Some
Systems Patterns

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Introduction

Our view of our world is system-centered. Building models of reality is an important part of learning. Systems Thinking is a way to manage the complexity. The systems approach can be found within many scientific disciplines like engineering and management. Systems Thinking seems to be a fundamental concept.

A key concept of Systems Thinking is to model parts of the surrounding world as systems with limiting boundaries and consisting of elements with interdependencies and mutual influences. Systems can be partitioned into subsystems or are themselves parts of others.

Systems Thinking has a long tradition, especially in western culture, where the analytical approach has arisen with the early emergence of science. In addition, systemic development is fundamental in nature.

Systems Thinking has several interrelated aspects:

- Thinking in dynamic processes
- System awareness by thinking in models
- Thinking in loops and networks
- Steering and systems control

Systems Thinking was introduced in management and organizational theory some decades ago by authors like Bertalanffy [Ber51], who developed a general systems theory linking different disciplines. With the work of Norbert Wiener [Wie48] and others (cfg. [Tur77], [Ros79]), cybernetics emerged as a branch of science seeking an interdisciplinary scientific approach:

> "Principles so general that they are applicable both to the evolution of science and to biological evolution require equally general concepts for their expression. Such concepts are offered by cybernetics, the science of relationships, control, and organization in all types of objects. Cybernetic concepts describe physicochemical, biological, and social phenomena with equal success." [Tur77]

Introduction

The different approaches to Systems Thinking all have a relationship to education in analysis and development. Many of these approaches pose basic questions that call for humanity and responsible dealing with natural resources. For instance, beginning with questions about the division of labor and responsibility in computer-supported complex technical systems, Rosnay raises appeals for humanity and the evolution of a new society.

> “What can be done? Shall we leave it up to the computers? ... The organization and the success of the Apollo program were due to the fact that it was a directed operation; those responsible were able to make choices, allocate time and resources, and organize time.
>
> Our societies, however, still do not know how to choose their goals. To liberate time, to restore to everyone his free time, neither growth nor a stationary economy will be enough. We must succeed in setting clearly our goals and deadlines. Perhaps then we shall be able to fight effectively against a form of waste much worse than the waste of energy or raw materials--the waste of human energy. But in order to accomplish this shall we have to go so far as to overturn our scale of values? Goals and deadlines imply choices among many types of constraints. Every choice at the highest level is based necessarily on a hierarchy of values. Ours has lapsed; the failure of our industrial societies testifies to it. Can we discern in the new generation, more open to the global approach, the emergence of new values?” [Ros79]

This is strongly related to the work of Christopher Alexander:

> “Alexander often refers to "*the quality without a name*" (abbreviated as *QWAN*). In **The Nature of Order**, Alexander has advanced his notion of this "quality" and now uses the term **wholeness**. Wholeness (and "life") emerges as a result of naturally occurring processes ...” [Cop79]

The pattern approach has its origin in architecture and was adopted by software engineering and areas related to software engineering, dealing with organizational and pedagogical questions.

Systems Thinking and system-centered modeling, engineering, and education are interdisciplinary. Systems Thinking can be seen as a foundation from which to spread the pattern approach and to provide a general platform for collaborative improvement.

The patterns in this collection focus on problems occurring in both natural systems and man-made ones. Observing solutions in nature – emerging and improving over the ages – can point us toward solutions for structurally and conceptually similar problems we face as actors influencing, designing, and running man-made systems.

Hence, the following patterns first extract fundamental problem solution pairs observed in nature and then deduce implications applicable in different disciplines, where humans design and improve systems.

Overview

Pattern	*Key question / key words*
Efficiency Prevails	How to enable evolutionary progress under conditions of scarce resources?
Actions Based on Feedback	How to design active system elements pursuing own or given objectives and able to react to changes?
Prepared in Advance	How can active elements react to changing situations fast and at the same time well justified?
Step-by-Step Progress	How to gain sufficient adaptation and pursuing improvement in dynamic systems, even though modifications are costly and risky?
Synergetic Collaboration	How to develop and employ efficient system elements able to accomplish complex tasks?

