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PRODUCT DEVELOPMENT AS A COMPLEX SOCIAL SYSTEM

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1 Introduction

You can sometimes wonder that product development creates successful products, while it seems to be quite a chaotic process. Product development is often not as rational as it is regarded in theory, as a sequence of logical steps, the use of clear rules, the calculation of parameters, etc. Research tries to capture the design rational for individual designers or small groups. But products, especially mechatronic products of a certain size such as cars or aeroplanes, have become more and more complex and so have the processes and organisations for their development, including thousands of engineers. While both more complex products require more complex organisations and more complex organisations make more complex products possible, the problem is how to manage this complexity. Call it rationality, call it transparency, call it control, they all decrease when complexity increases; though common design methodology helps a lot [1], it can hardly manage these processes completely: A lot of problems in industry still cannot be solved by design research; some phenomena cannot even be described adequately. At the same time, a lot of academic methods and tools cannot be applied by industry. It does not help declaring academia and industry two independent domains or to disavow those problems due to courtesies. There *is* a need for new approaches and a new understanding of product development. The answer might be another level of product development, where other principles apply than mere rationality, creativity or the like. This level is the complex social level of product development.

2 Approach

Product development and systems engineering have always been strongly connected, either by systems engineering being a basis for design methodology, by systems thinking being part of it, or by generally using similar approaches in order to achieve similar targets. Nevertheless, system theory, which again is the basis and the more general approach of systems engineering, has gone through some developments that design methodology has not considered yet. Actually it might be by this strong connection to systems engineering, which had separated from system theory and developed independently, that modern approaches are to be found in other disciplines. Its most modern approach is found in sociology, social systems being the most complex systems at the moment [2]. It focuses on how systems naturally emerge and preserve themselves, not on decomposing closed systems from a reductionism's point of view. This system theory helps both extending systems engineering and addressing problems and that social level of product development.

Thus the 'method' of our approach is to transfer and apply principles of system theory and sociology to product development. While a mere and straight transfer might be questionable, it can be definitely used as an inspiration for process improvement measures. These in turn have been proven by a multitude of projects in industry. The products we address are complex mechatronic products such as cars or aeroplanes, products with ten thousands of components developed in organisations with thousands of engineers. But the principles might be valid for smaller companies and less complex products, too.

3 System theory

3.1 Emergence of Systems

Sociologists have investigated how social systems, (over)simplified a group or organisation of people, emerge. Though different models exist, six steps or functions have been identified that have to be fulfilled to be a proper system (Table 1).

Table 1. System functions – emergence of systems (adapted from [3])

Function/step	Purpose	Problem	Following problem
Differentiation	-	Environment	Factual complexity
Gaining of resources (specialisation)	Satisfaction of needs	Scarcity	Social complexity
Structuring (differentiation of roles)	Warranty of satisfaction	Organisation	Temporal complexity
Process control (process rules)	Collective targets	Time	Operative complexity
Reflection	Self-determination	Identity	Cognitive complexity
Genesis (generative differentiation)	Growth	Evolution	System complexity

This process can be described as follows. A quasi-system is formed by some people coming together and perceiving themselves as somehow belonging together. E.g. a group of people comes together because they all have the idea or wish to build a new product. Factual complexity is the next problem, meaning that many such systems compete for scarce resources. The gaining of resources can be achieved by a specialisation of the system and an assimilation of its members. By the way, one important resource is people, i.e. the members of the system themselves. The group e.g. specialises on developing a new bicycle. This product has to bridge a gap in the market and attract more developers or members of the team in general.

The social complexity of interacting people and systems leads to the need of structuring the systems. Within a system, functions are defined, so that not everybody has to deal with everything; e.g. one person is responsible for the mechanical design, one for the purchasing of standard components, one for testing, etc. The growing system disables a direct communication between all of the members, thus process rules how to interact are implemented. Furthermore, temporal changes of the environment constitute a complexity that has to be answered by a process control of the system, i.e. how the members of the system react to changes of the environment. So the rules concern the acting of the system as well as the change of the system and its structure itself. The members of the system are now reduced to roles. In the example, clear rules might be necessary to tell how and when a specific property has to be tested or how new members can join the team.

Increased process control enables the system to do more than just react; it can do anything, it can *act*, which leads to an operative complexity through its multitude of possibilities. This is solved by reflection, the perception of the system by itself and as part of the network of systems. It develops a consciousness of its position and responsibility in the higher system. The development team might reflect their mission after the first product is released and decide that it is the innovation of mechatronic adjustments of a bicycle defines and differentiates their company. The consciousness leads to cognitive complexity, we all know, that can be solved by purposeful integration in the system of systems, together with an acceptance of other systems, and a generative differentiation: by generating new systems, the system can grow further and develop different solutions. Our development team might be capable of founding new subsidiaries with their successful product. This finally leads to a new level of complexity.

It is interesting that the same process is valid for the phenotypic emergence of multi-cellular organisms [4]. By reproduction similar cells in a bounded location form a first system. They build an environment only suitable for them and specialise in relation to the remaining environment. The cells themselves specialise like first organs and structure the organism. Nerve cells enable a communication within the system over relatively large distances. The interconnection of nerve cells constitutes a brain and finally by reflection a consciousness. The complexity of thoughts requires a meaning or identity in the social environment. Finally, the genesis refers to a more elaborated advancement of higher developed organisms.

