (see Box 5.A for an example of conditions for control). The normative state defines the standards for the control processes and the aspects or properties that will be measured. Effective interventions should allow reaching that normative state. An example of an ineffective intervention appeared once when quality problems were experienced with the motor for the tape drive of video recorders: the electrical connections were internally broken. To reduce the quality problems extra tests were introduced. However, these additional tests did not change the occurrence of quality deficiencies. What seemed like an effective intervention turned out to have no effect at all: the wiring was once more bended resulting in new faulty connections. While the extra

Box 5.A: Example of Hydro-Electric Power Generation

One of the ways to generate electric power is by converting the energy of (fast) moving water into electricity. There are many famous examples of dams built for this purpose, the largest one being the Three Gorges Dam in China, the Itaipu Dam across the border between Brazil and Paraguay (see picture; source: Wikipedia [2013]) and the Guri Dam in Venezuela. Those and other dams generate electricity to the distribution net (see figure); however, electricity itself is difficultly stored.



Normative State

Therefore, the power generation should not be less than the actual consumption but also not more. The normative state is that the hydro-electric power generation by the dams should match the actual power consumption.

Measurement of Normative State

To be in balance, that means that both the generation and consumption of electricity should be measured. Electric power generation and power consumption are relatively easy to measure; it only requires the measurement of the voltage and the current.

Capabilities for Intervention

There are a number of interventions possible to match the power generation with the energy consumption:

- Switching on and off turbines in the dam (symbol in flow elements between ‘Storage of water’ and ‘Power Generation’).
- Regulating the flux of water to each of the turbines (same symbol).
- Reducing the consumption of electricity (for example, by asking air-conditioning to be switched off at hot days when there are low levels of water in the basin behind the dam).

In this example of hydro-electric power generation all three conditions for control are met. That means it is possible to control the amount of power generated and to a certain extent also the power consumed; these possibilities for control will be discussed in Boxes 5.B–5.E.

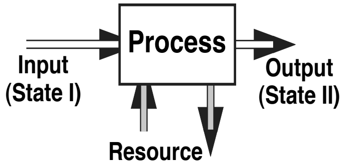


Figure 5.1 *Target states for control. Control aims at keeping the output - the properties of the flowing elements after the execution of the primary process (State II) - within predefined limits. Variations in the input (as reflected in State I) and the resources might cause aberrations of the targeted state.*

quality check eliminated faulty connections, at the same time it introduced faulty connections. Later on, this could be corrected by changing the design of the connection and wiring system for the motors. This example illustrates that effective control depends on the capability for measuring properties and the effect of interventions that potentially will result in achieving the normative state.

In that respect of reaching a normative state, Beer [1959, p. 22] remarks that the big feature of natural, and especially, biological, control mechanisms is that they are simply homeostats; see Section 3.3 on homeostasis. A homeostat is a control device for holding some variable between certain limits. The classical biological example is the homeostasis of blood temperature, which varies little although the human body might pass from getting supplies out of refrigerated storeroom into a fully heated function room. A homeostat holds a critical variable at a desirable level by a self-regulatory mechanism. This means to say the value is always at its intended level to a know standard of approximation, and that there is a compensatory mechanism which edges it back to wards that mean whenever it begins to wander away. But homeostats assume that control is always a kind of self-regulatory mechanism, which is not necessary the case when control mechanisms are explored in more detail.

5.2 Control and Directing

Basically, four main mechanisms of control exist: directing, feedforward control, feedback and completing deficiencies. These control mechanisms act on the state of the flowing elements or the state of the process; the process itself transforms flowing elements in State I to elements having State II (see Figure 5.1), which will be omitted from the later figures that depict control mechanisms (for reasons of simplification). Bookbinding is such a process: single sheets, leafs as they are called, are sewn together into sections, which are bounded together and completed with a book cover. In this example, State I is the loose leafs and the book cover and State II the completed book that can be shelved. However, the objective of control is to maintain the State II, the state of the flowing elements, as output within predefined boundaries. That means for control that after an intervention takes place the desired state of the output will be achieved.

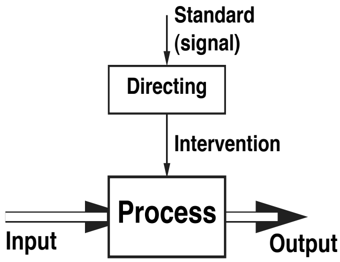


Figure 5.2 *Directing. A control signal, the standard, is converted into interventions for the process (or input). Observe that no measurement takes place, the control process relies on the adequate translation of the standard into an one-time intervention (or directives).*

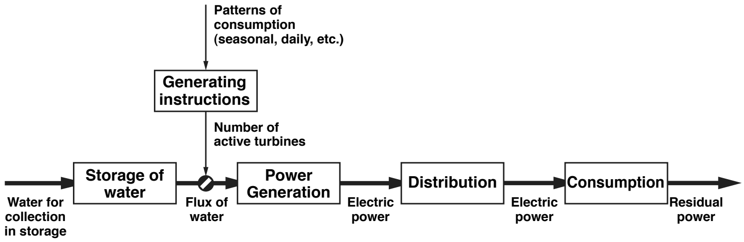
Directing represents the simplest form of control. A (one-time) signal is passed to the process as a directive and one might assume that the desired state will be reached (see Figure 5.2). It looks much like pushing the gas pedal of a car to a pre-set position corresponding to the speed that needs to be reached. The actual speed that the vehicle reaches might depend on other conditions, like the type of road surface, the inclination of the road and the wind direction. However, the controller does not intervene in the case of directing, since the desired state has been translated into a directive that governs the transformation process.

Hence, this type of control process, directing, refers to an intervention in terms of giving a directive to the primary process. It is especially called a directive because of its one-off characteristic of generating. That means that if the state of the output needs alteration the only event required is a new signal or standard; see Box 5.B for the example throughout the chapter. Using the case of driving a car again, the gas pedal is set for a specific speed no matter the actual conditions and the speed of the car will only change if a new normative speed is 'entered' in the control system. Therefore, directing means generating a one-time intervention by the control process for the primary process. The intervention might occur in terms of timing, location, aspects and intensity, according to a certain standard, which is the primary input for the directing process. In case one solely applies directing as the primary control process for the process under observation, there is no monitoring of relevant aspects after the execution of the intervention. There is no measuring process, which monitors any exceeding value of any parameter belonging to any aspect. The lack of a measuring process is a relevant characteristic of directing.

The generation of the intervention as an activity for directing might consist of setting the value of a parameter based on the structure of the flowing elements or changing the structure of the process. After this intervention, the primary process should produce the desired output without further interference, e.g. setting the temperature of a house; in general, directing generates norms for processes seen as blackboxes no matter their internal structure. Another possibility is changing the structure of the process

Box 5.B: Directing – Case Hydro-Electric Power Generation

In the case of hydro-electric power generation, as described briefly in Box 5.A, the intervention could be the switching on and off of water turbines coupled to generators that convert the energy of the rushing water into electricity. How many of these water turbines coupled to generators are operating at the same time determine the output of electric power. That allows the operators to match the power generation with the demand for electric power.
If that matching is based on demand patterns for hours during the day, weekly variation and seasonal influences that will be called directing; in essence, these demand patterns are based on predictions rather than actual measurements of power consumption. In such a case, the switching off and on of water turbines is independent of actual demand. In the figure below that intervention is depicted by the use of valve. Any deviation of that pattern of consumption will not result in a correction, meaning that there is too much power or too less power distributed.



– often found in organisations. Whatever primary process, after setting the signal or standard no correction will take place. The controller must know exactly which signal produces those results, i.e. the setting of the value of the standard or introducing a new structure for the process; that implies that the controller possesses a causal model that relates the directives to the desired output of the process. The control of most processes does not comply with this prerequisite of stability due to disturbances in the input of flowing elements, the deployment of resources and variations in the throughput (process variation).

Principally, directing cannot classify as a control mechanism for maintaining homeostasis. The principle of directing assumes that a one-time signal (or interventions) will suffice for reaching a desired state of the output of the process; however, that requires a model that univocally links the directives to the target state of the output. For example, a homeostat aims at keeping a variable with certain pre-set limits. Hence, it reacts on deviations from the variable through which the regulatory mechanism intervenes in the input, the resources, the process or the output. Therefore, if it is necessary to maintain homeostasis, then directing as control mechanism is not adequate and other control mechanisms need to be used.

5.3 Feedback as Control Mechanism

As one of those other control mechanisms that can be deployed to maintain homeostasis, feedback measures the output of a process and intervenes in the input, the resources or the conversion process itself. Feedback is observed or used in various areas dealing with complex systems, such as engineering, architecture, economics and biology. The process of feedback consists of the following sub-processes: measuring, comparing, actuating and intervening (see Figure 5.3). This control mechanism enables the primary transformation process to be successful by adjusting parameter values of the flowing elements or modify parameter values of the resources or of the primary transformation process (see Box 5.C for the example throughout the chapter), if necessary. The following is an example of a feedback loop used in web-based workflows. Feedback loops are established by Internet Service Providers for unwanted messages. When subscribers click the 'This is Spam' button in their web mail clients, the feedback loop sends a message back to the Internet Service Provider letting them know to filter these specific messages next time. The control of a system by feedback requires getting information from the output back to the input of a system or to the process parameters. Alternatively, the feedback might measure the state of the process and intervene in the input or resources. In both cases, this involves the replacement of the open, linear chain of cause and effect familiar in most science by a circular causality, a closed loop that implies the merging of causes and effects. Hence, feedback represents the measuring of output and then undertaking corrective actions upstream.

Although using the same principles in cybernetics and control theory, feedback is a control mechanism whereby some proportion or in general,

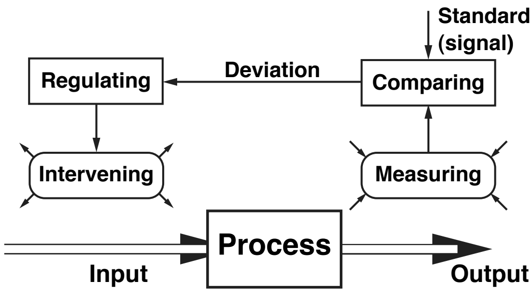
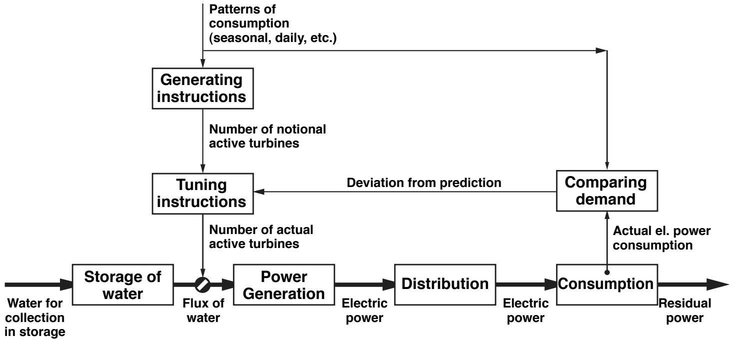


Figure 5.3 *Feedback. Deviations in the measurement of parameters of the output's state lead to interventions in either the input or the process' parameters. The comparison might include calculations to make it possible to compare the standard with the measurement. The intervention depends on a model to convert deviations into interventions.*

Box 5.C: Feedback – Case Hydro-Electric Power Generation

In addition to directing for the case of hydro-electric power generation, see Box 5.A, a feedback loop could also match the power generation with the actual demand for electric power. That means that the actual power consumption should be measured and compared with seasonal patterns; that leads to switching on and off of turbines. However, this feedback loop tunes the electric power consumption to the predicted patterns set by directing. Please note in the figure how the feedback is used in conjunction with directing (from Box 5.B).



function, of the output of a primary process is passed (feedback) to the input or sometimes to the conversion process. Often this is done intentionally, in order to control the dynamic behaviour of the system. The difference between the more generic principle and this technological approach is that the comparison and actuation are more or less integrated and that the intervention is directed mostly at the input.

Feedback as a control mechanism, measuring the output (or the state of the process) and then taking corrective action, comes in two forms. Feedback may be negative, which tends to neutralise disturbances, or positive, which tends to increase disturbances. Both manifestations of feedback have their own applications:

- The one generally used is negative feedback, and this acts to counter the gap between the actual value and a reference value. For example, if the external temperature rises (the disturbance), the internal temperature of a refrigerator will move upwards (the actual value) and the control process will activate a cooling system to maintain the refrigerator temperature (the reference value). The ultimate aim of negative feedback is to maintain equilibrium.
- The less-known form is positive feedback, which responds so as to increase the magnitude of any particular perturbation, resulting in amplification of the original signal instead of stabilisation. Often this is

undesirable and is complemented by negative feedback measures, leading in complex systems to a mix of feedback influences. However, this form does have its uses in ensuring a fast transition between an unwanted state and a target state. This is seen in evolution where species try to reach higher levels of fitness, success breeds more success. Therefore, the aim of positive feedback is reaching a new state.

The interactions between these two types of feedback lead to self-limiting processes, and often to cycles and oscillations in nature. Processes that include feedback are prone to hunting, which is oscillation of output resulting from improperly tuned inputs of first positive then negative feedback. Audio feedback typifies this form of oscillation. In a technical sense, these might also be caused by the intervention and signal being in phase; that means that an amplification of the input as an intervention occurs at the moment of that input being at its peak, resulting in the amplification. Without going into too much detail, it requires feedback systems to be designed in such a way that interventions do not lead to instability, even for social organisations. Therefore, feedback requires an appropriate understanding of the relationship between the characteristics of the primary process and the effects and timing of interventions.

Traditionally, feedback has found many applications in *electronic engineering*. The processing and control of feedback is designed into many electronic devices and may also be embedded in other similar technologies. The most common general-purpose control system is the so-called Proportional-Integral-Derivative controller. Each term of the Proportional-Integral-Derivative controller copes with the aspect time for the behaviour of a process. Without going into much technical and mathematical detail, the proportional term handles the present state of the primary process, the integral term handles its past state, and the derivative or slope term tries to predict its future state. An everyday example of a Proportional-Integral-Derivative controller is setting the temperature of a shower head; you sense the difference in temperature (comparing it with the temperature in mind), adjust the hot water flow according the response to earlier changes while predicting how much adjustment is need to achieve a certain (agreeable) temperature for taking the shower. If the deviation is inverted on its way round the control loop, the system is said to have negative feedback; otherwise, the feedback is said to be positive. The feedback process might consist of specific terms from the Proportional-Integral-Derivative controller as well as having specific settings for each of the terms to meet the specific characteristics of a process.

Feedback has been applied in *mechanical engineering* as well. Going back to ancient times, float valves were used to regulate the speed of Greek and Roman water clocks. Another example is the fantail of the windmill; in 1745 blacksmith Edmund Lee invented the ‘self-regulating wind machine’, a fantail and a set of gears, to keep the face of the windmill pointing into the wind. Later, other self-regulatory mechanisms were contrived for windmills to control speed and load. Self-regulatory mechanisms appeared in steam engines as well; the centrifugal governor by James Watt in 1788 to control the speed of his steam engine was one factor in its development that made this type of power one of the symbols of the later Industrial Revolution. Steam engines also use float valves and pressure release valves as mechanical regulation devices, see the mathematical analysis of the fly-ball governor by Maxwell [1868], mentioned in the introduction of this chapter. In addition to using regulating the speed of steam engines themselves, steam was initially used for controlling the rudders of ships. For example, *The Great Eastern* was one of the largest steamships of its time and employed a steam-powered rudder with feedback mechanism designed in 1866 by J. McFarlane Gray (according to White [1900: 669]). Later, Farcot [1873] coined the word servo to describe steam powered steering systems. After that hydraulic servos came into use for positioning guns. A next notable development was the first autopilot designed by Elmer Ambrose Sperry, Sr. in 1912. It was Nicolas Minorsky [1922] who published a theoretical analysis of automatic ship steering and described the Proportional-Integral-Derivative controller. The utilisation of mechanical feedback continued, like the internal combustion engines of the late 20th century had mechanical feedback mechanisms such as vacuum advance. However, mechanical feedback devices were gradually replaced by electronic engine management systems once small, robust and powerful single-chip microcontrollers became affordable. These examples show the wide range and importance of feedback controller devices utilised in mechanical engineering.

Furthermore, feedback exits in *nature*. Generically speaking, biological systems contain many types of regulatory circuits, among them positive and negative feedback cycles. The purpose of those cycles is that in biological systems, such as organisms, ecosystems and the biosphere, most parameters must stay within narrow boundaries around a certain optimal level under certain environmental conditions; this is called homeostasis (see Section 3.3). An example is keeping the pH level of water reservoirs (an indication how acidic or basic a substance is) at a specific value, which allows certain flora and fauna to flourish; the chemical composition of a water reservoir acts like a buffer so that a certain pH level will be maintained. In other biological systems, like the human body, the value of the parameter to maintain is recorded by a reception system and conveyed to a regulation module via a transmission channel. An example of that type of negative feedback is the reaction activated by heat receptors in the skin. A sudden increase in temperature will trigger a neuro-physiological signal, in turn activating a muscle contraction. Another example of biological feedback, but in this case positive feedback, happens at the onset of contractions during childbirth. When contractions occur, oxytocin is released into the body stimulating more contractions; this hormone helps to relax, to reduce blood pressure and cortisol levels and to increases pain thresholds, among other effects. Thus, the result is an increased amplitude and frequency of contractions. In general for biological systems, the negative feedback loops tend to slow down a process, while positive feedback loops have a tendency to accelerate it.

Moreover, feedback can also be found in *economics and finance*. A most famous example is the stock market, which has both positive and negative feedback mechanisms. This is due to both cognitive and emotional factors that belong to the field of behavioural economics. In the example of the stock exchange, the following applications of feedback can be identified:

- When stocks are rising (a bull market), the belief that further rises are probable gives investors an incentive to buy (positive feedback); however, the increased price of the shares and the knowledge that there must be a peak after which the market will fall, ends up deterring buyers at the same time (negative feedback).
- Once the market begins to fall (a bear market), some investors may expect further losses and refrain from buying (positive feedback), but others may buy because stocks become more and more a bargain (negative feedback).

The existence of negative and positive feedback mechanisms make the stock market prone to hunting (oscillating). Well-know investor George Soros [1987] described the workings of feedback in the financial markets based on those self-reinforcing effects of market sentiment and developed an investment theory based on those principles. However, the more traditional economic equilibrium model of supply and demand supports only ideal linear negative feedback and was heavily criticised by Ormerod [1994] in his book 'The Death of Economics', which in turn was criticised by traditional economists. The discussions are a reflection of the changing perspective as economists started to recognise that non-linear feedback processes might apply to financial markets (non-linear behaviour is the topic of Chapter 8). Hence, feedback mechanisms play an important role in the understanding of phenomena in economics, as also exemplified in the recent economic crisis.

The principles of feedback processes have also been applied to the domain of *organisations and management.* For example, as an organisation seeks improving its performance, feedback from customers (in the form of sales, complaints, etc.) assists it in improving quality of products and components as well as adjusting organisational processes and structures. Within organisations, feedback is used as well: performance measurement of organisational units, 360-degree feedback, etc. Most particularly, feedback constitutes an essential part of the movement of cybernetic management (see Section 10.3). Hence, feedback as control mechanism has found its way in a wide range of practices in organisations and management.

5.4 Feedforward as Control Mechanism

While the emphasis from feedback as control mechanism in all its applications is on reacting to already existent deviations, feedforward is a term describing a control mechanism that reacts to changes in its environment, usually to maintain some desired state of the system, before the actual primary process

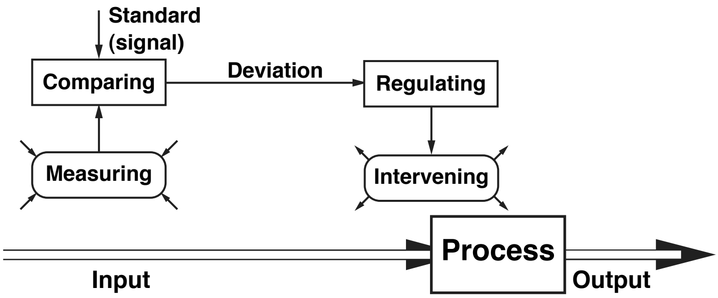


Figure 5.4 *Feedforward. Generic representation showing that a measurement taken from the properties of the input results in an intervention downstream. The regulatory mechanism depends on a model connecting the deviation to the intervention.*

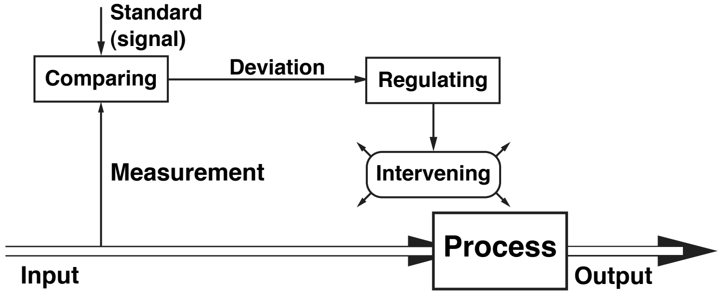
takes place. The mechanism of feedforward control can be illustrated by comparing it with a familiar feedback process for the cruise control of a car. When in use, the cruise control enables a car to maintain a steady speed. When an uphill stretch of road is encountered, the car slows down below the set speed; this speed error causes the engine throttle to be opened further, bringing the car back to its original speed (this is feedback). In contrast, feedforward control would in some way 'predict' the slowing down of the car. For example, it could measure the slope of the road and, upon encountering a hill, would open up the throttle by a certain amount, anticipating the extra load. The car does not have to slow down at all for the correction to come into play. However, other factors than the slope of the hill and the throttle setting influence the speed of the car: air temperature, pressure, fuel composition, wind speed, etc. Just setting the throttle based on a function of the slope may not result in the constant speed being maintained. Since there is no comparison between the output variable, speed, and the input variable, it is not possible to resolve this problem with purely feedforward control. A process that exhibits feedforward behaviour responds to a measured disturbance in a pre-defined way.

Looking at the general concept of feedforward for the transformation process, this type of control embeds the concept of intervening prior to the execution of the primary (transformation) process in a downstream direction, when following the flowing element (see Figure 5.4). The intervention is performed on the flowing element itself or on the primary transformation process. In the case that a deviation from the desired value of the specific parameter is being identified an intervention will follow to compensate for this deviation. Feedforward control is about preparing flowing elements for the primary process or adjusting the primary process to handle the flowing elements. Feedforward encompasses measuring, comparing, assigning and, if necessary, intervening. But such measurements and interventions lead to four specific cases of feedforward, see Box 5.2. These four cases demonstrate that the exact configuration of feedforward depends on the type of disturbance occurring in the input prior to the transformation process.

Box 5.2: Basic Types of Feedforward

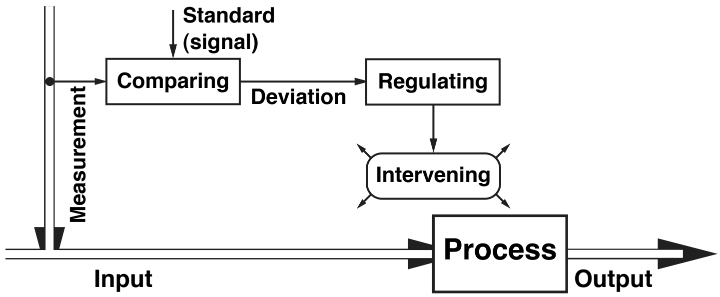
1st case – intervention after measurement input

In this case of feedforward, the properties of the input are measured and translated into an intervention downstream. For example, this type of feedforward occurs if a supermarket would measure the number of customers entering the store and adjust the number of cash registers that are open to the expected queues. To be effective, this case requires that the time delay between measurement and intervention suffices not to disrupt the primary process and the output.



2nd case – disruptions as different input

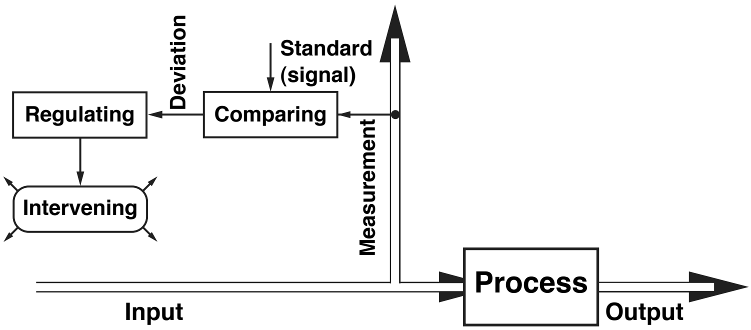
In this particular case, the disruptions enter the main flow of elements, and create an amended input for the primary process – note that the disruption is viewed as a different input rather than a property of the flow as in the first case. An example of this type of disruption would be rush-orders for a company that will go through the same primary process as the regular orders; the tuning of the capacity of the primary process, or alternatively prioritising orders, would constitute possible interventions (note that rush orders are measured separately in this example). To be effective, this case also requires that the time delay between measurement and intervention suffices not to disrupt the primary process and the output.



Box 5.2 (continued)

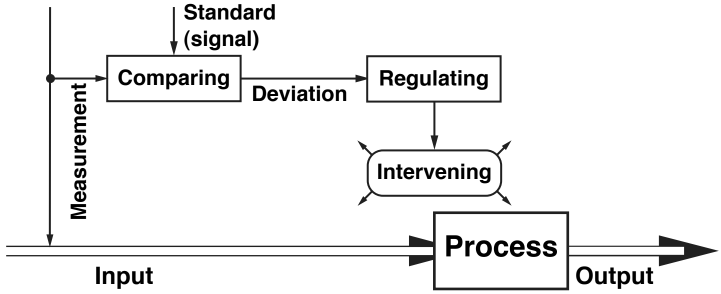
3rd case – Discharge of input flow

Furthermore, a discharge of the input flow to the environment might lead to disruptions. In this case, feedforward control measures this emission and adjusts the input of flowing elements through an intervention. For example, if leakages appear in a pipeline and it is measured how much leakage occurs and that will result in adjusting the flow. If the discharge is harmful to the environment, e.g. leakage of oil and chemicals, then the intervention should result in closing down the input.



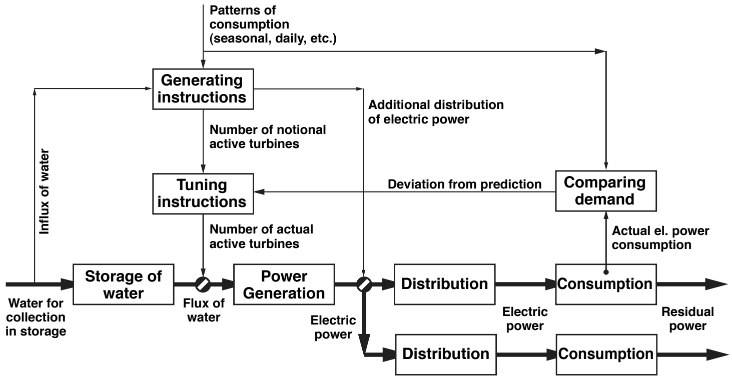
4th case – intervention base on a qualitative measurement input

The fourth case happens when the measurement leads to an intervention downstream based on a qualitative description of the input. In the case of the supermarket, that would mean not measuring the number of people entering the store, but their reasons for entering. If they enter the store looking for a quick ready-made meal for the night or they have extensive shopping lists, that would determine how the supermarket would adjust the number of cash registers. Typically, this type of control anticipates on other than quantitative measurements and results in fine-tuning of parameters of the process.



Box 5.D: Feedforward – Case Hydro-Electric Power Generation

For the case of hydro-electric power generation, see Boxes 5.A–5.C, it could also be that an additional influx of water could lead to overcapacity in the power generation. A potential intervention might be diverting the additional potential for power to another distribution channel; if that is done in advance then it would be called feedforward. Note in the figure how the feedback is used in conjunction with directing (Box 5.B) and feedback (Box 5.C). For example, the Paraguayan side of the Itaipu Dam (Box 5.A) uses this principle for 'selling' its overcapacity to the Brazilian distribution network.



Because of the response being known in advance, some prerequisites come along with a feedforward control scheme:

- the disturbance must be measurable;
- the effect of the disturbance on the output of the system must be known;
- the time it takes for the disturbance to affect the output must be longer than the time it takes the feedforward control loop to affect the output.

If these conditions are met, feedforward might be extremely effective. Feedforward control will respond more quickly to known and measurable disturbances, but will not cope with novel disturbances. For example, the sight of food triggers an anticipatory salivary flow as a form of preparing the human body for eating and digesting food. However, food disguised as another shape will not set off this reaction. In contrast to only dealing with known disturbances, feedback deals with any deviation from nominal process behaviour; however, it requires that the measured variable of the process (in most cases, the output) reacts to the disturbance in order to notice a deviation. Such a response is always subject to a delay in time, caused by the execution of the primary process and the time to intervene. In that sense, the response by feedforward is only driven by the time lapse between the occurrence of the deviation and the intervention. Feedforward control can be exemplified by learned responses to known cues. Applications of feedforward control systems can be found in control theory, physiology and computing.

The two types of control, feedback and feedforward, are not mutually exclusive. For example, the feedforward control just described could be combined with the feedback of conventional cruise control to allow quick response with the feedback cleaning up for any error in the predetermined adjustment made by feedforward control. Or the feedforward acts as a complementary control mechanism, as shown for the case of hydro-electric power generation in Box 5.D. Most importantly, feedforward does not have the stability problems that feedback can have. As mentioned feedforward needs to have a pre-calibrated cause-effect relationship, where feedback does respond to any deviation despite their cause. Another way of saying would be that feedforward control applies to measurable disturbances with known effects and feedback control reacts to any disturbances but with delay. For that reason, in most cases, feedforward needs to be complemented with feedback.

5.5 Completing Deficiencies

The fourth concept for control mechanisms is the concept of completing deficiencies. This control mechanism compares aspects of the output with standards and then aims at recovering the deficiencies; it has some similarities with the feedback amplifier invented by Harold Stephen Black in 1927 [Black 1977]. Most importantly, this control mechanism does not lead to an intervention of the primary process or an adjustment of the input (flowing elements), but recuperates the flowing elements as output.

To that purpose, the control process of completing deficiencies comes into action after the primary process. After the transformation process, the flowing elements are being measured in terms of relevant aspects. In the case that a deviation to the normative values of these parameters is ascertained, not a feedback loop comes into action but an intervention takes place by completing the deficiencies of the flowing elements. An example is when a product is made and a part is missing, the adding of the missing part is completing the deficiency; in the case of feedback, the process or the input would be adjusted, ensuring that the next products will be complete (and the deficient product will be simply discarded). This process of completing

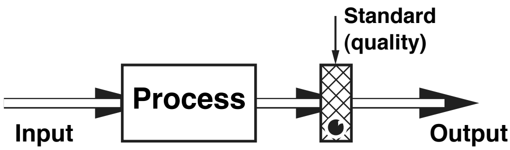


Figure 5.5 *Completing deficiencies by an additional process. After the primary process, a check on properties will reveal deficiencies, which will be completed; note that this is an additional process to the primary process.*

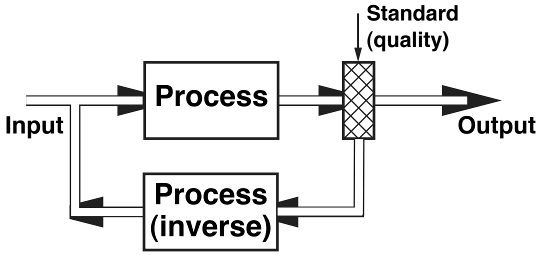


Figure 5.6 *Completing deficiencies by a feedback loop in the primary process. After a check on the properties, the output of flowing elements (the defected ones) is fed back to the input of the process. Note that in practice this requires an additional process to convert the flowing elements to a state that re-processing becomes possible (as indicated in the figure).*

the deficiencies should be viewed as an additional process to the primary process. Its value resides in the objective to reduce the defects in the overall output given the characteristics of the primary process. The (sub)process of completing implies correcting until the desired value has been reached. Principally, the recovery from deficiencies takes two forms:

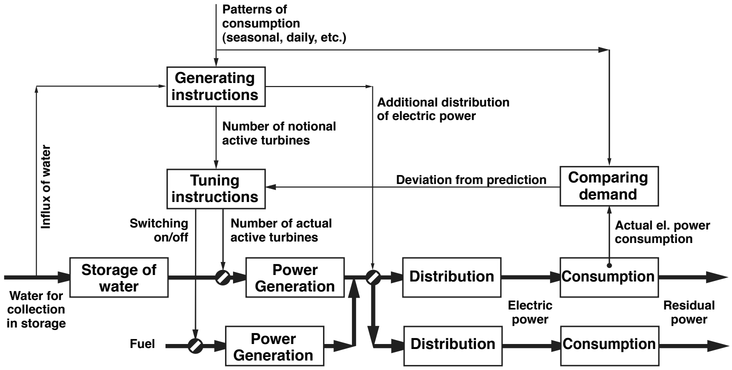
- By completing deficiencies as an additional process (see Figure 5.5). This type of correction can be characterised as feedforward after the transformation process has taken place before other processes happen; however, it does not generate an intervention, like the feedforward processes in Section 5.4. An example of this type of control is when cars have been assembled, they are checked and then missing parts added or faulty parts replaced; that is necessary as the next stage, driving the car, can generally not happen without all parts installed in the car or with parts being defected.
- By a feedback loop into the process or the input of the process (Figure 5.6). After a qualitative measurement of the properties of the input, the flowing elements are fed back into the primary process. In practice, that means that the input has to be converted to possess properties that make this type of recycling possible; for example, a product has to be dismounted before putting back together again during the primary process.

Completing deficiencies is a control process that consists of the following processes: measuring and adjusting or reversing. Typically, the intervention takes place on the flowing element only; see Box 5.E for the example throughout the chapter. However, interventions to prevent these deficiencies recurring again will require a feedback mechanism.

5.6 Application of Control Mechanisms

The application of the control mechanisms presented in this chapter (directing, feedback, feedforward and completing deficiencies) depends on the required state of the output and the capability to intervene, see Table 5.1. Even then, Box 5.E: Completing – Hydro-Electric Power Generation

It might be that in the case of hydro-electric power generation, see Boxes 5.A–5.D, the actual demand for electric power outstrips the power generated. That means that either the actual power consumption should be reduced of additional electric power generated. In practice, such additional power could come from gas turbines that use traditional fossil fuel (oil or gas). That could be seen as completing the deficiency in the output of power generation (see figure below).



that might leave options for the design of a control system since each control mechanism has its own characteristics; even a combination integrated into one design of a control system might be necessary to meet a wide range of disruptions (see Boxes 5.A–5.E). But not only does the design for a definite control mechanism depend on the effectiveness, the resources for the control process itself need consideration as well. For example, if the use of additional resources should be limited, completing deficiencies is a less preferable option. Hence, the choice which control mechanism(s) to deploy and how to design a control system, depends on the capabilities for effective interventions and the resources needed to exert the interventions.

When looking at the mechanism of directing again, first of all, it can be considered a subprocess of control, particularly present in feedforward and feedback. Somehow, standards from the environment have to be converted into directives for control, this will also be discussed in Chapter 6; the basic mechanism for directing does that. An example is a deadline for a project. For managing individual processes, the directing process, called project planning in this case, transforms the deadline into a project plan. And it is that project plan that allows monitoring activities and forms the base for interventions. That means that directing might be used in connection with other control mechanisms to be fully effective. Applying directing only is also possible, and is appropriate for single events or situations when there is

Table 5.1 *Overview of control processes. This overview takes Figure 4.2 as starting point (input, throughput, output, resources). The application for the diverse control mechanism is indicative.*

	Directing	**Feedforward**	**Feedback**	**Completing deficiencies (additional process)**	**Completing deficiencies (loop)**
Principle	'One-time' intervention.	Intervention downstream of measurement.	Intervention upstream of measurement.	Recuperating deficiencies in output by recovering 'faulty' flowing elements.	Recuperating deficiencies in output by sending them through primary process again.
Measurement	No measurement.	Measurement of input: 1. Flowing elements. 2. Additional input as disruption. 3. Discharge of flowing element(s). 4. Quality of input.	Measurement of output and process parameters.	Comparison of output with quality standard for output.	Comparison of output with quality standard for output.
Intervention	Only based on changes in standard.	Downstream of measurement (input, resources, process parameters, except Case 3).	Upstream of measurement (input, resources, process parameters).	Recovery of flowing elements at or near position of measurement.	Inversion of flowing elements and processing them again.
Characteristics	Lack of monitoring output or state of resources.	Prevents output to be outside set boundaries.	Corrects output with time lag.	Recovers from deficiencies by using additional resources.	Recovers from deficiencies by using additional resources (loop).
Application	Limited to situations where output is predictable once standard is set (causal model for intervention).	Application limited to causal model for known potential disturbances.	Correction for all kind of disturbances related to aspect of measurement (see also Figure 2.2).	Recovery of flowing elements when corrections by feedback are difficult.	Recovery of flowing elements when corrections by feedback are impossible.

at least a considerable amount of time between every intervention and when the state of the output is predictable and acceptable within set boundaries; actually, any change in the intervention by directing depends only on changes in the standard.

Feedforward control is preferable in case the input as flowing elements needs adjusting in any sense to make it suitable for the transformation process; the same applies to tuning the resources and the process parameters. But this type of control requires a causal model for associating a deviation (mostly the measurement) with an intervention. For example, the flowing element needs to have a certain temperature before the actual transformation takes place; think about the stages in heat treatment of metal products. In this particular case, the causal model is that metal being a certain temperature before the next step in a heat treatment results in certain properties; if the product needs specific properties then the metal product should be at a specified temperature before the next step in the heat treatment. In case of a deviation of the normative temperature, the actual temperature has to be corrected to enable the transformation process to be successful. Applying feedforward seems necessary in case the flowing element is rather 'raw' (or 'coarse') and needs to be adjusted in any sense prior to the transformation process. This principle can also be applied when the deviation measured is relative easy to compensate by adjusting the primary transformation process. A case in point is when a teacher adjusts the teaching methods depending on the level of proficiency in a class. Another reason for applying feedforward can be that, when for example the products are very expensive, one could not permit one product to show any malfunction; a quality check of parts before assembling is a case in point. This is related to the fact that correction in the case of feedforward takes place before the actual transformation process. Theoretically, the advantage of this control mechanism is that not a single flowing element has to be discarded. In all cases, the adequate application of feedforward depends on the capability to exert an intervention prior to the execution of the transformation process; or, even better, the principle of feedforward results in an intervention downstream relative to the point of measurement.

