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Alexis Quesada-Arencibia
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Computer Aided Systems Theory – EUROCAST 2024

19th International Conference
Las Palmas de Gran Canaria, Spain, February 25 – March 1, 2024
Revised Selected Papers, Part II

2 Part II

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Alexis Quesada-Arencibia · Michael Affenzeller ·
Roberto Moreno-Díaz
Editors

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Preface

The EUROCAST conference is particularly unique among the European Scientific Technical Congresses because it is one of the few periodic meetings promoted and organized exclusively by university and socio-cultural institutions, without the tutelage, direction or funding of associations, professionals or companies. It is currently the oldest of those. It is celebrated every two years, initially alternating Las Palmas de G.C. and a university in continental Europe, and since 2001, always in Las Palmas de G.C.

The idea of the first EUROCAST was developed in 1988 by Franz Pichler of the University of Linz and Roberto Moreno at a meeting in Vienna promoted by the past Honorary President, the late Werner Schimanovich. The first meeting, EUROCAST 1989, took place in February of that year, at Las Palmas School of Industrial Engineers, promoted by the Faculty of Informatics of Las Palmas and the Institute of Systems of the University of Linz. The Opening Session took place in the town of Gáldar, on February 26th, 1989.

Science, and especially technology, have moved in an almost vertiginous way, driven by the need for the promotion of consumerism, which is associated with the change of values that has taken place in recent generations. And EUROCAST, within what we understand as a certain freedom, and with prudence, has been adapting the profile of its organization from a meeting of very specific specialists, to a practically multidisciplinary, flexible and changing conference, which in each event tries to attract experts and especially young researchers, facilitating the interaction between them, which is a generator of creativity.

The key to the success of EUROCAST for 35 years has been in the quality of the contributions of its participants. This has to be recognized in the first place. They have made possible, with the help of the Springer publications in Computer Science, the worldwide distribution of the most important effect of EUROCAST: bringing together for many years scientists and engineers of different ages, training, interests and from very different European and non-European institutions. And they could share their experiences in the design and analysis of systems using the most advanced mathematical methods to make efficient models and algorithms in computers. And this from the socio-economic, biological, medical technologies and sciences and information and communication engineering topics. All in a multidisciplinary atmosphere, which has facilitated the appearance and discussion of new and creative ideas and developments.

Selected papers from previous editions have been published as Springer Lecture Notes in Computer Science volumes 410, 585, 763, 1030, 1333, 1798, 2178, 2809, 3643, 4739, 5717, 6927, 6928, 8111, 8112, 9520, 10671, 10672, 12013, 12014 and 13789 and in several special issues of Cybernetics and Systems: An International Journal. EUROCAST and CAST meetings are consolidated, as shown by the number and quality of the contributions over the years.

In this open multidisciplinary spirit, the 2024 Conference was composed of three plenary lectures by distinguished international Professors and 14 major thematic workshops, which covered a broad spectrum of cutting-edge research in Systems Theory, Applications, Pioneers, and Landmarks, Theory and Applications of Metaheuristic Algorithms, Mechatronic Product Development, Model-Based System Design, Verification and Simulation, Applications of Signal Processing Technology, Applied Data Science and Engineering for Intelligent Transportation Systems and Smart Mobility, Computer and Systems-Based Methods and Electronic Tools in Clinical and Academic Medicine, Systems in Industrial Robotics, Automation and IoT, Systems Thinking: Applications in Technology, Science, and Management, Data Science in Medical and Bio-Informatics, Modeling, Simulation, and Optimization in Production and Logistics, "Green AI" and SW-Tools for Sustainable Energy and Materials Consumption, Stochastic Models, Statistical Methods, and Applied Systems Simulations.

In this conference, as in previous ones, most of the credit for the success lays in the quality of proposals of subjects for Workshops, their resonance and impact, their diffusion and their strict selection of the many intended contributions. From 150 proposals, 104 revised papers were selected to be included in these volumes. The reviews of papers and their selection was made by the agreement of at least two members of the Program Committee, listed in the following pages, by a double open peer review process.