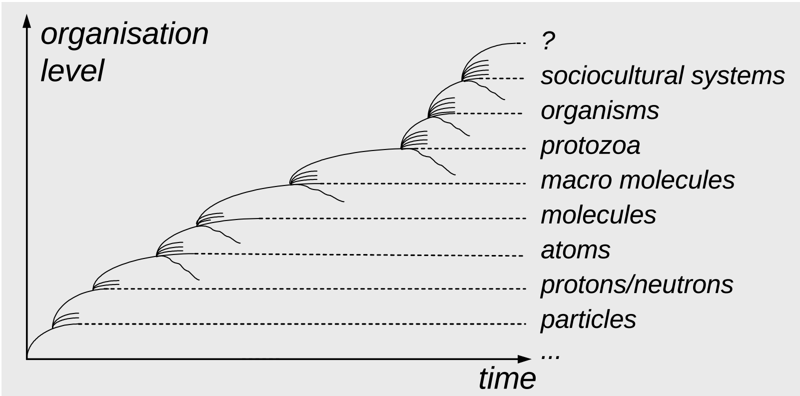

Figure 1. Organisation levels and the General Theory of Evolution [5]

The psychic system develops in a similar way. Furthermore, the six steps correspond with the *need pyramid of Maslow* with basic needs, the needs for security, social relations, social appreciation, and self-actualisation. In a similar manner all systems emerge from elementary particles to social systems (Figure 1); but only humans and social systems reach the last steps of reflection and genesis. Emergence means that qualitatively new behaviours ‘emerge’ on a new system level, which only base on the behaviour of the system’s elements, but cannot be predicted a priori. One example for a new level might be the emergence of thoughts, which are ‘physically’ based on just the quite simple interaction of neurons. Another, even simpler example is the *Game of Life*, where on a matrix the fields can be marked or unmarked. This mark changes depending on its previous state and the number of marked fields around it in the previous state. Despite these simple rules, special patterns can show relatively complex behaviours, such as moving over the matrix. This is enough to understand everything.

Another important aspect is that behaviour is always an adaptation of a system to its environment. Behaviour, intelligent behaviour, or even the system itself only exists if someone—which need not be a person—is regarding it in that way. ‘Radical constructivism’ states that the world as we perceive it only or at least mainly exists in our mind. The different viewpoints of different individuals are what cause all the problems and the need for communication. It also leads to the importance of follow up actions, i.e. the activity of one individual is always based on the activities of other individuals. Actually, there is nothing else than follow up actions. There is no big plan, it is all action following upon action.

3.2 Complexity

System theory can also be called complexity theory. Before we look at communication in detail, it is important to define complexity adequately. The six system functions are progressive ways to process complexity. They also produce complexity on another level. E.g. the process orientation reduces the complexity—or the meaning—of the temporarily changing environment; it also increases the complexity of your possibilities to act, leading you from reacting to really acting. Can we now say what complexity is? *Complexity is the multitude of possibilities how the system's elements can interplay, from which only a few can be realised.* Actually this includes other definitions of complexity such as the amount of elements and their relations. Within a complex social system, everybody might talk to anyone else; but due to the large amount of persons it is not possible that really each person is talking to everyone else. Complexity needs organisation and selection, but it also means possibilities. You can reduce complexity, but not completely. The actual question is how to process and use complexity. Complete transparency of a complex system is not the answer; the answer lies in communication and adequate media. See centrally organised economy that was not able to fulfil the needs of an (eco)system; free enterprise economy was able to do it without aiming at transparency.

Contingency names this multitude of possibilities: the current, actual state is only one of many possible other ones, not meaning a clear choice, but the consciousness of its indetermination. Bifurcations, splitting paths in chaos theory, lead to alternative worlds, from which just one is realised—or is perceived by us as being realised. Contingency means that this one world with its animals, humans, plants, social systems, etc. could look completely different.

3.3 Communication

Communication is now the major principle in system theory, which again can also be called communication theory. *Communication is understood as any form of social coordination of activities* ('social' only referring to the interplay of many elements of a system). By that definition, all of the system functions can be interpreted as communication: the structuring by assigning coordinated tasks, the reflection by implementing the same background, etc. On a more specific level communication takes place via different kinds of media (Figure 2).

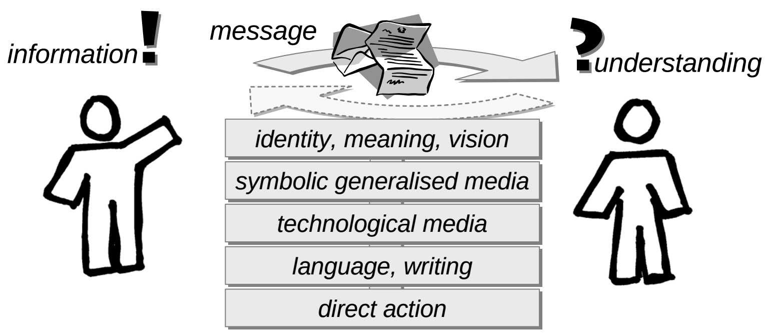

Figure 2. Communication and media

Communication can take place via direct action (e.g. showing someone how to do something). Language and writing allow communication of complex knowledge over long, temporal distances, enhanced by technological media such as the internet. Symbolic generalised media allow the communication of elements that are hard to compare. An easy example is money, enabling the exchange of different articles and labour ('symbolic' because it has no value on its own, 'generalised' because other elements are related to them). Another medium is identity, a vision, or a meaning, coordinating the acting of individuals without direct interaction.