EFFICIENCY PREVAILS

Design, control, and progress of man-made dynamic systems restricted by scarce resources.

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In almost all dynamic systems – natural as well as man-made – resources are scarce. Scarce resources limit the total number of system elements. Evolution is primarily based on the emergence of new variants of existing system elements. New variants have to prove their fitness in competition with existing ones. Development of a wide range of different elements is costly and restricted by available resources. On the other hand, without the emergence of new variants no advancement can happen.

How to enable evolutionary progress under conditions of scarce resources?

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Design or choose elements which are most efficient in terms of construction and functionality as well as interaction with others.

In natural systems with scarce resources those elements prevail that are most efficient; at least in mid-term. Efficiency can be seen as the primary selection criterion in nature. System efficiency is determined by efficient constituent elements and processes.

There are many ways to obtain efficiency – proven in nature or created by human ingenuity – that suggest how to design, construct, implement, and refine systems. The following patterns capture these experiences and describe their application in man-made systems:

- **ACTIONS BASED ON FEEDBACK**
- **PREPARED IN ADVANCE**
- **STEP-BY-STEP PROGRESS**
- **SYNERGETIC COLLABORATION**

These patterns are a first pass at a pattern collection that has yet to be completed. They provide implementation details. The general solution that EFFICIENCY PREVAILS leads to implications for different domains as explained below.

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Engineering / Software Development

> **As an engineer you expound efficient system design knowing that efficient processes have a certain human quality and imply products with this characteristic.**

As an engineer, create efficient human-oriented production processes, driven by the needs of the user, involving them during the development process, which itself must consider the needs and abilities of those who are part of the process.

Development of new artifacts like products, machines, or buildings should try to reach a high level of efficiency in terms of the above mentioned principles. Artifacts created by a production processes are determined by the quality and organizational aspects of the process. At least in the mid-term, a waste of resources by inefficient processes and ill-designed systems lessens quality.

Of course goals related to resources like time and budget have to be reached. But in the mid-term, those products and production processes will predominate that are characterized by high efficiency on a comprehensive scale.

Ecological Systems

Humans influencing or determining ecological systems should be aware that, at least in the mid-term, efficiency determines which elements from flora and fauna are dominant under the conditions set by those humans.

Any environmental changes caused by human intervention or nature affect efficiency. Every intervention in an ecological systems must therefore be carried out very cautiously or not at all.

“Survival of the fittest” is an important selection mechanism in ecological systems. From this pattern's point of view, fitness is a question of efficiency in the actual context. An individual may survive in a threatening situation – i.e. the smallest system boundary. In the mid-term, larger boundaries have to be considered with a wider scope.

Economic Systems

As an active and responsible entity of an economic system you have to decide and act to maximize profit and increase efficiency in the short term. But not only short-term goals need to be considered. Successful economic systems are the result of progress in accordance with the above mentioned solutions to reach lasting efficiency.

In economic systems, efficiency is measured as the ratio of financial output and input. Efficiency is a decision factor. A small number of input and output factors is easy to measure but may provide insufficient information. For better decision making, efficiency should be based on a wider scope considering the above mentioned principles. For example, the Balanced Scorecard approach takes several weighted ratios into consideration.

Humans are the determining factor in economic systems. To fail their needs may cause a deficiency in the whole system. For example, pure “Stake-Holder-Value” oriented economies seem to lose out to economic structures that consider human factors and quality of working conditions.

Social Systems

People influencing social systems should be aware that the processes of interaction and behavior of the persons involved are evolving toward more efficient forms.

Social systems are constituted by a set of commonly accepted or – in a worse case – forced set of rules. These determine the system boundaries and the degrees of freedom of its elements: individuals, groups, and organizations. The determinants can change – planned and put into action by man or caused by environmental upheaval or technical breakthroughs.

Social systems tend to be constellations and forms of organization and interaction that are most efficient; at least in the mid-term having run through phases of adaptation. Change often means a loss of influence of established authorities. However, suppression of such development requires effort and as history shows, in the final analysis, not successful: serfdom, slavery, and totalitarian systems have largely disappeared.