The editors would like to express their thanks to all the contributors, many of whom have already been EUROCAST participants for years, particularly in the considerable interaction of young and senior researchers, as well as to the invited speakers, Manuel Maynar from the University of Las Palmas de Gran Canaria; Ryszard Klempous from Wrocław University of Technology; and Dirk Jacob from Kempten University of Applied Sciences. We would also like to thank the director of the Elder Museum of Science and Technology, José Gilberto Moreno, and the museum staff. Special thanks are due to the staff of Springer for their valuable support.

October 2024

Alexis Quesada-Arencibia
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Contents – Part II

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Systems Thinking: Applications in Technology, Science, and Management

Variety Engineering – A Cybernetic Concept with Practical Implications

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Abstract. Management in systemic terms means to cope with complexity. Ross Ashby's Law of Requisite Variety shows the way, - to maintain the varieties of interacting systems in balance. To denote that process, we use the cybernetic concept of «Variety Engineering», which we also formalize. It refers to processes of mutual complexity amplification and attenuation by interacting agents. The purpose of this contribution is to explore ways of coping with complexity by means of Variety Engineering. The abstract concepts are illustrated by examples from ecological, social, and economic contexts. The cases in point will be used to demonstrate how complexity can be managed, to foster sustainability in these three dimensions.

Keywords: Management of complexity · variety engineering · sustainability · systemic management · requisite variety

1 Introduction

This is a methodological essay on an abstract topic: variety engineering. We will illustrate this concept using the topic of sustainability. This way the path from theory to practical application can be shown.

Enabling and fostering sustainable ways of coexistence with the environment is a burning issue of managing complexity.

Sustainability has been defined in ecological and systemic terms by at least two authors: First, by Gro Harlem Brundtland, a prime minister of Norway and chairwoman of the United Nation's Commission on Environment and Development (WCED) that published the report «Our Common Future»: «Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs.» (1987). Second by Michael Ben-Eli, the founder of the Sustainability Lab in New York defines sustainability as «a dynamic equilibrium in the processes of interaction between a population and the carrying capacity of its environment such, that the population develops to express its full potential without producing

This contribution is the updated version of an article by Schwaninger and Ott (2023).

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irreversible adverse effects on the carrying capacity of the environment upon which it depends» (2012).

Meanwhile, the ecological focus has been complemented by the goal of "socially inclusive and environmentally sustainable economic growth" (Sachs 2015: 5). Figure 1 shows that these three dimensions of sustainability are linked in principle.

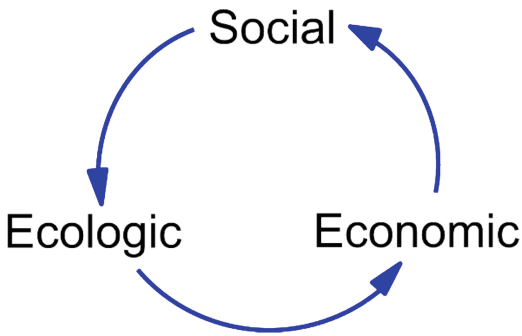

Fig. 1. Three dimensions of sustainability

The purpose of this contribution is to explore ways of coping with complexity by means of Variety Engineering. Our research questions are:

1. What is Variety Engineering?
2. Why do we need it?
3. How does it work?

Cases in point will be used to demonstrate how complexity can be managed, to foster sustainability in the three dimensions outlined.