It is necessary to understand that we do not focus on the aspect of communication being just an exchange of information. For us communication is an improbable action. One person has 'an' information, which is translated in a message, which is finally somehow understood by another person. What the latter person understands cannot be determined by the information, the message or the first person. System theoretically it can only be intervened. The understanding of the second person is a new information, so that the communication (acting) can go on.

It is now quite interesting that the media and their continuous exchange, i.e. the communication, finally constitute the system. This holds especially for social systems or functional systems. Different systems are constituted by different media. Table 2 gives some examples, which shall illustrate the concept. E.g. economy is constituted by the exchange of money. E.g. 'justice' still has the function of individual administration of justice, but the functional system of justice is based on the continuous communication of justice in form of laws and sentences. This continuous communication or self-preservation by self-reproduction is also valid for e.g. organisms, which are constituted by the continuous reproduction of their cells[1], i.e. a communication of their genetic code and structure, or for a species reproducing itself.

Table 2. Media of different systems

System	medium	purpose	criteria
Economy	money	satisfaction of needs	value, need
Politics	power	common decision, balance of powers	security
Science	perceptions	development of knowledge	usefulness, credibility
Justice	laws, judgments	conflict regulation	morality

The meaning of a system again defines the media that are 'meaningful' for the communication in the system. This could also be defined the other way round, but the point is that e.g. communication via money does not make sense in the science system. In the same way, e.g. different scientific domains communicate with different sets of knowledge and media, making it hard to communicate between them. The interfaces between different systems seem to be the reason for actual problems (e.g. science and religion, economy and justice etc.).

Now that we have said that the communication constitutes a system, it still has to be defined what a system actually is. A system might be defined as an amount of elements and the relations between them. But this leaves to much arbitrariness in the systems border. A better definition is that the elements of a system have quantitatively and qualitatively more relations (related to the 'meaning') within the system than with other elements outside the system. The people within a company 'talk' unquestionably more about issues of that company than they do with others. Again, a system is a differentiation from its environment; by that it also defines its environment as everything not belonging to the system. You could say that the differentiation defines the meaning, which again defines meaningful communication, which again defines and constitutes the system. By the way, it has been shown that a complete logic can be set up by nested and sequenced differentiations [6], giving systems theory its fundament.

Systems are defined by differentiations, thus systems can overlap. This is the difference to a classification, which becomes problematic nowadays in many disciplines (e.g. plants and animals and fungi in biology). Systems are defined by differentiations, not by categories. Hierarchies are just nested differentiations, not the main structure of the overall system.

3.4 Development of system theory and systems engineering

Similar to the emergence of systems, system theory itself has evolved. While its origin was to develop principles that are valid throughout the disciplines and techniques that can explain phenomena within one discipline, it has become some kind of 'holistic' thinking—whatever that does mean—and only parts of the potential of interdisciplinarity are used. System theory itself developed from a general system theory with closed systems and the target of control to a first order cybernetics of open systems with the aim of steering a self-regulating system. It finally moved to a second order cybernetics of autopoietic (self-reproducing), integrated (the

[1] Actually, sociology adopted this principle from biology: the definition of life as systems that continuously reproduce themselves, i.e. their elements, e.g. an organism reproducing its cells.

observer is part of it) systems with the aim and only possibility of intervention. Regarding its origin, system theory might need the emphasis of interdisciplinary approaches again [7] and an aim of development or reflective evolution in future (see ‘from evolutionary consciousness to conscious evolution’ [8]).

Harsh criticism on modern system theory can be found due to its relative lack of definition and its applicability to all systems, which actually is the aim of system theory. But then the understanding and inspiring aspects of system theory are forgotten. In the same way it is to differentiate which system is regarded with which system theory: a technical system can be regarded with systems engineering, a social system can be regarded with modern system theory. To regard them the other way round has advantages and disadvantages. Finally, new concepts have always started in a blurred way, becoming mathematically clear only after a while. There is no reason why this system theory cannot be transformed to a mathematical theory.

So there is no insurmountable contradiction to systems engineering. The viewpoints and the regarded systems are different. While most of the principles in system theory have equivalences in systems engineering (e.g. system border vs. differentiation, variation vs. genesis, etc.), systems engineering has its strengths in modelling and in the strategies, systems theory in the communication and in the concept of continuous self-reproduction. This is the main difference: systems engineering focuses (to be) finalised systems, i.e. how to develop, run, and maintain complex systems; system theory looks at the continuous development of systems.

It shall only be addressed that systems theory is found in other disciplines. E.g. quite a harmony exists between system theory and quantum physics, which cannot be explained here.

What has to be summed up is that

- complex system cannot be controlled nor can complete transparency be achieved, instead of which communication and differentiation become central,
- hierarchies and classifications are overcome by systems and differentiations, and
- systems emerge in a describable way and preserve themselves by reproducing the elements of which they consist.

