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Frank Schweitzer:
The Bigger Picture: Complexity Meets Systems Design
in: Gerd Folkers, Martin Schmid (Eds.): *Design. Tales of Science and Innovation*, Zürich: Chronos (2019), pp. 77 - 86

The Bigger Picture: Complexity Meets Systems Design

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Freedoms and limitations. Systems design - the term immediately evokes associations with the freedoms of a divine creator. However, it is precisely this idea that already describes the problem: like any other design, systems design must respect certain boundaries. And that means, first of all, knowing these limitations. A product designer's creativity is bound to the material properties that determine the load-bearing capacity and minimum dimensions of his product. He must know how this product behaves in a dynamic environment, how it is compatible with other products, and how robustly it fulfils its functions.

Queries. The same applies to systems design, but the complexity of the design is far greater. Before we can even formulate systems design questions, we must first clarify what we want to mean by a system, which approach we choose to system modelling, and how we validate these models. This addresses the methodological-*technical* aspects of systems design. The methodological-*critical* perspective focuses on the limits of systems design. What do we actually want to achieve with systems design? It doesn't take long to draw up a wish list. But how meaningful or feasible are these wishes? Here, we must critically question our expectations.

Systems. Systems usually consist of a multitude of interacting elements with their own properties, which is why we speak of complex systems. Since we are primarily interested in socio-economic systems, these would be, for example, a social online platform or a network of companies that jointly develop patents.

At the same time, systems are embedded in an environment with which they are connected through exchange processes. This distinction inwards and outwards – what is an element, what is the environment in relation to the system – defines what we want to understand by the respective system. Since systems can contain sub-systems and at the same time be part of super-systems, there is no unambiguous definition. Instead, a variety of perspectives on a system must be taken into account.

The most important question concerns the inherent dynamics of systems – i.e. their behavior before we exert a targeted influence on them. Only if we understand this self-dynamic, have captured it in the model and reproduced it, can we formulate requirements for systems design in the first place. Two special features have to be taken into account.

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Self-organization. Complex systems have the ability to self-organize, because they are capable of producing new order structures and collective dynamics, provided that certain critical conditions are fulfilled. This transition into a new system state usually occurs by leaps and bounds and is referred to as emergence. Some emergent properties are desirable, such as conductivity in metals or consciousness in the brain; others are undesirable, such as traffic congestion on the motorway or mass panic at a rock concert. It is difficult to specifically influence such self-organization processes, because collective characteristics cannot be reduced to individual system elements.

Adaptivity. Complex systems are also adaptive systems that constantly adapt to changes. These can be external changes in relation to the system, for example a change in the corporate tax rate leading to the arrival or departure of companies, but also internal changes, such as the loss of an employee resulting in a redistribution of tasks. This adaptivity – also referred to in social systems as collective learning – is the prerequisite required in order to be able to influence the behavior of systems at all. Here, too, it is difficult to induce a particular development.

Agent-based models. These peculiarities pose major challenges for the modelling of complex systems. State-of-the-art models of complex systems are usually based on agents that represent the system elements. These agents follow their own dynamics, for example they want to maximize a utility function. At the same time, their behavior is determined by interaction with other agents, but also by changes in the environment. The goal of modelling complex systems is not to develop an image of each individual agent that is as accurate as possible – this would be the task of the individual sciences. In the context of a statistical approach, we are interested in the expected behavior of a large number of agents. One of the most important insights of research on complex systems is that systemic properties can be reproduced even with simplified models and incomplete information. The structure and dynamics of the system can therefore be explained without having to make statements about each individual agent.

Calibration and validation. In order for the agent-based models to serve their purpose, they must be calibrated against available data and then validated. Only the enormous amount of available data makes this form of data-driven modeling possible. This will be explained using the example of research cooperation between companies. Databases have documented for more than 25 years which companies in which industrial sector have entered into research cooperation and when. However, they do not contain any information on exactly why these companies decided to cooperate, how long the cooperation lasted, and whether it was successful. An agent-based model can therefore not start making assumptions about the reasons for cooperation as long as they are not known. Instead, simple rules are formulated that contain probabilities of whether new firms or

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firms that already have research collaborations are establishing collaborations with other new or established firms in the same or different sectors. These probabilities are determined in a complex statistical procedure according to whether they best reflect known systemic structures from the data, for example the distribution of the number of research partners across all companies. After this calibration comes the validation: is such a model also able to reproduce systemic properties that are not included in the calibration, for example the formation of small and large clusters of cooperating companies from different sectors? If this is the case, i.e. if the model has demonstrated its suitability on the basis of various problem dimensions, then it can serve as a starting point for questions of systems design.

Bottom-up and top-down approach. In systems design we fundamentally differentiate between a top-down and a bottom-up approach. The top-down approach starts with the boundary conditions under which systems can form and develop. In socio-economic systems, for example, these are laws that create a climate of legal certainty and indirectly define freedom for companies or individuals. The boundary conditions also include tax regulations that enable location-related advantages, or environmental standards.