In cybernetic terms, dealing with complexity hinges on Ross Ashby's (1956) Law of Requisite Variety: «Only variety can absorb variety». In other words, to maintain a system under control, the control system needs a variety that is (at least) equivalent to the variety of the system controlled. *Variety* is a measure for *complexity*, which stands for the property of a system to adopt many different states or behaviors. Variety then denotes the (potential or actual) set of states or modes of behavior of a system. A synonym for *variety* is *repertoire of behaviors.*

Ashby noticed that the variety of a system is not an intrinsic property of that system. "The observer and his powers of discrimination may have to be specified if the variety is to be well defined" (Ashby 1956: 125). In the context of the management of complexity, different distinctions can apprehend variety, e.g.:

– as a set of components or elements of the system or its environment: V_c
– as a set of states of the system or its environment: V_s
– as a set of modes of behavior of its environment: V_b
– as a set of perturbations coming from the environment: V_p
– as a set of actions or responses of the systems: V_r

In an earlier treatise, variety engineering is conceived as "managing the complexity of a situation", in terms of the mutual adjustment of V_p and V_r (Espejo and Reyes 2011: 50f.). We revert to the more abstract concepts of VE and VH – eigen-variety and hetero-variety. Any one of the distinctions listed above can be used, if a given situation of variety engineering is analyzed. Two examples:

1. VE_c/VH_c, i.e. eigen- and hetero-variety, each of a set components.
2. VE_b/VH_b, i.e. eigen- and hetero-variety, each of a set of (modes of) behaviors.

We are going to use these two variants in the following cases. A characteristic of these sets is that their properties can be represented by quantitative data (ibidem).

Any agent – individual or collective – confronts complexities that are superior to what he or she can attend fully with their variety, i.e., their capacity of absorbing complexity. Variety engineering is the general strategy to offset this deficit.

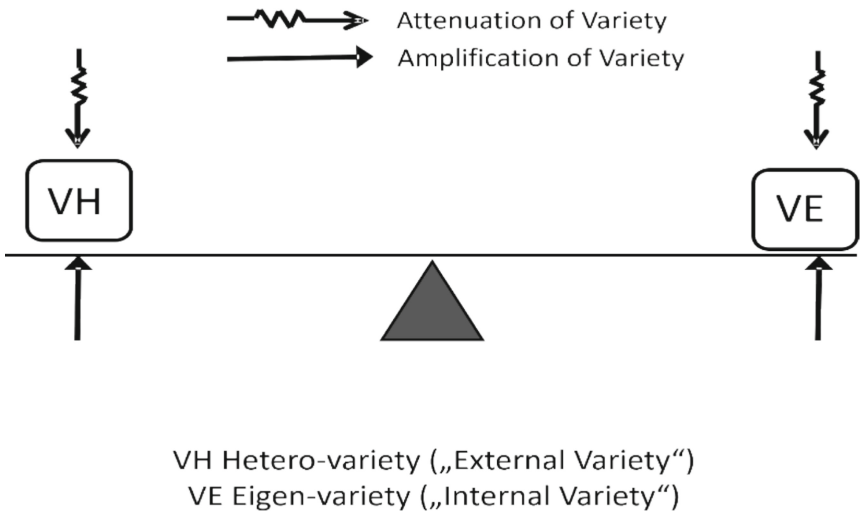

Fig. 2. Levers of variety engineering –attenuation and amplification

«Variety Engineering» is a term coined by Stafford Beer (1979: 39). It stands for the combination of amplification and attenuation of variety used to bring a system of interactions into balance (Fig. 2). Amplification and attenuation are the actions or strategies by which the hetero- or eigen-varieties of a set or agent are changed, according to a quantitative measurement scale. These changes are triggered by factors which we also call *levers*.

Literature about variety engineering is rare, with few exceptions of publications that show its relevance and practical dimension (Espejo & Reyes 2011; Jackson 2019; Espejo 2022; Schwaninger & Ott 2023).

The primary modes of variety engineering consist in attenuating hetero-variety (also: external variety) and enhancing eigen-variety (also: internal variety), see Fig. 2. Let us take, as two interacting agents, a complex market, and a company. In this example, the company has two options:

a) To attenuate the complexity/variety of the market, e.g., by modeling, structuring, or segmenting it, inventing new ways of clustering market objects, targeting its own activity to parts of that market only (e.g., segments of the market), or reframing the system-in-focus.
b) To amplify its own variety/complexity, e.g., by enhancing its market intelligence, adopting better information systems, increasing the sales force, strengthening its capabilities, etc. Also here, reframing is the most powerful device of variety engineering.