In the following we will transfer these principles to product development and adjacent areas.

4 Product development

Product development is often regarded as a rational process, where systems theory is covered by systems engineering [9]. Systems engineering consists of systems thinking, decomposing the product hierarchically, of the problem solving cycle as well as strategies such as ‘consider variants’. Nevertheless, some phenomena can hardly be explained by ‘rationality’, e.g.:

- there is hardly any transparency in cost, variants, processes, etc.; nevertheless, these chaotic situations result in good products;
- the willingness to change and flexibility is lacking; decisions are made late; responsibilities are unclear;
- the potentials of large organisations with ten thousands of employees do not seem to be exhausted.

Many approaches regard product development as a ‘social’ process, as a process taking place in a team or a group of few people, e.g. [10], [11]. However, they assume some kind of shared understanding, working on the same problem, and the possibility of controlling that group. Our approach is to understand product development as a social process on a completely new level of complexity. Figure 3 illustrates this. The previously set up definition of complexity elucidates this qualitative difference: now, too many persons are involved in the design process, so that not everybody can directly communicate with everyone else.

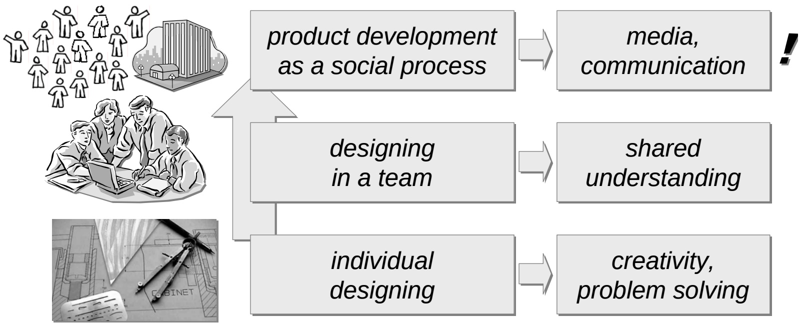

Figure 3. Complexity levels in product development

Before we look at how to deal with this new level of complexity, what the media and the communication are, we try to make the understanding of product development as a social process clearer (Figure 4). Product development is not a sequence of process steps, which have been more and more parallelised in simultaneous engineering. It has always been a system of parallel, interdependent processes, a system of people working concurrently.

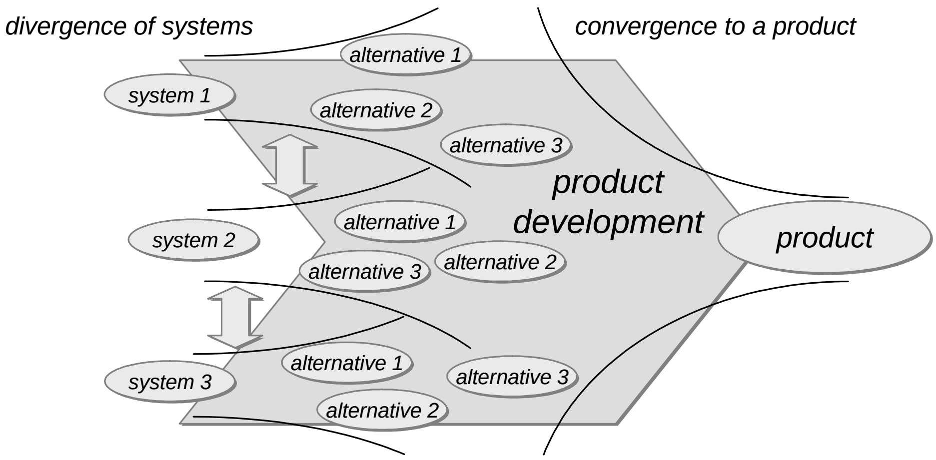

Figure 4. Product development as a social process

One can imagine the product as an ecosystem with the systems (or main components) as the species, which in an evolutionary process adapt to *each other*. This picture is not too far fetched if you consider that the systems are represented by organisational units, which actually *form* a social process. Though the single systems develop variants ('mutations'), they finally have to converge into a functioning product (the 'ecosystem').

If we now regard product development as a complex social process or more accurately as a complex social *system*, we can ask for the media constituting that system and enabling communication. For that we have to distinguish two kinds of product development:

1. the long term development of technology in the meaning of history of technology, we will now call *technology development*, and
2. the development of one new product or product line.

Regarding the development of technology, it is hard to prove that every product is based on existing products; but the other way round, it is easy to find predecessors for each product definitely influencing the ‘shape’ of the new product. The media in the technology development are the products, the ‘technologies’ themselves, either as a real product on the market or a patent, an idea, an invention, etc. You can even say that products communicate with each other: modern cars look the way they look like, because they are based on classical coaches; the coach communicated with the car, because the car adapted its ‘acting’ (its appearance) to the coaches ‘acting’ (appearance). This is not too far fetched. In how far new technologies based on new physical principles (see e.g. semiconductor electronics based on quantum physics) are completely new or are also based on former technologies, shall not be discussed here.

For us the media in single product development processes are even more interesting. Of course, language is still one of the most important media, since product development takes place in a locally and temporarily relatively close environment. But it often fails where different ‘languages’ are used (e.g. between different domains) or where conflicts of interests arise; then other media have to support communication.