Where feedforward measures and intervenes prior to the transformation process, feedback operates where a measured aspect of the output shows a deviation from the normative value; the correction always takes place after the execution of the actual transformation process. Practically, that means that at least part of the output has to be scrapped. This is the case when cooking and the food does not taste at all good. The prepared dish is thrown away and a new preparation starts; however, this will only be successful if there is some understanding about the relationship between the deviation and what to change. Feedback is likely to be applied in case the to be transformed aspect(s) of the flowing element are difficult to measure prior to the transformation process or intervention at that stage proves difficult. Feedback operates as well when the relationship between effect and cause has not yet been clarified. The principle of feedback implies an intervention upstream relative to the point of measurement.

The fourth control mechanism for reaching a target state of the output is completing the deficiencies. Completing seems to be a rather good solution in case of a one-time executed transformation process and when the objective is to achieve output without deficiencies for the overall process. Another situation leading to completing can be that the aspect is difficult to monitor and would require much effort and investments. Taking the example of preparing a dish again, simply adding salt might resolve that it did not taste very well. Also when the rate of occurrence of rejected flowing elements is low, it could be preferable to apply completing the deficiencies. Nevertheless, the principle of completing deficiencies applies to output of the primary process and requires additional resources for the subprocess of completion or inversion.

The order of the presentation of control mechanisms in this section reflects their capability to predict outcomes on before hand and their capability to correct for unknown sources of deviation. Take directing, which entirely depends on the capability to predict in advance the outcome of the directives given the process. On the other hand, one does find feedback and completing the deficiencies where a causal relationship between the source of deviation, i.e. the cause, and the effect do not have to be known; these control mechanisms simply measure the outcome and intervene. They rely on a model relating intervention to deviations but the relationship does not have to be one-on-one (for example, control mechanisms based on fuzzy logic). Although the capabilities for intervention do quite differ, all control mechanisms need some kind of understanding for relating deviations to interventions.

5.7 Echelons of Control

So far, the control mechanisms, introduced in this chapter, have been treated more or less as single processes leading to an intervention. But in practice, one control process, which does it all, hardly exists and combinations of control mechanisms constitute practice in all kinds of domains. That is demonstrated by the case of hydro-electric power generation. Also, the co-existence of positive and negative feedback in biological systems has been mentioned in this respect. Moreover, the control mechanisms complement each other. Feedforward control might act on the input of flowing elements entering the process while at the same time feedback control corrects for deviations occurring during the execution of the process. The design and implementation of control processes might employ the different control mechanisms to supplement and to complement each other.

Furthermore, a primary process consists mostly of cascading subprocesses, each having their own characteristics and therefore, requiring control mechanisms that fit with the change of state of flowing elements and the capabilities for intervention. Output of one subprocess might be the input

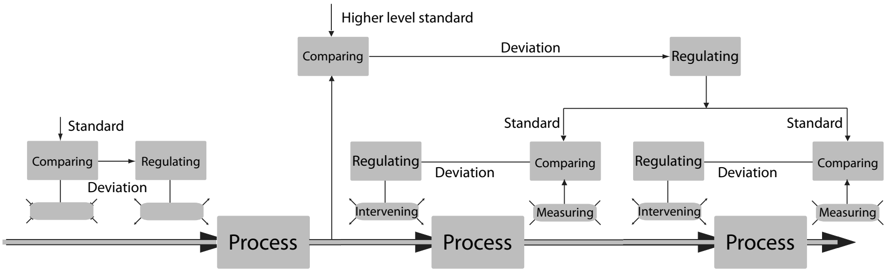


Figure 5.7 *Symbolic representation of echelons of control. Higher levels of control supersede the control mechanisms at lower levels making sure that control is adapted to overall process rather than the optimisation of individual subprocesses.*

for the next step; on the output of the process feedback might serve as an adequate solution, while the input of the next step might have a feedforward control to correct for any remaining disturbances. Hence, control processes are also linked to each other by the subsequent steps in a primary process.

The cascade of subprocesses with their own control mechanisms leads to a situation that either all control process act independently or the need arises for an overarching control mechanism (or mechanisms). Those echelons of control, overarching control mechanisms, act very much on the same mechanisms as the individual process (see Figure 5.7); each higher level of control interacts with a number of control processes at a lower level. These echelons should also prevent that the individual control mechanisms contradict each other; the higher levels of control mechanisms might integrate different aspects, whenever that is possible (remember that distinct types of aspects are hard to compare and to integrate, see Chapter 2).

Therefore, control mechanisms complement each other for a single transformation process, link to different steps in the primary process and might have echelons of control. The application and design of a specific control process for a specific primary process does not only depend on the effectiveness of an individual control mechanisms but also on how several control mechanisms can be combined for overall effectiveness.

5.8 Law of Requisite Variety

That necessity for a wide variety and complementarity of control mechanisms comes also into play when considering the phenomenon of variety. Suppose that a complex system has to be controlled: it has a high variety in elements and relationships, and that variety cannot be ignored. A complex system, looked upon from the content and internal structure, has many interrelationships between all the elements and then most likely covering a variety of aspects. Ecological systems represent such systems, many elements of various types constitute the whole and it has been difficult or even impossible duplicating it because of its variety and complexity (think about the dome Biosphere II, see Section 10.2). Even then in a controlled environment it appears difficult to predict the behaviour. For the sake of control, a complex system must be represented in a homeostatic causal model and itself capable of maintaining its state. However, simple control mechanisms might have insufficient variety to cope with the variety of perturbations from within the system and from the environment. The notion: 'Give me a simple control system; one that cannot go wrong' underestimates the complexity of variety. Building further on this argument, control or regulation is most fundamentally formulated as a reduction of variety: perturbations with high variety affect the system's internal state, which should be kept as close as possible to the target state and, therefore, exhibit a low variety. In that sense, control mechanisms aim at preventing the impact of the variety of disturbances present in the environment to variations in the state of a system (or process) itself.

However, the variety of systems This might be the opposite of transmission of information, where the purpose is to conserve variety maximally. In active (feedforward or feedback) regulation, each disturbance will have to be compensated by an appropriate counteraction from the regulator. If the regulator would react in the same way to two different perturbations, then the result would be two different values for the essential variables and, thus, imperfect regulation. This means that if we wish to completely block the effect of disturbances, the regulator must be able to produce at least as many counteractions as there are disturbances. Therefore, the variety of the regulator must be at least as great as the variety of disturbances. Ashby [1956] has called this principle the Law of Requisite Variety: in active regulation only variety can counteract variety. It leads to the somewhat counter-intuitive observation that the regulator must have a sufficiently large variety of actions in order to ensure a sufficiently small variety of outcomes in the essential variables. This principle embedded in the Law of Requisite Variety has important implications for practical situations: since the variety of perturbations a system (or process) can potentially be confronted with is unlimited, we should always try maximise its internal variety (or diversity), so as to be optimally prepared for any foreseeable or unforeseeable contingency.

Ashby's Law of Requisite Variety can be seen as an application of the principle of selective variety (the larger the number of states a system goes through, the more likely that one of these states will be retained). However, a frequently cited stronger formulation of Ashby's Law, 'the variety in the control system must be equal to or larger than the variety of the perturbations in order to achieve control' does not hold in general, according to Heylighen and Joslyn [2001]. The underlying 'only variety can destroy variety' assumption contradicts with another principle, called the principle of asymmetric transitions [Heylighen 1991], which tells that transitions from unstable states to a stable state is possible but the converse is not likely (think about systems maintaining homeostasis). The principle implies that spontaneous decrease of variety is possible. An example of this the principle of asymmetric transitions is a bacterium searching for nutrition and avoiding poisons; a bacterium has a minimal variety of only two interventions: increase or decrease the rate of random movements. Each position after a random movement is a new state and searching the space for states leads to it find a favourable set of positions. Its random movements are normally sufficient to find a favourable situation, thus escaping all dangers. That demonstrates that this bacterium with only two possible interventions is capable of coping with a quite complex environment, with many different types of perturbations and opportunities. This example also shows that not necessarily many interventions are necessary to counteract variety. That implies that the interventions of a composite control system (through complementary control mechanisms and echelons of control) might have few interventions at is disposal to respond to a complex environment but that the sensing of the environment (measurements) should at least address that variety and complexity.

For both the understanding and design of control mechanisms, Ashby's law is perhaps the most famous principle of cybernetics. It found its way into many applications, like electronic control systems and design of computer systems and software. Many did build on the Law of Requisite Variety for their own purposes; for example, Beer [1979, p. 286] restated the law as 'variety absorbs variety'. While the core of this law takes many forms, it depends on simple principle: a control system or controller can only model or control something to the extent that it has sufficient internal variety to represent it. For instance, in order to make a choice between two interventions, the control processes must be able to assert at least two possibilities, which requires distinguishing at least one characteristic of the primary process or the flowing elements. From the perspectives of comparing alternative interventions, the quantity of variety that the control process encompasses provides an upper bound for the quantity of variety in the process or flowing elements it can control or model.

From that point of view, the blackbox approach, as presented in Sections 3.2 and 4.7, facilitates dealing with variety; according to Beer [1959, p. 50], a suitable blackbox model will contain enough information to handle the variety of a complex system [*ibid.*, pp. 52–, 76–]. This has much to do with ignoring the internal structure as additional variable(s): the control mechanisms focus only on the external effects of the interventions. The blackbox approach has been introduced as reducing the information to these external effects, allowing an overall view on the process and system. In that sense, the blackbox approach only works when the internal structure of the system and the process possesses the capability to handle the potential disturbance; when this exceeds the capability an intervention in the structure becomes necessary.

Particularly, this is the case for organisations when their environment changes. In that case homeostasis, balancing the internal structure and the environment, might not fit as model for change when talking about dynamically changing environments in which less time remains to implement gradual changes. If the structures for increasing the Complexity Handling

Capability, the ability of an organisation to deal with the imposed complexity by its environment, exist, homeostasis does not drive adaptation [Boswijk 1992, p. 101]; his proposition looks much like an extension of the Law of Requisite Variety to the changing and modification of structures of firms. Companies that do not employ processes and structures to cope with the imposed complexity are forced to exert severe interventions heavily drawing on resources within and in reach of the company, decreasing the chances of survival. To increase their Complexity Handling Capability, organisational entities might decrease their internal complexity through redefining their organisational structures and their product structure (products seen as output to the environment and fulfilling the function of an organisation as a system, according to Applied Systems Theory). The effect of these internal measurements seems limited; an organisation might win more by learning to increase its base of capabilities for dealing with the imposed complexity of the landscape in which it operates [Dekkers, 2005]. Hence, in any case, organisations might improve their Complexity Handling Capability by modifying their organisational structure to comply with the Law of Requisite Variety.

5.9 Summary

Control is all about interventions in the flowing elements, the primary process or the use of resources (consistent with the definition and scope of a process in Chapter 4). If one wants to reach certain objectives or better states of the flowing elements as output, interventions in processes (by tuning parameters) will correct deviations happening during the execution of primary processes. Even in its simplest form, control acts on processes and flowing elements for standards to be maintained, whether it concerns technical processes or organisational processes or any other process; those standards are derived from objectives for the system and they define the states of the flowing elements or resources.

For the control mechanisms four basic principles to exert interventions are at hand with their own advantages and consequences:

- Directing: this control mechanism converts standards into directives without any measurement of the state of the flowing elements or the process.
- Feedforward control: this control mechanism measures the input and intervenes in the inflow of elements or in the parameters for the process (the intervention takes place downstream).
- Feedback control: this control mechanism intervenes based on the measurement of the output and the intervention takes place upstream.
- Completing deficiencies: this control mechanism checks the state of the output and corrects any deficiencies as a complementary primary process or as feedback loop for the flowing elements.

The first three control mechanisms rely on the availability of a model to relate settings or deviations to an intervention, while the fourth one simply corrects deficiencies.

For the effective deployment of control mechanisms, the Law of Requisite Variety simply means that a flexible control system with many options is better able to cope with variety in change. One that is tightly optimised for an initial set of conditions might be more efficient whilst those conditions prevail but fail totally should conditions change. In its original setting of control theory, Ashby's Law of Requisite Variety concerns controllers trying to keep a system stable. The more options the control process has, the better able it is to deal with fluctuations in the flowing elements, the system of resources and the process. For organisations that means they might have to improve their Complexity Handling Capability by modifying their organisational structure to match the variety imposed by the environment. Variety in input, resources and processes can only be dealt with by variety of interventions.

References

Ashby, W. R. (1956). An introduction to cybernetics. New York: J. Wiley.

Beer, S. (1959). Cybernetics and Management. New York: Wiley.

Beer, S. (1979). The Heart of Enterprise. Chichester: Wiley & Sons.

Black, H. S. (1977). Inventing the negative feedback amplifier: Six years of persistent search helped the author conceive the idea "in a flash" aboard the old Lackawanna Ferry. IEEE Spectrum Magazine, 14(12), 55–60.

Boswijk, H. K. (1992). Complexiteit in evolutionair and organisatorisch perspectief, het zoeken naar balans tussen vermogens en uitdagingen. Rotterdam: Erasmus Universiteits Drukkerij.

Dekkers, R. (2005). (R)Evolution, Organizations and the Dynamics of the Environment. New York: Springer.

Farcot, J. (1873). Le servo-moteur ou moteur-asservi. Paris: J. Baudry.

Heylighen, F. (1991, Nov.). The Principle of Asymmetric Transitions. Principia Cybernetica Web Retrieved 14th Sept., 2013

Heylighen, F., & Joslyn, C. (2001, 31st August). The Law of Requisite Variety. Principia Cybernetica Web Retrieved 12th Sept., 2013, from http://pespmc1.vub.ac.be/REQVAR.html

Maxwell, J. C. (1968). On Governors. Proceedings of the Royal Society of London, 16, 270–283.

Minorsky, N. (1922). Directional stability of automatically steered bodies. Journal of American Society of Naval Engineers, 42(2), 280–309.

Ormerod, P. (1994). The Death of Economics. New York: St. Martin's Press.

Soros, G. (1987). The Alchemy of Finance: Reading the mind of the Market. New York: Simon and Schuster.

White, W. H. (1900). A Manual of Naval Architecture: For Use of Officers of the Royal Navy, Officers of the Mercantile Marine, Yachtsmen, Shipowners, and Shipbuilders. London: John Murray.

6 Steady-State Model

The steady-state model adds the control for the system boundary, or more precisely the process boundary, in addition to the control processes of the previous chapter, like feedback and feedforward. The two previous chapters have emphasised the (primary) process and its control, based on the premise that a process constitutes an interaction between flowing elements (as system) and resources (as an other system). In addition, systems operate in relation to their environment and interact with other elements from that environment. The processes that occur in systems convert input, consisting of flowing elements, into output by changing the state of these flowing elements. The resources that execute that conversion might have a limited capability for dealing with variations in input and throughput. Hence, it becomes necessary to handle the varieties in input and output, as the steady-state model will describe.

The steady-state model builds on the concept of homeostasis and cybernetic principles in the writings of Miller and Rice [1967] and Emery and Trist [1969]. Although, those writers apply these principles to organisations, it applies to technical systems and biological systems as well. Particularly, the consequences of such thinking for organisms and organisations are found in the next chapter on autopoiesis (Chapter 7). Maintaining homeostasis applies to fourth level of Boulding and higher (see Section 3.5); from that level on, systems are called open systems, which interact with their environment, and it is that interaction that calls for the need of boundary control.

Section 6.1 will expand on the implications of boundary control, following the concept of Miller and Rice. They discuss the concept of boundary zones for organisational systems; however, this section will also talk about the validity for technical systems and biological systems. Chapter 7 will deal with the concept of autopoiesis, which application resembles in some aspects the steady-state model, but has a limited application to biological and organisational systems; the current chapter focuses on open systems in general. The treatment of the three boundary zones is the subject of Sections 6.2–6.4. For each of the boundary zones, the main concepts are elaborated. Finally, Section 6.5 will discuss the limitations of the steady-state model.

6.1 Boundary Control

Processes and systems only operate within certain boundaries of control and throughput. For example, a banking process only allows authorised users to enter the system and discards any other entities through an electronic signature or password or any other form authentication. This process executed by computer systems identifies authorised users and ideally prevents unauthorised customers and others to enter and use information. That

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way it secures the input of data by users and the output of an accurate and authenticated report of banking accounts and it prevents unauthorised access to information recorded in the system. Those actions take place principally before and after entering and converting data, which is the primary process for a bank; hence, the authentication of users happens in the boundary zone relative to the entering and converting of data. That so-called boundary control acts on the primary process itself and the internal control processes and at the same time serves as an intermediary between the environment and the core (primary) processes.

Most processes are in some measure self-regulating in the sense that the nature or structure of the processes imposes limitations and constraints on the associated processes and systems of resources. Thus, a given activity (whether part or no part of a process) is regulated by preceding and succeeding activities. An example is the capacity of a process, which is mostly determined by the availability of the system of resources; hence, output of a process is limited by the capacity of the system of resources. Regulatory activities that relate a set of processes to its environment, from the perspective of the allocated resources, occur at the boundary of the process and its resources, and they control the input and output for the process to maintain a steady-state. Before expanding on the steady-state model, this section will first expand on the concept of steady-state, boundary zones and the particular phenomenon heterostasis as key concepts for self-regulation.

Steady-State

When all variables in a system are balanced to the point where no change is occurring, the system is said to be in a state of static equilibrium. The internal processes do not take place since no deviation activates control processes. In practice, that seems hardly the case. Perturbations enter the system (read the system of resources) and activate process within the systems boundary to maintain a balance with the environment. Even when everything is in balance, that denotes the situation where forces dynamically interact to maintain a point of equilibrium. The human body when standing up is a case in point; muscular actions ensure a posture that might look static for an external observer. A dynamic (steady-state) equilibrium exists when the system components are in a state of change, but at least one variable stays within a specified range. Homeostasis is the condition of dynamic equilibrium between at least two system variables.

It is necessary for many systems to maintain their equilibrium in changing environments or disturbances, otherwise they cannot function properly or their goals cannot be attained. In living systems, the process of self-maintenance or 'homeostasis' proves essential to ensure their survival and sustained viability. The term homeostasis is referred to by Flood and Carson [1993] as a process by which a system preserves its existence through the maintenance of its dynamic equilibrium. By some this equilibrium is termed 'homeostatic equilibrium' [*e.g.* van Gigch, 1978]. Even when a

Box 6.1: Key Concepts for Steady-State

Static Homeostatic Equilibrium

Static homeostatic equilibrium refers to a steady-state situation with no dynamic events acting on the system of resources. By definition, in a state of static equilibrium there is balance, but no change, disturbance or movement.

Dynamic Homeostatic Equilibrium

In contrast, dynamic homeostatic equilibrium occurs when perturbations or changes act on processes or systems of resources causing a temporary deviation from the equilibrium. By activating internal processes in response to that perturbation or change, the process or system of resources tries to regain its point of equilibrium with the environment. Sometimes, this concept is also used for the situation where a system loses its equilibrium and finds a new state of balance (for example, when a glass of water is tipped over and comes to a rest at the counter).

Self-regulation

Although self-regulation has many connotations, in the context of Applied Systems Theory, it refers to the capability of systems of resources or processes to maintain a (fixed) state. This state might be subject to external influences or perturbations; when these occur internal process within the system of resources ensure appropriate responses to maintain that state. Self-regulation might cover simple control processes, like the ones from Chapter 5, or complex interactions with the environment, as shown in this chapter.

mature organism as an open system appears to be unchanged over a period of time, there is a continuous exchange and replacement of matter, energy, and information between the system and the environment. Homeostasis is not only one of the most important properties of any living organism, but is also readily applicable to human or work organisations treated as open systems. The organisation needs to recruit new employees to replace those who retire; it also needs raw materials, energy and information for use in its processes and operations to maintain a steady state. In fact, an organisation that appears externally static and unchanged to outside observers is internally in a state of flux, in a state of dynamic equilibrium (as with most open systems). Maintaining equilibrium constitutes a major activity for open systems.

Another significant aspect of an open system in a state of dynamic equilibrium is that it relies on feedback mechanisms to remain in that state. Based on the Systems Hierarchy of Boulding (see Section 3.5), which classifies the system according to its complexity, it is not surprising to find that properties exhibited by systems lower in the hierarchy are also found in those higher in the hierarchy because the latter are built on the former. Therefore, a system that is classified as an open system would possess all the qualities that belong to the system at a cybernetic (or self-regulated systems) level; open systems are found at the fourth level, while many of the principles are derived from cybernetic systems, the third level of Boulding, including feedback mechanisms. The behaviour of open systems is determined, to a great extent, by the feedback mechanisms present in them. Negative feedback reduces or eliminates the system's deviation from a given standard, so a negative feedback mechanism tends to neutralise the effect of disturbance from the environment. Positive feedback amplifies or accentuates change, which leads to a continuous divergence from the starting state. Positive feedback works together with negative feedback in living systems (e.g. in organisms), and organisations too; both types of feedback are present during adaptation even though the net result might be positive. However, the operation of positive feedback alone will eventually result in the system's disintegration or collapse. Negative feedback plays the key role in the ability of open systems to achieve a steady-state, or homeostasis; therefore, negative feedback mechanisms are inherent to systems achieving and maintaining a steady-state.

Boundary Zones

Any open system, read a system of resources in the spirit of Chapter 4, interacts with its environment and mostly through a conversion process. Take (living) cells, for example. Living systems require the continuous uptake of energy and nutriments from their environment, to excrete and to react in specific ways. Therefore, cells – just like all other biological systems – have to be regarded as open systems that are characterised by inputs and outputs and a transition. These open systems are never in a stationary equilibrium but always in a steady-state as a dynamic equilibrium. As long as we do not know what happens in the transitional element (in this case the cell) it can, according to system theories, be regarded as a blackbox. The relation between input and output characterises a flow of (coded) information through the system. A physical or chemical energy may influence the system through the input and cause certain changes that may again have an influence on other systems or system elements via the output. From a cybernetic point of view, neither the inner structure of the transitional element nor the form of the energy is of importance. The input and output as events in the boundary of a system and the connection between both is decisive for determining the behaviour of an open system.

Therefore, the boundary of a system of activities implies both a discontinuity and the interpolation of a region of control [Miller and Rice, 1967, p. 9]. Difficulties arise if a boundary is imposed at a point in the process, which does not satisfy these two criteria of the boundary of an activity system.

Unless there is a discontinuity, there can be no boundary to separate a system from its environment and thus no distinction in which activities are carried out within the supposed system and that are insulated from other activities “outside”. Such a discontinuity happens, for instance, when somebody wants to use a copier or printer; the paper arrives in packs and needs to be unwrapped and put into stored in the device before the actual copying or printing starts. A different example of discontinuity is imports at the level of a national economic system; while these imports are a necessity for factories, acquiring goods as imports constitutes a discontinuity. The second criterion for the boundary zone implies that the discontinuity leads to regulatory activities of some sort. The discontinuity results in a mismatch between the two systems of processes, regulatory mechanisms aim at achieving equilibrium so that outputs of one process match with the input requirements for the next process. A case in point is a water collection and irrigation system in agriculture that ensures relatively constant water supply even though it might rain at very unpredictable times. But also raising import levies on goods in the context of a national economic system constitutes a regulatory mechanism. Therefore, boundary zones indicate both a discontinuity and the presence of regulatory activities of some kind.

Regulation in the boundary zones itself can be analysed as an input-conversion-output process. Input activities are the collection of data from measurement or other observation, conversion activities the comparison of these data with objectives or standards of performance and output activities the decisions to stop or modify the process or to pass the product. An example is the inspection processes of goods at manufacturing enterprises; raw materials are tested before being accepted and products inspected before being dispatched. In larger factories, inspection processes are also imposed between departments. Provided the inspection occurs at boundaries between the enterprise and its environment or between distinct constituent systems of the total enterprise, there are few problems with regard to confusion about boundaries. Coordination problems at the boundary increase when we consider the (organisational) effect of the introduction of continuous automatic controls, particularly those that incorporate feedback and self-correcting devices. Consequently, these automated regulatory activities eliminate time lapses between checks for one system of operating activities and the next system. Hence, the design of regulation in the boundary zones should allow effective interventions that compensate the (potential) discontinuities.

The boundary zones can be divided into three zones, the input boundary zone, the output boundary zone and the regulatory boundary zone (see Figure 6.1). Each zone fulfils a specific function. The input boundary zone acts on the inflowing elements and their properties so that the primary process at the heart of processing will operate within its boundaries. An example of that is the filtering of air through respiration systems before it enters the lungs. The output zone operates the other way around: output of the process is converted to be suitable for entering the environment. When software generates a report

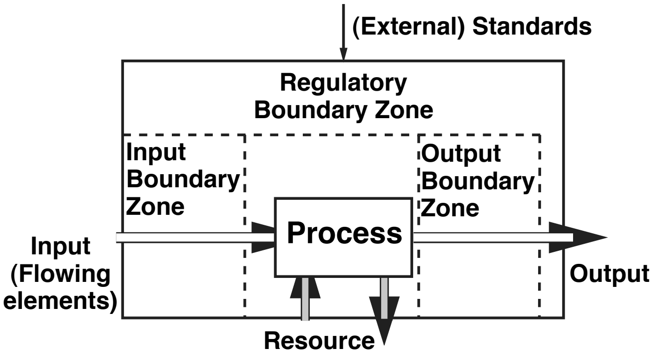

Figure 6.1 *The three boundary zones of a process. The boundary zones for the input and the output interact directly with environment through the flowing elements. The regulatory boundary zone converts standards imposed on the system to the internal control processes.*

and completes the data with other information, like headings, tables and figures, the output is ready for use by an operator or manager. The regulatory zone translates external standards and information from the environment to operational directives for the control processes. All three zones constitute the boundary zone of a process and system of resources.

Heterostasis

Through the three zones, processes and systems maintain homeostasis, a property of an open system, especially living organisms, regulate their internal structure and state to maintain a stable, constant condition, by means of multiple dynamic equilibrium adjustments, controlled by interrelated regulation mechanisms. The term is used most often in the sense of biological homeostasis. Multicellular organisms require a homeostatic internal environment, in order to live; many environmentalists believe this principle also applies to the external environment. Many ecological, biological, and social systems are homeostatic. They oppose change in favour of maintaining equilibrium. If the system does not succeed in re-establishing its balance, it may ultimately lead the system to stop functioning; the extinction of species is a case in point. Complex systems, such as the human body, must strive for homeostasis to maintain stability and to survive. Each of the three boundary zones contributes to that purpose of maintaining the steady-state.

These systems do not only have to endure to survive; they must adapt themselves and evolve to modifications that fit with the dynamics of the environment. The now widely accepted concept of complex adaptive systems, see Chapter 8, was first suggested by Selye's Adaptation Syndrome, which emphasises, among other things, the positive role of inflammation in striving for homeostasis [Selye, 1976]. This is observed in the self-limiting illnesses and many febrile conditions, where complementary and alternative treatment may be supportive, or enabling the self-healing process, as long as the effort is within the vital capabilities of the patient. Selye also coined the term heterostasis to describe the potential of healing, such as the inducement of a febrile response by Echinacin in herbal medicine, or constitutional hydrotherapy in naturopathy. Klopf [1972] developed a basis for learning in artificial neurons based on a biological principle for neuronal learning called heterostasis. He states that organisms are not hiding in the environment; on the contrary, they are trying to minimise action and change. In general, organisms actively seek stimulation. Heterostasis is the seeking of maximum stimulation. For example, all parts of the brain are independently seeking positive stimulation (or "pleasure") and avoiding negative stimulation (or "pain"). Emotion provides the sense (a measure) of what the organism needs, cognition provides the means for achieving those needs. The concept of heterostasis is currently applied to the body's endurance when taking out organs and conducting an external treatment before placing them back; that (temporary) change in internal structure forces the system to function at a different point of dynamic equilibrium than usual. Heterostasis implies that open systems might temporarily operate at other points of dynamic equilibrium than an optimal point of homeostasis.

6.2 Input Boundary Zone

One of the three boundary zones to maintain homeostasis is the input boundary zone. This constitutes the zone before the transformation process where the regulatory activities act on the properties, *i.e.* the quality, and the quantity of the input as flowing elements. By doing so, the process ensures that the input matches the properties of the flowing elements as input with the capability of the transformation process; the same applies to the quantity of the input. The generic, regulatory activities of the boundary input zone are shown in Figure 6.2 and explained in the subsections.

Coding

Often the input does not have the properties for the transformation process to identify it or the properties for further processing. For example, an order is sent to an English company written in the Chinese language. After receipt, the translation of the document into to a native language constitutes coding as well as the identification of which products and services the order refers to (*e.g.* article numbers). But also chewing food before swallowing to facilitate digestion is an example of coding. The coding also requires determining which aspects are crucial to the further processing; hence, coding is related to the aspects for modelling (see Sections 3.1 and 3.4). The principles of coding go back to Shannon's Communication Theory [1948], his proposition that still reverberates today. Coding constitutes a necessity for either identification during the later stages of regulatory activities in the steady-state model or for matching properties of the input to the capability of the transformation.

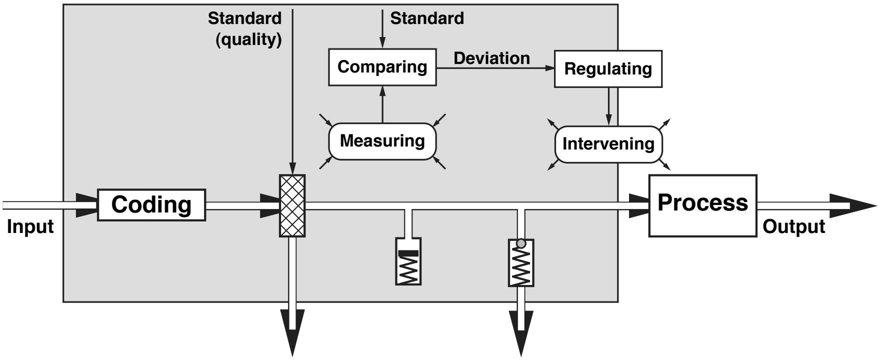

Figure 6.2 *Boundary control at input zone. Elements flowing into the boundary zone will be coded first before a check on appropriate properties. After that the combined regulatory activities of feedforward control, the input buffer and the valve prevent the input exceeding the capability of the primary process.*

Generically speaking, only after coding, it becomes possible to activate other regulatory activities. Without the identification of the flowing elements needed for further processing, a quality check becomes difficult to perform. Even the coding as a conversion process could be looked at from this perspective; unpacking paper from a box to put into a large volume copier makes it possible to control the flow of paper into the core processing unit of that copier. Internal standards are mostly linked to classification of the flowing elements. In case of an organisation, the goods receipt for stationary and raw materials for the primary process differ substantially and have very different standards to adhere to. For the transformation process itself the input needs to be coded before passing through a filter for acceptance.

Quality Filter

The filter of acceptance, called the quality filter, checks the coded input against standards for its properties. If the qualitative standards of defined aspects are not met, then the flowing elements should be brought up to standards; however, generally, this takes place outside the system's boundaries and is symbolised by the discarding of the elements that do not meet those standards (system refers to the system of resources). Under normal circumstances, not all properties of the flowing elements undergo a quality check, but only those that represent 'critical' properties to the transformation process. Taking the case of imports of goods again. It might be that the imported goods are inadequately labelled or packaged; in that case, the goods are refused by the customs and returned to producer in the country of origin, where it can be repacked, re-used or discarded. The packaging and labelling represents only one specific aspect of the imported goods. The customs officers do not check other properties, like geometry, which is important for another plant using the goods. When the quality of the input meets the standards, the flowing elements can be processed further. The quality filter checks against standards as set by higher echelons of control and it accepts or rejects the flowing elements for the transformation process.

Control Mechanism

After the acceptance of the quality in the input boundary zone, the regulatory activities on quantity follow. Quantity refers to the parameters (and aspects) that trigger control mechanisms to adhere to standards with respect to performance. In that sense, the quality filter checks only the 'feasibility' of flowing elements for entering the transformation process; but it does not check against the performance (for example, the capacity of the transformation process). If the control of quantity is placed before the quality check, it might occur that defected flowing elements are accounted for when exerting intervention; in that case the intervention might be based on inaccurate parameters. To avoid that systematic error, the control mechanisms for quantitative aspects (or parameters) position itself after the coding and quality check.

As the control mechanism feedforward measures the quantitative aspects of the flow and exerts an intervention. The intervention leads to a correction before the transformation process takes place or to adjustment of the transformation process. This could be the case when the influx of orders is measured and depending on volume of these orders the number of workers is adjusted. Or it could be that the parameters for printing are adjusted when using certain types of paper (many inkjet desktop printers offer that change of settings for printing). Therefore, feedforward ensures the more quantitative interventions in the flowing elements as part of the input boundary zone before the transformation takes place.

Input Buffer

The input buffer corrects for differences in supply of flowing elements by the environment and the capability (or capacity) of the transformation process. When the inflow is too much or irregular in comparison to the capability of the transformation process, the excess of flowing elements is buffered. At moments that the supply undercuts the capability of the transformation process, the input buffer supplies the deficiencies in the influx depending on its own capacity. However, the input buffer does not necessarily have to be positioned away from the flowing elements; for example, with a 'First-In-First-Out' approach all flowing elements will enter the buffer. An example is queuing in a post office; people enter the post office, take their position at the end of the queue and wait their turn. As a different approach, in the case of a production line, the excess of goods might be put into a separate storage area until the influx of elements is insufficient for the transformation process; then the excess of goods will be put back to the further processing. Such an approach is only possible when flowing elements do not deteriorate with regard to their properties. Both examples show that the input buffer corrects for irregularities in the influx of flowing elements.

Valve/Overflow

When the system of resources cannot cope with the supply of flowing elements, then the abundant flowing elements will be discarded into the environment. This acts as a last resort in case the feedforward loop could not anticipate sufficiently and the input buffer has reached its maximum capacity. An example of this is a parking garage when it is full; cars wanting to park are turned away and have to find another possibility for parking or change destination. This overflow of flowing elements makes it possible that the transformation process operates within it set limits with respect to the aspect of the control mechanism

The three mechanisms – the feedforward loop as control mechanism, the input buffer and the valve/overflow – have similar contributions to the input for the transformation process. The feedforward loop controls the flux of flowing elements (by linking it the capability of the transformation process), while the input buffer and valve react beyond the deviations that the feedforward control mechanism handles. It could be that not all three are necessary or useful in certain cases. In the example of serving coffee, serving is the transformation process, it makes no sense to have a buffer of filled coffee cups since the drink will cool down and become distasteful. Hence, the feedforward control mechanism, the input buffer and the valve/overflow have distinct and yet complementary functions for the input boundary zone for the transformation process.

6.3 Output Boundary Zone

The transformation process might have its own regulatory activities to generate output that matches with what is needed by the environment, see Sections 5.3–5.7. Sometimes, those control processes for the primary process suffice to generate output that meets standards set by the environment; in other cases, additional control mechanisms in the boundary zone are needed to achieve an output that conforms to those standards. In addition, a primary process might also consist of subprocesses that need individual control loops. That might evoke the necessity to deploy higher internal echelons of control to avoid contradictory interventions and to achieve overall objectives for the primary process. Because of meeting overall objectives, regulatory activities in the boundary zones are mostly connected to internal regulatory processes as well as higher external echelons of control for interaction with the environment.

Hence, the output boundary zone, positioned after the primary transformation process, regulates the transfer from flowing elements into the environment. The boundary zone at the output-side of the transformation

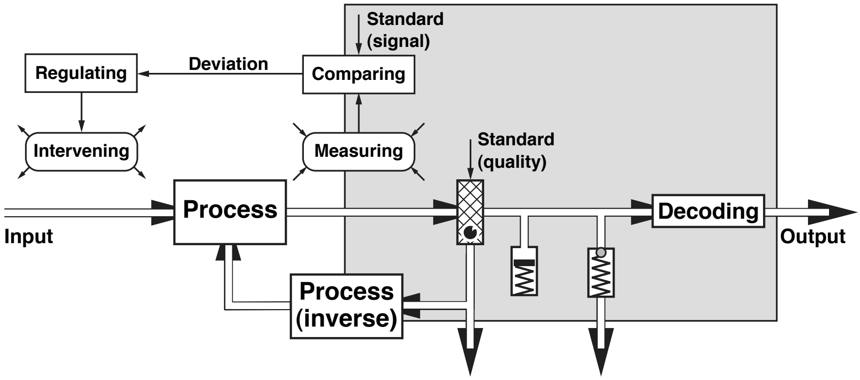

Figure 6.3 *Boundary control at output zone. Elements flowing through the boundary zone will be checked on appropriate properties and that might result in discarding them or completing the deficiencies; note that in case the deficient elements are fed back into the primary process an inverse process takes place, which might be part of the boundary zone of the system of resources or not. After that the combined regulatory activities of feedback control, the output buffer and the valve prevent the output exceeding the capability of the environment. The final step is decoding the flowing elements.*

process (see Figure 6.3) constitutes much of similar processes as in the input zone (Figure 6.2) and these will be elaborated in the following subsections.

Control Mechanisms

In the output boundary zone, there are principally two control mechanisms as discussed in Chapter 5 active. The first one is the feedback control mechanism that measures the flowing elements against standards set by the environment and intervenes in the primary process or its input. It could be that the output of a factory lags behind on the delivery schedule for orders; the intervention could be either increasing the capacity of the primary process or reducing the input of orders, resulting in less materials and components entering the transformation process. A quality filter on the output side supplements the feedback control. That filter measures the state of the flow out of the process, compares that with the qualitative standards and exerts an intervention; that intervention is either discarding the flowing elements or adding and replacing deficient elements or recuperating the flowing elements by using an inverse process and passing on the flowing elements to the primary process. In the case of a factory, it could be that some products as output are discarded because they are beyond repair, other products might just need a few components to be added before they can be shipped to customers, like adding user instructions, and some products might have to dismantled and the components can be used again for making the products. Both control mechanisms, feedback and completing deficiencies, have a different function and exert different interventions.