Hence, the ultimate way of both attenuating hetero-variety and amplifying eigen-variety is reframing, i.e., redefining the context or the system[1]. These changes rely on inventing alternative realities and therewith creating new possibilities: in this way, new opportunities are created (amplification) and the strategy becomes more focused, i.e., the context is made less complicated (attenuation).

Attenuation and amplification go hand in hand. A case in point is the question of the company's identity. The company should ask herself, if the markets it is engaged in have a fit with its identity, or if the target markets need to be redefined or refocused (attenuation of complexity). At the same time, it needs permanently to ask the question, if it is viable in the long run, respectively if its traits, structures, and capabilities, etc., need to be reframed or improved (amplification of variety).

The two minor levers of variety engineering are less triggers of action than of perception and understanding:

a) Amplification of hetero-variety: Let us assume, that in our example, it is not possible to change the market (we know that in other cases this might be different). It is important to understand which are the factors that generate the complexity of the market, e.g., individualization, fragmentation, specialization, etc.
b) Attenuation of eigen-variety: Equally significant is gaining knowledge about the factors that reduce eigen-variety. In our example this could be operational blindness, bureaucratic obstacles, rigid habits.

Both approaches, attenuation and amplification can be a blessing: they can lead to an equilibrium of varieties between competing or conflicting agents. At the same time, any one of these strategies can also lead to failure if it provokes a crass imbalance. So much for the «mechanisms» of variety engineering.

At this point, a methodological note is necessary:

[1] To frame, in a shorthand definition, is to make a mental model that enables us to make sense of new situations (Cukier et al. 2021). More extensively defined, framing is the observation or activity by which a new perspective on some part of reality is disclosed, therewith giving rise to a new meaning. The new perspective can come from a change in the apprehension of the system-in-focus or of its environment. Authoritative writings have dealt with reframing as bringing about new ways of "how we think and make sense of the world around us" (Bolman and Deal 2021). They have shown how strategy-making is supported by "re-framing and re-perception" (Ramirez and Wilkinson 2018), providing examples and cases that lend themselves to the analysis from the stance of variety engineering (Normann 2001; Bolman and Deal 2021).

1. Complexity/variety is relative. It denotes something subjective that re-sides in the (embodied) mind[2] of an observer.
2. Let us take the example of a light bulb. For someone reading a book, it is likely to have two possible states of interest: On and Off. For an electrician, it would be at least three: On, Off and intact, Off and broken.
3. Changes in variety (of an agent, set or system) are not necessarily induced from outside. They can also come from within. For example, self-organization can be a powerful attenuator, but also an amplifier. An example of self-organization as a formidable damper of complexity is given in the section on residual variety. In this case, self-organizing "mechanisms" in the environment are used to cope with its own variety, without drawing on the system´s capabilities or resources (Espejo & Reyes 2011).

We will now present four cases on variety engineering to illustrate how it works and how it can be used in practice to promote the sustainability of the economy and society. The first case is about ecological sustainability. It is followed by one case on each, social and economic sustainability, and finally a case in which the partial perspectives are integrated. Finally, the topic of residual variety is raised, and conclusions are drawn.

2 The Ecological Dimension of Sustainability

CASE A: Design for Self-control
This case is about variety engineering by organizational design. It starts at a huge environmental problem, - the pollution of rivers and other water bodies. This is an idealized case that could be located on any one of the world's continents. We have the typical situation of a factory on the bank of a river. Here, the varieties of the regulating authority (VE) and the factory (VH) face each other.[3] These varieties are, for each of the two parties, the respective numbers of available options for action.

Figure 3, left, shows a mill that draws pure water from the river at the top (grey arrow) and discharges polluted water into the river downstream (black arrow): a process of pollution that occurs every day in many places of the world. What can be done about it?