Astonishingly, **money** is no major medium for communication between departments *within* product development. Money is just assigned in form of budgets. Between OEMs and suppliers money *is* a medium for communication, but here as well, money is not an exact property of a product, but a negotiation between the communicating partners. Lacking competition finally disables the use of all of the advantages of money, e.g. showing efficiency or demands.

Decisions are the media constituting an organisation [3]. One might think that people are the media of an organisation, reproducing the organisation, but in effect people are replaced by roles. And both, decisions are made due to the expectations on roles, roles are defined by decisions. Decisions are also the main driver for product development. But making decisions in order to enable other units to progress their work based on that decision contradicts keeping them open in order to react to changing market requirements. This is the contradiction of closing or preserving contingency in system theory. Decisions should be made or not depending on how many follow up actions are possible: if a decision is necessary to enable even one action, it should be made, if it is not necessary, but limits the activities, it should be deferred.

Models now seem to be one of the most important media in product development, since they allow communication between different people as well as different domains. Actually, the whole development process is based on models, even the final product is just a reference model of the mass product. And models are closely linked to methods.

Some reasons argue for seeing **methods** as a medium for communication, next to their function of systematic problem solving:

- one’s acting can be totally focussed on the method without always questioning the purpose behind it (one of the original, later perverted advantages of e.g. money, too)
- the result of a method is generally accepted, if the method is generally accepted
- many methods combine different viewpoints of the product and by that domains that can hardly communicate with each other (e.g. QFD as a combining of the customer’s and the technical view)
- it is theoretically possible to describe the whole process via methods; methods can also be a product of an company improving its processes and do not have a meaning on their own.

Uniting methods and models, one could say that product development is a system constituting itself by the communication of product models. However, this is not everything since the direct interaction still predominates. Methods in product development also cover tools such as e.g. PDM-systems, serving communication. And a process model can be understood as a medium for communication, too, in the meaning of everybody following this plan as a rough frame. It does not contradict the general approach that there are different media in one system. It has been shown in detail that technology development can be regarded as an evolutionary process and that even in biology media alternate (genotype and phenotype) [12].

Before looking at the implications of this regard, i.e. how to improve development processes, some hard to explain phenomena of product development shall be discussed in this light.

5 Observations in industry and their explanation

In the course of various projects conducted with industry and referring to various methodological topics and product development in general, recurring phenomena have been observed. Though these phenomena have just been observed in individual enterprises, they seem symptomatic for large companies. They are no criticism on large companies, which still work fine. They only show that there is partly a wrong understanding of the processes running there.

The most astonishing phenomenon was the complete lack of overview or transparency of costs in any company. This refers to part, tooling, and developing cost as well as to labour, material, and overhead cost. They were neither complete nor coherent with other account schemes. Nevertheless the companies were more or less successful and made their profit. But they reach their goal and cover the uncertainty of ‘normal’ costs by high prices for spare parts and additional equipment. The problem seems to be that money was a medium that helps handle complex processes, where complete overview or central planning is *not* possible. It is right that still overview should be possible, at least in an analytic way and a limited area. But by the assignment of budgets and the allocation of costs, money seems to have become more a medium of disguise than of control; a medium to justify the status quo. It is still a medium of communication in the meaning of putting pressure on the design process or giving targets. But it has lost its original meaning of communication, its advantages as a measure for efficiency, demands, etc. When used as such, when units of the company are economically independent entities, overview in definite areas should be possible, which can be added up to higher levels. Again, the current situation is like centrally planned economy, which has not worked in national economy. And again, this is not criticism; it shall only make clear how things work.

Company departments show seldom a willingness to change. This can be referred to the system functions: the departments do not want to change from a specialisation to a clear structuring or from a clear structuring to a process control (e.g. introducing sub-departments, implementing a building set strategy, a workflow management, etc.). This unwillingness is understandable since the transition to another state means leaving a secure area and is connected to efforts. Thus a transition will only be done, if an external demand or a crisis requires a change. It is imaginable to set up a crisis—to bring the system to a state far from equilibrium—just to force the system to a new state, where it finally performs qualitatively better [13].

The unwillingness to implement a process control or process management has also its origin in the problem, that product development has hardly repeatable processes. This is most of the time the reason why process management for product development is neglected or reduced to administrative activities. Actually, process management need not mean that the whole process is described, but that single process steps give orientation and facilitate communication in the system (e.g. ‘what to do if a supplier does not cooperate’). They are no must that is to follow, but an aid so that not everybody has to think about a problem’s solution anew. Finally, process management must not be limited to the processes performed by the system; it must also cover processes changing the system itself, e.g. how to change the composition of a team.

Other observations have shown that problems are often quite trivial, e.g. when two departments just do not talk to each other. Often enough the solution to a problem is already known by someone, but it is not revealed due to a lack of communication. This lack of communication can be helped by little methods.