It should be noted that the filter of acceptance, called the quality filter, checks the coded output against qualitative standards of pre-defined aspects. If the quality of the output meets the standards, the flowing elements can be further processed. When the qualitative standards of the aspect are not met, then the flowing elements should be brought up to standards. However, this recuperation might take place outside the boundaries of the system of resources in general and is then symbolised by the discarding of the elements that do not meet those standards. It is also possible that the recovery takes place within the boundaries of the system of resources. Whether the recuperation takes place within the system or outside it depends on the processes needed for converting the defected output into flowing elements that can be processed again by the system of resources of the primary processes.

Output Buffer

Similarly to the buffer in the input boundary zone, the output buffer corrects for differences in supply by the transformation process and the capability (or capacity) of the environment to absorb the process' output. When the outflow is too much or irregular in comparison to the capability of the environment, the excess of flowing elements is buffered. At moments that the supply undercuts the capability of the environment, the output buffer supplies the shortages in the flowing elements depending on its own capacity, for part depending on its own capacity. An example of this is a petrochemical plant. Switching on and off capacity or even tuning capacity is often lengthy and difficult. To match demand with capacity of the plant, they use storage of finished products as output buffer, for example by using oil tanks in depots. Hence, the function of output buffer is mediating between variances of the process and the intake of flowing elements by the environment of the system of resources.

Valve/Overflow

Again similarly to the input boundary zone, if the environment of the system of resources cannot cope with the supply of flowing elements and the output buffer has reached its maximum capacity, then the abundant flowing elements will be discarded into the environment (the valve). This is a very different process from the quality filter directly after the primary process. The valve acts as a 'safety' measure to prevent an overload of flowing elements to the environment by discarding acceptable products from a quality perspective. Such a mechanism might be used by factories when they get rid of products they cannot sell anymore (products at the end of the life-cycle or competition from more attractive products); however, companies discard those products sometimes by selling them through different distribution channels at reduced prices. Therefore, the valve represents a principal safeguard against overloading the environment.

Similar to the regulatory activities in the boundary zone for the input, the three mechanisms – the feedback loop and quality filter as control mechanisms, the output buffer and the valve – have similar contributions but yet distinct functions for the flow of elements into the environment. The feedback loop controls the flux (by linking it the capability of the transformation process) while the output buffer and valve react beyond the deviations that the feedback loop handles. It could be that not all three are necessary or useful in certain cases. In the example of serving coffee, serving is the transformation process, it makes no sense to have a buffer of filled coffee cups since the drink will cool down and become distasteful. Again, the design and the set-up of the boundary zone depend much on the characteristics of the primary process and the requirements set by the environment.

Decoding

Decoding happens after the completion of the process and adopts the flowing elements to the environment. For example, exhaust gasses of a car are processed through a catalyser before streaming into the environment, that way reducing the output of CO and NO_2. Again, this process of decoding stems from Shannon's Communication Theory [1948]. It can be a simple process of labelling to more complex steps of identification or even shaping the flowing elements. An example of the latter is the adding of a scent to natural gas to make it detectable when leakages occur in the distribution systems. It should be kept in mind that principally decoding does not change the properties of the flowing elements as such.

6.4 Regulatory Boundary Zone

During the discussion of the two boundary zones and the preceding chapter about control mechanisms the standards for comparison with measurements were more or less treated as coming from outside the system. These standards will vary between precisely defined and vague. In addition, the environment will set the standards but not relate or assign them directly to a specific control mechanism. Therefore, the system has to covert these external requirements into operational standards that will allow the system of resources to fulfil its function within the larger whole. For tuning the system's internal control processes to the environment, there is a regulatory boundary zone, see Figure 6.4. That zone deploys the initiating process and the evaluation process for maintaining the function of the system of resources.

Initiating Process

The process that transfers relatively vague requirements into standards for internal control mechanisms is called the initiating process. Through initiation the standard as imposed by the environment is transformed into

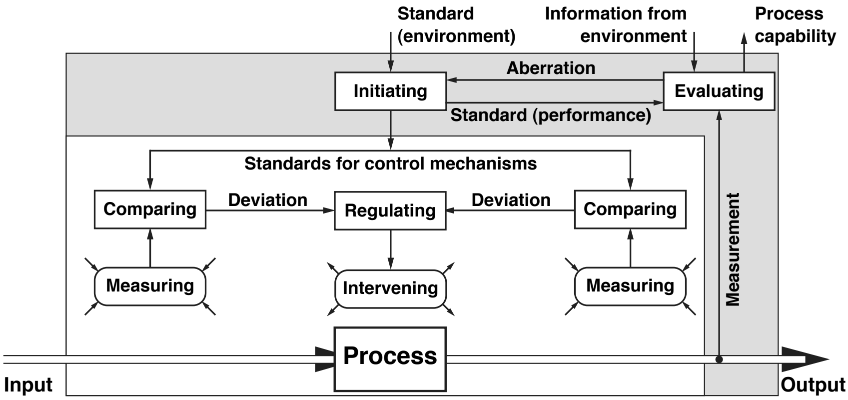

Figure 6.4 *Regulatory boundary control. Standards from higher levels are converted into standards for the control mechanisms by the initiation process. The evaluation process compares internal measurements with the standard set by the initiation process and the information obtained from the environment. The evaluation process passes on aberrations to the initiating process and information about the system of resources' capability to the environment.*

standards suitable for use by the internal control process. An example of a standard is the reliability for delivery of customer orders by a company; the key performance indicator itself is not directly usable for the control process but needs to be translated into acceptable queue lengths before the primary process (feedforward) and internal performance evaluation (feedback). Within this line of thought, the initiating function bridges the transformation process with its environment for the interpretation of externally generated standards and is considered as part of the boundary of the system of resources.

Ideally, this conversion from external standards to internal standards (or directives because of the similarities with the control process of directing) requires no elaboration. Coding, akin Shannon's Communication Theory [1948], might occur to internal standards to make them fit to the internal control mechanisms. However, the coding is generally not necessary for the link to the evaluation process and is not displayed in Figure 6.4.

Evaluation Process

The process of evaluation consists of obtaining information, comparing that to the standard and informing the initiating process about aberrations. That is necessary because a standard makes less sense when no regular check takes place on its validity. For example, changes in sales and lead-times of parts do directly effect requirements for minimum levels of inventory. Hence, changes in the environment or within the system might induce updating of the standard. In this respect, it is absolutely necessary to evaluate the standard and to revise it when deviations show up.

One source of information for the evaluation process comes from internal mechanisms for measuring the output. Those measurements are not necessarily linked to the internal control mechanisms. An example is measuring how many individual customers (output) were served in a restaurant, while internal control mechanisms might focus on the individual dishes (each customer might order one or more dishes). Once the information is obtained, it is compared with the standard as issued by the initiating process. On assessment, when aberrations occur, these will lead to the initiating process to issue revised standards for internal control mechanisms.

In addition, as a second source, information from the environment might influence that evaluation process. Take for example, changing weather conditions and the effect on the human body. In such a case the homeostasis becomes influenced about the perception of the external conditions; for example, long periods of rainy weather might make people more pessimistic. Therefore, the evaluation process should not only account for the internal information about the performance process but also consider the (relevant) information it obtained from the environment.

Moreover, the evaluation process might conclude that the internal process is not capable of maintaining homeostasis; in that case, a signal is sent to the environment about the capability of the process (and the capability of the system of resources, if applicable). For example, when experiencing fever, the human body sends signals like a rise of temperature, transpiration and expressions of pain to the environment. Another case is a factory unable to cope with orders or with structural issues affecting the output; the environment (management) might have to make a decision for expanding resources. This signal that the process and the system of resources is not capable anymore of sustaining a static or dynamic equilibrium is informing the environment that the capability for self-regulation (see Box 6.1) is exceeded.

6.5 Limitations of Steady-State Model

These two control processes in the regulatory boundary zone (see Figure 6.4), initiating and evaluating, could concern quantitative standards as well as qualitative standards based on information of the environment. The initiating process should also consider for which of the aspects to generate the operational standards. Following the thoughts of Sections 2.3 and 2.4, this implies that the steady-state model with its control mechanisms applies to only one aspect system at a time. For example, such a situation occurs when the processing of orders does take structurally two weeks rather than the standard of one week. To perform the evaluation, information from the environment helps to assess the standards or creates the need for adaptation. Market growth might end up in increasing the levels of inventory to allow the same degree of service levels for delivery to customers. If the change of standards affects the performance to the environment, a signal will be generated to inform the environment of the changing capability of the transformation process. But how does that work if the quality of products is put into the equation? It will be difficult to compare the quality of delivery with the quantity of delivery;

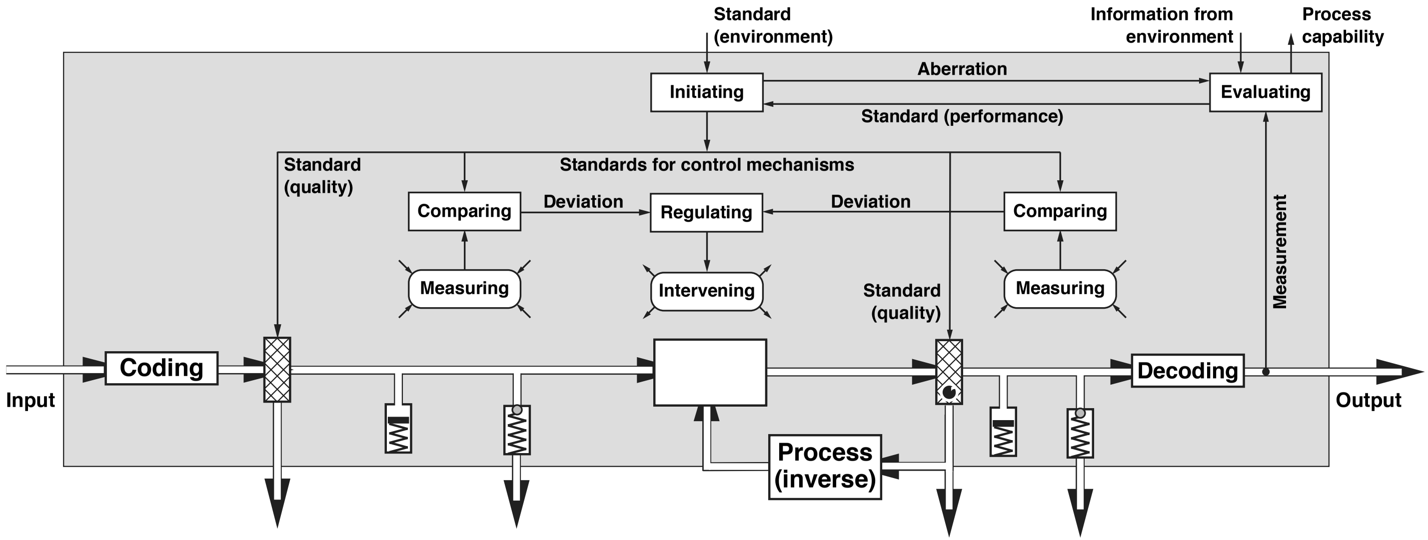

Figure 6.5 *Steady-state model. This generic model provides a complete overview of all processes in the boundary zones, the regulatory activities and the control mechanisms. For reasons of simplification the resources needed for all processes (primary process and control processes) have been omitted.*

in case of conflicts, which one takes precedence for decision-making. Hence, the processes as depicted in the boundary zones as basis for the steady state model principally apply to one defined aspect.

In addition to the limitation of being focused on one defined aspect, the steady-state model (see Figure 6.5) only applies to recurring processes. Through the control processes it will adapt to changes in its environment and the adaptation is limited to scope of the primary process and its limits of control. Do we want to go beyond the existing capabilities of a process, then we have to introduce a new internal (and if necessary an external) structure for the system of resources. When the system of resources and its processes proves incapable of coping with the perturbations imposed by the environment it means that the limits of the existing capability have been reached (the signal from the evaluating process to the environment).

The maintenance of a homeostatic equilibrium depends strongly on the capabilities of resources; however, the system of resources might also operate at another equilibrium caused by stimuli. The concept of heterostasis denotes such states that might even be beneficial to the system of resources. At best, the representation in the steady-state model would indicate a temporary setting of standards operating at different levels (aligned with stimuli). The steady-state model does not incorporate the concept of heterostasis adequately.

One cause might be that it should be noted that the steady-state model only covers one aspect of a system. This has much to do with the conversion from external standards to internal directives for the control mechanisms. The limitation that the steady-state model applies to one aspect brings up the question how to handle situations with multiple aspects, when strictly following the definitions of basic concepts as introduced in Chapter 2 and the modelling principles in Chapter 3. As outlined for modelling in Section 3.4, Applied Systems Theory indicates: ‘create or design a new model for each aspect’, which aligns with the definition of a system. That means that multiple steady-state models might be needed for describing separate control processes for each aspect; each steady-state model offers a different view on the control processes. This is not far from reality. Just look at how organisations divide the financial responsibilities and the responsibilities for quality and logistics; this notion suggests that different steady-state models for different aspects are common in organisations. Additionally, comparison between aspects remains in this view always subjective; for example, one individual manager will value some issues higher than peers do and weigh them different in a specific situation. The implication is that steady-state models apply to only one aspect for solving problems adequately and also for practical reasons of valuating and weighting different aspects.

Another limitation of the steady-state models occurs when the environment has no longer the need for the output of the transformation process; the standards will reduce to ‘zero’. Theoretically, this leads to a standstill of the system even though (people and) resources within the system can still fulfil their functions. In such a case, the system looses its right of existence but will enhance itself after exploration of other needs and goals that the same resources can fulfil. The only way for the system to sustain is either an external intervention especially for technical systems – or adaptation – especially for living systems and organisations. Both the external intervention and the adaptation call for re-arrangements in the structure of the system of resources considered (although for living systems this depends on the occurrence of mutations). These topics and related processes will be discussed in Chapter 7–9.

6.6 Summary

The steady-state model adds the control for the system boundary to the control processes for the primary process (directing, feedback, feedforward, completing deficiencies), which were presented in Chapter 5. The steady-state model has three boundary zones: the input boundary zone, the output boundary zone and the regulatory boundary zone for the system of resources. Those three zones ensure that the system of resources is capable of taking in flowing elements from the environment and transferring the transformed elements to the environment (that means after the primary process) in a controlled way.

In the input boundary zone the regulatory activities ensure the suitability of the influx of flowing elements for the transformation process. First the input is coded before it is checked on its qualitative properties against standards. Then, an input buffer smooth out irregularities in the influx of flowing elements, whereas an overflow assures that the flux of flowing elements aligns with the capabilities of the transformation process. Hence, the input zone aims at offering the flowing elements to the primary process that it is capable of transforming, both in a quantitative and qualitative manner (depending on the aspect considered).

Conversely, the boundary zone at the output of the transformation process ensures the transition from the flowing elements to the environment. As part of this zone, the feedback control mechanisms checks the flowing elements against standards. In addition, if necessary, a quality filter as control mechanism, discards the flowing elements into the environment, completes the deficiencies or feeds them back into the transformation process. An output buffer and an overflow smooth the irregularities between the supply of the transformation process and the absorption by the environment. Finally, the step of encoding makes the flowing suitable for the environment.

For aligning the control mechanisms of the system of resources to the environment, the steady-state model deploys the initiating process and the evaluation process in the regulatory boundary zone. Through the initiating process the standard, imposed by the environment, transforms into standards suitable for use by the 'internal' control processes. By evaluating the aberrations (as input from the evaluation process) and the external standards from the environment, the initiating process issues new or revised standards.

These appraised standards and the performance of the process combined with information from the environment constitute the input for the evaluation process; that process informs the initiating process about deviations and also relays the capability of the system of resources to remain within its own standards to the environment.

The steady-state model (resulting from the three boundary zones and the control mechanisms for the primary process) applies to only one (selected) aspect and aims at maintaining homeostasis. The limitation that the model covers only one aspect indicates that principally for each different aspect a separate steady-state model should be developed. Furthermore, the maintaining of a homeostatic equilibrium means also it depends strongly on the need of the environment, i.e. the continual existence of the function it fulfils. When that function is no longer necessary, the system of resources with its process is no longer able to produce output.

References

Emery, F. E., & Trist, E. A. (1969). Socio-technical Systems/Systems Thinking. London: Penguin.

Flood, R. L., & Carson, E. R. (1993). Dealing with Complexity: An Introduction to the Theory and Application of Systems Science. New York: Plenum Press.

Klopf, A. H. (1972). Brain Function and Adaptive Systems - A Heterostatic Theory (No. AFCRL-72-0164). Bedford, MA: Air Force Cambridge Research Laboratories.

Miller, E. J., & Rice, A. K. (1967). Systems of Organisation: Task and Sentinent Systems and their Boundary Control. London: Tavistock Institute.

Selye, H. (1973). Homeosatis and Heterostasis. Perspectives in Biology and Medicine, 16(3), 441–445.

Shannon, C. E. (1948). A Mathematical Theory of Communication. The Bell System Technical Journal, 27(3), 379–423.

van Gigch, J. (1978). Applied General System Theory. New York: Harper & Row.

7 Autopoietic Systems

While the previous chapters have mostly focused on cybernetic systems cumulating in the steady-state model, this chapter moves to more recent development in systems theories, particularly the theory of autopoiesis. Autopoiesis literally means ‘autocreation’ (from the Greek: auto - αυτο for self- and poiesis - ποιησις for creation or production) and expresses a fundamental complementarity between the structure and the function of a system. Originally, autopoiesis was formulated as an alternative to Darwinian ecology theory [Hernes and Bakken, 2003, p. 1512]; now it is seen as being complementary to existing models for evolution and change. It presents a different way of looking at how entities interact with their environment and how they evolve.

The theory of autopoiesis has found its way into explanations for biological evolution, interactions between humans and organisational development. Especially four fields have adapted the concepts of autopoiesis: evolutionary biology, sociobiology, economics and organisational science. At the moment, there seems a revival of academic interest into this topic to deploy these principles to a larger variety of phenomena observed in nature and science. Many of the topics presented in this chapter and Chapter 8 have interrelations and are mostly used in combination to explain these phenomena that otherwise seem difficult to comprehend. For part, these constitute qualitative approaches and they often link the autopoietic principles to complex adaptive systems (see Chapter 8). Although autopoiesis appeals as a concept for explaining phenomena, it has proven difficult to connect to practice and implement it; related concepts such as self-organisation serve sometimes better as description for the same phenomena.

Therefore, this chapter will take a broad view on autopoiesis and relate it to the different disciplines for explanation. Section 7.1 will shortly describe the concept of autopoiesis as a different way of looking at systems from both a closed systems view and an open systems view. Section 7.2 pays attention to three main principles of autopoiesis that govern the development of systems. That results in Section 7.3 discussing the interaction of autopoietic systems with their environment. Section 7.4 explores perception and cognition. A slight different theory is presented in Section 7.5: allopoiesis for systems that do not have all properties of autopoietic systems.

7.1 Autopoiesis

Morgan [1997, pp. 253-258, 413-414] points to the theory offered by Maturana and Varela [1980] to explain evolutionary processes: autopoiesis, the ability to self-create or self-renew through a closed system of relations, whether that concerns living organisms or possibly organisations and society.

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In this view, living systems engage in circular patterns of interaction whereby change in one element of the system is coupled with changes elsewhere, setting up continuous patterns of interaction that are always self-referential. A system enters only interactions that are specified by its structure. A system's interaction with its environment is a reflection and part of its own structure. It interacts with its environment in a way that facilitates its own self-production; that way, the environment becomes really a part of itself. These implications of the concept of autopoiesis mean that it needs a further explanation.

When the term autopoiesis was originally introduced by Chilean biologists Francisco Varela and Humberto Maturana in 1973, the described it as:

'An autopoietic machine is a machine organized (defined as a unity) as a network of processes of production (transformation and destruction) of components which: (i) through their interactions and transformations continuously regenerate and realize the network of processes (relations) that produced them; and (ii) constitute it (the machine) as a concrete unity in space in which they (the components) exist by specifying the topological domain of its realization as such a network.' [Maturana & Varela, 1973, p. 78]

'(...) the space defined by an autopoietic system is self-contained and cannot be described by using dimensions that define another space. When we refer to our interactions with a concrete autopoietic system, however, we project this system on the space of our manipulations and make a description of this projection.' [Maturana and Varela, 1973, p. 89]

The most used example of an autopoietic system is the biological cell (and one of the entities that motivated these Chilean scientists to define autopoiesis). For example, the eukaryotic cell is made up of various biochemical components, such as nucleic acids and proteins, and is organised into bounded structures like the cell nucleus, various organelles, a cell membrane and cytoskeleton. These structures of resources, based on an external flow of molecules and energy (the flowing elements), produce other elements, which, in turn, continue to maintain the bounded structure that gives rise to these elements. Examples of those elements are chromosomes and cell membranes that are created during and after a division of single cell. During the study of biological entities, Maturena and Varela [1980] arrived at some fundamental notions[1]:

- Individual systems are characterised by their autonomy. Even when they are part of organisms or populations and when they undergo environmental influences, the individual entities remain internally closed and self-defined.

[1] The word 'component' has been replaced with 'element' for overall consistency throughout the book. Element might mean subsystem at times but that depends on the level of aggregation.

- Living systems consist of elements with different properties. These elements, and their interaction with adjacent elements, determine the total behaviour of living systems.
- All explanations and descriptions of these living systems are generated by observers external to the system. Such an observer will denote the entities and the environment in which they exist. Elements within the entity do not possess this capability of observation and will only react to behaviour of other elements existing within the entity.
- An observer can describe the objectives and functions of elements present in the entity; the living system itself is incapable of to do these observations. Only the interactions of elements with adjacent internal elements can be observed.

The development of autopoiesis is a reaction to the cybernetic movements within the General Systems Theory and aims at explaining the unique features of biological systems and entities. Three principles dominate the thoughts of autopoiesis: self-reproduction, being structurally-closed and structural coupling.

7.2 Principles of Autopoiesis

The first principle of the theory of autopoiesis is the possibility for self-reproduction by systems. This concept of self-reproduction is also used by the attempts of Kauffman [1993, pp. 298-341] to explain the origin of life when he relates it to the concept of autocatalytic sets. The concept of autocatalytic sets builds on the combinatorial consequences of polymer chemistry. As the maximum length in a system of polymers increases, the number of reactions by which polymers can interconvert rises faster than the number of polymers present. Then, a sufficiently complex set of polymers has very many potential reactions leading to the synthesis of any of these polymers. Consequently, for many possible distributions of catalytic capacity for those reactions among the same set of polymers, autocatalytic sets will emerge, such as peptides stepping up to DNA. The hypothesis proposed by Kauffman is that life is a collective emergent property of complex polymer systems seems likely to give an answer to the critical question why free-living systems exhibit a minimal complexity. The self-reproduction principle of autopoiesis tells that the structure of all components and processes together produce the same components and processes to ensure the continuity of the living system [Maturana and Varela, 1980]. This principle creates an autonomous, self-producing entity.

Furthermore, as a second principle, autopoietic systems are structurally-closed which does not imply that no interaction takes place with the environment. For example, living entities feed themselves through input (food) taken from the environment. Those inputs do not account for changes as such in the living entity and generally support the continuity of the system. However, within the definitions of autopoiesis, perturbations lead to disruptions within the system. For example, disruptions and irregularities in the food supply lead to reactions within the living system to cope with the changes in the environment. To a certain extent, the environment has little influence on the responses by the system and the consequences for the structure and composition, and vice versa.

The connection to the environment is called the structural coupling, the third principle. Structural coupling is the term for structure-determined (and structure-determining) interaction of a given system with either its environment or another system; this should be viewed particularly through the lens of the external structure (see Section 2.2). An example is the vision of living systems; one set of interactions takes place through eye contact between human beings. Both the possibilities and limitations of eye contact determine the effectiveness of that visual interaction as communication. Structural coupling between living systems facilitates the realisation of autopoiesis. When the homeostasis created by the organisational closure of the systems can no longer be maintained, the disintegration of the systems occurs which leads van der Vaart [2002, p. 5] to the statement: *Autopoiesis is all or nothing!*

Using the three principles – self-production, being structurally-closed and structural coupling – an autopoietic systems can be defined as a composed unit with a network of components (see Figure 7.1) that

- through interactions repeatedly completes the production process of components by which the self-production sustains,
- and that realises a unit for self-production in a space in which the system exists by creating and specifying boundaries in which only components are allowed that participate in the realisation of the production process.

When reading this definition think about cells and organisms as examples of autopoietic systems. Also, the Earth can be viewed as an autopoietic system, referred to as Gaia; think about the exchange with its environment (energy in the form of solar energy and radiation). Hence, there are many examples of autopoietic systems when looking at the definition.

7.3 Autopoiesis and Self-Organisation

Particularly, with autopoietic systems being structurally-closed, self-organisation has a prominent position in maintaining these entities. Self-organisation can be seen as a process in which the internal structure of a, normally an autopoietic, system increases in complexity without being guided or managed by an outside source. Self-organising systems typically display emergent properties (see Section 2.2) as a result of transitions in states. The concept was first noted in physics, such as convection cells in gravity fields and spontaneous magnetisation. Self-organisation is also relevant in chemistry, where it has often been taken as being synonymous with self-assembly (defined as a reversible process in which the pre-existing parts of a pre-existing system form structures of patterns, as is the case for some

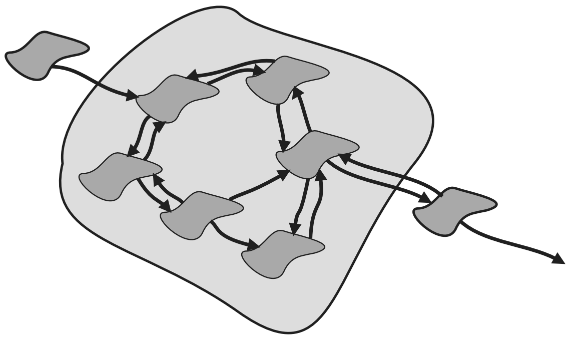

Figure 7.1 *Symbolic representation of an autopoietic system. Internal components interact with the environment and have internal relationships that build the structure of the system. At the same time, the boundary of the system defines the internal structure as being closed and it defines the interaction with the environment through its external structure.*

complex polymers, see also the previous section). Furthermore, the concept of self-organisation is essential to the description of biological systems, from the subcellular to the ecosystem level. 'Self-organising' behaviour also appears in many other disciplines, both in the natural sciences and the social sciences, such as economics or anthropology. It has also been observed in mathematical systems such as cellular automata, which are grid of cells that have a finite set of states. All these examples and domains show that self-organisation constitutes a basic process that allows systems of resources, particularly autopoietic systems, to adapt to stimuli by the environment without the guidance of an external resource (which does not mean that they do not interact with the environment).

That process of adaptation might sometimes lead to the notion that self-organisation is mixed with that of the related concept of emergence. However, there may be instances of self-organisation without emergence and emergence without self-organisation. In this respect, it is useful to distinguish between emergent properties and emergent behaviour. Emergent properties might already appear when elements of a system are put together. For example, a car you can drive but you cannot do the driving with just the parts without assembling them. In such cases, emergent properties do not result from self-organisation. Contrastingly, in the case of emergent behaviour, the system responds to external stimuli. This happens with heterostasis (see Section 6.1) when the system searches for a temporary equilibrium in a poised state. In the case of self-organisation, not all the time emergent properties or behaviour will result. The internal complexity of the system might increase without it necessarily performing another function or meeting another scope of environmental constraints. This is the case for random mutations in cells; quite a number of these can be classified as neutral genetic drift, having no effect on the functioning of cells. However, that means that emergence properties and behaviour are not necessarily related to self-organisation and that self-organisation does not necessarily imply emergent properties or emergent behaviour.

The concept of self-organisation is a process where a system searches for internal adaptation to external events (or stimuli) and to that purpose usually relies on three basic ingredients [Halley and Winkler, 2006, p. 12]:

- Positive feedback amplifies certain deviations rather than damping them, giving a greatly increased output to any input change from flowing elements or resources. Often amplifying deviations is undesirable and is countered by negative feedback measures, leading in complex systems to a mix of feedback influences. However, positive feedback might ensure a fast transition between a detrimental state and target state. This can be seen in evolution where fitness of species operates in this way, success breeds more success. The interactions of these types of feedback lead to self-limiting systems and often to cycles and oscillations in nature.
- Negative feedback maintains equilibrium and counteracts positive feedback when reaching new states. While most self-organising systems use positive feedback to reach new states, for such systems both negative and positive feedback are indispensable. Camazine et al. [2001, p. 489] point out that negative feedback often takes the form of regulation, competition, reduction or saturation. For example, in the ants' nest negative feedback dominates when there is competition among food sources, the food source is fully consumed, too many ants are feeding from a food source, there are not enough food sources in a particular area, lack of space or any other similar event that overtakes the positive feedback processes of the ants' nest. Consequently, the ants are forced to hunt for other food sources and commence the feeding cycle again. An another example used in biology is the case of pillar formation in termite nests [e.g. ibid., 402]. In this event, negative feedback takes over when there is no more material in the area close to the formation of these types of pillars. It has also been observed that there seems to be a certain type of competition among termites building other pillars in the same area. This pattern of competition is recognised as negative feedback. So negative feedback complements positive feedback for reaching new states as well as maintaining equilibrium.
- Multiple interactions enable self-organising systems to respond to external events and stimuli. It is the reliance of internal processes on multiple interactions through the external structure and passing of information among subsystems and elements; information can also appear in physical or chemical form, like physiological reactions. As Fuchs [2003, p. 161] points out, '… all self-organising systems are information-generating systems'. Self-organisation takes place in systems with multiple active interactions among many subsystems and elements (sometimes these are called actors when referring to social systems). Because there are many, often identical, subsystems and elements, there is no requirement for a

single one to carry out a series of connected processes. Those sequences of processes result in the emergence of a new order.

So, self-organising systems use information of some kind as events through multiple interactions to trigger internal and external processes of positive and negative feedback that ultimately establish new structures within the system by going through transitions of states.

Self-organised Criticality

During those transitions of states self-organised criticality might occur. This is a property of (classes of) dynamical systems, which have a critical point as an attractor, mostly a phase transition. An attractor is a set of states of a dynamic physical system toward which that system tends to evolve, regardless of the starting conditions of the system. An example is a pile of sand. By continuously adding new grains of sand to a small pile of sand, the formation of small local avalanches starts. The small local avalanches decrease the local slopes whenever they become to steep. Perturbing the system, the small sandpiles, provoked by avalanches, create still greater sandpiles and eventually we end up with only one big sandpile. At some point (the transient point) this pile ceases to grow. The (global) average slope has reached a steady state corresponding to the angle of repose that the sandpile cannot exceed no matter how much sand is added. That means that the pile has reached a statistically stationary state and additional grains of sand will ultimately fall off the pile. This particular state reflects self-organised criticality and the pile of sand is just one of many examples.

That phase transition takes place without the need to tune parameters to precise values. Contrary to intuition, parameters themselves tend to gravitate towards a dynamic equilibrium. This happens in work groups that have to perform complex tasks; a work division will occur over time, while different groups might create different divisions, though these have similarities as well. The concept of self-organised criticality implies that larger interactive components (in terms of autopoiesis subsystems or elements in Applied Systems Theory) will self-organise into a critical state. Once in the critical state perturbations result in a chain of events among the elements and subsystems, which can affect a number of elements within the system. Hence, it is the perturbations that lead the self-organising system towards the critical state or the transition phase.

Self-organisation vs. Entropy

The idea of self-organisation challenges an earlier paradigm of ever-decreasing order that was based on a philosophical generalisation from the second law of thermodynamics. Each system that has a number of states (structure, properties of elements and relationships) has also a likelihood that a particular state might exist. The concept of 'entropy' expresses that measure of the statistical 'disorder'. That also means that the higher the 'entropy', the less likely that a discrete state will occur. In other words, entropy is an expression of randomness. A practical example is a black marble in a box full with white marbles. In the first scenario the black marble is put into a large box and the box is shaken intensely. Because the box is large, there are many possible places inside the box where the black marble could be, so the black marble in the box has high entropy (many possible states). The second scenario is repeating this experiment with a small box. In the case of a small box, the black marble has low entropy (more limited number of states). Entropy plays a large role in self-organising systems.

In open systems, it is the flow of elements and energy through the system that allows the system to self-organise and to exchange entropy with the environment. This is the basis of the theory of dissipative structures by Nicolis and Prigogine [1977]. Dissipative structures are not limited to living things, such as cells, organisms, trees, internal organs and people, but might also include some non-living structures. For example, a whirlpool is a dissipative structure requiring a continuous flow of matter and energy to sustain its form. At the same time, its entropy is transmitted to its environment as it seeks to reduce (read: stabilise) itself. At the same, such a dissipative structure displays self-organisation that can only occur far away from (thermodynamic) equilibrium. Since closed systems cannot decrease their entropy, only open systems can exhibit self-organisation.

However, such open systems can gain macroscopic order while increasing their overall entropy. Specifically, a few of a system's macroscopic degrees of freedom can become more structured at the expense of microscopic disorder. In many cases of biological self-assembly, for instance metabolism, the increasing entropy of small molecules more than compensates for the increasing organisation of large molecules; this is especially the case for water. At the level of a whole organism and over longer time scales, biological systems are open systems taking in input from the environment and discarding waste into it (as output). In economics, such a concept exists under the label: externalities. These externalities are costs or benefits that result from an activity or transaction and that affects an otherwise uninvolved party (system, subsystem or element) who did not choose to incur that cost or benefit. Some examples of these externalities are pollution, dumping of toxic waste and labour conditions that they not allow employees to sustain themselves reasonably. Therefore, the concept of entropy entails looking at a more aggregated level of order while considering effects at a lower level of detail.

Autopoietic Aspects of Self-Organisation

The concept of autopoiesis is linked to self-organisation and with self-assembly. Self-assembly is a spontaneous process that searches for equilibrium and happens in nature, in biological systems (created systems) and human engineered systems (that includes organisations). It leads to an increased complexity of the internal structure to respond to organisational and externally imposed constraints. Both self-organisation and self-assembly happen within the system. Additionally, autopoiesis is based on reproduction leading to mutations as a result from internal reproduction processes, self-assembly being one of them, and happens as well from within. During these reproductions errors might happen during mutations, so-called point mutations, which lead to changes in reproduced elements and indirectly to changed structures. Therefore, observed mutations of autopoietic systems can be the result of self-production or of errors – the point mutations; when detecting those mutations, their origin might not necessarily be clear.

The new internal structure of autopoietic systems might possibly induce changed behaviour, either by constraints of functions or by new functions. It is written as 'might' since some mutations do not yield any effect themselves. An example is the use of a calculator for the addition of two figures instead of adding them up manually. However, if this was done electronically in a spreadsheet and stored at a server centrally, then others in an organisation might use those data for other purposes resulting in new patterns of interaction within the organisation. Therefore, self-organisation during these (point) mutations leads to integration, which in turn might end up in new structures. These adapted structures imply changes in processes and therefore in behaviour, which is either covering a different range of constraints or generating new functions; selectional forces in the environment determine the viability of these mutations as interaction between the autopoietic system and the environment.

7.4 Interaction with Environment

For the interaction with the environment, the structural determinism of autopoietic systems and the related principle of structurally closed entities constitute the most important principles for selectional processes, such as evolution. The structural determinism tells that all changes are embedded in the structure of the entity itself. Each change of a composed unit is a change of the structure moulded by the properties of the elements and subsystems in that very same structure. A case in point is the construction of eyes that is very similar across a wide range of (related) species and serves the same functions. A true change will occur as a reaction to the internal dynamics of the system or the interaction with the environment and, even then, the internal relations of components shape the change rather than the environment dictates the internal adaptations.

This view of structural determinism of autopoietic systems does not imply that autopoietic systems are isolated. Those types of open systems interact with the environment through a continuous pattern that has principally no end or beginning since it is a closed loop of interaction. For instance, living beings absorb flowing elements as food from the environment and have to continue to do that; and if they cease to exist themselves, they have passed that on to the next generation. However, the theory of autopoiesis includes that systems can be recognised as having environments but insists that relations with any environment are determined internally by their structure. That is because the boundary of the system consists of elements and subsystems generated by the interactions of internal elements and subsystems of the system with the environment. Relations and interaction with adjacent elements and subsystems in the boundary maintain the boundary. Without these elements and subsystems, the autopoietic system does not sustain self-referring processes for retaining its autonomy and steady-state.

The structural coupling governs by which interactions a element or subsystem of an autopoietic system is influenced. When interactions initiate changes in the structure and composition, the structure is called plastic. Through repeated interaction and initiations, selection of subsequent structures happens by the environment. In a way, the environment and the plasticity of the structure drive the selection by its own elements, subsystems and internal relationships. The environment does not determine the internal adaptations! Therefore, autopoietic systems are interactively open and structurally closed [van der Vaart, 2002, p. 11].

Structural coupling in biological systems arises as a result of the plasticity of their internal structures and the plasticity of the interaction with the environment. As suggested above, autopoietic systems are structurally determined – how they respond to environmental events – and indeed what events they respond to is something that is determined by their structure at a given moment in time (the same goes for the interaction with the environment). Since a plastic structure is one that can be affected by outside events, it can be perturbed. So, structure determines what an autopoietic system does, and when the structure of such a system changes, what it does is likely to change in a manner determined by its system's structure. The similar reasoning applies to the interaction with the environment. Over time, the structure of both system and interaction with the environment change as a result of mutual non-destructive perturbations. An autopoietic system strives to respond to events in its environment in an appropriate manner; minimally, the system seeks not to be destroyed.

7.5 Perception and Cognition

One of the foremost reasons for the research into autopoiesis stems from the quest for the nature of perception and cognition in the interaction with the environment. Perception and cognition derive from the internal processing of stimuli in the interaction with the environment, consistent with the concept of autopoiesis. To exist, continuously interactions should be repeated since the structural coupling exists; in this sense, cognition represents gathering knowledge about all effective interaction for sustainability, particularly for living systems.