However, the determining criterion is efficiency. When short response times and homogeneity of action are required, centralized systems have advantages with respect to information transfer and decision making. Examples are organizational forms and mechanisms in the military, fire fighting or disaster control.

Efficiency must be seen on the level of system elements, which themselves may consist of other elements. In social systems, fitness as an instance of efficiency applies not only to individuals. Group fitness is crucial for the survival of groups and species. Culture as a product of human intellectual abilities reaches a new dimension, that of memetic evolution:

> "Higher-level societies are usually marked by culture, which can be defined simply as models which are inherited between organisms in a non-genetic manner. We can define such non-genetic information, when carried between people, as memes. Memes, similar to genes, undergo a variation and selection type of evolution, characterized by mutations and re-combinations of ideas, and by their spreading and selective reproduction or retention." [Principia Cybernetica Web]

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Efficiency generally can be considered a ratio of output compared with the required input. In most sciences, precise definitions exist specifying the appropriate input and output, measurement units and methods, and boundaries of the examined system. Comparison implies at least two samples taken at different times. Samples have to be measured and evaluated so the method of measurement as well as the selection and weighting of the variables to be measured influence the result. Furthermore, the time elapsed between samples has to be considered. In many social or engineering systems influencers or designers are part of the implemented system or at least influenced by it; they are "bitten by the results." In addition to the scientific basis for efficiency, it seems that humans and other living organisms have a natural feeling of efficiency and are attracted to it.

Actions Based on Feedback

Design and implementation of system elements that are able to react to changes and can pursue objectives.

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Dynamic system elements have an effect on their environment, on those system elements to which they have relationships. These effects may result in changes that are better for the acting element or not. If the active element can choose actions based on an internal representation of the related parts – a model of the world relevant in the actual situation – they can choose actions on better knowledge. However, considering this information can not guarantee success or improvement due to possible insufficient or incorrect modeling.

How to design active system elements pursuing own or given objectives and able to react to changes?

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Therefore design and use active elements that are able to act according to the results of past actions.

To ensure progress toward objectives, relevant parts of the result have to be measured and compared to the desired values for those parts. Recursively actions are chosen depending on that comparison and the actual (sub-)goals.

Compared to a simple forward acting system, two additional elements are necessary to enable reaction based on a comparison of goal and current result: capabilities to recognize the relevant parts of the environment and capabilities for comparison.

In negative feedback loops, dynamic variables representing the differences between the desired and current states are continually minimized. In general, negative feedback loops create robust systems as continual adjustment copes with disturbances.

However, a negative feedback loop can lead to increasing oscillations and thus possible instability. When making all-or-nothing decisions, positive feedback loops may be preferable, as discussed in [Cin02].

To pursue objectives, these have to be represented. To develop objectives, models of the surrounding world and of desired states of the active part within this model have to be represented, too.

There is a wide range of representation mechanisms in existing systems: from physically manifest implicit representations like the simple reflex in nervous systems to explicit knowledge representation like computer programs and beyond to models of cultural evolution of societies with a shared body of knowledge, as described by Karl R. Popper (cfg. [Pop87]).

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Engineering / Software Development

As an engineer or developer you should implement feedback loops in both dynamic products tending to instability and complex production processes. Implement feedback loops in production processes using both:

- **mechanical or electrical elements and**
- **humans as part of the production process and as users of its results.**

Negative feedback loops are widely applied in technical systems, especially in electrical or chemical plants or in complex products, like cars. If a human is part of the loop, the feedback has to conform to human expectation based on the experiences of ordinary life. This is an important issue when designing man-machine interaction.

In many production processes, humans control the feedback loops. Short loops are effective, because any divergence can be adjusted immediately. Examples include:

- Workers doing quality assurance for their part of the production process or product. This not only allows a short and effective feedback loop to be achieved, but it also increases individual responsibility and self-esteem.
- In software development, feedback for the programmer can be machine generated – e.g. from compilers, testing and QA tools – which is useful for a quick response to minor, syntactic mistakes. At a higher, semantic level, feedback based on experience is valuable. Examples are review techniques and pair programming.
- When developing products, feedback about functionality can be generated in actual use or by anticipating the usage scenario. For products that are parts within a larger system, the parts can be tested using "hardware-" or "software in-the-loop" techniques. For products used by humans, involve customers to evaluate the extent to which their requirements have been met. Examples are software development processes like Rapid Prototyping or XP principles like "Frequent small releases that incorporate continual customer feedback."