6 Approaches of a system theoretical product development

A major problem of methods as well as process models, tools, etc. might be their striving for the big picture and the neglect of their communication function. The approach is now quite obvious. Firstly, the communication aspect of methods has to be emphasised. E.g. brainstorming is a communication of ideas between developers; QFD has to become a communication of requirements between marketing and development, etc. Secondly, and actually this is the same, methods need not cover the whole process. They only have to combine small aspects of the development process. They only have to support the developer in one step. The whole picture needs flexibility, which is added by the developers themselves. As in economy, you do not need money everywhere; you only need it as an exchange between not so close parts. Going back to methods, methods can fulfil all of the system functions (Table 3).

Table 3. Media of different systems

System function	understanding of methods – methods…	example
Differentiation	…help differentiating systems	functional analysis, DSMs
Specialisation	…make capable of acting without thinking about it	procedures
Structuring	…support single activities; …help structuring	statistical/mathematical methods
Process control	…support communication and combine viewpoints	QFD, requirement analysis
Reflection	…help reflecting the own proceeding	procedures, evaluation methods
Genesis	…help develop new products and new methods	creativity methods

All of the system functions are as well usable for communication, again meaning a coordination of activities: this can be supported by common visions or ‘corporate identity’, by the structuring of the development system, by definite media, etc.

We have looked at a different understanding of methods within product development. But also the evolutionary process of what we called technology development has its implications on product development. This shall be called *evolutionary development*. Central idea is that every product is based on other products [14]. Some implications might be:

- Not the final solution has to be achieved, more important is the first step towards it (e.g. do not develop a building block strategy, but set the organisational boundaries so that it develops itself by forcing suppliers to fit their components in a common structure).

- “Phylogenesis recapitulating ontogenesis” also holds for products: a product shall be developed in the way its parts evolved in history, the same for its variants and for the domains involved. In an easy way, start with the component that defines the product.

- Clearly state the components that have to be changed compared to the preceding product. Justify each component. Refer the whole development to one central model; this can already be seen in industry.

- Push developments that are obvious from the phylogenesis of the product. Look at solutions in other domains (technical, artistic, etc.). Search for techniques that can be combined. Imagine how the product will look in 10, 20, 50, 100, 500 years.

- Successful products or product types, such as cars or mobile phones in general, seem to clearly address one system function, e.g. communication.

So these implications have importance for innovation and creativity, too. Even the opposite can be used (e.g. not to develop based on a predecessor), but it should be done consciously in order to understand the principles of development. The system functions themselves can be interpreted as a procedure model for product development, both for product development as a department and for the technical aspects.

But more important, still the concept of ***systems*** itself has to be explained in detail. As we have said, a system is some kind of differentiation from its environment or, in other words, a meaning that leads to qualitatively and quantitatively distinct relations within the system. We can now transfer the system concept to products: a system is any differentiated scope of the product (Figure 5). It might be the electrical system, the braking system, the metal system, the aesthetics system, the aerodynamic system, the steering system, the screw system, the safety system, the quality system, etc. Whatever you like. Just ask: what belongs to that system? Here, the meaning might be the function of the system, leading to distinct relations within that assembly, e.g. in an engine the relations referring to the function of energy conversion. The relations finally define the system.

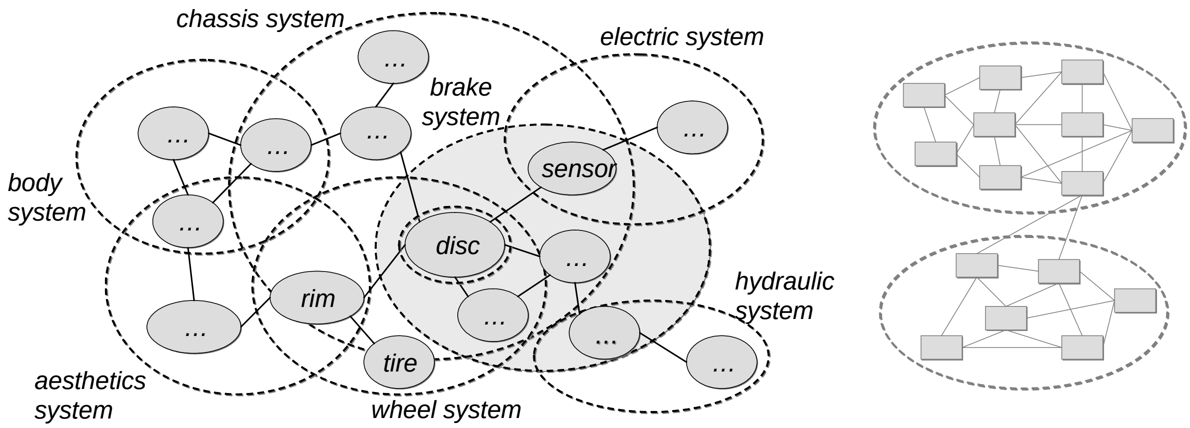

Figure 5. It is like set theory for product architecture

More important than the meaning is the structure of the system(s). Stop imagining the product as a hierarchy of parts, which is never consistent. A few different hierarchies in the meaning of views only fight the symptoms. Imaging the product as ten thousands of parts combined together. There are no functions, no requirements, no properties, no domains; except as views on the parts and their relations. Now fill that network of parts with these views; differentiate systems; project hierarchies on it. A hierarchy is only a special structure of systems, roughly projected on the net of ten thousand of components. Even two assemblies or modules linked together are ultimately just two sets of separate components linked together. A component is just a special kind of system. An abstract function is just one special kind of system. The whole product, the whole system consists of systems, which consists of systems that can arbitrarily overlap. Systems are any kind of differentiations. Differentiations again can be logically differentiated in decompositions (AND-relation—the car consists of body AND engine) and specifications (OR-relation—the car might be a sedan OR a convertible). A third relation is a direct link between two (decomposed) components or systems. These technical relations have to be regarded as technical systems, too. A hierarchy consists of clearly nested differentiations. The systems come first, then the hierarchy, not the other way round. *Think in systems.* This is important. This does not only hold for products, it also holds for organisations.