Learning as a process of cognition originates in the properties of self-reference of the system. When learning exceeds the level of direct interaction and moves towards orientation in the common domain of two autopoietic systems, communication is established. When descriptions lead to being observer of its own behaviour, self-conscience arises. Hence, the composition of a system related to an external point of reference defines the identity of an autopoietic system [van der Vaart, 2002, pp. 7, 24-25]. The identity is strongly related to the composition of the entity, changes in the composition lead to a changed identity; through self-reference autopoietic systems seek to maintain their identity unless perturbations provoke adaptations. These notions lead Mingers [1995] to connect the theory of autopoiesis to the systems hierarchy of Boulding (see Figure 7.2); see Section 3.5 for this hierarchy. The higher the system is positioned at the levels in the hierarchy of Boulding, the more pronounced and complex the perception and cognition processes.

An example of the application of perception and cognition processes is the 'Living Company'. Connecting it to the capabilities of autopoietic systems, de Geus [1999, p. 111] points to learning as characteristic for organisations (similar to learning by organisms). Learning becomes possible through self-cognition as typical for the higher levels of the systems hierarchy of Boulding. Following the ideas laid down by de Geus, it was Senge [1992] who has expanded these theories and gained recognition about the importance of the continuous process of gathering understanding about the interaction between organisation and environment. For part, that concept of the learning organisation originates in the principles of autopoiesis.

7.6 Allopoietic Systems

However, organisations are an example of entities that do not self-produce by generating offspring. In such a case, we talk about allopoiesis; that is the process whereby a system produces something other than the system itself. Social organisations, like manufacturing facilities are examples of

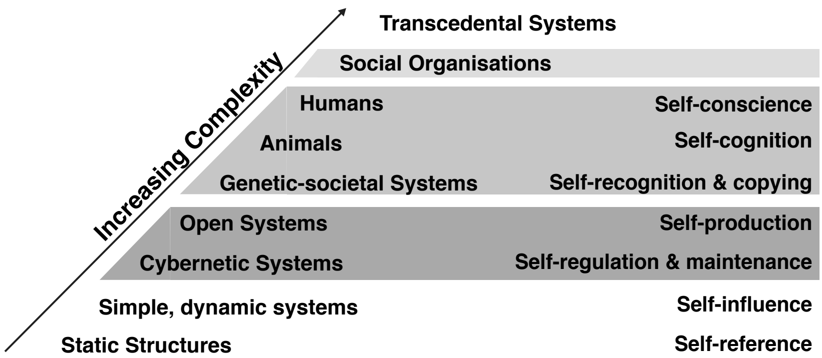

Figure 7.2 *Connection of the theory of autopoiesis to the systems hierarchy of Boulding according to Mingers [1995]. The interaction with the environment changes because of the model of reference to the environment, which induces internal processes at the higher levels of the systems hierarchy.*

allopoietic systems. In such a case, the entities that are produced consist of other elements or subsystems than those required for producing them. Some say that even reproduction in biology is allopoietic to some extent because offspring is materially distinct from the parent organisms and might even occupy different spaces. In that sense, reproduction is not equal to self-production.

Allopoiesis is neither a separate concept nor even a background for the articulation of an autopoietic system, but rather an ideal construction of a non-autopoietic system, while sharing some of its characteristics, see Figure 7.3. The main difference between autopoietic and allopoietic systems appears to be the difference in their structures. While the former have a structure that is defined by the relationships between processes of production of elements and subsystems, the latter thus have a structure that is defined by the spatial relations between elements and subsystems [Maturana and Varela, 1980, pp. 79-80]. Therefore, autopoiesis and allopoiesis belong to different domains, namely, the domain of the 'concatenation of processes' and the domain of the 'concatenation' of components that participate in one and the same production process that is not linked to other such processes in a network [ibid., 80]. But if structure in general is to be understood in terms of relations between processes of production of elements and subsystems, then the term structure in principle becomes inapplicable for system's description on the level of allopoiesis.

Allopoietic Systems as Creation

Thus, by definition, allopoietic systems (drawn partially from [Maturana and Varela, 1980, p. 81]) are:

(1) non-autonomous systems as they are dependent on the continuous influx of flowing elements;

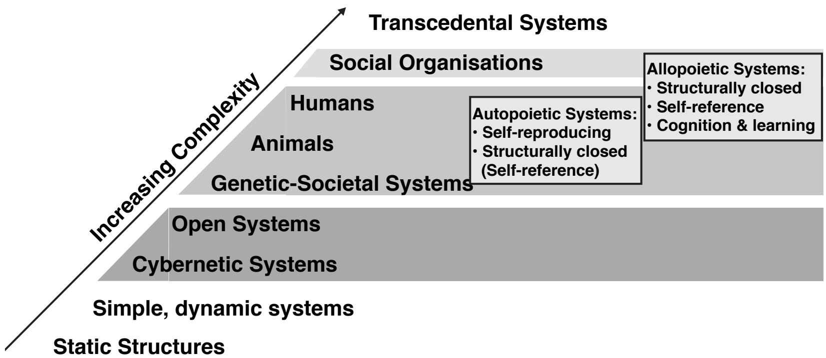

Figure 7.3 *Connection of the theories of autopoiesis and allopoiesis to the systems hierarchy of Boulding, according to Dekkers [2005, p. 148]. Allopoietic systems have a different domain of application than autopoietic systems, particularly for cognition and learning.*

(2) systems without individuality because their identity depends on the observer (note the parallel with de Geus' [1999] proposition of 'persona');
(3) systems which are not unities because they do not have self-defined boundaries but rather have boundaries defined from without [allopoietic systems are created or emerge in creation];
(4) systems with inputs and outputs which can be perturbed by external events.

However, to these distinctive characteristics one more could be added, which, although of crucial importance, still remains without articulation. Zeleny [1981, p. 96] remarks that autopoiesis and allopoiesis should be treated as inseparable concepts in the same way in which 'organisation is inseparable from structure'. He further concluded that while an allopoietic system may emerge out of chaos and disorder, or out of 'non-systems', autopoietic systems cannot but emerge from another system. This is based on the argument that processes producing elements or subsystems must exist before the process of their linking together can take place. Such considerations gave Zeleny certain grounds to question the possibility that autopoietic systems operate on an essentially unordered environment of components. He was rather inclined to accept the other alternative, namely, that an autopoietic system acts 'upon an already ordered, structured milieu, favourable to its enhancement and maintenance' [ibid., p. 95]. Hence, autopoietic systems might emerge rather than be created and allopoietic systems are created.

According to Misheva [2001], this shows that the domain that the term allopoiesis was supposed to designate still remains undefined. Because an allopoietic system is created by an external entity (or entities), its lacks the links between independent self-production processes as autopoietic systems do have. Also, for autopoietic systems maintaining homeostasis is an artificial construct. Thus, allopoietic systems lack the ability to maintain certain critical systemic variables within unchangeable limits; there is some parallel with the capability for self-regulation as mentioned in Section 6.4. In that sense, allopoietic systems lack permanence and sooner or later vanish without leaving any trace of their existence. In that sense, think about manufacturing organisations, such as early iron furnaces in the German region of North Rhine-Westphalia. Except the artefacts, remains of building and traces in the soil, almost all traces of its organisation have disappeared. However, in human beings there are still traces of the origins in the RNA and DNA, dating back 85,000 years and more. In the view of Misheva, this is so because allopoietic systems lack an essential 'device' and are basically non-homeostatic systems; even when they briefly attain the autopoietic structure, they lose it and revert to their previous state [Zeleny, 1981, p. 93]. Hence, the theory of autopoietic systems does not explain, observe, or describe life or living systems, but rather only the 'device' that makes a living system a homeostatic machine capable of maintaining its own structure under some strictly defined range of conditions; this is commensurate with the definitions;

one could say that even allopoietic systems are dependent on an external entity to remain purposeful.

Stakeholders and Boundary Critique

If allopoietic systems are dependent on an external entity, or may be more than one, then the purpose is defined by these entities; that investigation into the purpose of an allopoietic system is called stakeholders' analysis. A stakeholder is an individual or group that is going to be affected by an event, action or intervention. That means that stakeholders are not limited to proprietors (or in business administration, shareholders) but also other that might be experiencing an impact. An example of that is when a new bypass is build around a village those near to new route might be experiencing noise pollution. There different techniques for assessing the impact of events, actions or interventions, for example [Bourne and Weaver, p. 101]:

- The influence-interest grid.
- The power-impact grid.
- The power-interest grid.
- The three-dimensional grouping of power, interest and attitude.
- The stakeholder circle.

All these techniques map visually stakeholders on the impact the event, action or intervention has on allopoietic systems and to what extent they can influence the outcome, albeit in different ways.

Moreover, when conducting a stakeholders' analysis, the inclusion or exclusion of specific stakeholders is part of what is called boundary critique. According to Ulrich [2002, p. 41] boundary critique means that 'both the meaning and the validity of professional propositions always depend on boundary judgments as to what 'facts' (observation) and 'norms' (valuation standards) are to be considered relevant' or not. That also implies that boundary critique is an extension of Kantian philosophy by including those actors that are sources of motivation, sources of power, sources of knowledge and sources of legitimation [Ulrich, 2000, p. 258]. Hence, the definition and existence of allopoietic systems relies on the inclusion of specific external stakeholders.

7.7 Social Systems as Autopoietic Systems

Despite that ambiguity of allopoietic systems being autonomous reproducing entities and at the same time dependent on external entities, the study of social systems as being autopoietic or allopoietic systems offers some interesting perspectives. However, traditionally, the focus is on autopoietic concepts rather than allopoietic considerations. That perspective reverberates when according to Luhmann [1986, p. 186] autopoiesis is 'a theory of self- referential systems, to be applied to observing systems as well'. This links social autopoiesis theory to second-order cybernetics, as expressed by von Foerster

[1981], Geyer and van der Zouwen [1978] among others. The second-order cybernetics evoke that an observer becomes also subject of study; that means that for the individual researcher that a study becomes just as much a question of self-observation as observation of the social system. Luhmann [1986, p. 187] remarks: 'To combine these two distinctions (between autopoiesis and observation, and between external observation and self-observation, our inclusion) is one of the unsolved tasks in systems theory'. Essentially, that suggests that an observer examining a social system constitutes an autopoietic system in its own right, i.e. when gathering information about social systems we cannot avoid collecting information about ourselves. Luhmann [ibid., p. 188] points out that in order to solve this ambiguous problem (paradox) a sort of exchange between external observation and self-observation is required.

Moreover, another property of autopoietic systems, the conceptual pairings (normatively closed and cognitively open), makes it possible for a social system to be simultaneously self-producing in terms of social norms and to still maintain the capability of learning, through the cognitive openness of the system. Luhmann [1986, p. 183] states: 'the concept of autopoietic closure has to be understood as the recursively closed organisation of an open system'. The point is the extent to which normative closure and cognitive openness exists in a specific system. According to Luhmann [ibid., p. 186], it is communication that constitutes the evolutionary potential for the structure of systems able to 'maintain closure under the condition of openness'. Even if the system is closed normatively, it does not follow that it is not subject to influences from the environment (not the universe, see Section 2.1 and 7.2). An autopoietic system is cognitively open, and, therefore, can both influence other systems and at the same time learn and adapt to the environment.

However, there is no agreement as to whether social systems can be truly regarded as autopoietic systems. The works of de Geus [1999], Luhmann [e.g. 1986] and Robb [1989] argue in favour of the contention that the theory of autopoiesis can be adapted to social systems. However, Maturana [1980], Varela [1981] and Mingers [1989, p. 175] cast more doubts about the fruitfulness of this analogy. From the perspective of systems theories and the systems hierarchy of Boulding (Section 3.5), autopoietic processes and systems can be used as metaphor, but that implies not as identical in social systems and organisations. Particularly, the cognitive and knowledge-based facets of the principles of autopoiesis at the cell level can be adapted for the purpose of acquiring knowledge of social processes in organisations regarded as social systems. For example, that is what Senge (1992) has done when introducing the concept of the Learning Organisation. This interpretation is similar to Luhmann‘s point of view [1986, p. 173]. Luhmann's application of the autopoiesis theory can be used to describe, explain and possibly predicate change or lack of change in social systems. But that also means that autopoiesis for social systems is an evolutionary model and relies on mechanisms derived from evolutionary biology, for example.

7.8 Summary

The theory of autopoiesis adds further insight in addition to the more cybernetic views that have dominated the previous chapters. Principally, it tells that next generations of autopoietic systems build on the elements and structures of previous generations. Such is the case in evolutionary biology for offspring. Autopoiesis implies also that these systems are self-referential in their interaction with the environment; only that what can be perceived acts as stimulus for activities in the system and for the next generation. However, it also a very difficult theory to apply to systems because the observers have also cognitive limitations. Therefore, the principles of autopoietic theory serve as explanation for higher levels in the systems hierarchy of Boulding but should applied with reservations.

A special class of autopoietic systems are allopoietic systems – by some considered an opposite to autopoietic systems. These systems do not self-produce as autopoietic systems do but are 'created' or emerge from systems external to them. The dependency on the external systems for justifying its existence means also that it depends on the perceived need of the output or function by the external actors. Therefore, adaptations of an allopoietic system are also driven by external enactment, while at the same time building on the self-referential aspects. A conversion of an allopoietic system relies on its extant subsystems and elements and in that sense follows autopoietic principles. Only when further adaptations are not possible the allopoietic systems become extinct and in the best case, elements or subsystems are re-used by external (perhaps, different) actors.

The application of autopoiesis to social systems proves not only difficult but also contentious. Social systems could be viewed from both an autopoietic perspective and an allopoietic view. The latter implies an account of stakeholders and their influence on the purpose of the system. Including or excluding particular groups of stakeholders might influence the outcomes of analysing a situation, advancing a solution and societal progress. Other aspects of autopoietic theories lead to more philosophical views on interaction between systems and actors, where the capability of self-reflection takes a paramount role.

References

Bourne, L., & Weaver, P. (2010). Mapping Stakeholders. In E. Chinyio & P. Olomolaiye (Eds.), Construction Stakeholder Management (pp. 99–120). Oxford: Wiley-Blackwell.

Camazine, S., Deneubourg, J.-L., Franks, N. R., Sneyd, J., Theraulaz, G., & Bonabeau, E. (2001). Self-Organization in Biological Systems: Princeton University Press.

de Geus, A. (1999). The Living Company. London: Nicholas Brealy Publishing.

Fuchs, C. (2003). Structuration Theory and Self-Organization. Systemic Practice and Action Research, 16(2), 133–167.

Geyer, R. F., & van der Zouwen, J. (1978). Sociocybernetics: An actor-oriented social systems approach. Boston: Martinus Nijhoff Social Sciences Division.
Halley, J. D., & Winkler, D. A. (2008). Consistent concepts of self-organization and self-assembly. Complexity, 14(2), 10–17.
Hernes, T., & Bakken, T. (2003). Niklas Luhmann's Autopoiesis and Organization Theory. Organization Studies, 24(9), 1511-1535.
Kauffman, S. A. (1993). The Origins of Order: Self-Organization and Selection in Evolution. New York: Oxford University Press.
Luhmann, N. (1986). The autopoiesis of social systems. In F. Geyer & J. van der Zouwen (Eds.), Sociocybernetic Paradoxes: Observation, Control and Evolution of Self-steering Systems (pp. 172–192). London: Sage Publications.
Maturana, H. R., & Varela, F. J. (1973). Autopoiesis and Cognition – The Realization of Living. Dordrecht: D. Reidl.
Maturana, H. R., & Varela, F. J. (1980). Autopoiesis and Cognition. London: Reidl.
Mingers, J. (1989). An introduction to autopoiesis - Implications and applications. Systemic Practice and Action Research, 2(2), 159–180.
Misheva, V. (2001, 25-26 January). Systems Theory from a Gender Perspective. Paper presented at the Annual Meeting of the Swedish Sociological Association, Uppsala.
Morgan, G. (1997). Images of organization. Thousand Oaks: Sage Publications.
Nicolis, G., & Prigogine, I. (1977). Self-organization in nonequilibrium systems : from dissipative structures to order through fluctuations. New York: Wiley.
Robb, F. F. (1989). Cybernetics and Suprahuman Autopoietic Systems. Systems Practice, 2(1), 47–74.
Senge, P. M. (1992). The Fifth Discipline. Kent: Century Business.
Ulrich, W. (2000). Reflective Practice in the Civil Society: The contribution of critically systemic thinking. Reflective Practice, 1(2), 247–268.
Ulrich, W. (2002). Boundary Critique. In H. G. Daellenbach & R. R. Flood (Eds.), The Informed Student Guide to Management Science (pp. 41–42). London: Thomson Learning.
van der Vaart, R. (2002). Autopoiesis! Zin of Onzin voor organisaties? (Literature Review Report). Delft: Delft University of Technology/Section Production Technology and Organisation.
Varela, F. (1981). Describing the logic of the living: The adequacy and limitations of the idea of autopoiesis. In F. Varela (Ed.), Autopoiesis: A theory of living organization (pp. 36–48). New York: North Holland.
von Foerster, H. (1981). Observing systems. Seaside, CA: Intersystems.
Zeleny, M. (1981). "What is autopoiesis." Autopoiesis: a theory of living organization. New York: Elsevier.

8 Complex Adaptive Systems

The previous chapter has already shown that the deterministic view of the early chapters remains insufficient to address the complexity at the higher levels of the systems hierarchy of Boulding. Building on this notion, the field of study of complex adaptive systems believes that the dynamics of complex systems are founded on universal principles that may be used to describe disparate problems ranging from particle physics to the economics of societies, such as in the work of Kauffman [1993]. In addition, the development of complexity science offers a shift in scientific approach with the potential to profoundly affect business, organisations, institutions and government about the effectiveness of change and interventions. The science of complexity science strives to uncover the underlying principles and emergent behaviour of complex systems that are poorly described by deterministic approaches. Generally speaking complex systems are composed of numerous, varied, simultaneously interacting agents (elements or subsystems in terms of Applied Systems Theory). The goal of complexity science is to understand these complex systems – what 'rules' govern their behaviour, how they adapt to change, learn efficiently and optimise their own behaviour.

This chapter intends to provide an introduction to the principles of complex adaptive systems but not go into detail for every application, method and laws; it will restrict itself to some main principles. To that purpose, Section 8.1 gives a brief introduction how concept of complex adaptive systems can be understood and to what domains it has been applied (some of the descriptions also appear in Dekkers [2005]). The attributes of complex adaptive systems constitute Section 8.2. Central to the understanding of the behaviour is the process of adaptation on fitness landscapes, which appears in Section 8.3. Akin the development in autopoiesis, the concept of self-organisation has been linked to complex adaptive systems; Section 8.4 gives a short overview on that matter and also discusses dissipative structures. Section 8.5 covers recursive behaviour. Finally, Section 8.6 relates complex adaptive systems to connectivity, one of the attributes of complex adaptive systems, for human-influenced networks.

8.1 Dimensions of Complexity

Adaptive behaviour, see Section 4.2 for introducing related processes, becomes complex when many elements or subsystems interact. However, we refer to complex adaptive systems, when exact behaviour is difficult to predict, although the behaviour of subsystems or elements might be known. A typical example is the weather system; the behaviour of tornadoes is known but the emergence and exact behaviour is more difficult to predict. Hence, complex adaptive behaviours that emerge as a consequence of non-linear spatial-

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temporal interactions among a large number of elements or subsystems are ubiquitous in nature. Further examples of complex adaptive systems that exist in nature include immune systems, multicellular organisms, nervous systems, ecologies, societies, etc. In addition, examples of synthetic (man-made) complex adaptive systems include parallel and distributed computing systems, large-scale communication networks, artificial neural networks, evolutionary algorithms, large software systems, economies, etc.; note that these could also be called allopoietic systems (see Section 7.6). Therefore, some will say that complex adaptive systems are and have become part of our real life and pose challenges for those interacting with them.

Those challenges have attracted researchers from a number of disparate areas to study the behaviour and application of complex adaptive systems. Their interest goes to the behaviour, control and coordination, communication, adaptation, learning and evolutionary structures and processes in complex adaptive systems. Of particular interest are algorithmic, information processing, and complexity-theoretic characterisations of complex adaptive systems. The study of those systems is found in computer structure and applications, information theory, artificial intelligence, cognitive science, neuroscience, psychology, sociology, control theory, complexity theory, economics, mathematics, physics, evolutionary biology and engineering among others. The resulting tools for analysis of complex adaptive systems have found applications in many areas of science and even the humanities. Computational experiments and simulations used in this strand of research have led to the development of mathematical and computational techniques that are equally applicable to the design of distributed control systems based on the model of a complex system composed of multiple, autonomous, intelligent agents, competing and cooperating in the context of the whole system's environment (note that this chapter is limited to some basic principles of complex adaptive systems).

However, the term complexity carries some ambiguity. This is mostly due to complexity being understood in two distinct ways:

1. As an expression of structure, mostly internally oriented, either as part of networks or as an individual system.
2. As an expression of emergence, more rooted in new behaviour and complexity imposed by the environment.

The first interpretation of complexity, internal complexity, can be seen as a design parameter, even though not sufficiently defined in cybernetic approaches. Returning to the basic definitions in Section 2.1, internal complexity simply means a large number of elements with a large number of interrelationships. The intricate interrelationships of elements within a complex system might give rise to multiple chains of dependencies. An example is an economic system of a country with many firms, government agencies, education institutes, etc. being dependent on each other. However, that means that a system cannot be reduced to simple understanding, but it does not mean it cannot be understood or its behaviour cannot be predicted.

Contrastingly, the second meaning of complexity is related to new behaviour that could not directly be foreseen. To cope with emergence, different entities might develop different types of Complexity Handling Capability [Boswijk, 1992, p. 100]; that means building on existing capabilities for new situations or incorporating new knowledge for creating new capabilities to cope. Under those conditions, balance will hardly be achieved, only paradigms that address the dynamics of networks constituting of agents and the environment will elect for elaboration within the context of complex adaptive systems. In an organisational context, complexity provides an explanatory framework of how agents behave, how individuals and agents interact, relate and evolve within a larger (social) ecosystem. Complexity as emergence also explains why interventions may have unanticipated consequences [Buchanan, 2004]. While an economy is an internally complex system, it also has emergent behaviour that might result from external interaction, such as its resilience to recover from global economic crises. It is the second meaning of complexity – emergence of new behaviour and imposed complexity by the environment – that is taken to the forefront in the remainder of this chapter.

8.2 Attributes of Complex Adaptive Systems

Those dependencies arise because complex adaptive systems constitute of agents that link together and that do form a network (note that the concepts for complex adaptive systems refer to agents instead of elements and subsystems). The actions and strategies of one agent depend on the actions of the other agents it relates to in the system. That differs slightly from the basic concepts as introduced in Chapter 2 because the individual elements of a system do not necessarily display individual behaviour. Because of individual behaviour of agents, the intricacies of complex adaptive systems reside in three unique attributes: distributed control, connectivity and co-evolution.

Distributed Control

The need for distributed control in complex adaptive systems came about because of the limitations of the hierarchic approaches (i.e. the traditional control mechanisms from Chapter 5). With the proliferation of the network paradigm the hierarchical approach towards control has lost its charm and attention in science. Inspired by the Zeitgeist of the late 1980s, the trend of decentralisation and the postulation of non-hierarchical, participative and distributed control in society and organisations also penetrated complexity science [Malik, 1992]. Starting with the works of the Santa Fe Institute in the early 1980s, the paradigm of self-organisation emerged and opened a new branch in the explanation and control of complexity [Jost, 2004]. With the increasing number of elements in artificial systems – turning them into net-like entities – their control became increasingly complex. This made the deterministic, top-down approach to systems control inefficient, if not impossible, especially against the background of a highly dynamic environment.

From the perspective of cybernetic control we would try to achieve control by building on lower levels of control and for higher levels of control impose echelons of control (see Section 5.7); in situations of interacting agents these echelons turn out to have moderate effects. An example is traffic control in case of congestion on highways; despite being able to regulate a local traffic jam, flows of cars on highways to avoid traffic jams are more difficult to regulate. Hence, complex adaptive systems rely on distributed control within the network. The interaction of distributed control from agents leads to dynamics that cannot be understood by deterministic behaviour but require modelling, analysis and design allowing for decision-making at lower levels than the level of the system as a total; this applies to technical systems, biological systems, organisations and society.

Connectivity

That implies that the ways in which the agents in a system connect and relate to one another is critical to the survival of the system, because it is from these connections that the patterns are formed and the feedback disseminated; this is the second attribute of complex adaptive systems. Those systems are made up of interdependent interacting parts. The relationships between the agents are generally more important than the agents themselves for understanding the behaviour of the whole system. In the case of an economy that puts the emphasis on how firms interact with each other; for example, the buyer-supplier relationships in a specific economic sector. If the onus were on the firm itself, their classification, size, revenue and profit would be of interest. To understand complex adaptive systems, the researcher would rather look at how companies compete, how they collaborate for delivering products and services, and how they disseminate new products and services (the latter is often called technology diffusion). Hence, the interrelations as being interconnected determine patterns that are formed and the related feedback mechanisms (both positive and negative, see Section 5.3).

The interconnectedness between agents in a complex adaptive system gives rise to non-linearity in behaviour. The concept of non-linearity is presented under very many different names: synergy, linkages, network effects, complementarity, superadditivity, etc. In the case of negative synergies there are terms such as diseconomies of scale, overcrowding or negative spillover effects, subadditivity, etc. For example, an organisation is made up of a network of interconnections at many different levels: teams, projects, divisions, functions and business units. In terms of management science, these ‘agents’ create synergy when collaborating. The interactions, not only internally but also externally, mean that it is often difficult to find the boundaries of organisations and for that reason many organisations are larger than their assets and resources (incl. human resources). Just think of the alliances and partnerships and the multiple formal and informal arrangements that the 'internal agents' have with other organisations. In this example if a supplier improves its performance, then expectations of the focal firm for all its suppliers might increase forcing the other suppliers to become better. As shown by the example, a change in one element of the organisation as a system of resources might cause changes in a second element and other elements that might come back to the first element and other elements than affected in the first instance. That implies that potentially every element of such a system is linked to every other element in one way or another. Thus we can no longer think in terms of simple cause effect relationships (A causes B) but of patterns of relationships, evolution and the emergence of novelty. The connections between agents have a profound effect on the behaviour of the individual agents and the complex adaptive system as a total.

Co-Evolution

The third attribute of complex systems, co-evolution, stems from the argument that complex adaptive systems exist within their own environment and at the same time they are also part of that very same environment. Therefore, as their environment changes, they need to change to ensure a best fit (that requires them to be autopoietic or allopoietic systems, see Chapter 7). Since they are part of their environment, when they change, they change their environment, and as it has changed they need to change again, and so it goes on as a constant process. Co-evolution relates to the two-way interplay between the system and aspects of its environment and can occur in various forms. First, the system can affect its environment, by changing the adaptive pressures on itself (e.g. by moving around, digging holes), thus the environment should not be regarded as a static 'object'. Second, changes in this environment can affect the system (for example, weather changes) leading to adaptation or changes in behaviour. However, most forms of co-evolution will occur with respect to other systems. Those interactions encountered can be with systems of its class or other classes, and be either competitive or cooperative. In evolutionary biology, economics and game theory the dynamics of such interactions lead to situations where no agent can improve its fitness so long as the others continue with their current strategy. This leads to repetitive behaviours (cyclic attractors), where stability is at best temporary due to the multiplicity of influences.

All these influences may be multi-faceted, i.e. they can affect several interacting values or properties of each system. A particular set of relevant interactions relates to symbiotic co-evolution, where a number of organisms have a mutual 'arrangement' such that the net benefit to all exceeds their individual costs (a win-win situation). This particular type of co-evolution takes many forms, including symbiotic, social and ecological networks. In general, symbiotic co-evolution will be present to some degree in any complex system, including economic, technological and cultural ones. Such co-evolving systems naturally adjust their parameters to maximise overall group fitness. However, co-evolving systems (or entities) does not necessarily mean beneficial relationships for both types of entities. Think about parasitism and mutualism, where one entity benefits more from the 'relationship' than the other one. Hence, symbiotic relationships can take the form of beneficial or detrimental effects for one of the parties.

At the level of biophysical co-evolution – akin the fifth, sixth and seventh level of Boulding (see Section 3.5) – biological organisms interact with the world's physical resources and with each other to ensure continued existence of species (or evolution). As one part of those interactions, matter is transformed into life and conversely (upon death) life is transformed back into matter (recycling is endemic to this process). That interplay between the physical and biological realms leads to dynamic evolutionary processes in which the interaction between organisms and species and other organisms and species plays a key role.

The next level, socio-biological co-evolution, comparable to the eight' level of the systems hierarchy of Boulding, adds the interplay between individual life forms and others life forms of the same class, the 'collective' behaviour. Hence, co-evolution becomes more complex and dynamic whereby many types of social structures become possible, including the move between individual and social forms. In this context, animal societies can take innumerable complex forms, as well as much human behaviour, especially for day-to-day social interactions – which take place largely unconsciously and are automatically constrained by cultural norms. This co-evolution between life and society has been described by Wilson [1999], who is known for his propagation of the concept of sociobiology. This level of socio-biological co-evolution relates to the maintenance of an autopoietic socio-ecosystem (akin to the structure of a multicellular organism, but rather less constrained), the emergence of societies and ecosystems.

The level of mythological-social co-evolution, akin the ninth level of the systems hierarchy of Boulding, is generally thought to apply only to humans, who uniquely have the ability to generate abstract ideas, non-material concepts like mathematics, philosophy, ethics and politics. Thus we have co-evolution between our social level and a mythological world of the imagination (yet very real to all the people involved), which takes place along many separate abstract dimensions. It is here that language and symbolism come to the fore and the autopoiesis here takes place largely in these realms; think about the concept of memes by Dawkins [1989, p. 192] as concepts, ideas and artefacts that are diffused in society similar to how genes are generating offspring. This autopoietic level maintains 'culture' itself, in the form of self-sustaining and self-reinforcing 'belief systems' or philosophical 'world views'. That means that this level might be more subject to perturbation and systemic disintegration by outside influences (e.g. extinction or transformation of human societies or civilisations – compared to either ecosystems or individual species).

8.3 Fitness Landscapes

All these three levels describe the search of systems or their entities for fitness through physical fitness and fitness in the social domain; note that the focus of the current section will be on biological systems mostly. To that purpose, one could view the adaptation as taking place in fitness landscapes where agents in complex adaptive systems search for a fit between traits and selectional forces from the environment. According to Colby [1996], natural selection may not lead a population to a state in which it possesses the optimal set of traits (or properties, see Section 2.1). In any population, a certain combination of possible alleles exists that would produce the optimal set of traits (the global optimum); alleles are two or more alternative forms of genes caused by mutation of an original set of genes. However, there are also other sets of alleles present that would yield a population almost as adapted (local optima). In social systems, the concept of genes for alleles might have to be replaced with memes. Transition from a local optimum to another optimum may be hindered or forbidden because the population would have to pass through less adaptive states to make the transition to optimal states.

Wright's Adaptive Landscape

One of the tenets of searching for fitness is that natural selection only works by bringing populations to the nearest optimal point. This theory is referred to as Sewall Wright's adaptive landscape [Wright, 1982], even though others have shown that, mathematically, his landscapes do not exist as envisioned. The fitness of species develops by moving from one to another selective peak (see Figure 8.1). As Wright wonders, which force will act against the pressure of selection moving species from one peak to another one? According to him [Wright, 1982, pp. 8–9], an effective shifting balance process involves three phases: first, extensive local differentiation, with wide stochastic variability in each locality; second, occasional crossing of a saddle leading to a higher selective peak under mass selection; and third, excess proliferation of, and

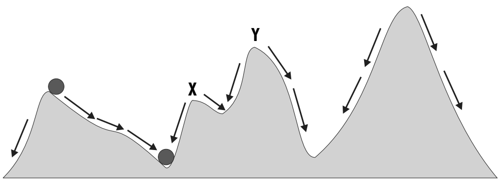

Figure 8.1 *Representation of Wright's adaptive landscape [adapted from Heylighen, 2000]. Species move from one peak to another (represented by the circle, being at a fitness peak, a stable position, and a saddle, representing a stable point with low fitness). During the move they might experience reduced fitness before reaching the more adaptive saddle. The ball will move most likely from the saddle to the nearest, highest fitness peak (on the left) or reach point X because each adaptive step yields higher fitness than moving left. Point X and point Y indicate stable positions of high fitness. A species at point X will have to move through a saddle with lower fitness before reaching the higher fitness peak Y.*

dispersion from, those local populations in which a peak-shift has occurred, leading to occupation of the superior peak as a whole. Not only do the species adapt to the landscape, the surface of fitness values changes with changes in environmental conditions. With changing conditions, the location of the species follows the movement of the peak if the change does not lead to extinction. That might lead to old adaptations are being lost as new ones are acquired. That means that populations, as systems, move from one peak to an other but not necessarily the optimal one and that they follow the dynamics of the fitness landscapes (emerging peaks and changes in existing peaks) by adaptations.

Referring to the development of species, Worden [1995] encourages the application of genetic algorithms for mimicking natural selection with limitations in terms of speed of development. He maintains that the development of species through the deployment of genetic algorithms is subject to the speed limits he proposes. The adaptations to the environment, homeostatic development, inhibit moving the development of a species to the next successful set of adaptation, like a ball rolling across hilly terrain. Then species are always trying to reach the adaptive peaks of the landscape and are continually modified in response to the shifting of the peaks. In that perspective, Gould [1980, p. 129] refers to the metaphor of Galton's polyhedron borrowed by St. George Mivart to describe the evolution of organisms and the state of equilibria. Prothero [1992] uses the metaphor of the polyhedron, which can roll rapidly over from face to face, but resists change when it is sitting on one of its stable faces. Change only occurs when the threshold necessary to tip it over has been exceeded, and then

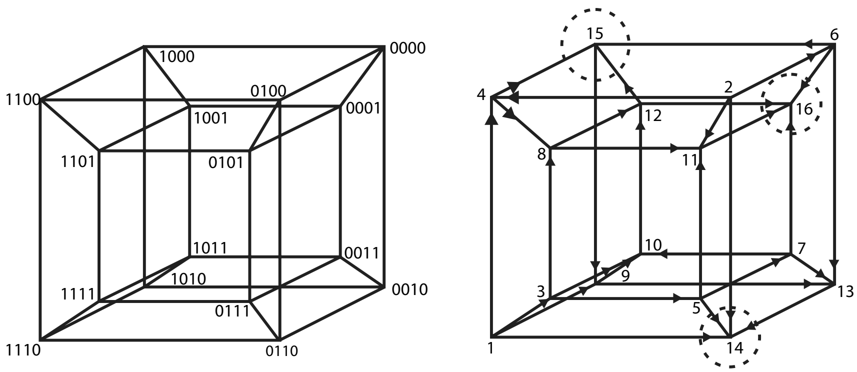

Figure 8.2 *The N-model (derived from Kauffman [1993, p. 38]). The 16 possible combinations of four digits are arranged as vertices on a four-dimensional Boolean hypercube. Each combination connects to its four one-mutant neighbours, accessible by changing a single digit from 1 to 0 or from 0 to 1. The hypercube on the left represents this four-dimensional space. In the hypercube on the right-hand side, each combination has been assigned, at random, a rank-order fitness, ranging from the worst (1) to the best (16). Arrows from the less fit to the more fit show directions of such moves between adjacent positions. Combinations fitter than all one-mutant neighbours are local optima (three in this case).*

the polyhedron will resist further change until that threshold is once again reached. Between stable states (the faces), the transitions are very rapid. The practical implication is that a lot of energy and momentum is needed to initiate a change process but once the system approaches a possible stable state in relation to the environment, the intended change will unfold very fast; furthermore, because of step-wise change in a given fitness landscape populations are limited by that landscape in how quick they adapt.

Random Fitness Landscapes

Building on the notions of Wright's adaptive landscape and how populations can move from one optimum to other ones, Kauffman [1993, 1995] has extended the concept of the fitness landscapes to explain the diversity of life. His two publications cover mostly the same grounds and provide different texts for explaining some phenomena during the evolution of life on earth. The theory of his fitness landscapes directly connects to the impact of natural selection. The framework of adaptation on rugged landscapes [Kauffman, 1993, pp. 36-67] applies to adaptive evolution in sequence spaces, i.e. spaces in which the successive steps depend on the preceding steps (the underlying mechanism for mutations to appear in a population), akin the principles of autopoiesis.

To explain the thoughts of Kauffman about the fitness landscape, this section captures the text for explaining the more simple N-model before moving on to the more complex NK-model. In both models, fitness is expressed as height, a measure for expressing the fitness of a genotype. An example of this is the darkening of the peppered moth population, which took place when the soot-darkened trees resulting from heavy industry made light-coloured moths easier targets for hungry birds [Max 2001]. According to Colby [1996], Kettlewell found that dark moths constituted less than 2% of the population before 1848. The frequency of the dark morph increased in the years following. By 1898, 95% of the moths in Manchester and other highly industrialised areas were of the dark type. Their frequency was less in rural areas. The moth population changed from mostly light coloured moths to mostly dark coloured moths, determined primarily by a single gene. This example shows that for the changing environment (industrialisation) dark moths have a higher fitness than light-coloured moths. Kauffman [1993, pp. 36-67] builds on this phenomenon by attributing fitter genotypes with have a higher number of heights than less fit genotypes.

The N-model uses this premise of attributing fitter genotypes with have a higher number of heights than less fit genotypes, when using this model for evolutionary biology. As an example, consider a genotype with only four genes, each having two possible alleles: *1* and *0* (i.e. a Boolean representation of the state of each gene; think as one of the genes the moth being dark or light-coloured). That results in 16 possible genotypes, from which each is a unique combination of the different states of the four genes. Each vertex corresponds to one of the 16 possibilities in a so-called hypercube (see Figure 8.2). A hypercube is used in mathematics to represent multiple dimensions, in this case four because of the four components of a gene. Each node on the hypercube (called vertex) differs only by one mutation from the neighbouring ones, representing the step of a single mutation; that means that each mutation as such is independent from the state of the other components of the gene. Each genotype is arbitrarily assigned to a fitness value ranked from worst (i.e. *1*) to best (i.e. *16*). An adaptive walk might start at any vertex (node on the hypercube) and move to vertices that have higher fitness values. An adaptive walk ends at a local optimum, a vertex that has a higher fitness value than all its one-mutant neighbours but that is not necessarily the highest optimum. Figure 8.2 shows that there are three local optima at which adaptive walks may end; only one of these is the global optimum. That means that in the N-model the search for fitness might end at either a local or a global optimum; moving from one local optimum to another optimum with a higher value means losing fitness.