Bottom-up access starts with the individual system elements. In principle, these can be influenced in two ways: with regard to their internal dynamics and with regard to their interaction with other elements. In the example of research cooperation, certain companies can be persuaded to cooperate with start-ups instead of established companies. The greater risk involved can be offset by monetary or tax incentives. This means that the benefit function of the company is directly influenced. It is also possible to promote interactions between companies by bringing together new partners at special trade fairs, promoting cooperation in desired sectors such as biotechnology by providing laboratory buildings, or increasing the efficiency of knowledge exchange through additional specialists. This directly influences the cooperation between companies.

The bigger picture. Both top-down and bottom-up access require that we use models to gain an idea of how individual systems design measures affect the system. Various scientific disciplines, such as macroeconomics or social psychology, have carried out important preliminary work, particularly on top-down access. The aim of systems design is to use these approaches to develop an even more comprehensive picture of the dynamics of such systems. Feedback between different system levels, for example between the economy and the environment, is particularly important. This feedback also plays a major role in spreading risks, which initially appear to be rather limited. Failure cascades on one level, for example in energy supply, can lead to systemic collapse on a completely different level, for example in telecommunications. The modelling of such meta-systems – "systems of systems" – becomes more and more important with increasing integration. Globalization, i.e. the interdependence of spatially separated economic activities,

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is only one driver of this development. Another is the vertical integration of different systems within the framework of digitization.

Interdisciplinary challenges. This makes it clear that modelling such systems has long ceased to be a task for individual disciplines. It is about interdisciplinarity – and that is what makes the tasks of systems design so difficult. The sum of individual scientific findings does not by any means result in an understanding of systems. Who should develop such systemic models? Will the pioneers of disciplinary research suddenly generate a systemic perspective? Or do we need a "systems science" in the best sense that is able to integrate disciplinary approaches while at the same time developing its own methodology? What helps us to understand and model not only special economic systems, but also socio-technical, urban or ecological systems from a general point of view? A degree in economics, biology or another traditional scientific discipline alone is no longer sufficient. Where are the education programs that enable interdisciplinary studies? Where are the journals that publish such publications? Where are the faculty positions advertised with such a profile? With these questions, we are suddenly no longer dealing with the methodological-technical aspects of system modelling, but instead with the profile of universities and with science policy.

Methodical-critical reflection on systems design also includes the question as to what we actually expect from systems design as a scientific discipline. The usual answers can be summarized as follows: systems should be designed, controlled, and optimized in such a way that the available resources are used in the best possible way, targets are met, risks minimized, and the welfare of all guaranteed. These are noble goals, but on closer inspection they are nothing more than a mixture of mechanistic control theory and social utopian designs that do not actually help us to understand the problems.

All lifeworld systems are adaptive systems that adapt to a given regulation. At the same time, they are capable of innovation, i.e. they are creative enough to break out of the given framework with new strategies. The term "innovation" has a positive connotation today – after all, our future depends on industry's ability to innovate. But the renowned economist Joseph Schumpeter has already pointed out the "creative destruction" that this entails. Not only are jobs being created – jobs are also being destroyed. This is not an either-or, but a both-one-and-the-other. This can be generalized to the fundamental insight of systems design that all interventions in system dynamics have both intended and unintended consequences.

Unintended consequences. Observers of this will not fall into unthinking enthusiasm about falling prices (thanks to globalization), endless communication possibilities (thanks to social networks) or automation (thanks to artificial intelligence). They will ask – right from the beginning – the question about unintended consequences. Any discussion on the advantages of systems

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design must also address the disadvantages. Decisions can only be made in the knowledge of these disadvantages.

That is easier said than done. Do we not all want poverty to be reduced or financial crises to be excluded? Of course. But the moralization of this discussion means that the paths to such a system change are no longer openly and critically discussed – especially not with regard to negative consequences. Those who reduce inequality through political measures also intervene in the dynamics with which the wealth to be distributed is generated in the first place. Those who over-regulate global financial markets with thousands of pages of legislation may exclude the financial crises of the present, but they do make the financial crises of the future possible.

Advantages and drawbacks. Ecology, which has always been a pioneer of systemic thinking, has provided us with enough examples of how seemingly positive interventions have led to negative consequences. It was by preventing small forest fires that the large and uncontrollable forest fire became possible. Only the extermination of the "evil" wolves led to the disappearance of entire species and to a radical change in the landscape. Of course, these negative consequences were unintentional – precisely because the interrelationships within the overall system were not understood. Better system models make this understanding possible. Yet, the expectation that we could design systems without negative consequences is misleading. It is the tension between desirable and undesirable system changes that ultimately drives the development of all systems. And even breakdowns are a part of system dynamics, because they create space for something new. Their systematic prevention also means that innovations cannot assert themselves. Instead of dreaming of eternally stable systems without errors and disadvantages, we should see systems design as a way to better understand the connection between advantages and disadvantages.