There are already tools according to and supporting this systems view, such as Design Structure Matrices [15], which can help differentiate or structure overlapping systems or show the communication in a system; a clear understanding of the system theoretical background can help enhancing these tools, too.

7 The dynamic organisation

The problem of hierarchies—that there is not *one* consistent one—is not only found within the product, it can also be found in the organisation. The contradiction of a project organisation and a functional organisation has been ‘solved’ by the matrix organisation [16]. This reorganisation by simultaneous/concurrent engineering had positive effects on flexibility and efficiency, but on one hand it also led to the new problem of multiple superiors, while on the other hand it structured the organisation for product development not even enough. From that point of view there are maybe eight ‘dimensions’ for structuring the organisation (Figure 6).

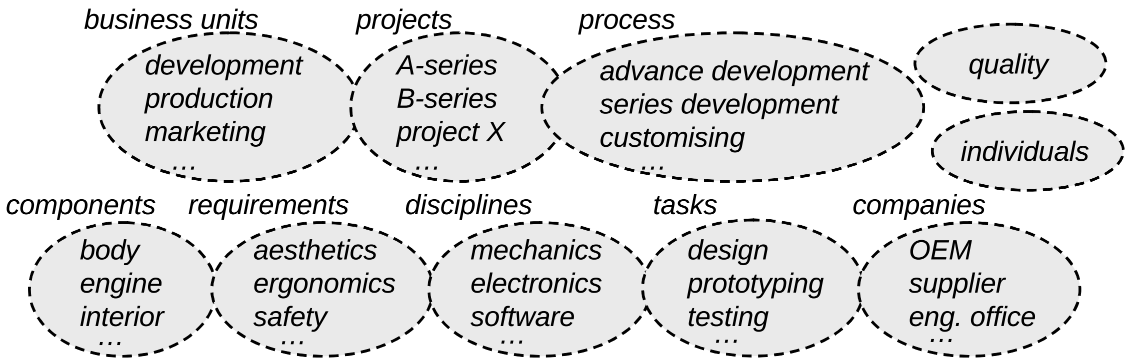

Figure 6. Dimensions or systems for the organisation of product development

Even if an organisation could be structured appropriately in all these dimensions, there is still the problem that the organisation will change over time. Take this together with the fact that a process model does not really reflect the actual process and we arrive at what we call the ‘dynamic organisation’. Figure 7 illustrates this.

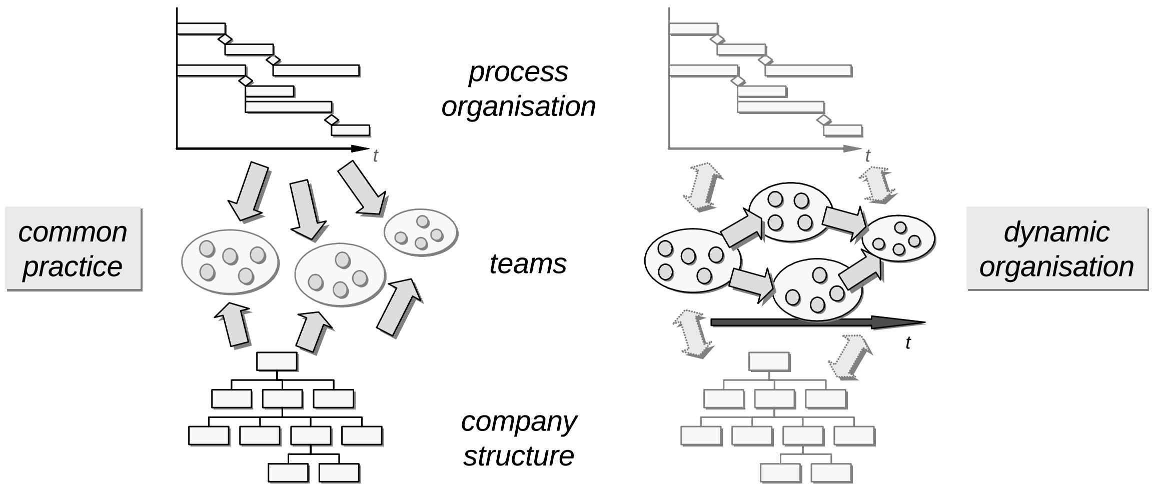

Figure 7. Concept of the dynamic organisation

Usually, the process organisation and the company structure are seen as the fixed drivers of the enterprise. But they are neither congruent nor cover all of the processes and structures alone. Teams are introduced to combine both aspects and overcome structural problems. But they are still predefined, badly defined regarding their composition, and fixed. The new idea is now to regard teams as the main process driver, what they actually are, and see the process organisation and company structure just as the temporal and spatial backbone. The teams have to define themselves, they are parts of larger teams, they may pass over to new teams, and they represent systems of the product. Actually, they are ‘systems’ that exactly follow the emergence of systems, i.e. the systems functions: differentiation (the topic), specialisation (finding its members), structuring (defining roles), process management (defining its communication and working style), reflection (about the task, its fulfilment, and the team's overall responsibility), and genesis (defining new teams for new (sub)tasks).