For finding optima, Kauffman [1993, p. 39] refers to Gillespie [1984], who has shown that the search by an adapting population corresponds to an adaptive walk. If the population begins at the less fit allele, a single mutant will eventually encounter the fitter allele. Either that mutant dies out before leaving offspring or a few of the fitter mutants are produced. Once the number of fitter mutants produced is sufficient to reduce the chance of fluctuation leading to their death, the fitter type rapidly takes over the entire population. Thus the entire population moves to the fitter genotype. Gillespie has shown that the entire adaptive process can be treated as a continuous-time, discrete-state process of transitions (that is called a Markov chain in mathematics). Hence, in practice, that implies that finding

It should be noted that evolution on landscapes that are random is a search by chance, as Kauffman [1995, pp. 166-167] states. In fact, finding the global peak by searching uphill on random landscapes is totally useless; the entire space of possibilities has to be searched to find the local optima as well as the global optimum. However, from any initial point on a random landscape, adaptive walks reach local peaks after some number of steps. Additionally, no matter, where an adaptive walks starts, if the population is allowed to walk only uphill, it can reach only an infinitesimal fraction of the local peaks. But in reality, the fitness landscapes that underlie the mutation steps of gradualism are correlated, and local peaks do often have similar heights. Hence, reaching a local peak, which might or might not be the global optimum, will generally end the search on a random landscape.

Rugged Fitness Landscapes

In reality, random fitness landscapes hardly occur. Each component of a system does not exist on its own; therefore, the notion of the random landscape has limited meaning for the evolution of life forms. For example, in the case of genes, some do have correlations to others, e.g. the hierarchy of genes, or sets of genes exist all contributing to particular appendages, organelles, or epistatic control genes exist. As Kauffman [1995, p. 170] notes: the fitness contribution of one allele of one gene may depend in complex ways on the alleles of other genes. This is often referred to as epistatic coupling or epistatic interactions for the components of a system. Rugged landscapes are those landscapes in which the fitness of one component of a system depends on that part and upon *K* other parts among the *N* present in the landscape [Kauffman, 1993, p. 40]. That model that expresses the interdependency of components and the fitness landscapes being less random is called the NK-model.

That NK-model offers further insight in the mechanisms of evolution and selection, from here on applied to genes. Let us look at an organism with *N* gene loci, each with two alleles (two possibilities), *1* and *0*. The parameter *K* stands for the average number of other loci that epistatically affect the fitness contribution of each locus; that means that they between the components there are connections that determine an individual component's fitness (for example, such is the case for an organisation with its products having a relationship between quality and price). Hence, the fitness contribution of the allele at the i[th] locus depends on itself (whether it is *1* or *0*) and on the other alleles, *1* or *0*, at *K* other loci, hence upon *K+1* alleles. The number of combinations of these alleles is just 2^{K+1}. The example of Kauffman selects at

1	**2**	**3**	**4**	w_1 (.4)	w_2 (.3)	w_3 (.2)	w_4 (.1)	**W**
0	0	0	0	1	1	16	1	4
0	0	0	1	1	1	16	16	6
0	0	1	0	1	1	1	1	1
0	1	0	0	1	16	16	1	9
1	0	0	0	16	1	16	1	10
0	0	1	1	1	1	1	16	3
0	1	0	1	1	16	16	16	10
1	0	0	1	16	1	16	16	12
0	1	1	1	1	16	1	16	7
1	1	0	1	16	16	16	16	16
1	0	1	1	16	1	1	16	9
1	1	1	1	16	16	1	16	13
1	1	1	0	16	16	1	1	12
1	1	0	0	16	16	16	1	14
1	0	1	0	16	1	1	1	7
0	1	1	0	1	16	1	1	6

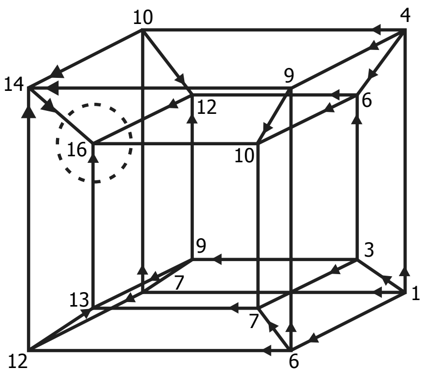

Figure 8.3 *NK-model derived from Kauffman [1993, p. 42] and Figure 8.2. The assignment of the fitness values to each of the four components. These fitness values then assign fitness to each of the* 2^3*=8 possible genotypes as the weighted value of the fitness contributions of the four components. The figure depicts the fitness landscape on the four-dimensional Boolean cube corresponding to the fitness values of the 16 genotypes. The coupling leads in this case to a smoother landscape.*

random a different fitness contribution to each of the 2^{K+1} combinations from a uniform distribution between *0.0* and *1.0* (this pattern has been followed in Figure 8.3 where only one optimum appears). The fitness of one entire genotype can be calculated as the average of all of the loci. When this example is visualised in a hypercube, it becomes clear again that more than one local optimum exists. However, normally, these the fitness landscapes become more rugged in comparison to the random fitness landscapes.

From the study of evolutionary biological phenomena by deploying the NK-model, a number of conclusions can be drawn. Kauffman [1995, p. 161] states that biologists hardly know what such fitness landscapes look like or how successful a search process is as a function of landscape structure. Nevertheless, these (imaginary) landscapes for selection of species may vary from smooth, single-peaked to rugged, multi-peaked landscapes. During evolution species search these landscapes using mutation, recombination and selection, a process for which the NK-model provides insights into particular phenomena accompanying the adaptive walk:

- On smooth surfaces and rugged surfaces of the fitness landscape, the search process might fail to find the high peaks [Kauffman, 1995, p. 161].
- The search process on rugged and random landscapes might be facilitated by multi-steps and long jumps [Kaufmann, 1993]. While these multi-step and long jumps are effective search strategies for those landscapes, they also increase the risk that local peaks or a global optimum might be missed.
- When on smooth surfaces the high peaks are found by a population, mutations might cause the complexity error catastrophe [Kauffman, 1993, p. 96; Kauffman, 1995, p. 161, 183-184]. Normally, when a species or population reaches a peak in the landscape, smooth or rugged, it remains stable at the peak. Through higher mutation rates, the population might increase by number and diversity, causing a greater area of spread. This spread might extend so far from the peak itself that part of the population starts the search for new peaks. Kauffman labels this phenomenon the complexity error catastrophe, which indicates that the mutation rate exceeds the equilibrium force of remaining at the peak.
- On random landscapes, finding the global peak by searching uphill is useless, the entire space of possibilities needs to be searched [Kauffman, 1995, p. 168]. At the same time, wherever the adaptive walk starts, only a fraction of the local peaks will be reached.
- When the population climbs higher to a local or global peak, it becomes exponentially harder to find the direction uphill [Kauffman, 1995, p. 178, 193-194]. As complexity increases, meant as number and diversity, blind long jumps become a more wasteful strategy, even on the best of landscapes [Kauffman, 1993, p. 74].
- Fitness can increase more rapidly near peaks when mutation and selection are joined by recombination [Kauffman, 1995, p. 182]. This covers both local and large-scale features of the fitness landscape.

- Complex artefacts or real organisms never find the global optimum of the fixed or adapting landscape [Kauffman, 1993, pp. 77-78].
- A breakdown of populations in patches enhances adaptability of species and populations, especially in changing landscapes [Kauffman, 1995, p. 263].
- Mass extinction [Kauffman, 1993, p. 78].

From these points it follows that adaptive evolution is a search process by populations – driven by mutation, recombination and selection – on fixed or deforming fitness landscapes. Nevertheless, the dynamics of the environment are driven in his view by the shape and the dynamics of the landscape. In the theories for the N-model and the NK-model, the landscape is more or less fixed by the values assigned to specific genotypes. The populations move around in this landscape and cause the dynamics. If the fitness landscapes are shifting, then the deformation of the landscape needs to be explained qualitatively, hence the shifting dynamics of the landscape are less present in the models and mathematical approaches underpinning this theory. The search in these (semi-)static fitness landscapes is directed to finding fitness peaks, and to which mutation types (one-step, multi-step or long jumps) fit best to the shape of landscape.

Co-Evolution and NK-model

Kauffman [1993, pp. 243-245] extends the NK-model to co-evolution by adding the constraint that each trait in species 1 depends epistatically on K traits internally and on C traits in species 2, the so-called NK[C]-model. More generally, in an ecosystem with S species, each trait in a species will depend on K traits internally and on C traits in each of the S_i among the S species with which it interacts. Therefore, if one species adapts, it also changes the fitness of other species and deforms their landscapes in the NK[C]-model. This does not only apply to biology but also to organisational constructs, such as supply chains. Therefore, the NK[C]-model offers an explanation for not only the development of individual systems and populations but also for the interconnection between systems and populations.

The coupling of the fitness landscapes will affect the search for increased fitness [Kauffman, 1993, pp. 252-253]. When a new link is introduced (i.e. increasing K) the genetic locus spreads throughout a population in three ways: (a) the new epistatic link, when it forms, causes the genotype to be fitter, (b) the new epistatic link is near neutral and spreads through the population by random drift, and (c) the new link not only has a direct effect on the fitness of the current genotype but also increases the inclusive fitness of the individual and its genetic descendants. It suggests that optimisation in co-evolutionary dynamics becomes possible by optimisation mechanisms that search for optimal traits in relation to the coupled traits (we could view the development of the Pearl River Delta as a complex adaptive system [Noori and Lee, 2002; The Economist, 2002]). The second option for a network consists of increasing its reach, which compares to increasing the number of species S. When that happens the waiting time to encounter a new equilibrium increases, the mean fitness of the co-evolving partners decreases [McKelvey, 1999, p. 312], and the fluctuations in fitness of the co-evolving partners increase dramatically. The increase of agents might lead to a new optimisation in traits and coupled traits but only after going through a period of instability

8.4 Self-Organisation by Complex Adaptive Systems

Because of these alternating phases of stability and instability, the behaviour of complex adaptive systems has been linked to self-organisation; for example, Kauffman [1993, pp. 567-568] connects the NK-model to the concept of self-organisation. However, the concept of self-organisation already appeared in Section 7.3; in the context of this section it should be noted that the concept of self-organisation of systems arose from early studies by Nicolis and Prigogine [1977]. The concepts of self-organisation have drawn the attention of researchers in many fields of science [e.g. Mikulecky, 1995]. The interests of all are directed to the explanation of emergent behaviour and the establishment of patterns that cannot be explained only by the actions of agents or reduced to the agents' behaviour [Stacey, 1996, p. 63]. The explanations for the emergence of behaviour and patterns vary; some of these explanations for complex adaptive systems will follow now.

Simple Rules and Complex Behaviour

One explanation for those complex adaptive systems states that simple rules might lead to complex behaviour. The famous and often quoted example concerns the flocking behaviour of birds, originating in the work of Reynolds [1987]. The simulation of Boids, an artificial creature, in computer applications shows the complex behavioural pattern of flocks that emerges when a Boid adjust its behaviour by only looking at its neighbour's position and speed. With no more than these rules, Boids flock, fly around obstacles and regroup. Another famous example is the Game of Life [Conway, 1970]. In that game, a grid of cells progresses from an initial state to form complex patterns; each cell can either be 'alive' or 'dead' and each can change from round to round. At the start of every new round, simple rules are concurrently applied to each cell to decide whether it is alive or dead:

1. Any live cell with fewer than two live neighbours dies, as if caused by under-population.
2. Any live cell with two or three live neighbours lives on to the next generation.
3. Any live cell with more than three live neighbours dies, as if by overcrowding.
4. Any dead cell with exactly three live neighbours becomes a live cell, as if by reproduction.

Those two experiments points to simple rules for complex patterns of behaviour, however, they limitedly explain how complex adaptive systems respond to changes in their environment.

Attractors

A second explanation for complex behaviour arrives through the insights of attractors [Kauffman, 1993, pp. 178–179; Morgan, 1996, p. 264; Stacey, 1996, pp. 58-60]. Attractors are set of physical properties toward which systems evolve regardless of their initial state. Note the parallel with equifinality (Section 3.3); however, the difference is that a system might have attractors consisting of a finite set of states, a curve or a manifold. A pendulum is an example of such a system that moves between two states (a state of balance with no movement and a state where the velocity is reaching its maximum). Even if there is a perturbation the system will return to the states associated with attractors. In the case of the pendulum, a force that is exerted will make it eventually move between the two states again. Hence, attractors are foremost representing 'predictable' behaviour that nevertheless might be quite complex.

When the control parameters in a deterministic non-linear feedback network are tuned up (e.g. when information or energy flows are increased), the behaviour of the network follows a potential bifurcating path in which it continues to display regular, stable patterns but they become increasingly complicated. A critical level of the control parameter moves the system in a state between stability and instability. Sensitivity of these patterns to initial conditions, tiny deviations, might result in vast differences in the subsequent behaviour of the system; this is the so-called butterfly effect [Lorenz, 1963]. That means that dependent on the initial condition, a complex adaptive system might end up in different attractors. An attractor does not mean bifurcation. Attractors only indicate points of stability with high or low dimensionality (states) to which the behaviour of a system evolves. Low dimensionality of attractors is mostly related to more orderly behaviour [Kauffman, 1993, p. 179].

Dissipative Structures

The theories of Prigogine and Nicolis [1977] expand this matter by introducing dissipative systems, whereby away from the point of homeostasis a temporary and complex order is maintained. Only a part of the exchange with the environment, such as the energy flow, sustains the order, most of it dissipates to the environment. At the end, a new state arises in which the internal complexity has been increased, and new structures and behaviour do emerge. Examples of dissipative systems are cyclones, hurricanes and living organisms in distress; these are instances of systems with a dynamic regime that nevertheless seems to be in reproducible steady-states. Those reproducible states may be reached by natural progression or by artifice. An example of the latter are Bénard cells; these occur in a horizontal layer of fluid on a plane heated from below, in which the fluid develops a regular pattern of convection cells. Hence, dissipative structures, naturally occurring or artificially created, are another source of complex behaviour.

Edge of Chaos

Another explanation for complex behaviour of complex adaptive systems arrives from so-called chaos theory. Four particular states arise when the NK-model is more closely looked at for the principles of self-organisation [Kauffman, 1993, pp. 191–203]. First, at $K=1$, the orderly regime appears, in which independent subsystems function as largely isolated islands with minimal interaction. At $K=2$, the network is at the edge of chaos, the ordered regime rules at maximum capacity but chaos is about to emerge. At values ranging from $K=2$ to $K=5$ the transition to chaos appears although indications are that this transition happens already before $K=3$. From $K>5$, the network displays chaotic behaviour. All these four possibilities of K indicate that the behaviour of networks strongly varies according to the connectivity, one of the principle attributes of complex adaptive systems.

Kauffman [1993, p. 198; 1995, p. 91] claims that a position in the ordered regime near the state of chaos affords the best mixture of stability and flexibility. Such a state optimises the performance of the complexity of connected tasks and optimises evolvability of complex adaptive systems. Although Kauffman's models merely generate fitness landscapes, they imply the similarity between structures within forms of life. The developmental pathways embedded in the fitness landscapes and the principles of self-organisation bind optimisation. Hence, the resemblance in existing forms of complex adaptive systems is no matter of chance but a result from previous mutations and developments.

8.5 Recursive Behaviour

Increasingly multi-agent systems are being used and designed for solving problems in a variety of complex and dynamic domains; the purpose of these multi-agent systems is mostly simulating and controlling complex adaptive systems. A multi-agent system is a computer application composed of multiple interacting intelligent agents within an environment. Those multi-agent systems can be used to solve problems that are difficult or impossible for an individual agent or a monolithic system to solve. The intelligence of agents may include some methodical, functional, procedural or algorithmic search, retrieval and processing approach. Typical applications are software engineering, collaborative networks and factory automation. Although there is considerable overlap, a multi-agent system is different from an agent-based model. The goal of an agent-based model is to search for explanatory insight into the collective behaviour of agents obeying simple rules rather than in solving specific practical or engineering problems. Some examples of the use of agent-based models are epidemics and economic analysis. The terminology of agent-based models tends to be used more often in the sciences and multi-agent systems in engineering and technology.

Effective agent learning in such domains raises some of most fundamental challenges for agent in these systems, whether it concerns agent-based models or multi-agent systems. Agents are autonomous but might lack a global view of the system; in addition, there is no designated controlling agent, hence, agents exert responses locally. Typical agents are software agents, human, teams (or groups) and autonomous equipment, such as robots. An agent may often need to model the behaviour of other agents, learn and adapt from its interactions, negotiate with other agents, and so on. The typical assumption in most of the studies on learning is that the data is uniformly distributed and available to agents. However, in practice, not all data are available to all agents, not even to similar agents, and not uniformly distributed either. Data are often available at progressively more detail, in similar patterns and recursively made available, though chaotic and random at times. For instance, almost all biological systems contain self-similar structures that are made through recurrent processes, while many physical systems contain a form of functional self-similarity that owes its richness to recursion. Therefore, this indicates that recursion plays a key role in the behaviour of complex adaptive systems.

If the tenet of complex adaptive systems is recursive behaviour, it would be expected that behaviour of the holistic system (complex adaptive system) is fairly predictable. However, as it turns out, the human mind, economic markets, network data, agent behaviour, internet browsing behaviour and nature create enormously complex behaviour that is much richer than the behaviour of the individual constituting elements. Complex systems with emergent properties can often be viewed as highly parallel collections of similar elements. A parallel system is inherently more efficient than a sequential system, since tasks can be performed simultaneously and more readily via specialisation. Parallel systems that are redundant have fault tolerance and subtle variation among the parts of a parallel system allows for multiple problem solutions to be attempted simultaneously. Hence, complex adaptive systems are characterised by agents operating in parallel that results in emergent and complex behaviour, although each constituent agent displays mostly recursive behaviour, while not necessarily behaving identical to a similar agent or similar agents.

8.6 Connectivity in Human-influenced Networks

In addition to the emergent behaviour resulting from connectivity, human-influenced complex networks, e.g. the World-Wide Web and human acquaintance networks, have common properties, which are hardly compatible with existing cybernetic approaches. Since that incompatibility has been recognised, increased efforts have been dedicated to identify other measures of complex (enterprise) networks [Fricker, 1996]. Therefore, this section looks more closely at interaction in networks.

The lack of network-orientation within traditional systems theories becomes obvious, considering that most companies nowadays act in such networks. More specifically, the network-orientation requires managing both the relationships between agents in networks (sometimes called actors) and the delivery of products and services. Such a model combines three parts of networks: resources, activities (processes), and actors; see Figure 8.4 for the model by Dekkers [2005, p. 330] and Dekkers and Kühnle [2012, p. 1095]. In this model, companies ensure value innovation spanning the entire value chain and the integration of skills and knowledge for meeting performance requirements through vertical collaboration; these complementary resources not only cover manufacturing and the supply chain but might also include product innovation and new product development. By horizontal collaboration, actors will increase the chance for achieving economics of scale for products or their components (which could include process innovation); that calls on supplementary resources (Das and Teng, 2000, p. 49), which should lead to synergy. Both vertical collaboration and horizontal collaboration allow companies to deploy effective resources for both product and process innovation and meet criteria of sustained competitive advantage. But ultimately, this model combines the linear cybernetic process for delivery of processes and services and the agent approaches from complex adaptive systems for managing the interrelationships between resources and agents.

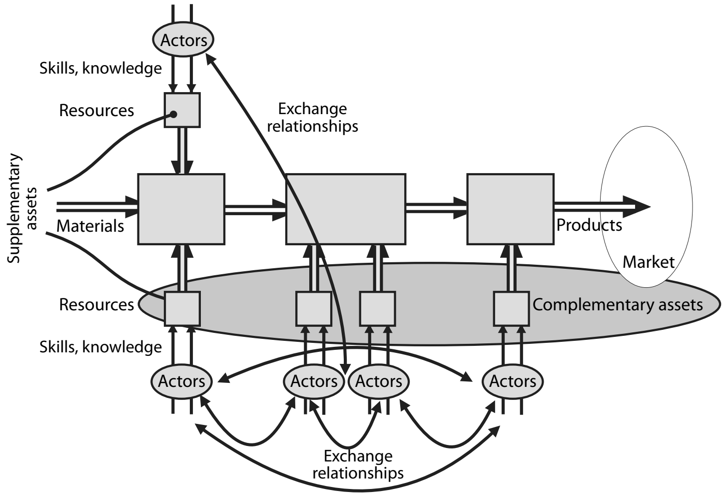

Figure 8.4 *Collaboration model for the value chain [Dekkers, 2005, p. 330]. Vertical collaboration (which is the horizontal dimension in the figure) indicates the capability of actors to manage the supply chain. Horizontal collaboration (vertical dimension in figure) contributes to the dynamics of the network by recombining resources or creating substitution.*

For both collaborative networks between firms and human acquaintance networks, there is a property that relates path length to size of the network. That so-called small-world property, the most known of specific properties for networks, states that the average path length in the network is small relative to the system size [Milgram, 1967]. This phenomenon has already been scientifically studied more than three decades ago, long preceding its notoriety. For example, the phrase *six degrees of separation* [Guare, 1990], another popular slogan depicting the small-world phenomenon, can be traced back to Milgram's 1967 experiment. Most famously, the actor Kevin Bacon became an unwitting part of networks with small-world properties, when a couple of decades ago some college students, scheming to get on Jon Stewart's show on MTV [Barabási, 2003; Durrett, 2007], seemingly decided that '6 degrees of Kevin Bacon' sounded enough like '6 degrees of separation' that it must imply that Kevin Bacon was the centre of the acting universe. Hence, the small-world property has been related to the potential of connectivity for human-influenced networks and become attached to complex behaviour.

Another notable property of complex networks is clustering, i.e., the increased probability that pairs of nodes with a common neighbour are also connected. That becomes apparent when a critical fraction of nodes (or links) is removed, then the network becomes fragmented into small, disconnected clusters. In mathematical terms that is called percolation theory. Clustering means also that sometimes nodes start to act as hub; these hubs connect to multiple nodes that have multiple connections. The further away a node is from a hub the lower the number of connections generally. In addition, an other approach to small-world networks was formulated by Watts and Strogatz [1998] that has helped network science become a medium of expression for numerous physicists, mathematicians, computer scientists and many others; mainly because it confirmed not only small-world properties but also clustering as essential trait of networks. In that sense, clustering facilitates the connectivity of the human-influenced networks.

Perhaps, the most important property of human-influenced networks is the distribution of degrees, i.e. the distribution of the number of links the nodes have. One way of looking at a network is that each node (or element) has a probability to be connected to an other node; such network are called random networks. However, it has been shown that several real world networks have scale-free distributions, often in the form of a power law. In these networks, a huge number of nodes have only one or two neighbours, while a couple of them are massively connected. Many networks are thought to be scale-free, including the World Wide Web, biological networks and social networks. Take for example a social network in which nodes are people and links are acquaintance relationships between people. In those networks people tend to form communities, i.e. small groups in which everyone knows everyone (subsystems). Moreover, the members of a community also have a few acquaintance relationships to people outside that community. However, some people are connected to a large number of communities (for example, celebrities and politicians), the earlier mentioned small-world property. Mostly, the behaviour of a randomly distributed network and a scale free network differs. The connectivity of a randomly distributed network decays steadily as nodes fail, slowly a into smaller, separate domains that are unable to interact. In contrast, scale-free networks may show almost no degradation as randomly nodes fail. With their very connected nodes, which are statistically unlikely to fail under random conditions, connectivity in the network is maintained. The distribution of those links among the elements of a scale free system means that relationships are not randomly or evenly distributed, generally speaking; that means that scale free networks are more robust towards perturbations.

These three specific properties – small world property, clustering, distribution of degrees – hardly appear in the original systems theories; however, they explain how agents in networks behave and how networks might be structured to be more robust.

8.7 Summary

The concepts and theories for complex adaptive systems aim at explaining non-linear behaviour. That type of behaviour cannot directly be explained by the behaviour of individual elements or subsystems (called sometimes agents). In addition to the concepts of autopoiesis, the theories about complex adaptive systems state that these have many autonomous entities, that they are able to respond to external changes and that they form self-maintaining systems with internal pathways for feedback. The concepts related to complex adaptive systems aim at explaining the behaviour of such systems, called non-linear behaviour, that cannot directly be explained as a result of the behaviour of individual entities of that system.

One of the mechanisms to explain that non-linear behaviour is that simple rules for the interaction between entities in a complex adaptive system could lead to complex patterns. A famous example is flocking of birds; computerised simulations that use rules such as maintaining a certain distance to the nearest-by entity result in patterns that look very similar to the patterns of flight by a large group of birds. However, such patterns might only appear in homogeneous and regular environments.

Another mechanism for explaining the non-linear behaviour is the search by complex adaptive systems for optimal points on a fitness landscapes. These landscapes can be imagined as real-life landscapes with rugged areas, hilly areas and flats. Complex adaptive systems seek out peaks on these landscapes, which might be either local peaks or global peaks. Moving from one peak to an other (higher) one follows pathways that will lead to passing through sub-optimal points, such depressions and valleys in the landscape. These pathways can be circumvented if a complex adaptive system takes larger steps (for mutations), however these steps also increase the chance of missing out on reaching other peaks. Note that complex adaptive systems consist out of more entities and its thoughts need to be applied to groups of entities, for example, species, economics sectors and national systems rather than a single specimen or firm.

References

Boswijk, H. K. (1992). Complexiteit in evolutionair and organisatorisch perspectief, het zoeken naar balans tussen vermogens en uitdagingen. Rotterdam: Erasmus Universiteits Drukkerij.

Buchanan, M. (2004). It's the Economy, stupid. New Scientist, 182(2442), 34-37.

Colby, C. (1996, 7th January). Introduction to Evolutionary Biology. The Talks.Origin Archive. Retrieved 14th November, 2012, from http://www.talkorigins.org/faqs/faq-intro-to-biology.html

Conway, J. (1970). The game of life. Scientific American, 223(4), 4.

Dawkins, R. (1989). The Selfish Gene. Oxford: Oxford University Press.

Economist, T. (2002, October 12th, 2002). A new workshop of the world. The Economist, 365, 59-60.

Gillespie, J. H. (1984). Molecular Evolution Over the Mutational Landscape. Evolution, 38(5), 1116–1129.

Gould, S. J. (1980). Is a new and general theory of evolution emerging? Paleobiology, 6(1), 119–130.

Heylighen, F. (2000, 6th August). Fitness Landscapes. Principia Cybernetica Web. Retrieved 20th February, 2005, from http://pespmc1.vub.ac.be/REFERPCP.html

Jost, J. (2004). External and internal complexity of complex adaptive systems. Theory in Biosciences, 123(1), 69-88.

Kauffman, S. A. (1993). The Origins of Order: Self-Organization and Selection in Evolution. New York: Oxford University Press.

Kauffman, S. A. (1995). At home in the universe: the search for laws of self-organization and complexity. New York: Oxford University Press.

Lorenz, E. N. (1963). Deterministic Nonperiodic Flow. Journal of the Atmospheric Sciences, 20(2), 130–141.

Malik, F. (1992). Strategie des Managements komplexer Systeme. Bern: Haupt.

Max, E. E. (2001, 1st September). The Evolution of Improved Fitness. The Talks. Origin Archive. Retrieved 6th July, 2014, from http://www.talkorigins.org/faqs/fitness/

McKelvey, B. (1999). Avoiding Complexity Catastrophe in Coevolutionary Pockets: Strategies for Rugged Landscapes. Organization Science, 10(3), 294–321.

Mikulecky, D. C. (1996). Complexity, communication between cells and identifying the functional components of living systems: Some observations. Acta Biotheoretica, 44(3-4), 179-208.

Nicolis, G., & Prigogine, I. (1977). Self-organization in nonequilibrium systems : from dissipative structures to order through fluctuations. New York: Wiley.

Noori, H., & Lee, W. B. (2002). Factory-on-demand and smart supply chains: the next challenge. International Journal of Manufacturing Technology and Management, 4(5), 372–383.

Prothero, D. R. (1992). Punctuated Equilibrium at Twenty: A Paleontological Perspective. Skeptic, 1(3), 38–47.

Reynolds, C. W. (1987). Flocks, Herds, and Schools: A Distributed Behavioral Model. Computer Graphics, 21(4), 25–34.

Stacey, R. (1996). Emerging Strategies for a Chaotic Environment. Long Range Planning, 29(2), 182-189.

Wilson, E. O. (1998). Consilience: the unity of knowledge. New York: Alfred A. Knopf.

Worden, R. P. (1995). A Speed Limit For Evolution. Journal of Theoretical Biology, 176(1), 137–152.

Wright, S. (1982). The shifting balance theory and macroevolution. Annual Review of Genetics, 16( ), 1-19.

9 Organisations and Breakthrough

So far, we have concentrated on reaching certain states of systems and process, through appropriate control processes and boundary control, embedded in the steady-state model and processes related to autopoiesis and complex adaptive systems. Organisations move at the eight' level of the systems hierarchy of Boulding (see Section 3.5), which tells that some laws governing change of lower levels might apply and others not. It seems unlikely that purely looking at control processes and steady-state processes will inform how to bring about change of structures and resources for (social) organisations. Within their limited capabilities control processes and the steady-state model allow hardly any response to changes in the environment. Therefore, this chapter addresses change, which is limitedly found in technical systems but potentially present at higher levels of Boulding; particularly, the ones that are describing evolutionary (biological) processes. However, those higher levels are also related to phenomena that can be described using the system theories for autopoietic and complex adaptive systems, the topics of Chapter 7 and 8. So, this chapter will build and extend the theories from the previous chapters to organisations.

Nevertheless, a central tenet of this chapter is using for part principles of biological adaptation, characteristic for levels just below that of organisations, for describing adaptations by organisations (Dekkers [2005, pp. 145–149] makes the case for that). Note that the term adaptation is also sometimes used as a synonym for natural selection, but most biologists discourage this usage. Adaptations are the way living organisms cope with environmental stresses and pressures. It can be either structural or behavioural (see also Section 4.2 for processes). Structural adaptations are special elements or subsystems of an organism that help it to survive in its natural habitat, for example, its skin colour, shape and body covering. Behavioural adaptations are special ways a particular organism behaves to survive in its natural habitat. Organisms that are not suitably adapted to their environment will either have to move out of the habitat or become extinct.

Likewise for organisations, adaptations to changes in the environment, selectional pressure, play an important role. In the previous chapters, organisations as systems have been linked to autopoiesis and complex adaptive systems, indicating that adaptations have to follow developmental pathways, the adaptive walks. Building on those concepts, those responses that point to the introduction of processes and structures for change in organisations constitute the contents of this chapter (some of the concepts have been presented in Dekkers [2005]). Section 9.1 will briefly address the nature of growth and change for organisations; particularly, it will look at evolutionary processes for change. Section 9.2 will deal with processes of foresight, a capability that hardly exist at lower levels of the systems

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hierarchy of Boulding. Section 9.3 presents the breakthrough model as a model for internal processes to cope with change. And finally, Section 9.4 will discuss the differences with the steady-state model.

9.1 Adaptation by Organisations

That the nature of change for organisations differs from those of technical systems and biological systems has profound effects for viewing adaptation by organisations. Change in technical systems mostly relates to steady-state processes for maintaining homeostasis (see Chapter 6). In technical systems, structural change is brought about by one-time external interventions; a designer (or engineer for that matter) determines the next contents and structure and implements these in the technical system. The outcome of a preliminary study into one-time interventions shows that these might have limited reach for organisations [Dekkers, 2005, p. 374]. In biological systems, the laws of natural selection and reproduction bind the evolution to latent change present in the contemporary structures (autopoiesis, i.e. memory decides on the evolutionary pathways). External events might have profound effects but adaptation depends on the capability to reproduce beneficial mutations. In contrast to biological and technical systems, organisations form a mental construct of the human mind. To that purpose, this chapter will look first at the how organisations can create mutations, how organisations compare to allopoietic systems and how organisations evolve over time.

Creation of Mutations

In addition to the structural analogies, as propagated by Beer [1972] with his Viable System Model, briefly discussed in Section 10.4, the development of organisations might follow universal laws that arrive from the conversion of models from evolutionary biology. Hence, a reference model has been developed to describe the interaction between organisation and environment (see Figure 9.1), consisting of two intertwined cycles: the generation of variation and the selection by the environment [Dekkers, 2005, p. 150]. Some suggestions have been made to what to consider the equivalent of the genes and the genome on which the biological evolutionary mechanisms build. One possible view concentrates on the division of an organisation in departments, groups, individuals, etc. Morgan [1996, p. 34, 43] did propose such when introducing the image of an organisation as an organism. Another view would be to look at organisations as a collection of resources with skills and knowledge present, expressing itself in the form of capabilities (and capabilities express themselves in function trajectories), like Nakane [1986]. The view on capabilities became later more popular with writings from Teece et al. (1997). Dawkins [1989, p. 192] has proposed memes, as unit for imitation and recombination. Memes constitute elements of a culture or system of behaviour that may be considered to be passed on from one individual to another by non-genetic means, especially imitation. Dawkins extends this concept to a wide variety of topics like ideas, artefacts, including people, products, books, behaviours, routines, knowledge, science, religion, art, rituals, institutions, and politics. In organisational studies memes enjoy a high degree of popularity. Kauffman et al. [2000] take technology as starting point for recombination. That way they connect the development of technology as genetic evolution to evolutionary biological models, esp. fitness landscapes. The study of Nelson and Winter [1982] uses organisational routines as unit for selection. Knudsen [2002, p. 459] remarks that Nelson and Winter draw on the term routine as replicator (routines as the genes of the organisation) and as interactor (routines as recurrent patterns of behaviour among interacting social agents). The choice for which term should substitute the biological genome in this reference model will depend on the object of a particular study.

For the purpose of comprehending adaptations by organisations to the dynamics of the environment, the differences between organisms and organisations for evolutionary processes are summarised [Dekkers, 2005, pp. 145–155]:

- Organisations do not have the possibility for self-reproduction in contrast to living entities. Recombination might occur through the concepts of memes and replicators; such recombination as a genetic formation exists in addition to non-genetic mutation in organisations. Reproducing through recombination has very positive effects on finding fitness peaks in the adaptive landscapes as demonstrated through the NK-model

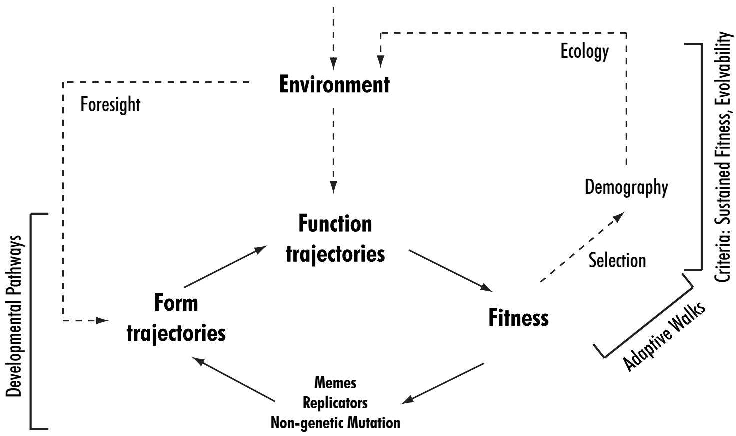

Figure 9.1 *Evolutionary mechanisms for organisations according to Dekkers [2005, p. 150]. Because organisations do not have genes, instead memes and replicators serves as input for genetic formation, which exists besides non-genetic formation. Pathways for development determine the form and function trajectories. These pathways also relate to organisations being a class of allopoietic systems. The selectional processes select beneficial phenotypes on fitness following adaptive walks based on the criteria of sustained fitness and evolvability. Organisations have the capability of foresight in contrast to organisms.*

developed by Kauffman (Section 8.3). Organisms have genes that allow recombination to occur by alleles. The direct deployment of the thoughts of genes to the domain of organisations carries the danger that any study will end up as a metaphor rather than an analogy. Therefore, the thoughts on organisations as allopoietic systems are more appropriate (see Section 7.6).

- Organisations have the capability for foresight; that capability is already latently present at the level of animals and present at the level of human beings. Through senses, organisms acquire information about the effects of actions and have the capability to learn by self-reference embedded in the structure of the entity (see Section 7.5). However, the evolution of organisms depends on the creation of mutations and selection of these by the environment. At the level of organisations, it becomes possible to influence the behaviour of other organisms and to include foresight in the evolutionary process.
- Organisations have fuzzy boundaries. Organisms as autopoietic systems not only reproduce, they also retain a boundary to the environment, they consist of elements and subsystems that make up a total functional entity and they are structurally-closed. Through these boundaries, the environment can only induce changes that are already present in the contents and structure of the entity, akin principles of autopoiesis. Organisations have boundaries too but have the capability to shift these, following the principles of allopoiesis. Additionally, some elements of an organisation cross the boundaries back and forth, e.g. employees.

Although these differences exist, analogies between organisms and organisation becomes only possible when sufficient similarities constitute a base for transferring the models of evolutionary biology to the domain of social organisations:

- Selection acts on mutations. Biological evolution generates a variety of phenotypes for organisms and the environment selects phenotypes for survival; phenotypes express the fitness an individual or population. Such a process exists also for organisations where the selection process finds itself in the competition for the customer base, the acquisition of resources, e.g. suppliers, and the acknowledgement of existence by society.
- Organisations and organisms are structurally-closed with relations between components and boundaries to the environment. The relationships between the components determine how the entity absorbs perturbations by the environment. Changes in the structure of organisations reside in the current structure and capabilities and depend less on principles of equifinality (for equifinality, see Section 3.3); that means that the design of organisations should account for the development of the current organisational structures and capabilities along its life-cycle.
- Organisations have the possibility of self-reference and learning, also found at the 5th, 6th and 7th level of Boulding (see Section 7.5). The

autopoietic principle of self-reference appears for both organisms and organisations; the latent changes are present in the structure of the entity. It is the environment that might induce these changes. Learning becomes possible because both organisations and organisms will deploy a set of sensors to acquire information about their behaviour and changes in the environment, although self-reference limits the possibilities to detect all changes and perturbations in the environment.