Ecological Systems

Human actors influencing ecological systems should be aware that ecological systems are dynamic and that man-made intervention will affect not only the initially targeted parts but beyond that to those elements involved in feedback loops.

There are many examples, where an apparently simple, apparently harmless man-made intervention has had tremendous consequences: the release of rabbits in Australia with the objective of producing more prey for hunting; the release of African bees in South America to increase honey production; several newly recognized fatal diseases – like SARS and Ebola. These are all the result of insufficient understanding of nature's systems or – even worse – irresponsible behavior.

Social Systems and Learning

As an active part of a social system you should be aware that human knowledge acquisition and behavior is feedback driven. Encourage positive, authentic feedback.

Learning is affected by feedback. Sources of feedback include other humans – parents, group members, teachers – and the physical environment itself. To be able to live and act in a complex world, building models of the world is crucial. From the baby's first experiments in touching, feedback from our senses determines whether our assumptions of behavior and features are correct or not. If positive experiences support our assumptions they become part of our world model. Such positive amplification is referred to as reinforcement.

To avoid misunderstanding, in technical systems, positive feedback means an amplification of an error leading to instability. In the context of learning, positive feedback means encouraging behavior that has created positive results.

To accomplish your goal, feedback is indispensable. From their earliest experiences, humans acquire knowledge based on feedback. In other words: learning is self-directed. Teaching supports this process by setting the context, providing instruction, and moderating feedback – from a teacher, peers or other members of the group. Since feedback is so fundamental, giving it or influencing it is a highly responsible task.

Consequently, rules for giving feedback have been defined. When starting to work or learn together, it is recommended that these rules be described and jointly agreed upon.

Amplifying feedback is a strong psychological determinant in both intra- and inter-individual processes. The phenomenon of "self-fulfilling prophecy" illustrates the amplification of anxieties. In an organizational setting, McGregor's XY-Theory of de-motivating or motivating leadership illustrates the consequences of amplifying feedback.

PREPARED IN ADVANCE

Design and implementation of active system elements that are in competitive or time critical situations.

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Static or deterministic systems are most effective when active elements can just fulfill the necessary tasks. Additional capabilities would be unnecessary and a waste of resources, and produce inefficiency.

If the available capabilities are just sufficient for the predefined tasks, active elements are not able to cope with a changed situation. In dynamic non-deterministic systems, new situations and new tasks arise over and over again. Thus, those elements will prevail that are capable of dealing with the changing task situation. On the other hand, to develop additional capabilities and have them ready is costly.

Change may lead to threatening and time-critical situations in which the fastest, most adequate reaction means a competitive advantage.

How can active elements react to changing situations fast and at the same time well justified?

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Therefore active elements able to represent information about their environment should anticipate probable critical situations and store solutions for reacting in advance.

In order to be able to react to new situations, efficient and appropriate capabilities have to be developed that anticipate probable critical situations. Dependent on the descriptiveness of the surrounding system and on the capabilities of information representation a conscious anticipation – planning – or an unconscious anticipation – like training – can be applied.

As a general rule, the ability to react fast to changed situations is an advantage. Due to the difficulty or impossibility of exact prediction an anticipation based on experience or assumed models of the behavior of the environment is an adequate approach. If the relevant part of the system cannot be modeled or the active element is not able to model it, anticipation has to be based on experience. If the surrounding system can be modeled in a sufficient grade and the active element is capable to store and process information about the environment, planning based on the internal model takes place.

Prerequisites for the ability to plan are of high effort: explicit knowledge representation, elaboration of structural and dynamic models of the relevant part of the system and inference mechanisms for reasoning.

Hence, in nature the less effort taking, straight and effective of preparing by anticipation is widely applied: training and playing, as a pleasure giving kind of training.