We still call them 'team' to differentiate between systems in the product and systems in the organisation. We could propose to call them '*SysTeams*'. The teams form according to the dimensions mentioned above. Those dimensions are, to be precise, also systems. For the product level this might be clear. Other dimensions or systems might need more brain squeezing. The disciplines dimension or system could be regarded as the scientific system. You could also say that mechanics, electronics, and software only exist through the differentiation against each other. This differentiation is a kind of relation forming a new system. It is the same in the quality system: the quality is a relative measurement of e.g. the minimum quality, the current quality, the target quality, and the ideal quality. They stand in relation to each other forming a system themselves, i.e. the system gives the meaning to a structuring.

Back to the dynamic organisation. Even technical departments are nothing more than teams with the specialisation of long term management of technical product knowledge or expertise. Management is also a special kind of team with the task of making decisions, supporting communication, and giving visions and identity. Management's main task is to ensure the functioning of the dynamic organisation. Part of it is the autonomy as well as responsibility for a department's economy and quality of its results. Ideally the demand for new products shall come out of the organisation itself, as within free market economy. Though both national economy and business administration then fight with the same problem, which is *not enough complexity*, steps toward a free market within the company (see also centres of competence or the like) are possible and should have advantages as it has in national economy. By the way, the communication via money can also help making the process able to evaluate, since aspects such as satisfactions of employees, efficiency, learning, process duration, etc. then is in the responsibility of the economically autonomous team or department.

Next to this communication via money (as well as the communication with models, etc.), we are now one step away from process management in product development. It is often said that process management in product development is hardly possible due to the ever changing processes. Regarding system theory, this is actually what process control is about:

- Not the complete process is to describe, but process steps in the meaning of "if… then…"
- Processes do not only have to describe the operating of the system (the "product development"), but even more important how the structure of the system has to be changed due to changing boundary conditions.
- The communication between different teams or departments has to be defined clearly. Who has to decide what and when and tell to whom.

This is process management in product development. It is partially what quality management according to ISO 9000 started—maybe with the wrong background, so that the approach has been limited to administrative activities. The described approaches actually reflect what is happening in industry, but they make those tendencies conscious and specific. We just emphasise what is happening. They also resemble approaches such as evolutionary management, virtual organisations, or total quality management, but are more tangible and focused on product development.

It has to say that this modular organisational approach also supports modular strategies such as platforms or building blocks within the product, and that a modular product architecture as well supports the dynamic organisation. The presented understanding of complexity has also a great deal of meaning for variant management ("complexity management"), e.g. that billions of variants are no problem, if they emerge as the product of some independent customer varieties, which have to be clearly differentiated from the technical variants.

8 Outlook

A lot of questions to answer regarding system theory and product development still exist. Some of these are:

- Control does not work because systems are too complex. The mere communication approach—as in national economy—has its problem in too less competition, too less complexity. It has to be considered how to deal with this lack of complexity.

- The approach of the dynamic organisation shall give enough understanding to implement measures improving the development system. Nevertheless it seems necessary to derive very clear guidelines for that.

- The system theory of sociology has to be expressed mathematically. There is no reason why this should not be possible. The approach is similar to using statistics for thermodynamics. It is also important to have a clear physical definition of complexity in correlation with entropy etc.

- The principles of system theory are also valid for psychic systems. It should be investigated which implications communication, complexity, etc. have for cognitive processes.

- We have regarded how to transfer principles from system theory and sociology to product development. The other way round, also system theory and sociology can learn a lot of product development and systems engineering, e.g. about strategies, modelling, simulation, influence analyses etc. This could lead to some kind of new *social engineering*.

While this contribution is the result of different projects mainly aiming at other targets, detailed studies have to be directly conducted on this topic now. It will be still a long way to understanding complexity and systems completely. Till then, the main approach is to make clear differentiations, to focus communication, to clearly think in systems, to consider how systems develop.

9 Conclusions

Complexity is not the problem. Intransparency is not the problem. The problem is (not) to find a follow-up activity in a complex environment. The real problem is a misunderstanding of complexity. Not only in product development. Everywhere around. How can complex systems as animals, humans, societies, etc. emerge 'out of nothing'? The real problem is an underestimation of complexity and its possibilities.

We have considered what it means to regard product development as a complex social system referring to system theory. Some things are not completely new, but it is important to apply them *consciously*. A final obstacle could be *too less complexity*. Complexity, meaning the possibilities of elements interacting, is the main topic behind this view. It is too easy to just say 'this is complex', to regard complexity as a problem, or to reduce any complexity. In a complex system, transparency and control have to be substituted by media and communication, meaning the coordination of activities. Finally, be sure to understand that this is just one subjective view on product development. If it is right or wrong has to be (and has been) proven by its effects in practice.

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