- Developmental pathways seem to exist for both organisations and organisms. Organisms can increase their fitness by undertaking an adaptive walk in a fitness landscape where selection acts on the phenotypes. Organisations can also create mutations by an adaptive walk.

When putting the similarities and differences together, organisations can be best described as allopoietic systems that might follow similar laws of evolutionary development as organisms. That metaphor can be used to describe both the internal processes in organisations and the interaction with the environment, while accounting for the limitations of such a metaphor.

Organisations as Allopoietic Systems

In that perspective, organisations can be considered as special class of allopoietic systems that have fuzzy boundaries and the capability for foresight [Dekkers, 2004, p. 309], see Figure 9.2. Allopoietic systems follow the evolutionary models for adaptation, derived from the theory of autopoiesis [Maturena and Varela, 1980], but these systems, and subsequently organisations, do not

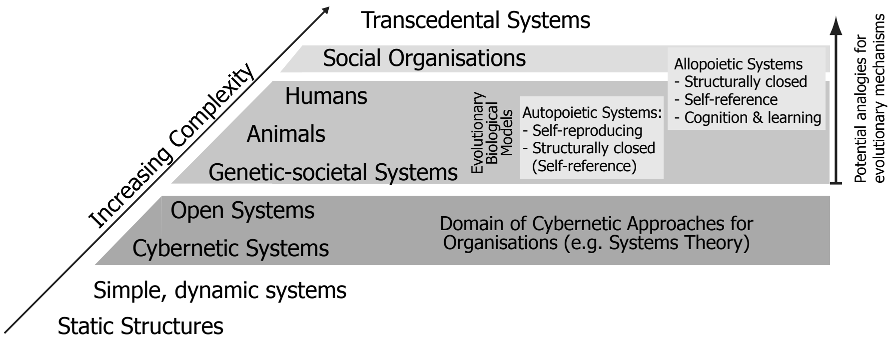

Figure 9.2 *Organisations as allopoietic systems depicted on the systems hierarchy of Boulding. The domain of organisations moves at the eight' level indicating the importance of meaning, value systems and symbolisation. The domain of traditional systems theories and some other approaches in management science (e.g. information technology) find themselves at the third and fourth level. Models from evolutionary biology might bridge the gap between some of the approaches in management science and the actual organisational domain. However, differences exist between organisms and organisations mostly denoted by the difference between autopoietic systems and allopoietic systems. Additionally, the boundaries of an organisation are relatively open; companies might shift the boundaries and employees are part of other social organisations and contexts.*

have the possibility for reproduction. Additionally, organisations have the possibility to shift their boundaries (mergers, outsourcing, alliances, etc.) due to interventions or design by external entities. Moreover, organisations have the possibility of foresight, which allows them to create purposeful mutations; this capability has been recognised by de Geus [1999] and others, leading to the models of the Learning Organisation [e.g. Senge, 1992]. Considering organisations as a special class of allopoietic systems concerns only a structural comparison but not necessarily isomorphism in terms of content (for isomorphism, see Section 3.4).

Another strand of research in the social-economical domain that draws on analogies with biology is called organisational ecology. This type of research investigates the factors that influence changes in the population, which leads to the perspective on populations of organisations and not on the individual firms themselves. Generally, these theories view organisations as relatively inert to environmental changes [Bruggeman, 1996, pp. 21–22], a perspective aligning with the principles of autopoiesis. This implies that most of the time organisations are not capable of substantially changing their structure in a way that results in successful and timely adaptation to new environmental conditions. This assumption is in line with the Darwinian perspective and in the view of organisational ecology the selection process creates the diversity of forms and not the adaptive behaviour of an individual organisation.

A crucial question in organisational ecology is which internal factors of a population and which environmental ones determine both the entry of new organisations and the survival, change, and failure of existing ones in product-market domains [Hjalager, 2000, p. 272]. Configurations of core features of the organisations are made to determine if certain forms and companies with the corresponding organisational form belong to the same population. Hannan and Freeman [1977, p. 935] state that forms are seen originally as the characterisation of the key elements within a decision-making framework. Forms have two purposes: to inform about the state of the external environment, and to activate responses to information. Hjalager [2000, p. 272] states that the organisational ecology has often been accused of ignoring firms' strategies and unique compositions of individual enterprises. However, this strand of research assumes that firms' choices on a population level determine the occurrence of crucial life events. Bruggeman [1996, p. 24] explains rational adaptation in organisational ecology as changes in the structure of individual companies in the case of substantial reorganisation and with that changes in the core features and form of the company.

Surely, the environment in which companies operate determines for a large part the prospects for the development of an organisation as an entity. For example, work forces might resist technological changes, reason to include employees in the (technological) development of a company when competition provides a base for technological progress; in turn, this depends also on the organisational culture whether such a style of leadership might hold (see Hofstede's assessment of cultures [1994]). Competitiveness and innovation (as technological development) have a strong link, therefore both a prerequisite for development and growth. It means for companies that pluralistic approaches offer opportunities for development (pluralistic refers to the markets, products and technologies). Yet, Hannan and Freeman [1977, p. 933] state that the evolution of industries as aggregate of individual companies follows different dynamics than those of individual companies. According to them, events at the higher level cannot be reduced to events at the individual level. Following the major findings of organisational ecology, age and size of an organisation matter for increased chances of survival and additionally a strong link exists between competitiveness and innovation (or technological progress).

Evolution by Organisations

The evolution of the individual firm has received attention in management literature. This subsection looks at three core concepts of life-cycles for companies: the growth model by Greiner [1998], the life-cycle model of Lievegoed [1972], and the investigation in longevity by de Geus [1999]. All three have in common that they look at how organisations develop during ageing and growth.

A reprint from an article by Greiner [1998] describes five phases of growth that a company goes through: creativity, direction, delegation, coordination and collaboration (see Figure 9.3). Each phase begins with a period of evolution, with steady growth and stability, and ends with a revolutionary period of substantial organisational turmoil and unrest in which organisations exhibit a change of management practices. Each evolutionary phase is

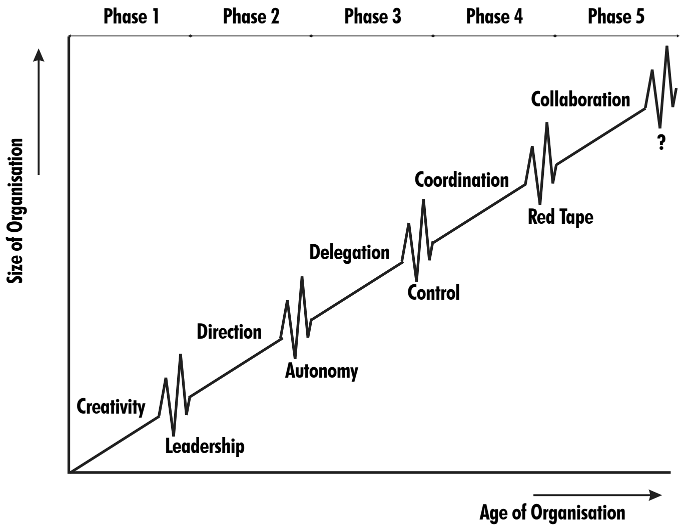

Figure 9.3 *The five phases of evolution according to Greiner [1998]. This classic approach distinguishes phases of growth interchanged by periods of turmoil moving into a next stage of development of a company.*

characterised by the dominant management style used to achieve growth. Moreover, each revolutionary period is characterised by the dominant management problem that must be solved in order to enhance organisational performance and maintain continuity. Both axes in Figure 9.3 represent the two main dimensions for survival according to organisational ecology: age and size.

It is important to note that each phase in the development of a company emerges from the previous one and acts as a cause for the next phase. For each phase, managers are limited in what they can do for growth to occur. A company cannot return to previous practices; it must adopt new practices in order to move forward [Greiner, 1998, p. 56; Lievegoed, 1972]. Greiner describes the five phases as follows:

- Phase 1: Creativity. During the earliest stages of the organisational life-cycle, the emphasis is on creating both a product and a market. The company is largely void of formal policies and structures, and often led by a technical or entrepreneurial leader. But as the organisation grows, production runs require more knowledge about the efficiency of manufacturing. Increased numbers of employees cannot be managed through informal communication alone. At this point, a crisis of leadership enfolds, because of the lack of managers that have the necessary knowledge and skills to introduce new business techniques. A new type of control structure is required.
- Phase 2: Direction. Those companies that survive the crisis of the first phase usually embark on a period of sustained growth, introducing a functional organisational structure. In most cases, departments arise, like marketing and logistics, where teams of lower-level managers are treated more like specialists than as decision-making managers. Although the new directive techniques channel the organisational resources more efficiently into growth, lack of autonomy on the lower levels becomes more and more problematic. Lower-level managers have to possess more direct knowledge, for example about markets and machinery, than their leaders at the top do. This introduces the second crisis, the crisis of autonomy.
- Phase 3: Delegation. The next period of growth evolves from the successful application of a decentralised organisational structure. The organisation will be divided into different units and the control paradigm becomes management by exception based on periodic reports from operations and order processing. This can only be done if operations and functions are narrowly described. A serious problem emerges eventually as top-level management feel that they are losing control over a highly diversified span of operations and market domains. The organisation falls into a crisis of control as top management seeks to regain control over the company as a whole. Those companies that move ahead find a solution in the use of new coordination techniques.

- Phase 4: Coordination. The evolutionary era of the coordination phase is characterised by the use of formal systems for achieving greater coordination and by top management taking responsibility for the initiation and administration of these systems. Those new coordination systems will allocate the organisation's limited resources more efficiently. The systems prompt field managers to look beyond the needs of their local units and will therefore make the company more externally oriented. Although these managers still have a great deal of decision-making responsibility, they learn to justify their actions more carefully to a watchdog audience at headquarters. Eventually, the company will become too large and complex to be managed by formal programs and rigid systems. Procedures take precedence over problem solving; a red-tape crisis is introduced.
- Phase 5: Collaboration. The last observable phase emphasises spontaneity in management action through teams and the skilful confrontation of interpersonal differences. Social control and self-discipline replace formal control. The collaboration phase builds around a more flexible and behavioural approach to management.

The question of what will be the next phase in response to the collaboration phase is difficult to answer. Greiner [1998] imagines that the next phase will centre on the psychological saturation of employees who grow emotionally and physically exhausted from the intensity of teamwork and the heavy pressure for innovative solutions. Although companies might experience periods of evolution interchanged by revolutionary periods of substantial organisational turmoil and change, each phase builds on capabilities acquired in the past and on decisions taken rather than projections of the future on the present.

The view on life-cycles of organisations has also been elaborated by Lievegoed [1972, pp. 54–85, 98–99]. He distinguishes three phases in the life-cycle of firms:

- Pioneering phase. The strength of a company in the pioneering phase is its potential and its powerful identity, concentrated in the founder or those who continue this style. Objectives and goals are visible at all levels within the company, everybody knows what to do and how to contribute to these objectives, even though the policy and strategy have not been formalised. The planning for the long term lacks but the organisation displays an enormous flexibility. The organisation is based on historical growth and tailored to the personal skills of the employees. Renewal and innovation happen through motivated employees that directly apply their own ideas. Managerial control processes are focused on direct contact with clients. The pioneer's model has its limitations in the health of the pioneer, the complexity of technology and the market in which the company operates.
- Differentiation phase. This phase finds its base in a hierarchical structure aiming at the expansion of the technical system, both for advancing

technologies for operations, and improving the organisation. Specialists have entered the company and the expansion leads to increasing the layers of command. (Sub-)optimisation of departments starts to take over and the attention of management shifts to control of the internal processes and structures, even into the direction of a mechanistic view on the labour force of the company. The rationalisation of the internal processes reflects also on the position of the customers. The market becomes more anonymous and the organisation moves away from the personal approach during the pioneering phase. Internal and external to the organisation the resistance builds up and companies find themselves more and more in conflicting situations.

- Integration phase. This phase calls for connecting all processes, departments and employees to a meaningful whole. Lievegoed states that this transformation should start at the top management level; eventually it should lead to a management style of coaching rather than directing. The internal organisation should allow participation of employees. It requires rethinking of all primary and control processes to suit the needs of customers and to appeal to the capabilities of employees. Decentralisation becomes a key-concept in this line of thought and the customers regain their position as focus of the internal processes.

The life-cycle of companies calls for interventions to sustain the organisations [Whetten, 1980]; however, according to those models for the growth of firms, the interventions differ for each phase.

The same question, renewal of companies, is at the heart of the studies performed by Shell, tells de Geus [1999]. The shift from forecasting in the 1960s to scenario-analysis for strategic planning and the implementation of business concepts has driven this study by a practitioner rather than an academic. This concept of the Living Organisation has four main principles:

- The capability of foresight by an organisation to anticipate on the future through the development of scenarios strongly determines the possible reactions to the shifts taking place in the environment. De Geus makes it clear that such an activity should not reside within the Financial or Accounting Department; rather it requires participation by all actual decision-makers to prepare for and to envision the future.
- Through learning, organisations develop an image of the effects of their actions and set the course for future actions. Thus, a continuous process of decision-making, studying effects of actions and evaluations enfolds which provokes learning cycles by which an organisation might increase its effectiveness.
- The organisation has an identity it wants to uphold and maintain, the so-called *Persona*. Continuous managerial attention focuses at the behaviour and attitude of people in the organisation.
- A solid financial policy is not only governed by the circumstances of the day. A study by Laitinen (2000) confirms this thought. His comparative study shows that in the medium term, investment in product development

and marketing and in the acquisition of additional resources, capabilities and market access proves the most successful strategy while a strategy heavily based on negotiating finance contracts and restructuring was the most unsuccessful.

The concept of the Living Organisation has been strongly influenced by sociological themes of identity and learning. The idea – the organisation as a living entity – arrives from the works of Maturana and Varela [1980] on autopoiesis for organisms (see Chapter 7); organisations differ from organisms in the capability of foresight, the theme of the next section.

9.2 Processes of Foresight

Hence, the strategic process should provide a more flexible approach for finding optimal solutions; therefore, this section will explore the themes of strategy and foresight in connection to the adaptation processes. After looking at what strategy constitutes, the concepts dynamic strategies, forecasting, techniques for foresight and scenario planning will be looked at.

Strategy

Foresight, one of the principle differentiator between organisations and organisms (see Section 9.1), traditionally connects to the setting of strategy. However, there is much confusion about what strategy encompasses. It is already Mintzberg [1987, pp. 11–12] who remarks that it varies between plan and ploy; however, he characterised strategies as made in advance of actions and interventions to which they apply and as being developed consciously and purposefully. Others perspective on what strategy exactly is differ markedly. For example, Burgelman et al. [1995] divide strategy into a resource-based strategy and a product-market strategy. Furthermore, Porter [1996, p. 64] defines the essence of strategy as choosing a unique and valuable position rooted in systems of activities. And, Quinn [1980] says: a strategy is the pattern of plans that integrates an organisation's major goals, policies and actions sequences into a cohesive whole. Putting all these definitions together, a strategy allocates the organisation's resources into a unique and viable posture based on its relative internal competencies and shortcomings, anticipated changes in the environment and contingent moves by opponents.

While definitions for strategy vary, so do methods for setting the strategy. In the early days of strategic management, Ansoff [1965] introduced a matrix of four strategies, which became quite well known – market penetration, product development, market development and diversification. But this was hardly comprehensive. Fifteen years later, Porter [1980] introduced what became the best-known list of generic strategies: cost leadership, differentiation and focus. Even the Porter list was incomplete: while Ansoff focused on extensions of business strategy, Porter focused on identifying business strategy in the first place. At the same time, Abell [1980] used three dimensions to define strategy: customer groups, customer needs and technology or distinctive competencies. This array of approaches was extended by Mintzberg [1987] by introducing differentiation strategies. Furthermore, adding to this variety, ten major schools characterise the strategy literature, according to Mintzberg and Lampel [1999]. All the different methods and schools of strategy were developed in a time of relative environmental stability.

Because of this relatively calm environment, there is a general lack of dynamics in most of these strategies. Most of the existing strategy schools are based on the assumption of competition in a stable and static environment, but technological advances and global changes have created a more dynamic, complex climate. Technology has lowered the market's entry boundary and geographical barriers are decreasing. To deal with these challenges, Porter [1980] has developed a model of forces affecting industry competition, subsequently threat of entry, powerful suppliers and buyers, substitute products and jockey for position. Rivalry among existing competitors takes the familiar form of jockeying for position – using tactics like price competition, product introduction and advertising. The forces described by Porter still exist, but they have changed in magnitude, creating a more dynamic environment.

Dynamic Strategies

These changes are forcing industries to react more quickly to changes in markets, in other words strategies need to be dynamic. In this context, there are two general interpretations for the dynamic strategy: constantly changing over time strategies or multiple strategies. Markides [1999, p. 63] finds that:

> *Designing a successful strategy is a never-ending, dynamic process of identifying and colonising a distinctive strategic position. Excelling in this position while concurrently searching for, finding, and cultivating another viable strategic position. Simultaneously managing both positions, slowly making a transition to the new position as the old one matures and declines and starting the cycle again.*

This phrase can be split into two parts. In the first part the assumption is that strategy presents a given position, which should be taken in by a firm. The second part is more concerned with the problems of competing today while preparing for tomorrow. The key is that strategy is a never-ending, dynamic process. This is a big difference from conventional conceptions of strategy. In the early days it was common that a strategy could be seen as a long-term process; meaning that once formulated strategies would serve a firm for many years. In an ever faster changing environment, dynamics are becoming an essential part of strategy. The more uncertain the future to deal with, the more sense it makes to create multiple scenarios and different strategies.

In that perspective, Beinhocker [1999, p. 106] recommends cultivating and managing populations of multiple strategies that evolve over time, because the forces of evolution acting on a population of strategies makes them more robust and adaptive. Note that his reasoning is based on the fitness landscapes, presented in Section 8.3, and the similarity to evolution in populations where several alleles are present at the same time ensuring adaptation to changing environments. In high-velocity, intensely competitive markets, traditional approaches to strategy give way to competing on the edge creating a flow of temporary, shifting competitive advantages and strategies. Eisenhardt [1999], in her research on entrepreneurial and diversified businesses, demonstrates that successful firms in these markets have fast, and high-quality, strategic decision-making processes. This is also what Williamson [1999, p. 126] concludes: the success rate of strategies can be greatly enhanced when they are not too specific. A company must keep tactical opportunism within the bounds of its overall strategy, ruling out options that might cause it to deviate from its long-term strategies.

A dynamic strategy consists of multiple strategies; these strategies should grow within the set bandwidths; these bandwidths are imaginary boundaries to the application a singular strategy. Only in this way can we be more certain about the long-term prosperity of companies in a fast changing environment. This is visualised in Figure 9.4, in which one sees a current position from which multiple strategies are pursued. These strategies are not strictly formulated; they have some variance in the set bandwidth, i.e. to their application. When an organisation finds that one of the possible strategies is not viable that strategy is terminated, as shown. The pursuit of the remaining strategies could be done by implementing the variety of strategies in its

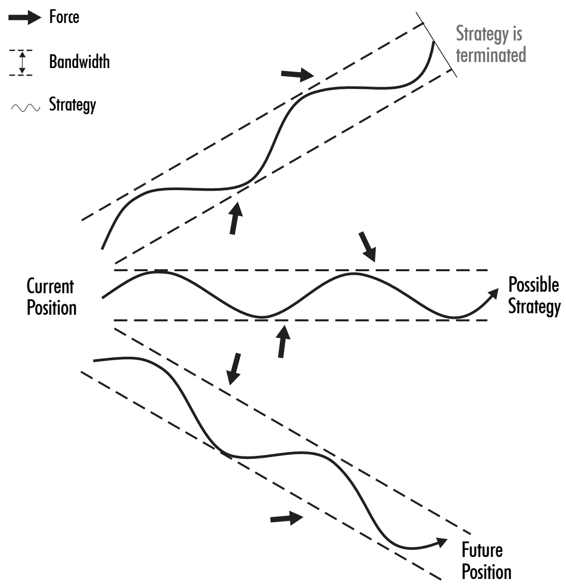

Figure 9.4 *Multiple strategies with bandwidths. Strategies are shaped by the forces of the environment and companies will have to adapt these during the course of time.*

overall business processes or create separate business units (the latter is a variant of Ashby's Law of Requisite Variety, see Section 5.8).

However, as discussed in Section 9.1, many of the organisations' challenges are rooted more in past decisions than in present events or they come about no matter the market dynamics [Greiner, 1998]. Moreover, the inability of management to understand its organisational development problems can result in a company becoming 'frozen' in its present stage of evolution or, ultimately, in failure, regardless of market opportunities. In successful organisations there is a tendency for inertia, because of given success, and with that for the focus on the successful strategy. In relative stable surroundings, the inertia of an organisation can be successful; there is a possibility that the efficiency and the efficacy of the organisation will increase. As a result, the flexibility and innovative potential may reduce and, if an organisation is operating in a fast changing environment, this inertia can create serious problems. Besides deducting the strategic direction from organisational growth phases, inertia can also be conquered through the active search for new opportunities.

Forecasting

As one of the possibilities for defining the position of a company and the strategy, forecasting dates back to the 1930s, according to de Geus [1999, p. 41]. The main objective of forecasting was to deal systematically with the future; in the centuries before, forecasting existed but was not yet incorporated into a process. A series of tools became available under the generic name of planning and managers used these tools during decision-making. Mostly, forecasting took place in separate back-rooms, planning departments and resided within the financial departments. This seemed logical because of the availability of figures, the data collection, and their objectives, resulting in balance sheets, profit-and-loss-accounts, budgets, etc. The planners handed their reports to management within the organisation supposing they would execute the plan. Essential to these planning processes, called forecasting, was the emphasis on the development of a plan based on historical figures, and only one route to achieve certain objectives.

This top-down approach continued until the early 1960s. After that more and more companies started with bottom-up planning. When asked for a forecast by management, for example, the planners went first to the district managers for predictions on sales figures for next year, two years or even five years. When all the data were collected, the planners added up the figures adjusting them for their own thoughts and generated budgets and forecasts. The predictions became part of the Management by Objectives movement, led by the well-known management guru Drucker [1978, pp. 100–113]. At the end of the 1960s, forecasts became an internal contract, based on little external information and derived from the same introvert process. It created also a culture of handing down safe figures so that performance of individual managers could be ensured.

The forecasting process turned from a simple one-minute job for line management into a complex and time-consuming process, not only for the planning department but also for the whole company. Every choice had to be double-checked and agreed upon. In times of prosperity, this posed no problem to companies but in times of crises and turbulence, the process took long and led to totally wrong predictions also caused by the elapsed time. For example, that was the case during the oil-crisis in the 1970s [van der Heijden, 1996; de Geus, 1999].

Despite its ineffectiveness in dynamic, contemporary environments, Millett and Honton [1991] state that predicting the future by trend analysis is still the most popular technique for technology forecasting. The different techniques have all some common assumptions and features, namely:

- the future is a continuation of the recent past and can be expressed quantitatively, as human behaviour follows natural laws as in physics and chemistry;
- there is one future and it is predictable if you understand the underlying laws as shown in the trend data.

This does not represent a realistic view of the world. Most environments of companies are so complex that it will be impossible to understand all underlying laws, and, even so, all these laws governing human behaviour are so complex that there are too many exceptions to the rule. Forecasting will only work in a perfect world.

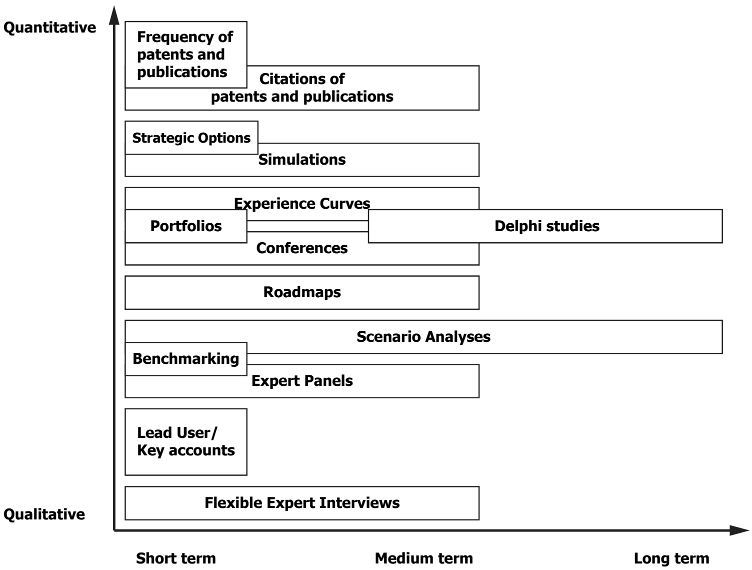

Figure 9.5 *Techniques for (technology) foresight mapped against time horizons [adapted from Lichtenthaler, 2005, p. 398]. The short-term generally indicates up to 5 years, medium term 5–10 years and long term more than 10 years, albeit that the exact time horizon might depend on a specific industry. The use of techniques is merely indicative.*

Techniques for Foresight

To that end, many more techniques have been developed. From a technological perspective, Lichtenthaler [2005] looks at the usefulness of the techniques for foresight from the perspective of the time horizon they apply to, albeit from a technology intelligence perspective; Figure 9.5 shows a selection of these techniques with their application. In addition, Popper [2008] even reports 33 different techniques for foresight, although they are not classified to time horizon, but divided into qualitative, quantitative and semi-quantitative methods. Hence, there is a multiple of techniques available that support setting out strategies.

For the long run, Lichtenthaler [2005] identifies two techniques. The first technique is Delphi studies. The Delphi method is a systematic, interactive forecasting method that relies on a panel of experts. The experts answer questionnaires in two or more rounds. After each round, a facilitator provides an anonymous summary of the experts' forecasts from the previous round as well as the reasons they provided for their judgments. Thus, experts are encouraged to revise their earlier answers in light of the replies of other members of their panel. It is believed that during this process the range of the answers will decrease and the group will converge towards the 'correct' response. The second technique is scenario planning, a strategic planning method that some organisations use to make flexible long-term plans. It is scenario planning that is elaborated in the next subsection.

Scenario Planning

Scenarios and scenario planning might offer a way out of the complexity of factors acting on organisations and at the same time increase the capability of an organisation to deal with the effects of these factors. The use of scenarios might be traced back to the traditions of the Oracle of Delphi and the premonitions by Nostradamus. The first modern scenario developer was Kahn [Kahn and Wiener, 1967]. Working for the US Air Force, Kahn developed scenarios to imagine what the opponents might do and to prepare alternative strategies to react to the opponent. This is one of the reasons that scenarios and strategies are regarded as the same thing, which is not the case. During the 1960s, Kahn refined his scenario development tools to fit business prognostications. Those scenarios are developed in three steps [Kahn and Wiener, 1967, pp. 5–10]:

- First, the Basic, Long Term Multifold Trends are described. These trends are derived from historical data, and do not change over the period that the scenario covers. They provide the basic structure on which the scenarios are built. Examples of these trends are birth rates, consumption of consumer goods, etc.
- After that, the Surprise Free Projections and the Standard World are described. These projections are based on basic trends at the time of the development of the scenario. Experts assess these trends and draw

plausible conclusions from them (for example, high and low trend developments of birth rates under different circumstances). These projections are intended to be used as basic vehicles for further discussion, explanation of underlying assumptions and systematic consideration of major alternatives.

- The last step in developing the different scenarios is the introduction of the Canonical Variations. These are designed to raise certain issues. The introduction of these issues leads to scenarios that are out of the expected Surprise Free Projections. In these Canonical Variations issues, such as a sudden rise of costs for energy or crude oil due to a war, can be introduced.

In their book, Kahn and Wiener use 13 basic trends and 8 canonical variations. Most of the time, these variations affect two or more basic trends. That way 9 different scenarios are developed. This approach to scenario planning was widely used until the work of Wack came to rise. Wack worked for the Royal Dutch/Shell in a newly formed department, called Group Planning [de Geus, 1999, pp. 58-60]. This group successfully predicted the oil crisis in 1973. After working in the Planning Department for several years, Wack came to the conclusion that the key point of scenario planning was not a clear picture of the future but what he describes as the gentle art of perceiving. He changed his efforts to enabling people to perceive different pictures of the future and act on changing circumstances.

In this perspective, scenarios should be seen as a hypothetical sequence of events with causal processes based on shared mental models. The sequence of events might help to generate a step-by-step description of multiple possible futures of the external world. Different scenarios might take place in the transactional and contextual environment as depicted in Figure 9.6; the transactional environment equals the definition of the environment of a system in Section 2.1, while the contextual environment is that part of the universe that connects to the environment of the system. According to van der Heijden [1996], scenarios are useful to create structure in events and patterns in the environment, to identify irreducible uncertainty, to confront different views with each other through dialectic conversation, to reveal individual

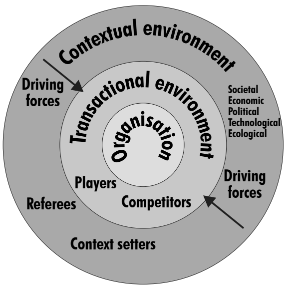

Figure 9.6 *Different environments of an organisation. The transactional environment consists of players (e.g. customers) and competitors. The transactional environment is influenced by driving forces from the contextual environment.*

knowledge of members of an organisation, to introduce external perspectives and to translate the above in a suitable form for strategic conversation.

Ringland [1997] identifies three types of methods in scenario development (Table 9.3 gives an overview of the methods and their steps):

- Trend-impact analysis (used by the Futures Group). Trend-impact analysis is concerned with the effects of trends, for instance in markets or populations. The method focuses on isolating the important trends, similar to that used in what is more generally called scenario planning; however, the basic premise within trend analysis is to look for the unexpected, in other words what will upset the trends. In addition, the trend-impact analysis can provide multiple pictures of the future. This method of trend-impact analysis closely resembles the method developed by Kahn. Most of the time, the scenarios look alike and cover a high, a medium and a low trend of a certain event. The risk exists that a company will always choose the medium prediction just to be on the safe side Ringland, 1997, pp. 47, 92]. Such a deployment of predictions within scenario development looks more like forecasting.
- Cross-impact scenario analysis (used by Battelle). Cross-impact is a method for the analysis of complex systems. It concentrates on the ways in which external or internal forces may interact on an organisation to produce effects larger than the sum of the parts or to magnify the effect of one force because of feedback loops. The method is used to orient strategic thinking about new products, technologies and marketing towards most likely future market conditions, including the net effects of various customers, regulatory, competitive, economic and technological trends. Within the method, looking at the future anticipates long-term (beyond three years) customer behaviour when customers themselves cannot articulate their own future behaviour. The method generates alternative scenarios for long-term business environments. It also serves as a tool to simulate what-if questions to see how actions and events may change the baseline (most likely) scenarios. To that purpose, simulations test potential business investments and strategies. Most likely scenarios are compared with most desirable scenarios to identify critical success factors.
- Intuitive Logistics (used by Royal Dutch/Shell and Global Business Network). The essence of this method is to find ways of changing mind-sets so that managers can anticipate futures and prepare for them. The emphasis is on creating a coherent and credible set of stories of the future as a wind tunnel (i.e. the basis) for testing business plans or projects, prompting public debate or increasing coherence. The term wind tunnel is used because intuitive scenarios can be seen as an analogy with wind tunnels in which strategy models can be tested under different circumstances.

  Key factor in Intuitive Logistics is the recognition of events and how these events form causal relationships under different circumstances. This can

Table 9.1: Steps of the three scenario development methods. More or less the same steps are present in each of the methods.

Scenario-writing (Global Business Network)	**Cross-Impact Scenario Analysis (Battelle)**	**Intuitive Scenarios (Shell traditionally)**
Identify focal issue or decision	Define and structure topic question	Analyse strategic concerns and decision needs
Identify key forces in corporate environment	Identify most important issues in response or topic questions	Identify key decision factors
List driving forces of the macro-environment	Select descriptors from most important issues	Identify key environmental forces
Rank driving forces by importance and uncertainty	Prepare descriptor white papers with projected alternative outcomes and a priori probabilities	
Select scenario logics structured by 2 axes and 4 quadrants	Cross-impact analysis	Analyse the key environmental forces
	Scenarios generated from cross-impact matrix (sorting of descriptor outcomes into alternative scenarios)	
Rashcut at least 4 scenarios and product narratives	Draw business-related implications from 5 scenarios and derive robust strategies	Define scenario logics (typically 2 critical issues)
	PC-based strategy simulations and scenario-sensitivity analysis, including disruptive events	Elaborate on two detailed descriptive scenarios
Draw implications and conclusions	Briefing discussions and implications focus groups	Draw implications for scenarios for strategic concerns and decision needs
		Make conclusions and recommendations
Select leading indicator sign posts for continued monitoring	Monitoring updates and revisions	

be visualised by systems thinking in the way Senge [1992] propagates, with cause and effect diagrams. Other visualisations for this scenario planning method use hexagons that can, connected together like a jigsaw puzzle, explain underlying trends, patterns and structures.

The three methods support scenario development but not all do address multiple strategies. Each of them is a way of arriving at a scenario; only the latter method does not arrive at a one particular state and, therefore, is more dynamic in its application.

9.3 Breakthrough Model

The breakthrough model comprises the overall processes necessary for implementing changes into the structure of organisations starting from strategies whether they are dynamic or informed by scenarios. This breakthrough model might apply to product development, process development, changes in organisational structures, etc., having a wide scope for any breakthrough or strategic renewal (Ravasi and Lojacono [2005, pp. 52–54] define strategic renewal as both structural transformation and as continuous innovation). Such adaptive processes continuously are at work, since selectional forces in the environment – either caused by competitive pressures or changing landscapes – force organisations to continuously generate beneficial mutations (by offering new or improved products or processes and by improved performance). However, the need to deploy this model will occur when the need for a certain output (or function) diminishes and an organisation needs to rethink its objectives, strategy and resource allocation.

The development of the original model for the breakthrough has been described in Dekkers [2005, p. 378], see Figure 9.6. It is a developmental model for organisations when they grow, building from operations towards objectives and strategy (akin the life-cycle models in Section 9.1). The model can be applied to any breakthrough for expanding entities and existing entities.

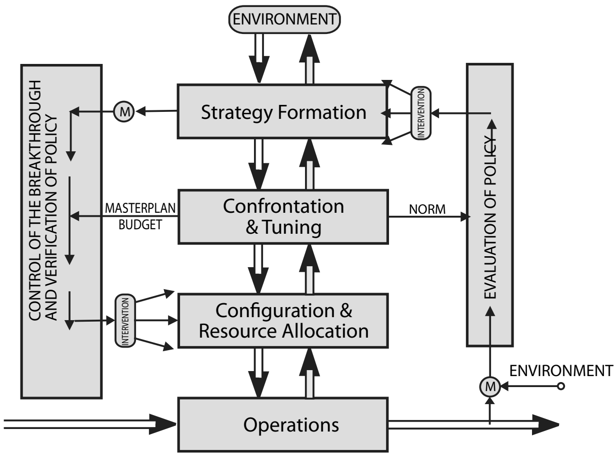

Figure 9.6 *Breakthrough Model. By scanning the environment new or adapted goals are set and the derived policy acts as a reference for the review of tactical and operational decisions. The process of confrontation and tuning takes the possibilities into account leading to specific decisions on the utilisation of resources and structures for operations. Through the configuration and resource allocation process the actual implementation of the structural changes in operations takes place. The evaluation of strategies might create new input for the breakthrough processes. The verification enables companies to follow the progress of the breakthrough processes.*

Because of the link between internal structure and the mutations – these are embedded in the current components of a system, i.e. an organisation in this case – the setting of objectives and strategy formation cannot be detached from each other.

Strategy Formation

By its capability of foresight, an organisation strives to adaptation by the generation of potentially beneficial mutations. Selectional forces, external to the organisation, will determine whether these mutations prove deleterious or beneficial. Nevertheless, the creation of purposeful mutations might change the fitness landscapes in which companies operate, giving them the possibility to influence the selectional forces. Note that this contrasts to organisms, which are hardly capable to shape the directional selection of fitness landscapes. The creation of purposeful mutations bears a strong resemblance to the concept of destructive innovation by Schumpeter [1911, 1934, 1954], telling also that continuous innovations are a necessary source for sustained competitiveness of organisations.

These adaptations appear by adapting to changing performance requirements or by filling adaptive zones (new functions or new performance requirements). Adapting to changing performance requirements means that the organisations performs according to improved criteria, for example shorter delivery times of orders. However, the adaptations can also apply to existing products and services or features that were not present before. The changes can be incremental or radical. In adaptive zones, positive feedback operates allowing an accelerated growth before limitations or constraints are reached (acting balance by negative feedback). The theory of fitness landscapes (Section 8.3) indicates that long jumps, i.e. radical innovation in either products and services or performance, might be deleterious. The mutations may occur at high speeds, even then each of the steps helps an organisation to improve its fitness and to explore the fitness landscape. These small steps and the exploration of the fitness landscape are brought about by the perception of the transactional and contextual environment in which an organisation operates.

By scanning the environment new or adapted goals are set and the derived policy acts as a reference for the review of tactical and operational decisions. In this sense, they are normative. However, the changes generated by organisations as allopoietic systems also reside in the components and internal structure of the organisation as a system. Allopoietic systems have self-cognition and self-perception as starting point for the processes of foresight, and, henceforth, for their strategy. Through active learning as present in the concept of the Learning Organisation [e.g. Senge, 1992], entities might adapt their perception and behaviour. Although internally normative, the strategy itself is relatively related to the self-perception of the organisation and, therewith, its perception of the environment.

Within the context of organisations as allopoietic systems, strategy formation consists of two major components. First, strategy formation comprises of the identification of objectives, the identification of means (incl. resources) and the development of principles. Objectives should be taken in the widest sense, e.g. market positioning for commercial organisations and addressing the needs of communities and citizens by governmental agencies. The second component concerns the selection of the objectives and the setting of priorities. Once the objectives and strategy relate to the deployment of resources, the process of tactical decision-making can take place (called 'confrontation & tuning' in the breakthrough model).