Higher animals and humans grow up learning by imitation of adult's behavior. Playing is important for both:

- applying, repeating and adopting the learned and
- developing and strengthening mental and physical abilities.

Learning and training are the key concepts for being prepared to cope with the dynamic, changing life.

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Engineering

As an engineer, you can achieve robustness, stability and shorter reaction time by

- **providing information processing capable elements with abilities to react due to a-priori knowledge about the influenced or controlled system**
- **anticipate situations of the product's use and design it usable in the most probable and in the crucial cases.**

If the directly concerned part of the system can be modeled and stored in a explicit representation form i.e. on a symbolic level, then model- and rule-based reaction procedures can be defined and stored hardwired or in software.

When developing software, reaction mechanisms for the most probable non-standard situations have to be built in, like fault tolerant processing of user input, exception handling, roll-back in transaction processing.

In general, when designing products higher robustness or wider application fields can be achieved by building in applicability for different situations - chosen automatically or customizable.

If the structure and behavior of the affected part of the surrounding cannot be represented on a symbolic level, sub-symbolic representation techniques like artificial neural nets have to be used. To capture the information about the relevant subsystem's behavior supervised or unsupervised learning. Similar to learning in biological systems the setting of the training and learning conditions is significant for the success.

Simulation of systems allows designers and developers to improve their solution based on experiences made without the costs and risks of failures in application.

A good, long-time proved engineering practice is to anticipate the most probable and crucial situations as test cases. Experience in the way the elements under construction or improvement face up to the tests helps to improve them. In software engineering this approach has been adopted by the agile methods, for example Extreme Programming.

Social Systems and Learning

As an active entity of a social system encourage acquiring skills useful in possible upcoming situations by appropriate training.

We can't teach, we just can provide structure and direct the environment for learning so that individuals can acquire knowledge or skills: so to state as devil's advocate.

Starting point of the learning process is each individual's state of knowledge and skills. Progress is highly dependent on the context in which the process takes place and the motivation for it: at the best by the expected usefulness of the learned, in the worse case by enforcement.

Because EFFICIENCY PREVAILS, fast access and ease of applicability of the learned is important. Both can be achieved by training and reinforcement.

Figure 1 illustrates the GEMS model of human task accomplishing known as the “Step Ladder Model” developed by Rasmussen (cfg. [Ras86]). In this model, if a situation is known and immediately recognized, then a pre-programmed response will be executed on the skill-based level. Shortcuts in this model can be seen as anticipated and fast accessible – by trigger – solution schemes. Unknown situations have to be solved on the higher levels; however, getting more experienced, execution of prior unknown situations moves towards the lower and faster levels.

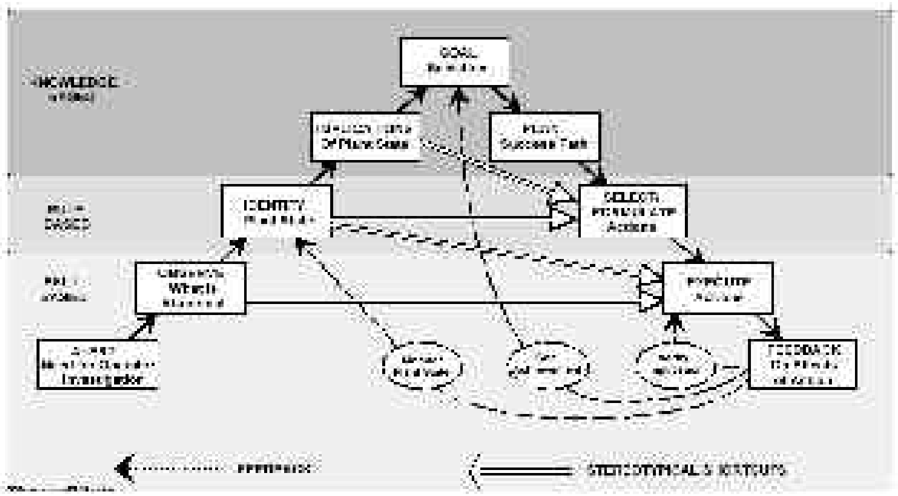

Figure 1: Decision-Making Model (adapted from Rasmussen)

Taking this model for granted, teaching has to focus to a larger extent on coaching the development of problem solving, as Dewey's cognitive approach to teaching emphasizes.