Confrontation & Tuning

When the strategy is set, decision-making takes place within the process of confrontation and tuning as optimisation of the deployment of the selected resources. This process takes the alternatives into account leading to specific decisions on the utilisation of resources and structures for operations. Characteristic is the iterative decision-making process. The strategy determines the direction and criteria of decision-making but is also influenced by the assessment of the available resources. Likewise, the iteration happens between 'confrontation and tuning' and 'configuration and resource allocation'. The decision-making includes the comparison of alternatives and considering the tactical level (deployment of resources). When there are no alternatives matching the requirement of the strategy, this process might result in the exploration of the environment again. This leads to a continuous stream of matching strategic requirements with the possibilities and capabilities for executing decisions.

Therefore, this calls for integrative decision-making as an effort to reduce unnecessary iterations. Additionally, the decision-making should cover the full scope of requirements set by the directives of the strategy. This might concern a broad range of aspects. The integration of the decision into the structures of the system of resources and the processes will only succeed when an integral approach is chosen.

The output of this process in the breakthrough model is the feasibility of a course of action. First, the feasibility of the Master Plan addresses the strategic direction chosen during the strategy formation. And second, the feasibility of the Master Plan should fit with the capabilities of the systems of resources or projected amendments. The output of 'confrontation and tuning' serves also as a Master Plan for later verification of the progress.

Configuration & Resource Allocation

Through the configuration and resource allocation process the actual implementation of the structural changes in operational processes takes place. The configuration concerns the structure (or some would call it the architecture) of operations. It might concern product or service development, the development of operations, the development of supply or the market development. Resource allocation directs towards linking the resources at disposal to the processes for the organisation; this covers both internal and external resources.

During this phase of configuring the structure of operations and the allocation of resources to that structure, it might prove difficult to realise the chosen course of action. In such a case, iteration between the level of 'configuration and resource allocation' and the level of 'confrontation and tuning' leads to revaluation of earlier decision-making. The feasibility of earlier options might be questioned, which could result in a revaluation of objectives and strategy.

For the allocation of resources, an organisation has two possibilities, which depend on the inclusion or exclusion of external resources. The first option for the allocation of resources is by relying on the same system of resources but that implies a redesign of the processes for meeting existing or shifting performance requirements. Only through a redesign of the process a different performance will eventually become possible; most of time that will result in a reflection on which resources are needed to conform to performance criteria and integration requirements. Secondly, by adjusting the system boundaries, an organisation automatically affects the control in the boundary zones at least. More often, it will impact the total processes, including control mechanisms, present in the organisation. Whatever option chosen, only through further detailing it will become clear whether the solution is feasible and whether implementation of the solution is possible in the primary process.

Operations

The new solution, or for that matter the new structure, will lead to different set-up of the primary process, whether it concerns changes in input, process configuration or control. Sometimes, the primary process does not need adaptation but the control mechanisms do. For example, when there is a constant and predictable flow, it does not matter whether feedforward or feedback is used for managing the throughput. But when fluctuations increase, feedforward might anticipate on demands for the capacity of the primary process; feedback will lead to correcting after deviations have entered the process and, therefore, be rendered less effective. Also new input, such as new materials or components, might be the objective of changes made in the operational system. In any case, the processes in the breakthrough model aim at introducing a new recurrent process with related resources and configuration of these resources in the (operational) primary process.

At the end, the primary process will reach a steady-state. When implementing the change, the new structure of the system of resources and the processes require fine-tuning. That might be partially encapsulated in the control mechanisms, such as present in the steady-state model, but it might also require modifications to make it work. Leonard-Barton [1987, p. 18] proposes that managing the integration of new technologies in the organisation yields better results than when companies adhere to an original strategy and implementation plan. She even states in another paper that implementation is innovation [Leonard-Barton, 1988, p. 265]. Based on empirical research and a model for adaptation by Berman [1980], she concludes that companies should allow adaptation cycles to actively link the actual implementation of technologies to the strategy. In the case of the introduction of an expert system at Digital, the success of the technology has depended on the interactive process to altering the technology to fit the organisation, and the simultaneously shaping of the user environment to exploit the full potential of the technology [Leonard-Barton, 1987, p. 7]. Douthwaite et al. [2001] do also confirm the conclusion that the more complicated the technology, the more it requires interaction between the inventors, researchers, and the user environment. A simple top-down approach is not sufficient any more. This leads Leonard-Barton [1988] to the proposition of small and large adaptation cycles to exist within the organisations. Misalignment between the strategy and objectives are viewed as normal and the misalignment evokes an adaptation cycle where both the merits of the technology and the impact on the strategy are considered. The larger the adaptation cycle, the more factors it affects within companies. Each evaluation of performance of the technology leads to considering the adaptation at aggregation strata given the impact of the misalignment. Hence, when we extend these findings to all organisational aspects, when introducing change, that might require active control and iterations as modifications to reach an optimal steady-state.

In practice, it has become much harder to reach a steady-state. The continuity of changes does not often allow an organisation to reach an optimal state of the primary process. Sometimes, and more often nowadays, the next change is already on its way before the old one has been implemented fully. This requires organisations to view breakthrough as a continuous process rather than a process aimed at one-time interventions.

Verification

Despite the iterative character of breakthrough, control is necessary to adhere to the Master Plan set by the process of confrontation and tuning and to review progress against the objectives set by the strategy. In that respect, two types of control exist within organisations in the context of breakthrough and renewal: verification and evaluation.

The process of verification is based on the Master Plan, which describes the milestones to be achieved for the processes of configuration and resource allocation and configuration of operations to meet performance requirements. During configuration and resource allocation, milestones define whether the progress and decisions made align with the Master Plan. Deviations should result in preventive and corrective actions to prevent further deviations from the Master Plan (this plan might also contain milestones for other aspects like quality, which does not necessarily mean that milestones equal deadlines).

During the implementation in operations the Master Plan serves as an indicator for when the steady-state will be reached. The verification enables companies to follow the progress of the breakthrough processes.

Evaluation

The performance of an organisation is measured by its output and to what extent it leads to fulfilment of the function; that results in feedback towards strategy formation through the evaluation as the column on the right hand side in Figure 9.6. The evaluation of strategies might create new input for the breakthrough processes. This requires aggregation of any kind of the evaluation to assess the strategy, or certain aspects of it.

9.4 Differences with Steady-State Model

The breakthrough model describes the processes necessary to adapt and to evolve an organisation. Similarly the steady-state model it converts signals from the environment into guidelines or directives for the internal organisation; however, it does so with a different purpose. The breakthrough model covers the changes in the internal structure as interventions (that might affect also the external structure) while the steady-state model focuses on the cybernetic control of recurrent processes within a given structure of the organisation.

Capability for Adaptation

When looking at the steady-state model, its cybernetic principles aim at maintaining homeostasis. This does not only concern the boundary zones at the input and output of the primary process but also the conversion from external standards into internal standards for the control mechanisms. When the environment indicates the reduced need, or even obsoleteness, for the output, the cybernetic mechanisms are unable to deal with that condition. The system of resources will collapse or disintegrate once the homeostasis cannot be maintained due to reduced need or obsoleteness of the output.

In that respect, the breakthrough model describes the internal processes for finding new positions of homeostasis. At these points a new internal structure is needed, either for producing under different constraints, different output with similar resources or new output with new resources; this process of adaptation might also entail adapting resources to fit with new constraints or new output. This process of adaptation happens at the same time as the continuous improvement for meeting short-term performance requirements; in fact, these processes have a strong interrelation, certainly when looking at the theories of complex adaptive systems (see Section 8.3).

In addition to its focus, the breakthrough model covers typically a multiple of aspects where the steady-state model describes one; note that for each investigation the aspects have to be redefined. For organisations decision-making as embedded in the breakthrough model depends on multiple criteria being assessed. These criteria constitute different aspects and, hence, the decision-making should not only cover these aspects but also account for integral decision-making (as synthesis). In any case, weighing of aspects and criteria involves the subjectivity of the actors involved and does not guarantee the best decision will be taken. The steady-state model singles out one aspect and optimises that aspect through its control mechanisms. In this respect, the scope of the steady-state model and the breakthrough model differ widely.

The steady-state model and the breakthrough model have in common that they both possess an evaluation process acting at the output of the primary process. Within the scope of the steady-state model that leads to corrections of the internal standards for the control process and externally to information about the control capability of the system of resources. The breakthrough model does evaluate too, but this might lead to revised objectives and strategies, even affecting the purpose of the organisation. Despite both models having evaluative processes, the purpose of these differ, though in practice they might be put together for use in the same reporting channels.

Linking Steady-State to Breakthrough

In addition to he steady-state model and the breakthrough model having evaluation processes in common, it might be possible to link the two models. The recurrent process of the steady-state model might occur at any of the phases of the breakthrough model. That means that we can describe the control of the internal processes for each of the levels by the primary process that takes place within that level and the control mechanisms to ensure its output. However, such an approach would need to take account of the iterative processes that are characteristic for the breakthrough model.

No matter, the steady-state model constitutes the process for the level of operations in the breakthrough model. The purpose of the breakthrough model is to adapt the steady-state process of the operations, i.e. the direct execution of the primary process, to changing circumstances. Ultimately, the breakthrough process aims at establishing recurrent processes, whether through implementing changes in its process structure (primary and secondary) and control structure or through the reconfiguration of resources (abolishing some of the existing resources or by including supplementary or complementary resources)

9.5 Summary

Building on the concepts of previous chapters, organisations can be considered a special class of allopoietic systems. Consequently, they follow certain patterns for development that could be derived from the reference model presented in this chapter. Those patterns are also found in three approaches to the life-cycle of organisations. The classification as allopoietic systems also implies that they are structurally-closed and uses self-reference as point of departure for interacting with the environment. That means that they are limited in the perception of changes, while subject to the dynamics of the environment.

The changing environment and the changes induced by organisations themselves require the implementation of strategies. Since the dynamics render the more static, canonical approaches defunct, it might be more appropriate for organisations to deploy dynamic strategies, foresight and scenario planning. Each of these strategies depends on how organisations perceive their environment, since they are allopoietic systems. The use of more dynamics forms of strategy should be used in conjunction with the breakthrough model.

That breakthrough model aims at implementing revised or new structures for operational processes; this might concern both internal structures (e.g. for operations and new product development) and external structures (for example, market segments). In the breakthrough model, by scanning the environment new or adapted goals are set and the derived policy acts as a reference for the review of tactical and operational decisions. The process of confrontation and tuning takes the possibilities into account leading to specific decisions on the utilisation of resources and structures for operations. Through the configuration and resource allocation process the actual implementation of the structural changes in operations takes place. The evaluation of strategies might create new input for the breakthrough processes. The verification enables companies to follow the progress of the breakthrough processes.

References

Abell, D. F. (1980). Defining the Business: The Starting Point of Business Strategy. Englewood Cliffs: Prentice-Hall.

Barábasi, A.-L. (2003). Linked: The New Science of Networks. New York: Persus Books.

Beer, S. (1972). Brain of the Firm - the Managerial Cybernetics of Organization. Chichester: John Wiley & Sons.

Beinhocker, E. D. (1999). Robust Adaptive Strategies. Sloan Management Review, 40(3), 95–106.

Berman, P. (1980). Thinking about Programmed and Adaptive Implementation: Matching Strategies to Situations. In H. Ingram & D. Mann (Eds.), Why Policies Succeed or Fail (pp. 205–227). Beverly Hills: Sage.

Bruggeman, J. (1996). Formalizing Organizational Ecology. University of Amsterdam, Amsterdam.

Burgelman, R. A., Maidique, M. A., & Wheelwright, S. C. (1996). Strategic Management of Technology and Innovation. Chicago: Irwin.

Das, T. K., & Teng, B.-S. (2000). A Resource-Based Theory of Strategic Alliance. Journal of Management, 26(1), 31–61.

Dawkins, R. (1989). The Selfish Gene. Oxford: Oxford University Press.

de Geus, A. (1999). The Living Company. London: Nicolas Brealy.
Dekkers, R. (2005). (R)Evolution, Organizations and the Dynamics of the Environment. New York: Springer.
Dekkers, R., & Kühnle, H. (2012). Appraising interdisciplinary contributions to theory for collaborative (manufacturing) networks: Still a long way to go? Journal of Manufacturing Technology Management, 23(8), 1090–1128.
Douthwaite, B., Keatinge, J. D. H., & Park, J. R. (2001). Why promising technologies fail: the neglected role of user innovation during adoption. Research Policy, 30(5), 819–836.
Drucker, P. F. (1978). Management in de Praktijk. Amsterdam: J. H. de Bussy.
Durrett, R. (2007). Random Graph Dynamics. Cambridge: Cambridge University Press.
Eisenhardt, K. M. (1999). Strategy as Strategic Decision Making. Sloan Management Review, 40(3), 65–72.
Fricker, A. R. (1996). Eine Methodik zur Modellierung, Analyse und Gestaltung komplexer Produktionsstrukturen. Aachen: RWTH Aachen.
Greiner, L. E. (1998). Revolutions as Organizations Grow. Harvard Business Review, 76(3), 55–67.
Guare, J. (1990). Six Degrees of Separation: A Play. New York: Vintage Books.
Hjalager, A.-M. (2000). Organisational ecology in the Danish restaurant sector. Tourism Management, 21(3), 271–280.
Hofstede, G. (1994). Cultures and Organizations. London: Harper Collins.
Kahn, H., & Wiener, A. J. (1967). The year 2000: a framework for speculation on the next thirty-three years. New York: McMillan.
Kauffman, S. A., Lobo, J., & Macready, W. G. (2000). Optimal search on a technology landscape. Journal of Economic Behaviour & Organization, 43(2), 141–166.
Knudsen, T. (2002). Economic selection theory. Journal of Evolutionary Economics, 12(4), 443–470.
Laitinen, E. K. (2000). Long-Term Success of Adaptation Strategies: Evidence from Finnish Companies. Long Range Planning, 33(6), 805–830.
Leonard-Barton, D. (1987). The Case for Integrative Innovation: An Expert System at Digital. Sloan Management Review, 31(1), 7–19.
Leonard-Barton, D. (1988). Implementation as mutual adaptation of technology and organization. Research Policy, 17(5), 251–267.
Lichtenthaler, E. (2005). The choice of technology intelligence methods in multinationals: towards a contingency approach. International Journal of Technology Management, 32(3–4), 388–407.
Lievegoed, B. C. J. (1993). Organisaties in ontwikkeling: Zicht op de toekomst. Rotterdam: Lemniscaat.
Maturana, H. R., & Varela, F. J. (1980). Autopoiesis and Cognition – The Realization of Living. Dordrecht: Reidl.
Milgram, S. (1967). The Small World Problem. Psychology Today, 2, 60-67.
Millett, S. M., & Honton, E. J. (1991). A Manager's Guide to Technology Forecasting and Strategy Analysis Methods. Columbus, OH: Batelle Press.
Mintzberg, H. (1987). The Strategy Concept I: Five Ps for Strategy. California Management Review, 30(1), 11–24.
Mintzberg, H. (1988). Generic Strategies: Towards a Comprehensive Framework. In R. B. Lamb & P. Shivastava (Eds.), Advances in Strategic Management (pp. 1–67). Englewood Cliffs: JAI Press.
Morgan, G. (1997). Images of organization. Thousand Oaks: Sage Publications.

Nakane, J. (1986). Manufacturing Futures Survey in Japan: A Comparative Survey 1983-1986. Tokyo: Waseda University.

Nelson, R. R., & Winter, S. G. (1982). An Evolutionary Theory of Change. Cambridge, MA: Belknap Press.

Popper, R. (2008). Foresight Methodology. In L. Georghiou, J. Cassingena, M. Keenan, I. Miles & R. Popper (Eds.), The Handbook of Technology Foresight (pp. 44–88). Cheltenham: Edward Elger.

Porter, M. E. (1980). Competitive strategy: techniques for analyzing industries and competitors. New York: Free Press.

Porter, M. E. (1996). What Is Strategy? Harvard Business Review, 74(6), 61–78.

Quinn, J. B. (1980). Managing strategic change. Sloan Management Review, 14(2), 3–20.

Ravasi, D., & Lojacono, G. (2005). Managing design and designers for strategic renewal. Long Range Planning, 38(1), 51–77.

Ringland, G. (1997). Scenario Planning: Managing for the Future. Chichester: John Wiley & Sons.

Schumpeter, J. (1911). Theorie der wirtschaftlichen Entwicklung. Leipzig: von Duncker & Humblot.

Schumpeter, J. (1954). History of Economic Analysis. New York: Oxford University Press.

Schumpeter, J. A. (1934). The Theory of Economic Development: An Inquiry into Profits, Capital, Credit, Interest, and the Business Cycle. Cambridge, MA: Harvard University Press.

Senge, P. M. (1992). The Fifth Discipline. Kent: Century Business.

Teece, D. J., Pisano, G., & Shuen, A. (1997). Dynamic Capabilities and Strategic Management. Strategic Management Journal, 18(7), 509–533.

van der Heijden, K. (1996). Scenarios, the art of strategic conversation. Chichester: Wiley.

Watts, D. J., & Strogatz, S. H. (1998). Collective dynamics of 'small-world' networks. Nature, 393(6684), 440–442.

Whetten, D. A. (1980). Organizational Decline: A Neglected Topic in Organizational Science. Academy of Management Review, 5(4), 577–588.

Williamson, P. J. (1999). Strategy as Options on the Future. Sloan Management Review, 40(3), 117–126.

10 Applications of System Theories

The previous chapters have elaborated the application of the concepts to examples drawn from technical systems, biological systems and organisational systems; this chapter intends to have a further look at the applications. Beyond those three domains, there are also other domains that have benefited from systems approaches, such as psychology and communication. For example, applications of non-linear dynamic systems theory to psychology have led to advances in understanding neuro-motor development and advances in theories of cognitive development [Metzger, 1997]. More recent literature on systems thinking has a general (often philosophical) perspective, concerns computer systems or focuses on one highly specific problem. Heylighen [1991] sighs:

The fundamental concepts of cybernetics (ed.: incl. general systems theory) have proven to be enormously powerful in a variety of disciplines: computer science, management, biology, sociology, thermodynamics ... A lot of recently very fashionable approaches have their roots in ideas that were proposed by cyberneticians several decades ago: artificial intelligence, neural networks, complex systems, man-machine interfaces, self-organisation theories, systems therapy ... Most of the fundamental concepts and questions of these approaches have already been formulated by cyberneticians such as Ashby, von Foerster, McCulloch, Pask, ... in the forties and the fifties. Yet cybernetics itself is no longer fashionable, and the people working in those new disciplines seem to have forgotten their cybernetic predecessors.

Systems theories have become part of science and practice; yet, progress is still made, especially in more advanced topics such as autopoiesis and complex adaptive systems, requiring the adoption by the specific domains.

Each domain of application requires an extensive treatment to do justice to those that have been and are working on it. The sole purpose of this chapter is to indicate the applications in the three domains and possible avenues for the reader's interest. Section 10.1 will discuss Systems Engineering, a traditional field of application for system theories. Two topics on biological systems constitute Section 10.2; these have been selected from a wide field in the biological domain. Section 10.3 covers the application to organisations. Finally, Section 10.4 addresses some other (popular) system theories, particularly those used in the domain of organisations.

10.1 Systems Engineering

Systems Engineering (or systems design engineering) as a field originated around the time of World War II, when the complexity of engineering projects increased. Large or highly complex engineering projects, such as

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the development of airplanes or warships, needed to be often decomposed into stages and managed throughout the life-cycle of the product or system; later this approach became common for all kinds of complex systems, such as petrochemical plants and information systems. This approach to engineering systems is inherently complex, since the behaviour of and interaction between system components is not always clearly defined. Defining and characterising such complex systems is the primary aim of systems engineering.

For managing these inherently complex systems, there are several methods and tools frequently used by systems engineers (some of these appear in Figure 10.1):

- Elicitation of requirements.
- Systems architecture and design.
- Functional analysis.
- Interface specification and design.
- Communications protocol specification and design.
- Modelling and simulation.
- Acceptance testing and commissioning.
- Validation, verification and fault modelling.

These methods and tools are necessary because the design and engineering of systems, both large and small, can lead to unpredictable behaviour and the emergence of unforeseen system characteristics. Moreover, decisions made at the beginning of a project whose consequences are not clearly understood can have enormous implications during the later phases of the life-cycle of a system; systems engineering explores these issues and aims at making critical decisions to decrease these consequences. However, there is no single method that guarantees that decisions made today will still be valid when

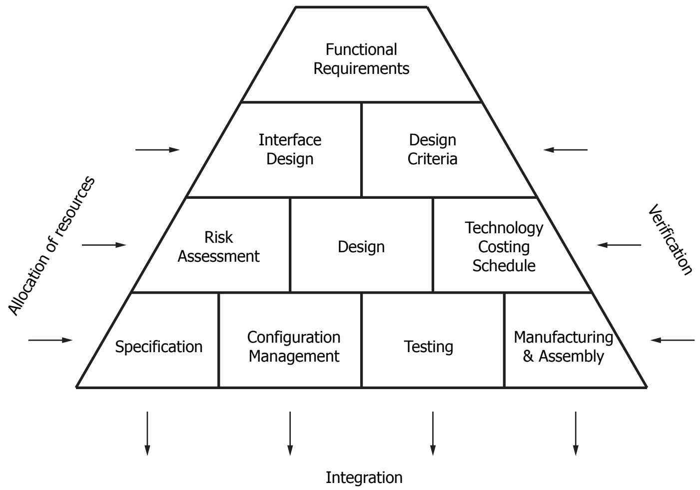

Figure 10.1 *Overview of methods and tools for Systems Engineering. Systems Engineering provides processes that ensure the functional requirements are satisfied by the final product or service. It covers the range from functional requirements to production and deployment of complex systems, spanning the entire life-cycle.*

a system goes into service years or decades after it is first conception but there are techniques to support the process of systems engineering. Examples include the use of Soft Systems Methodology (see Section 4.8 and 10.4), System Dynamics [Senge, 1992; Sterman, 2001] (see also Section 10.4) and the Unified Modelling Language (see Section 4.8), each of which are being used to support the decision making process during product (and service) design and engineering.

Often, systems engineering involves the modelling or simulation of some aspects of the proposed system in order to validate assumptions or to explore theories. For example, highly complex systems such as aircraft are usually modelled and simulated before the maiden flight. In this way, the initial aerodynamic properties and control systems can be drafted initially and improved before the physical system itself is constructed. Since complex systems aircraft are often very expensive, this reduces the efforts and the difficulty of debugging the control system and the risk of crashing real aircraft with all potential complications. The use of advanced modelling and simulation software has created opportunities to reduce the engineering efforts during later stages of product (and service) design engineering and to predict behaviour of complex product (and service) systems more accurately.

However, despite all modelling and simulation, initial testing and commissioning are still required to reach acceptable levels of safety and performance in advanced product (and service) systems. Systems engineers still perform validation and verification when a system has to have predictable behaviour. As case in point is medical support equipment, such as heart and lung machines, that usually consists of several parts, engineered by different companies. Validation and testing assures that normal operation and possible failures of each part will not harm patients. Other applications are communications systems and banking software, where failures can cause loss of property or liability. Test plans can often be adjusted to save significant amounts of efforts by testing partial systems or by including special features in a system to aid testing.

Because of its scope and because of the design of complex systems, many related domains use different techniques and methods useful for systems engineering. Some of those areas that contributed methods for systems engineering will follow now:

- Software Engineering has more recently helped to shape modern systems engineering practice to a great degree. The techniques used in the handling of complexity of large software-intensive systems has dramatically reshaped the tools, methods and processes in Systems Engineering (for example, Systems Modelling Language, Capability Maturity Model Integration, Object-oriented analysis and design, Requirements Engineering, Formal Methods and Language Theory).
- Control Systems Design. The design and implementation of control systems, used extensively in nearly every industry, is a large subfield of

Systems Engineering. The cruise control of a car and the guidance system for spacecraft constitute two examples.

- Operations Research. This is an interdisciplinary science that deploys methods such as mathematical modelling, statistics and algorithms to decision making in complex real-world problems, which are concerned with coordination and execution of the operations within an organisation. The eventual intention is to find the best possible solution to a problem, which either improves or optimises the performance of the organisation.
- Safety Engineering. The techniques of safety engineering can be applied by non-specialists in designing complex systems to minimise the chance or the effect that the safety-critical failures can cause. Safety engineering helps to identify safety hazard areas of emerging designs and uses methods for mitigating the effects of safety-hazard failures that cannot be designed out of systems.
- Reliability Engineering is the discipline of ensuring a system will meet the customer's expectations about a failure-free product life-cycle. Reliability engineering applies to the entire system, including hardware and software. It is closely associated with maintainability engineering and logistics engineering. Two methods that are well known are the Failure Modes and Effects Analysis and Fault Tree Analysis. Reliability engineering relies heavily on statistics, probability theory and reliability theory for its tools and processes.
- Interface specification and design are concerned with making the subsystems desirably connect with and interoperate with other subsystems within the system and with external systems. Interface design also includes assuring that system interfaces should be able to accept new features, including mechanical, electrical, electronic and logical interfaces. The human-computer interaction is another aspect of interface design and is a vital part of modern systems engineering when considering the user of a system.

More recently, the methods of systems engineering have reached the field of biotechnology. Hence, systems engineering has a wide range of applications spanning domains where design and engineering activities play an important role.

10.2 Biological Systems

Most biological systems have an even higher degree of complexity than the technically complex systems outlined in the previous section. Complex systems research overlaps substantially with non-linear dynamics research, but complex systems specifically consist of a large number of mutually interacting agents, as is the case in biological applications. Especially, two areas of interest linked to systems theories have gained in ground in the past years: systems biology and ecosystems.

Systems Biology

Systems biology covers an emergent field that aims at understanding of biological systems as a whole. Since the days of Norbert Wiener, this holistic understanding has been a long-standing goal of biological sciences; this is a reversal of the early days of systems theories, when many concepts in systems theories had their foundation in concepts arriving from biology. For example, cybernetics lent some concepts, such as homeostasis and boundary control, from biology to complement its own control concepts. Molecular biology had just started at the same time and only phenomenological analysis was possible in that discipline of science. Only more recently, can the system level analysis be grounded on discoveries at molecular level. With the progress of the genome sequence project and a range of other molecular biology projects that accumulate in-depth knowledge of molecular nature of biological systems, scientists are now at the stage to seriously look into the possibilities of understanding biological systems as a whole.

What does it mean to understand at *system level* in systems biology? Unlike molecular biology, which focuses on molecules, such as the sequence of nucleotide acids and proteins, systems biology concentrates on systems that are composed of molecular components (either subsystems or elements as denoted in Applied Systems Theory). Although biological systems are composed of matters, the essence of a system lies in its dynamic behaviour and it cannot be described merely by enumerating elements of the system. Not only system structures, such as network topologies, are important but also the diversities and functionalities of elements. Both the structure of the system and the components plays an indispensable role forming the symbiotic state of the system as a whole. Within this context, (1) the understanding of a system's structure, such as gene regulatory and biochemical networks as well as physical structures, (2) the understanding of the dynamics of a system, both quantitatively and qualitatively, as well as construction of models with powerful prediction capabilities, (3) the understanding of control methods for the system and (4) the understanding of the design methods for the system, are key milestones to judge how much we understand the biological system [Kitano, 2002, p. 1662].

More recently, the prospect of designing biological systems has become feasible. Currently, this is mostly done by improving plants or animals by adding genes from other organisms, but the first simple from-scratch designs of biological functional modules are starting to appear [McAdams and Kitano, 2000]. Examples are designed cells as thermometers and oscillators that are independent of the cell cycle. Even before all this became possible, the possibility of using methods from Systems Engineering to assist in reverse engineering for nature had attracted some biologists. One of the goals of systems biology is to understand a complex biological process in such sufficient detail to allow the building of a computational model. That would allow simulations of behaviour and lead to a quantitative understanding of function.

The implications of thinking in terms of systems are starting to take hold in research into systems biology. For example, the concept of modularity, which has served engineers and systems theorists well for some time, has been rediscovered for biology. Modularity is used as an equivalent to subsystems and aspectsystems. Many organisms consist of modules, both anatomically and in their metabolism. Anatomical modules are usually segments or organs. Classical biology already had this concept on a rather macroscopic scale, without explicitly calling it by this name. Now researchers see a modular framework for biology, treating subsystems of complex molecular networks as functional units that perform identifiable tasks perhaps even able to be characterised in familiar engineering terms [Lauffenburger, 2000]. This coincides with the concept of systems in systems theory (system, modularity), where scientists think in terms of classes of systems, defined by a certain set of common characteristics, which can be handled by a common set of methods. It would also be the base for future developments to more complex models, once the cellular and sub-cellular levels can be described in sufficient detail. This could be seen as a macro-scale extension to the modular concepts and as an application of systems engineering practice to biological engineering.

One major goal of these efforts is a better understanding of how cells work through modelling (see Section 3.4). This is different from the way biologist defined models in the past, using pure descriptions of concepts and ideas as models. The most feasible application of systems biology research is to create a detailed model of cell regulation, focused particularly on transduction cascades and molecules to provide system-level insights into mechanism-based drug discovery. Such models may help to identify feedback mechanisms that offset the effects of drugs and predict systemic side-effects. Some of the possibilities for application are: drug design, personalised drugs, i.e. built for purpose, medicines free of side-effects, developed for (or at least adapted to) individual patients, directed, reliable manipulation of gene information (e.g. treatment of tumours or hereditary diseases) and more. Such a systemic response cannot be rationally predicted without a model of intracellular biochemical and genetic interactions. With such models another transfer from engineering practice would become possible: newly designed drugs could be tested in simulations before going into clinical testing.

One of the more recent advances in systems biology is that the complexity, which is unarguably present in biological systems, is often not a complexity of function. It is rather a complexity of regulation that is necessary to ensure that a relatively simple function can be maintained robustly in spite of severe perturbations from the environment (robustness); compare this with Ashby's Law of Requisite Variety (Section 5.8). In other words, the objective of this complexity is to guarantee that the core function will generate reliable output; the system complexity is built in to provide for simple behaviour (please note the parallel with the concepts of autopoiesis in Section 7.1). This is in sharp contrast to the popular chaos and complexity theories, which associate complexity with fractals and edge-of-chaos, originating in simple systems (see Chapter 8). This distribution of complexity can also be observed on a level of aggregation even lower than that of cell functions. As the various genome projects are showing, there are more regulatory sections to a genome than there are for metabolic functions and a lot of sections have no essential function at all (or not yet discovered). If this inference proves to be generally true, it could be speculated that the compositional complexity of cells is designed chiefly to enable cells to maintain simple functions reliably in uncertain and variable environments (robustness and sensitivity). Another aspect of complexity at the genetic level is contained in the realisation that there is no strict demarcation between information storage and functional units. Gene regulation is embedded in basic processes within cells, though complex in their interactions for maintaining a steady-state.

Biological Ecosystems

Whereas systems biology focuses on micro-level, may be building up to organisms, ecosystems consist of the biological communities that occur in some locales and the physical and chemical factors that make up their non-living or abiotic environments. There are many examples of ecosystems – ponds, forests, estuaries and grasslands. The first principle of ecology is that each living organism has an on-going and continual relationship with every other element that makes up its environment. An ecosystem can be defined as any situation of interaction between a range of organisms (species) and their environment. Such boundaries are not fixed in any objective way, although sometimes they might be obvious, as with the shoreline of a small pond, but even there some species might cross this boundary back and forth. Usually the boundaries of an ecosystem are chosen for practical reasons having to do with the goals of the particular study (commensurate with the definition of systems in Section 2.1).

The study of ecosystems mainly consists of the study of certain processes that link the living, or biotic, components to the non-living, or abiotic, components. The ecosystem is composed of the entirety of life (called the biocoenosis as closely integrated community of different organisms) and the medium that life exists in (the biotope – the region or habitat). Within the ecosystem, species are connected and dependent upon one another in the food chain; and they exchange energy and matter between themselves and with their environment. Energy transformations and biogeochemical cycling are the main processes that comprise the field of ecosystem ecology.

Within the domain of ecosystem ecology, there are different kinds of studies. The studies of ecology happen at the level of the individual, the population, the community and the ecosystem itself. The studies of individuals are concerned mostly about physiology, reproduction, development or behaviour, while studies of populations usually focus on the habitat and resource needs of individual species, their group behaviours, population growth and what limits their abundance or causes extinction. The studies of communities examine how populations of many species interact with one another, such as predators and their preys or competing species that share common needs or resources. Ecosystem ecology puts all of this together, which means trying to understand how the system operates as a whole. This means that, rather than worrying mainly about particular species, the study of ecosystems tries to focus on major aspects. These aspects include the amount of energy that is produced by photosynthesis, how energy or materials flow along the many steps in a food chain and what controls the rate of decomposition of materials or the rate at which nutrients are recycled in the system. Ecosystems have energy flows and ecosystems cycle materials. These two processes are linked, but they are not quite the same:

- Energy enters the biological system in the form of light, or photons, and is transformed into chemical energy in organic molecules by cellular processes including photosynthesis and respiration, and ultimately is converted to energy in the form of heat. This energy is dissipated, meaning it is lost to the system as heat; once it is lost, it cannot be recycled. Without the continued input of solar energy, biological systems would quickly shut down. The earth is an open system with respect to energy.
- Elements such as carbon, nitrogen, or phosphorus enter living organisms in a variety of ways. Plants obtain these elements from the surrounding atmosphere, water or soils. Animals may also get elements directly from the physical environment, but usually they obtain these mainly as a consequence of consuming other organisms. These materials are transformed biochemically within the bodies of organisms, but sooner or later, due to excretion or decomposition, they are returned to an inorganic state. Often bacteria complete this process, through the process called decomposition or mineralisation. During decomposition these materials are not destroyed or lost, so the earth is a closed system with respect to elements (with the exception of a meteorite entering the system now and then).

Hence, the earth as a system is open with respect to energy but closed with regard to its elements. The elements are cycled endlessly between their biotic and abiotic states within the ecosystem earth. Those elements whose supply tends to limit biological activity are called nutrients. So that means that a continuous chain of (re)cycling elements drives ecosystems, such as the earth, driven by the openness with regard to the aspect energy

In reality, the organisation of biological systems is much more complicated than can be represented by a simple ‘chain’. There are many food links and chains in an ecosystem and all of these linkages are called a food web. Such food webs can be very complicated, where it appears that ‘everything is connected to everything else’ and it is important to understand what are the most important linkages in any particular food web. Biosphere II demonstrated how fragile the balance can become (see Figure 10.2). This grand experiment attempted to replicate natural ecosystems inside a self-contained world. However, the system started to fail several months into the experiment. All parts of the ecosystem were in jeopardy because the experiment's designers had overlooked the importance of every part in the ecosystem, including the microbes. This only demonstrates how complex adaptive systems, such as ecosystems, are actually complex and difficult to grasp.

10.3 Organisations

The next domain that systems theories have been applied to is that of organisations. Some advocate that the nature of management may be conceptualised from a perspective of systems theories as the process by which an organisation generates a global representation of its own processes (as present in Soft Systems Methodology, see Section 4.8, or latently present in the Viable System Model from Beer [1972], see Section 10.4). In other words, management depends upon modelling an organisation from its own perspective. Modelling allows management to perform its distinctive activities such as monitoring, evaluation, prediction and control. The purposes to which these activities are directed, is a product of the interaction between an organisation and its environment. This is a consequence of the way that the organisation will tend to adapt to survive and grow in whatever specific context in which they are operating – this can lead to very different management processes and structures in different environments. Within the application of systems theory for organisations, three main streams can be

Figure 10.2 *The dome of the project Biosphere II (picture edited from: http://upload.wikimedia.org/wikipedia/commons/d/d3/Biosphere2_1.jpg, accessed: 9th July, 2014). The Biosphere II was an experiment conducted in the early 1990s. It was supposed to be a self-contained ecosystem with a team of scientists locked into it for 2 years. The 3.15 acre facility, made of glass and space-frame, was the largest total enclosed ecosystem ever built. All of the living things inside were taken directly from Biosphere I (i.e. the Earth). All seven ecosystems of Earth existed within the confines of Biosphere II. They were a rainforest, a desert, a savannah, a marsh, a farmland (in an area called the Intensive Agriculture Biome) and a 'human habitat'. Thus, it contained soil, air, water, animals and plants. About 4,000 plants and animals were introduced to Biosphere II and its ocean contained 3,400 cubic metres of water. It was hoped that these provisions would give the ecosystems enough material to be self-sustaining.*

distinguished: management cybernetics, analysis and design of organisational systems and evolution of organisations.

Management Cybernetics

Management cybernetics, or also called organisational cybernetics, is the concrete application of cybernetic laws to all types of organisations and institutions created by human beings and to interactions with and within them. For example, Beer's cybernetic management theory (driven by the Viable System Model) is not limited only to industrial and commercial enterprises. It also relates to the management of all types of organisations and institutions in the profit and non-profit sectors: from individual enterprises to large multinationals in the private and public sector, and from associations to political bodies. In addition to the Viable System Model, this approach to management has become most known through the St. Gallen Management Model [Schwaninger, 2001], see Figure 10.3; for how the development of the St Gallen Management Model is influenced by the Viable Systems Model, see Pruckner [2002]. Most characteristically, cybernetic management takes as premise that it should not only cover general management issues and actions by top managers but also that every individual encounters and it is not restricted to the actions of top managers. In that sense, cybernetics in management is also a way of considering and thinking about things that can

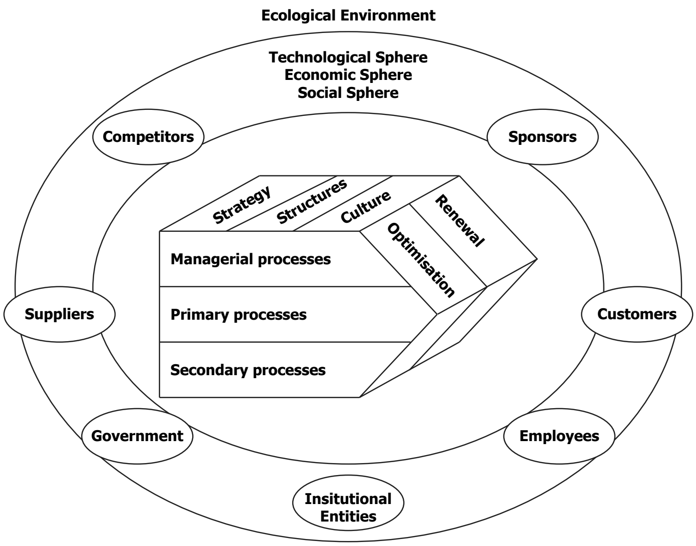

Figure 10.3 *Adapted St. Gallen Management Model. The original model [Schwaninger, 2001, p. 1212] has been complemented by including managerial processes and using terminology that is also found in Applied Systems Theory (primary and secondary processes). There is also a strong parallel with concepts about stakeholders in Section 7.6.*

be used to analyse the thinking, communication, acting and functioning of human beings themselves and to give them an effective meaning.

Analysis and Design of Organisations

Another strand of systems thinking using cybernetic principles applied to organisations has focused on its design. This stream builds on the steady-state model (Chapter 7) and the breakthrough model (Section 9.3) as notional concepts for analysis and design. The approach to organisational design is depicted in Figure 10.4. In the perspective of this methodology, the design of the organisation should combine processes and resources within the system from a strategic point of view (i.e. the re-design of an organisation might cause a breakthrough); that means grouping the tasks and activities into an organelle structure according to criteria. Therefore, the design of organelle structures strongly depends on the set or imposed performance criteria. More specifically, strategic choices relate the organelle structure to external performance criteria dictated by product-market combinations and internal performance criteria. Hence, there are organelle structures that range from the functional structure (job-shop) to the product flow organisation with their impact on design requirements for organisational structures. Factually, the organelle structure as core concept represents the trade-off between the requirements for exerting control, the capabilities of an organisation and the utilisation of resources.

In addition to the organelle structure, the structure of the hierarchy represents the management of the resources. To that purpose, leadership issues, span of control and communication structures play a paramount role in the choice for the most adequate structure. Also, the hierarchical structure accounts for communication, coordination and control related to the organelle structure and the control structure (i.e. the steady-state model). However, the choices for this structure might be subject to biased views within the organisation.

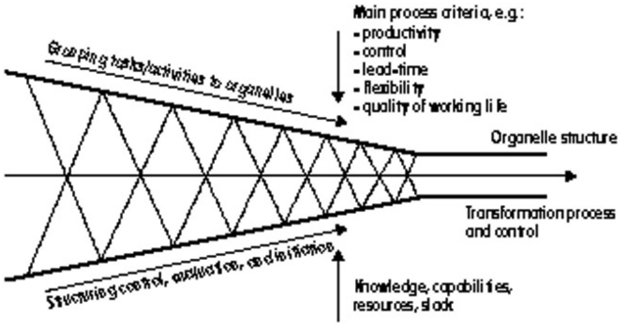

Figure 10.4 *Design process for the organelle structure [Dekkers, 2005, p. 433]. The organelle structure affects both the grouping of tasks in the primary process as well as the control processes. By subsequent integration and iteration, the design of the organelle structure meets performance requirements.*

The design of an adequate organisational structure should incorporate the opportunities provided by product and process characteristics in addition to meeting all performance requirements. It should be noted that the management of resources incorporates both the primary process and control processes. Each of these processes deploys resources, with specific skills and knowledge, to achieve outcomes whether it concerns the manufacturing of products or the transformation from signals into interventions (the domain of control processes). Optimisation by management, the hierarchy, concentrates on all available resources for the primary process and control processes to reach organisational objectives.

The design methodology follows two principles. First, an organisation is analysed, and after the analysis of bottlenecks, the design follows the requirements derived from the strategy of the organisation (see Figure 10.5). Changes in the (corporate) strategy, external developments, internal performance information or any combination of these factors set new requirements for an organisation. External developments might concern market investigations, technological changes or other information from the outside that influence the business processes. The internal information refers to data about the performance, the structure and the activities of the organisational unit. The changes in general policy, external developments, and internal information should lead to either a radical or an incremental upgrade of the organisation. Second, the performance requirements reflect on the different design issues. Moreover, the design approach relies on a step-wise approach: first, the setup of the primary process is considered, then the design of the control processes, followed in iterations by consecutively the organelle structure and the hierarchical structure (see Figure 10.4). During each stage, potential performance of possible solutions is compared with design requirements.

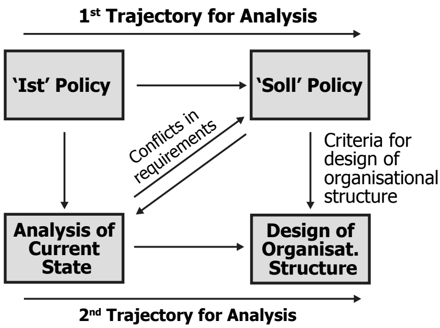

Figure 10.5 *Simplified version of the methodology for (re-)design of organisations [Dekkers, 2005, p. 434]. The first trajectory investigates prevailing strategies for the 'Ist'- and 'Soll'-state ('Ist' can be translated into 'As-Is' and 'Soll' into 'Ought-To-Be'). The second trajectory analyses the current organisational structure (primary process, control process, organelle structure, hierarchy) and arrives at a redesign of the integral organisational structure. The two trajectories are intertwined through the criteria for analysis and redesign.*

Organisations as Allopoietic Systems

No matter how they are structured, organisations can be considered as special class of allopoietic systems that have fuzzy boundaries and the capability for foresight [Dekkers, 2005, p. 397]; see also Sections 7.6–7.7. The usual organisation science perspective that an organisation adapts to its environment, or at least influenced by it, is fundamentally turned around. An ‘autopoietic’ organisation, on the contrary, is self-referentially closed. It only perceives its environment as a projection of its self-identity. It only functions in order to survive and to maintain its identity. An example of such thinking is found in the book about the Living Organisation by de Geus [1999], as mentioned in Section 7.6. He refers to the existence of an organisational identity even if it is present in the actions of the individual that constitute that organisation. That it might have far-reaching consequences is brought to our attention by Bakan [2004] who characterises firms as psychopathic, mainly to indicate the lengths to which an organisation might go to preserve itself.

In autopoiesis, systems are both open and closed and this applies to organisations, too. Autopoietic organisational systems interact with their environment, which consists of other systems (i.e. are open interactively), see Section 7.2. But they are closed by the boundaries of meaning as the meaning creation takes place through the system’s auto-referencing [Hernes and Bakken, 2003, p. 1516]. The system can only make sense of the outside world through the observation of its own experiences. As mentioned in Section 7.6, the concept of the Learning Organisation, coined by de Geus [1999] and expanded by Senge [1992], has become a popular way to describe the interaction between organisation and its environment and the learning experiences of organisations. In some way, this is analogous to the steady-state model (Chapter 6) and the breakthrough model (Chapter 9). In the steady-state model learning is present through the direct evaluation of the output, the information from the environment and the assessment for revaluing the standards and determining the control capability of the system of resources. The breakthrough model takes this evaluation even further by determining new structures to fulfil functions or reprogram functions. The interaction through the operational processes as throughput characterises the organisation as an open system while the structural changes and the perception of the environment denote the organisation as a closed system.

Evolutionary Approaches for Organisations

In addition to the more structural approaches of cybernetic management and analysis and design of organisations, economists and management scientists have embraced the core thoughts of evolutionary approaches, either explicitly or implicitly and that way including core thoughts of systems theory. This was already true for the early contributions by Veblen [1898] and Schumpeter, even though Schumpeter was highly critical of attempts to apply theories from the natural sciences to economics [Fagerberg, 2003,

p. 127, 144]. Later on, evolutionary approaches experienced a revival with the writings of Nelson and Winter [1982] and Hannan and Freeman [1977]; especially, Nelson and Winter denounced pursuing biological analogies, for their own sake or for the purpose of developing a general evolutionary theory applicable to both natural and social sciences [Nelson and Winter, 1982, p. 11]. Since then, an increasing stream of publications has employed evolutionary approaches, following the founders in avoiding to use analogies from evolutionary biology.

Within this context, it is useful to examine some of the crucial differences between economic and biological evolution (see, e.g. Dekkers [2005], Eldredge [1997], Hodgson [2005], van den Bergh and Gowdy [2000]):

- Whereas in biology the genotype-phenotype distinction is very clear, in economics and management science no such distinction exists. For there is no singular equivalent in economics to the most basic unit of selection, i.e. the gene. Related to this is the fact that the distinction between 'ontogeny' – development of an organism – and 'phylogeny' – 'family tree' or evolutionary history of a group of organisms – has no counterparts in economics. Both these differences relate to the fact that biological evolution is genetic evolution, whereas social-economic evolution is a combination of genetic and non-genetic evolution, where the latter is dominant in the short run. Nevertheless, some authors have tried to strictly impose the genotype-phenotype analogy to economics (Boulding [1981], Faber and Proops [1990]).
- Ideas and artefacts, including people, products, books, behaviour, routines, knowledge, science, religion, art, rituals, institutions and politics are all concrete and durable information carriers and can act as 'genes' if this is relevant for the study concerned. Some authors prefer to refer to cultural and economic genes as 'memes', a term originally proposed by Dawkins [1989] and by others examined from various disciplinary perspectives [e.g. Aunger, 2000]. According to Norgaard [1994, p. 87], 'one type of gene is no more real than the other'. This suggests that there is no objection against choosing the 'gene' in economics ad hoc, i.e. depending on the context or type of analysis. Note that if macro-evolution and higher level sorting exist in biological systems, the gene is not the exclusive unit of selection, and selection is not the only mechanism of durable change, in biological evolution anyway. Therefore, the lack of an equivalent to the gene in economic evolution would not be such a serious criticism after all (e.g. Hodgson [1993]).
- Lamarckian or goal-oriented evolution occurs at various levels in economic systems: individuals, groups and sectors. This is due to social, organisational, group and individual learning and search, notably through education and R&D. In biological systems and most animal species such learning is largely absent, and mutations are mainly random and certainly not the result of purposeful search. The distinction between selection as social learning (selection, diffusion) and individual learning (which

is very limited for most species) is clear-cut in biology. In contrast, in economics such a distinction is blurred, as technologies developed and lessons learned in one sector can be easily transferred to other sectors. In summary, characteristic for economic-cultural evolution is that information can be purposefully accumulated (learning), that changes (mutations) can be purposefully stimulated and that innovations can diffuses very easily across sectors.

- The biological sexual recombination mechanism to generate new genetic structure has no direct economic analogue. In economic systems, inheritance can occur in different ways and on different levels of aggregation. Nevertheless, ideas in economics and technology suddenly often increase in value when combined. In fact, major innovations often result from combining existing insights, concepts, technologies or institutions. This suggests that recombination as an abstract concept may be valuable to evolutionary economic reasoning.

Apparently, the structure of organisations, embedded in the economic environment, differs from those of organisms. This might indicate that comparisons and analogies apply more to the governing principles for the evolution of organisations and economies than to the resulting structures; O'Shea [2002] provides a similar argument evolutionary approaches for new product innovation, based on Bergson [1911]. For example, comparing an organisation with the human body would be Hodgson's [2002, p. 263] literary ornament and add little to the understanding of the evolution of organisations. The stance that limitations apply to analogies is supported by the systems hierarchy of Boulding (Section 3.5); in view of the levels of Boulding, evolutionary models aimed at describing the evolution of species (levels of genetic-societal systems, animals, humans) do not directly apply to the evolution of organisations (level of social organisations). Hence, it seems plausible to direct the use of analogies towards those of governing principles.

10.4 Other Systems Theories in Brief

During and after the development of the General Systems Theory, in the 1950s and 1960s particularly, scientists have developed applications of system theories. Initially, the focus of system theories was on epistemological and ontological issues; for example, what are the definitions of systems and how are they described. That resulted in books, such as von Bertalanffy [1973] and West Churchman [1979]. However, in parallel a stream existed that was more directed at solving problems; a case in point is the development of control theory. That lead to different strands in system theories, see Figure 10.6. Some of these aimed developing theoretical concepts and others are more oriented on applications and solving problems. This happened especially in the domain of organisations and social organisations. Moreover, some management scientists consider system theories a basic tool for studying organisational entities. Note that Applied Systems Theory, as presented in this

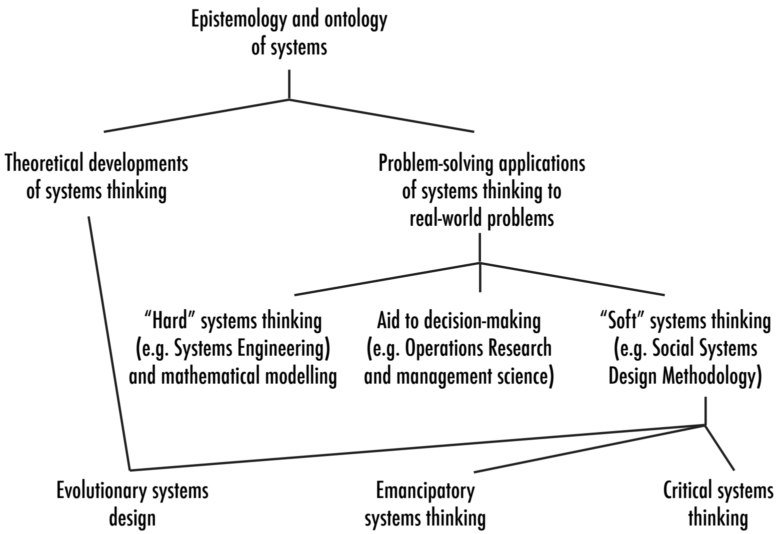

Figure 10.6 *Overview of the systems movement (adapted from Laszlo and Krippner [1998]). Systems theories have evolved from the movement of defining them (epistemology and ontology, characteristic for the search into the early General Systems Theory) into two main strands. The first one of theoretical development resulted in interests in evolutionary systems design, which can be linked to the science of complexity. The second stream focused on the application and divided quickly into three directions: hard systems thinking, support to decision-making and soft systems thinking. Ultimately, soft systems thinking triggered critical systems thinking (using the theories for social problems), emancipatory systems thinking (similar) and evolutionary systems design.*

work and being a methodology for qualitative analysis and design (see Section 10.3), combines 'hard systems' thinking, the development and use of systems engineering methodology, and 'soft systems' thinking, the development and use of social systems design methodologies. The main theories that evolved besides Applied Systems Theory as a collection of thoughts about systems are: System Dynamics, the Soft Systems Methodology by Peter Checkland, the Viable System Model by Stafford Beer and Critical Systems Thinking.

System Dynamics

System Dynamics is a an approach to understanding the behaviour of complex systems over time. It is mainly based on internal feedback loops and time delays that affect the behaviour of the entire system. Generally, it is applied to analyse any dynamic system that is characterised by interdependence among elements, mutual interaction between actors and elements, feedback loops and circular causality. Circular causality means that the effect of an event or variable returns indirectly to influence the original event itself by way of one or more intermediate events or variables; for example, event A causes event B, consequently event B causes event C and eventually event C

Box 10.1: Leverage Points for Intervention in a System

Based on the core concepts of System Dynamics, Meadows [2008] has identified twelve leverage points for interventions in a system. They are presented in order of increasing effectiveness; some have been adapted to fit with the terminology in this book. The interventions are:

- Constants, parameters and values (as properties of systems). Such interventions include subsidies, taxes and standards.
- Size of buffers and other stabilising stocks. This might concern their and should be considered in relation to the flowing elements
- Structure of material stocks and flows. This is the structure of a system and how processes are interrelated; examples are transport networks and population age structures.
- Length of delays. This refers to how fast control mechanisms respond relative to the rate of changes in the system of resources and the processes.
- Strength of negative feedback loops. This concerns the magnitude of the response by control mechanisms relative to the deviations they are trying to correct against.
- Gain around driving positive feedback loops. This indicates the strength of positive feedback mechanisms.
- Structure of information flow. This intervention considers who does and does not have access to what kinds of information.
- Rules of the system. This refers to responses that are triggered, such as incentives, punishment and constraints.
- Power to add, change, evolve, or self-organise system structure. These interventions reflect the capability of stakeholders to change parts of the system.
- Goal of the system. The key question is here whether stakeholders cannot only change the system but also influence its purpose.
- Mindset or paradigm. Going beyond the purpose of the system, this reflects the transcendental system level in the hierarchy of Boulding.
- Power to transcend paradigms. Again, this reflects the transcendental system level in the hierarchy of Boulding.

The latter four interventions are strongly related to the concept of boundary critique in Sections 7.6 and 10.4.

influences the original event A. The application of System Dynamics is often supported by simulation software.

The approach of System Dynamics for simulation begins with defining problems dynamically and proceeds through mapping and modelling stages to steps for building confidence in the model and its policy implications. Mathematically, the basic structure of a formal system dynamics computer simulation model is a system of coupled, non-linear, first-order differential (or integral) equations. Simulation of such systems is easily accomplished by partitioning simulated time into discrete intervals and stepping the system through time one interval at a time. Conceptually, the feedback concept is at the heart of the system dynamics approach. Diagrams of loops of information feedback and circular causality are tools for conceptualising the structure of a complex system and for communicating model-based insights. The concept of endogenous change is fundamental to the system dynamics approach. It dictates aspects of model formulation: exogenous disturbances are seen at most as triggers of system behaviour; the causes are contained within the structure of the system itself. These ideas are captured in Forrester's [1969] organising framework for system structure as well as the work of de Rosnay [1975]. The system dynamics approach emphasises a continuous view. The continuous view strives to look beyond events to see the dynamic patterns underlying them. Moreover, the continuous view focuses not on discrete decisions but on the policy structure underlying decisions. Events and decisions are seen as surface phenomena that ride on an underlying tide of system structure and behaviour.

Soft Systems Methodology

The Soft Systems Methodology [Checkland, 1981; Checkland and Scholes, 1990] is an approach for tackling soft, ill-defined real-world problems by formulating the concept of a purposeful human activity system (see Figure 10.7). A human activity system is a notional purposive system, which could in principle be found in the real world; for describing the root definition of a such system, the acronym CATWOE is used, see Section 4.8 (noteworthy is that the language in which human activity systems are modelled is in terms of

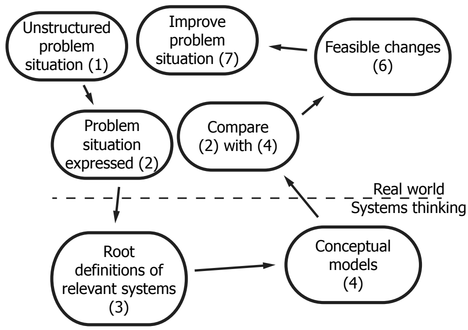

Figure 10.7 *Soft Systems Methodology. The methodology is based on a seven-stage process that moves from clarifying an unstructured or messy problem situation through designing ideal or conceptual human activity systems that would help improve the situation. These conceptual models are then compared with the problem situation in order to identify desirable and feasible change. The methodology integrates thinking about the logic of how to improve a situation with what is socially and politically feasible.*

verbs). Such systems are notional in the sense that they are not descriptions of actual real-world activities but are constructs of the mind for solving problems. Those descriptions facilitate discussions about possible changes, which might be introduced into a real-world problem situation. The Soft Systems Methodology provides a way of getting from ‘finding out’ about a problem situation to ‘taking action’ to alleviate it.

One of the major strands of application of Soft Systems Methodology is business modelling and support for developing information systems. The literature shows a number of methodologies based on Soft Systems Methodology relevant to business modelling in information system development. Examples of them are: the Information System Analysis Methodology [Wilson, 1990], the Methodology for Functional Analysis of Office Requirements [Schäfer, 1988], the Compact Methodology [CCTA, 1989] and the MultiView methodology [Avison and Wood-Harper, 1990]. However, the flexibility in the way of operationalising and the low level of formality of the Soft Systems Methodology modelling language limit the application of Soft Systems Methodology in practice.

The Viable System Model

Arriving at a very different approach to systems thinking, management cybernetician Stafford Beer [1959, 1966, 1979] spent many years researching the necessary and sufficient conditions for an organisation as a complex system to be viable. As one of the key figures in the systems theories movement, he determined that viability was maintained by engaging in different activities, keeping them from interfering with each other, managing them together, focusing on the future and doing so in the context of an identity within which the interests of the whole over time could be considered. In his perspective, this is how the human nervous system works and how successful collective enterprises work, too; see notes on comparison of biological concepts with organisational entities in Section 10.3. Most of all, his so-called Viable System Model uses the resemblances in both governing laws and structure for organisations and organisms as point of departure.

The Viable Systems Model, see Figure 10.8, represents this thinking and consists of five essential functions or systems. These management functions Systems One through Five, and they are repeated at different levels: the individual, the work group and on to each successive category, as long as it remains relevant (this has some similarity with aggregation strata, see Section 3.1). The five crucial functions of the Viable Systems Model act in a similar, holistic, way in each ‘cell’. They are connected together in the same way as the various organ systems in the human being and are responsible for performing the following tasks: (1) executing processes, (2) coordinating, (3) optimising, (4) observing and drawing conclusions and (5) deciding on and keeping track of values and ensuring identity. System 1 stands for what is done in the organisation and System 2 for how it is coordinated. System 3 stands for operative corporate management, System 4 for strategic

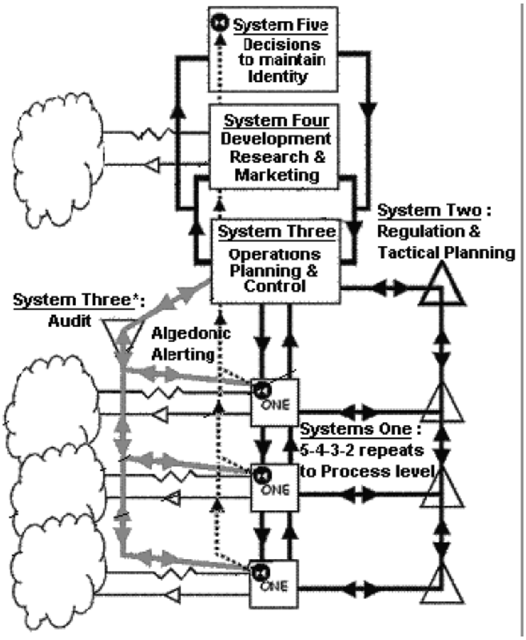

Figure 10.8 *Viable System Model (source: http://en.wikipedia.org/wiki/Viable_system_model#mediaviewer/File:Vsm.gif). System One comprises all activities that are undertaken in the organisation, i.e. its operations or primary process; it also might include control processes. System Two symbolises all the activities and resources involved in the coordination between the operative units . System Three stands for all the activities and resources that focus on the optimising of the operations of the individual systems. Part of System Three are the individual operative units of the organisation that interact with the environment, and all the activities and resources that serve to observe the environment and to gain experience from it and to allow strategies to be developed for the future. System Four indicates all the normative rules and regulations that apply in the organisation, such for example as the entrepreneurial ones relating to the creation and safeguarding of both identity and quality, the ones relating to ethical attitudes and to statutory and contractual provisions, and the ones relating to mandatory instructions.*

corporate management and System 5 for normative corporate management. The only criterion for using the model is that the System One units, which these management functions support, must produce something of value for the environment such that it could be, in its own right, a viable system (this has similarity with the steady-state model, see Chapter 6, whereas the processes of maintaining identity and development of strategies resemble that of the breakthrough model). When using the Viable System Model, it is often helpful to consider one level of recursion (see Section 8.5) as the 'system in focus' and to explore the levels of recursion immediately above and below it, again similar to the distinction of aggregation strata in Section 3.1.

The Viable Systems Model has been used to both diagnose existing organisational structures and to design new ones. Many applications of the

Viable Systems Model have been undertaken, by Beer and others, in business, government, non-profit organisations and non-organisational systems [Espejo and Harnden, 1989]. It also provides a useful template against which to consider alternative structures and new challenges the system is facing, like integrating its internal and its external knowledge or monitoring the evolution of its identity in a changing market.

MetaSystem Transition Theory

Very differently, the metasystem transition theory is the name for a particular cybernetic philosophy about the evolutionary process by which higher levels of complexity and control are generated [Joslyn and Heylighen, 1995]. According to Joslyn and Heylighen, it also includes views on philosophical problems and makes predictions about the possible future of mankind and life. Their goal is to create, on the basis of cybernetic concepts, an integrated philosophical system, or 'world view' (also called 'Weltanschauung'), proposing answers to the most fundamental questions about the world, ourselves and our ultimate values.

Three concepts dominate metasystem transition theory. The first one of the central concepts is that of evolution in the most general sense, which is produced by the mechanism of variation and selection (i.e. following mostly a Darwinian perspective on selection); for the application of such thinking, see for example Dekkers [2005], who uses the metaphor between organisms and organisations. The second is control, defined in a cybernetic sense, and asserted as the basic mode of organisation in complex systems (see Chapters 5 and 6 for the basic concepts of control mechanisms). This brings us to the third concept for metasystem transition theory, that of the metasystem transition, or the process by which control emerges in evolutionary systems. This third concept implies that the creation of variants calls for requisite mechanisms of dealing with variety (akin Ashby's Law of Requisite Variety, see Section 5.8). For those that are interested, this also corresponds with the increasing number of dimensions for fitness in evolutionary systems; see Dekkers [2005, pp. 126–128] for a more detailed discussion. Those three concepts help to explain the emergence of control during the development of systems.

As an application, Turchin [1977] shows that the major steps in evolution, both biological and cultural, are metasystem transitions of a large scale. The concept of metasystem transition allows introducing a kind of objective quantitative measure of evolution and distinguish between evolution in the positive direction, progress, and what we consider an evolution in the negative direction, regress (cf. the direction of evolution). For example, here is the sequence of metasystem transitions which led, starting from the appearance of organs of motion, to the appearance of human thought and human society: movement as the control of position, irritability (simple reflex) as the control of movement, (complex) reflex as the control of irritability, associating (conditional reflex) as the control of reflex, human thinking as the control of associating and culture as the control of human thinking. It is possible to explain all those transitions in evolution as logic sequences from a metasystem transitions perspective.

Critical Systems Thinking

As the final strand of system theories, critical systems thinking and the methodologies associated with it have been developed for the analysis of complex societal problems and interventions to resolve such problems (note that some points related to critical systems thinking appeared in Sections 7.6 and 7.7). Early approaches employing system thinking, such as operational research, system analysis and Systems Engineering (Section 10.1), are suitable for tackling certain well-defined problems, but have limitations for complex problems involving people with a variety of viewpoints and frequently at odds with one another. Systems thinkers responded with approaches such as system dynamics and organisational cybernetics to deal with complexity, Soft Systems Methodology and interactive planning to handle subjectivity and critical systems heuristics to help the disadvantaged in situations involving conflict. Because of the corresponding enlargement of the context of problems when applying systems theories, it is critical systems thinking that aims at providing a more holistic picture from a stakeholders' perspective.

Critical systems thinking draws on the combination of social theory and systems thinking [Jackson, 2001]. Social theory provides material for the enhancement of existing and the development of new systems approaches. Not all the fine theoretical distinctions drawn by social scientists make a difference when applied in the real-world, but some are of considerable importance and must be regarded as crucial for systems practice. Social theory also provides the means whereby systems practitioners can reflect on and learn from their interventions. Within that perspective, systems thinking can assist in the task of translating the findings of social theory into a practical form and encapsulating those in well-worked out approaches to intervention. The success of systems thinking in linking theory and practice provides a model, which can be used and applied to disciplines generally.

One of the core concepts of critical systems thinking is an approach called Critical Systems Heuristics that refers to the concept of the critical employment of boundary judgments [Ulrich, 1983, pp. 225–314], also called boundary critique. It says that the practical implications of a proposition (the 'difference' it makes in practice) and thus its meaning as well as its validity depend on how we bound the system of concern, i.e., that section of the real world which we take to represent the relevant context. The judgment of the merits of a proposition (it being preferred above some alternative proposition or its 'rationality') will depend heavily on this context, for the context determines what 'facts' (for example, consequences) and 'values' stakeholders and individuals will identify and how they will assess them. With respect to this crucial issue of boundary judgments, experts are no less lay people

Box 10.2: Example of Boundary Critique – Housing Services for the Elderly

This example about applying the boundary critique is described in Midgley et al. [1998].

Case Description

In that paper they describe how they were called in for the multi-agency development of housing services for older people. In the remit of the project it was not only about providing 'brick and mortar' but also a wider scope that also included adaptations of existing housing so that the older people could stay in their home. In that perspective the project covered public housing provision, housing associations, the voluntary sector, privately rented accommodation, owner occupied housing and related support services. Such a wide ranging coverage also implies a broad range of stakeholders; some of these stakeholders might be willing to seek influence of the solution at the expense of others, particularly the group for which it is all meant, the elderly people themselves.

Application of Boundary Critique

The authors show how through stages they achieved involvement of stakeholders that would be marginalised otherwise. Those stakeholders that are marginalised are found at the distinction between what they call the primary boundary and the secondary boundary; in addition, these stakeholders are found in the beyond the primary boundary. By interviewing all stakeholders they could clarify the planning provision itself would define a too narrow focus for the project. That allowed during the second phase of the project, the actual defining and organisation of services to achieve a wider focus of these services than a provision that would otherwise have resulted from only involving stakeholders within the primary boundary. However, it is the provision of feedback by parties that do not directly participate in the project and that cannot be associated with its outcomes that make it possible to set different boundaries; however, the condition is that this 'mediating' function is accepted by all stakeholders.

than citizens or other stakeholders in processes of societal change. Surfacing and questioning boundary judgments thus provides people with a means to counter unqualified rationality claims on the part of experts or decision makers – as well as other people – by demonstrating they way they may depend on debatable boundary judgments. The boundary critique demonstrates how systems thinking immediately translates into methodologically cogent forms of argumentation, i.e. they can make a difference between valid and invalid claims. The concept allows identifying invalid claims by uncovering underpinning boundary judgments other than those intended (or pretended) by the proponent. It explains why and how people and stakeholders in change processes are capable of contesting propositions and of advancing counter-propositions, without risking of being immediately convicted of lacking competence. Box 10.2 gives a concise description of how this was used for the development of housing services for older people in the UK. Hence, the concept of boundary critique indicates that critical systems thinking aims largely at resolving social problems through elevating conflicting arguments (for the purpose of discussion between various stakeholders).

10.5 Concluding Remarks

This chapter has shown that system theories have a wide variety of applications, spanning from technological systems to societal systems. In some fields the system theories have integrated into comprehensive approaches while in others they constitute an upcoming paradigm, e.g. systems biology. The range of applications extends beyond biological, technological and organisational systems from which most of the examples have been drawn in the text of this book. A case in point for stretching beyond those examples is that some of the theories and applications address societal challenges; an early example is System Dynamics for limitations to societal growth and later methods are Soft Systems Methodology and critical systems thinking. Although the basic concepts and some methodologies have been existent for a while, the concepts undergo further development and extension to new applications.

Because the system theories have been applied to so many different domains, it is also those domains that inform the further development of system theories. While not addressed in this chapter explicitly, the extension to complex (adaptive) systems (Chapter 8) and autopoietic systems (Chapter 7) are instances of the further development. These developments make it possible to understand better complex and non-linear behaviour. Also, mechanisms for networked structures that display that same complex and non-linear behaviour (see Section 8.6) can be better understood by these new developments. However, those developments sometimes do not deliver on promises made, sigh Richardson et al. [2001, p. 7] for the domain of organisations. Therefore, the concepts and theories for systems are subject to further development, though sometimes they might be considered to be in stages of infancy.

In that respect, systems theories also underpin inter-disciplinary approaches. The theories draw concepts from different and broad-ranging disciplines and they find their application in other domains. This to be considered the foremost characteristic of inter- and trans-disciplinary approaches (following the terminology of Aboelela et al. [2006]). And it makes system theories a true domain for consilience by analysis and synthesis [Wilson, 1998, p. 68]. However, we have not reached a stage where inter-disciplinary systems thinking serves a bridge between disciplines. Even within disciplines strands have emerged that hardly refer to each other. While inter-disciplinarity poses its challenges, it is also that it makes system theories so exciting, for both theoretical and practical developments. However, there is still a long way to go in developing both its applications as well as its theoretical foundations.

References

Aunger, R. (2000). Darwinizing culture: the status of memetics as a science. Oxford: Oxford University Press.

Avison, D. E., & Wood-Harpet, A. T. (1990). Multiview: an exploration in information systems development. Oxford: Blackwell.

Bakan, J. (2004). The Corporation: The Pathological Pursuit of Profit and Power. London: Constable.

Beer, S. (1959). Cybernetics and Management. New York: Wiley.

Beer, S. (1966). Decision and control: the meaning of operational research and management cybernetics. London: Wiley.

Beer, S. (1972). Brain of the Firm - the Managerial Cybernetics of Organization. Chichester: John Wiley & Sons.

Beer, S. (1979). The Heart of Enterprise. Chichester: Wiley & Sons.

Bergh, J. C. J. M. v. d., & Gowdy, J. M. (2000). Evolutionary Theories in Environmental and Resource Economics: Approaches and Applications. Environmental and Resource Economics, 17(1), 37-57.

Bergson, H. (1911). Creative Evolution. New York: Dover.

Bertalanffy, L. v. (1973). General System Theory. New York: George Braziller.

Boulding, K. E. (1981). The Economy of Love and Fear: A Preface to Grants Economics. Belmont, CA: Wadsworth.

CCTA. (1989). 'Compact' Manual (No. Version 1.1). Norwich: Central Computer and Telecommunication Agency.

Checkland, P. (1981). Systems Thinking, Systems Practice. Chichester: John Wiley & Sons.

Checkland, P., & Scholes, J. (1990). Soft Systems Methodology in Action. Chichester: John Wiley & Sons.

Dawkins, R. (1989). The Selfish Gene. Oxford: Oxford University Press.

de Geus, A. (1999). The Living Company. London: Nicolas Brealy.

de Rosnay, J. (1975). Le Macroscope: Vers une vision globale. Paris: Éditions du Seuil.

Dekkers, R. (2005). (R)Evolution, Organizations and the Dynamics of the Environment. New York: Springer.

Eldredge, N. (1997). Evolution in the marketplace. Structural Change and Economic Dynamics, 8(4), 385-398.

Espejo, R., & Harnden, R. (1989). The viable system model : interpretations and applications of Stafford Beer's VSM. Chichester: Wiley & Sons.

Faber, M., & Proops, J. L. R. (1990). Evolution, Time, Production and the Environment. Berlin: Springer.

Fagerberg, J. (2003). Schumpeter and the revival of evolutionary economics: an appraisal of literature. Journal of Evolutionary Economics, 13(2), 125–129.

Hannan, M. T., & Freeman, J. (1977). The Population Ecology of Organizations. American Journal of Sociology, 83(4), 929-984.

Hernes, T., & Bakken, T. (2003). Niklas Luhmann's Autopoiesis and Organization Theory. Organization Studies, 24(9), 1511–1535.

Heylighen, F. (2013). Building a Cybernetic Philosophy with Cybernetic Tools: the Principia Cybernetica project. Principia Cybernetica Web Retrieved 31st December, 2013, from ftp://ftp.vub.ac.be/pub/papers/Principia_Cybernetica/Papers_Heylighen/Unifying_Cybernetics_PCP.txt

Hodgson, G. M. (1993). Economics and Evolution - Bringing Life Back into Economics. Cambridge: Polity Press.

Hodgson, G. M. (2002). Darwinism in economics: from analogy to ontology. Journal of Evolutionary Economics, 12(3), 259–281.

Hodgson, G. M., & Knudsen, T. (2005). The Nature and Units of Social Selection (No. 0424). Jena: Max Planck Institute for Research into Economic Systems.

Jackson, M. C. (2001). Critical systems thinking and practice. European Journal of Operational Research, 128(2), 233–244.

Joslyn, C., & Heylighen, F. (1995, 29th June). Metasystem Transition Theory. Principia Cybernetica Web Retrieved 5th January, 2014, from ftp://ftp.vub.ac.be/pub/projects/Principia_Cybernetica/PCP-Web/MSTT.html

Kitano, H. (2002). Systems Biology: A Brief Overview. Science, 295( ), 1662-1664.

Laszlo, A., & Krippner, S. (1998). Systems Theories: Their Origins, Foundations, and Development. In J. S. Jordan (Ed.), Systems Theories and A Priori Aspects of Perception (pp. 47-74). Amsterdam: Elsevier Science.

Lauffenburger, D. A. (2000). Cell signaling pathways as control modules: Complexity for simplicity? Proceedings of the National Academy of Science, 97(10), 5031-5033.

Meadows. (2008). Thinking in Systems. White River Junction, VT: Chelsea Green Publishing.

Metzger, M. A. (1997). Applications of nonlinear dynamic systems theory in developmental psychology: Motor and cognitive development. Nonlinear Dynamics, Psychology, And Life Sciences, 1(1), 55-68.

Midgley, G., Munlo, I., & Brown, M. (1998). The Theory and Practice of Boundary Critique: Developing Housing Services for Older People. Journal of the Operational Research Society, 49(5), 467–478.

Nelson, R. R., & Winter, S. G. (1982). An Evolutionary Theory of Change. Cambridge, MA: Belknap Press.

Norgaard, R. (1994). Development Betrayed: The End of Progress and a Coevolutionary Revisioning of the Future. London: Routledge.

O'Shea, A. (2002). The (R)evolution of New Product Innovation. Organization, 9(1), 113-125.

Pruckner, M. (2002). Management Cybernetics and St. Gallen (Essay). Lampeter: Cwarel Isaf Institute.

Richardson, K. A., Cilliers, P., & Lissack, M. (2001). Complexity Science: A "Gray" Science for the "Stuff in Between". Emergence, 3(2), 6–18.

Schäfer, G. (1988). Functional Analysis of Office Requirements: a multiperspective approach. Chichester: Wiley & Sons.

Schwaninger, M. (2001). System theory and cybernetics. Kybernetes, 30(9/10), 1209–1222.

Senge, P. M. (1992). The Fifth Discipline. Kent: Century Business.

Sterman, J. D. (2001). System Dynamics Modeling: Tools for Learning in a Complex World. California Management Review, 43(4), 8–25.

Ulrich, W. (1983). Critical heuristics of social planning: A new approach to practical philosophy. Bern: P. Haupt.

Veblen, T. (1898). Why is economics not an evolutionary science? Quarterly Journal of Economics, 12, 373–397.

West Churchman, C. (1979). The Systems Approach: Revised and Updated. New York: Dell.

Wilson, B. (1990). Systems: Concepts, Methodologies and Applications. Chichester: Wiley & Sons.

Wilson, E. O. (1998). Consilience: the unity of knowledge. New York: Alfred A. Knopf.

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