STEP-BY-STEP PROGRESS

Designing, implementing, running or improving man-made dynamic systems under conditions of planned or externally caused change.

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A characteristic of most dynamic systems is that their elements must collaborate to deal with change over time. New situations occur and elements have to deal with them. To be able to cope with new challenges the elements often need better adopted abilities and features.

Emergence of variants that might be better adopted can be driven from outside, like in technical systems, or is intrinsic, like in biological systems. In both cases the scale of occurring differences can vary in a large range.

Modifications to a great extent accompany with larger risks of deficiency and failure. On the other hand, without modification adaptation of elements and hence progress of the system itself is impossible.

How to gain sufficient adaptation and pursuing improvement in dynamic systems, even though modifications are costly and risky?

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Therefore new variants or modifications should differ only slightly in each progress step. Apply ACTIONS BASED ON FEEDBACK **to plan changes for the next iteration.**

In nature adaptation is a selective process in which such kinds of variants overcame that are able to deal with the changed situation most efficiently and successfully. For the most part, different types of elements arise from alternation of already existing features. Emergence of completely new abilities is unlikely in nature.

In technical systems variations are initiated and performed from outside: developers, engineers. Extensive changes can be carried out. In analogy to nature, stepwise modification, refinement and adjustment is a success promising procedure to achieve progress with probable minimal risks. Stepwise modification has advantages:

- The production of variants is in general not so costly.
- If modified elements are not suitable the lost effort is not too high.
- Emergence of variants and their prove to be successful in changing situations is a continuous process; a feedback loop.

However, there is no guarantee of progress hence iterations may result in a divergence from objectives. In nature several large progress steps were results of tremendous changes due to crucial events, like asteroid impacts or climatic changes. In man-made systems dramatic changes may occur but are normally not wittingly provoked due to risks and costs. Nevertheless, in case of stagnating progress a radical change may be considerable.

In nature emergence of variants is mainly caused by combination of features from the origin elements – like the parent generation – or probabilistic occurrence of different attributes: i.e. mutation. Those mechanisms are system intrinsic. In other systems – like technical and economy ones – progress is in the main externally driven. Human actors are able to plan and implement new types of elements as well as their functionality and collaboration. Consequently those active instances – individuals and organizations – should be responsible for their action, too. Consequences of the solution are illustrated in the following implications.

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Engineering / Software Development

As an engineer, develop products in processes of incremental improvement and stepwise refinement. Apply ACTIONS BASED ON FEEDBACK: Test and review the reached result and then plan next steps according to the result's tendencies during the last steps and based on own and others domain experience.

Start with existing solutions, if available and proven. Determinants in the stepwise adaptation of products and production processes are physical constraints – e.g. material characteristics, laws of physic – and user's requirements and abilities. The latter constraints are dynamic and change according to training, further development and adaptation of the users and to a large extend of new generations of users.

Examples in Software Engineering:

- Rapid or Incremental Prototyping
- Stepwise Refinement
- Piecemeal Growth
- Executable versions after short time and each iteration (“Short Releases” in [Bec99])
- Reviews and testing after short modifications and each iteration

Social Systems / Learning Context

As learning seems to be the process of building associations between already known and new contents, learners and teachers should be aware that acquisition of knowledge happens generally as a stepwise movement towards contents of related domains – learning by analogy – or by generalization and specialization within already known field.

To provide a path from known to new content giving examples and metaphors is widely used. In [MR03] the pattern STEP-BY-STEP describes an incremental approach to introduce new ideas into organizations. In other words: teaching learners as elements of a social system.

Synergetic Collaboration

Development and employment of resources to accomplish extensive tasks.

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If a single system element has to accomplish a complex task, extensive capabilities are necessary. In general, to develop and provide this abilities is resource consuming and costly. Often a single element is not even sufficient for a larger job.

How to develop and employ efficient system elements able to accomplish complex tasks?

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Therefore enable a coordinated collaboration of smaller less resource consuming elements using synergetic effects.

In a Synergetic Collaboration several small elements or process steps – each unable to accomplish a task alone – work together as a larger unit. The result is not only a quantitative accumulation, but a qualitative effect: synergy. This phenomenon occurs over and over again in evolution of social and economic systems, physical and chemical reactions as well as technical processes and progress. A “critical mass” of identical or interdependent small transitions is necessary to enable qualitative transitions.

[Tur77] refers to this phenomenon as the “Stairway Effect”, shown in figure 2: No progress is possible until capabilities are sufficient to overcome the first step. Sufficiency for the first step results in a breakthrough since the other steps with similar tasks are no longer a hurdle. Turchin gives a graphic description of this effect:

> “A baby is playing on the bottom step of a gigantic stone stairway. The steps are high and the baby cannot get to the next step. It wants very much to see what is going on there; now and again it tries to grab hold of the edge of the step and clamber up, but it cannot.... The years pass. The baby grows and then one fine day it is suddenly able to surmount this obstacle. It climbs up to the next step, which has so long attracted it, and sees that there is yet another step above it. The child is now able to climb it too and thus, mounting step after step, the child goes higher and higher.” [TUR77]

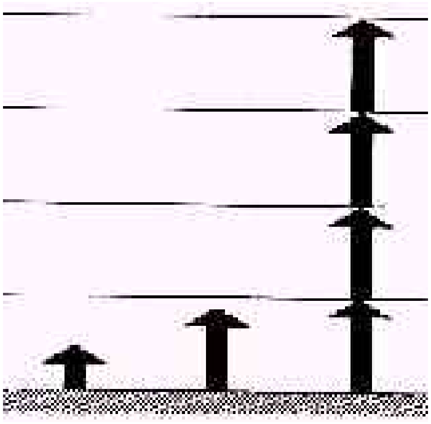

Figure 2 Stairway Effect [TUR77]

This effect can be found in several chemical or physical processes, like crystallization or chain reactions.

Social systems evolved based on evolutionary breakthroughs, like emergence of language enabling reflective thinking and forward planing, both pushing progress of language at the same time. During human evolution, emergence of new technologies and their manageability initialized deep-rooted changes in society: e.g. Agriculture, writing, printing, industrial production, and electronics. Availability of apparently all information at any time and in any place, enables the next large evolutionary transition allowing SYNERGETIC COLLABORATION to an unequaled extent.

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Engineering / Software Development

As an engineer, design systems consisting of small elements working together jointly and effectively.

This solution applies to both production and products. For example, designing production plants not as monolithic systems but consisting of smaller collaborating elements leads to higher flexibility and robustness, if abilities to task accomplishing overlap.

Depending on the social abilities, humans as parts of production processes are more productive working together in a group. Synergetic effects within a group manifest not only in productivity, but also in terms of creativity and easier coping with stress and workload.

SYNERGETIC COLLABORATION in modular designed technical products – software included – obtain higher flexibility, robustness and adaptability for different usage.

However, building systems consisting of small collaborating units - group working of humans, modular designed technical processes and products - is no silver bullet, elements need capabilities to interact and coordination may be necessary. This is an additional effort that has to be weighted up against the benefits of SYNERGETIC COLLABORATION.

Social Systems / Learning Context

As a part of social system, you should be aware that acquisition of knowledge or new behavior often is not a linear process but happens suddenly when a critical mass of new knowledge or abilities is accumulated.

Non-linear progress in learning is a result of SYNERGETIC COLLABORATION. If both – teachers and learners – are aware of this effect, their expectations should be more realistic, not expecting results linear proportional to the effort. This applies especially at the beginning of learning new content or training new abilities. For example, a certain vocabulary has to be learned and several exercises have to be done, before a learner starts speaking a foreign language fluently and a feeling for that language is established.

In general, group performance and problem solving / task accomplishing abilities do not evolve proportional to the effort of teaching, leading or training the group. Increase to a larger extent needs SYNERGETIC COLLABORATION.

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