Different solutions exist, - prohibitions, constraints, requirements and prescriptions, etc. What we are suggesting is a reframing, i.e., a reformulation of the problem in a different context than the current one. The status quo frames the problem as an issue of a question of violation, sanction, and subsequent control: in short, a policing issue.

Cybernetics has a more general solution to offer: To the right in Fig. 3 is a version based on framing that focuses on a design issue. By reversing the point of extraction and flow of the water (punctuated arrows), the factory sets up its processes so that no toxic wastewater is produced, because otherwise it becomes a victim of water pollution itself. Elegant, isn't it? A reframing/redesign has created new possibilities.

[2] The attribute "embodied" emphasizes the indissoluble connection of body and mind, reason, and emotion (Varela et al. 1991; Damasio 1994).

[3] The distinction between VH vs. VE is defined in each case by the vantage point. If we speak of VE in Case A, this is the viewpoint of the state, the regulatory authority or similar, in any case not that of the company as we have it in Case B.

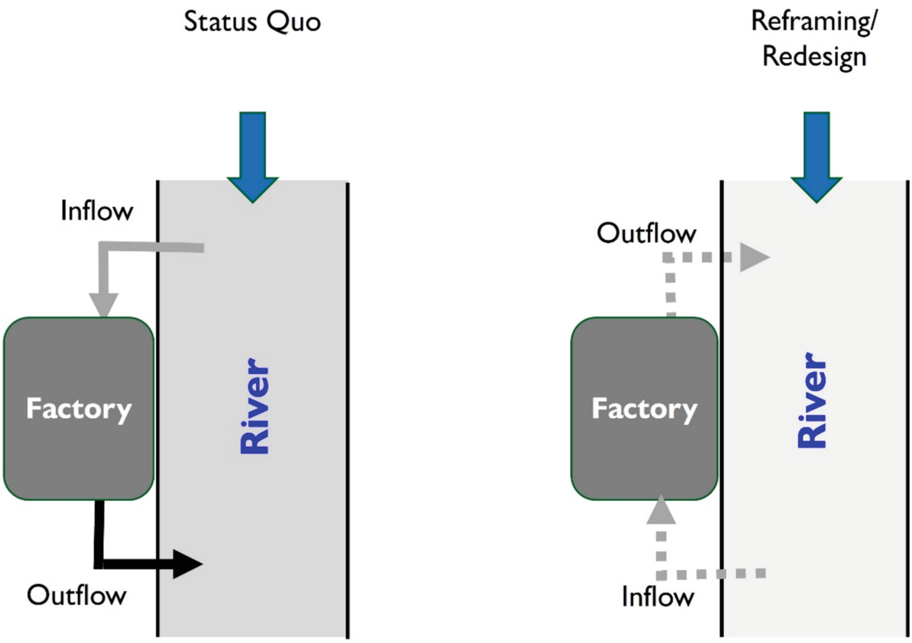

Fig. 3. Cybernetic Reframing (The first author owes this example to his friend and mentor Stafford Beer.)

The beauty of the solution is enhanced by the variety equation:

$$VH_1 \rightarrow \infty \tag{1}$$

$$VH_2 \approx 1, \tag{2}$$

where VH is the external variety, i.e., the variety of the factory. In the Status quo version, VH_1 is virtually unlimited. In the reframing/redesign version the variety VH_2 roughly equals 1, i.e., the factory is forced to discharge clean water into the river purely out of self-interest. In other words, the change is effective.

This is a general solution. It represents an ideal-type, and therefore is not necessarily implementable, in a concrete case, exactly as shown here. However, its rationale can influence the way of thinking about this problem and possibly stimulate new approaches.

3 The Social Dimension of Sustainability

CASE B: Unintended Side-Effects and How to Cope with Them
This case visualizes a path-dependent loss of variety of an organization, incurred by social dynamics. We start from an economic crisis of the type that occurred in 2008/9, in many countries. A collapse followed by a deep recession hit the economy worldwide. The consequences at the level of a concrete company are pictured in the Causal Loop Diagram in Fig. 4.

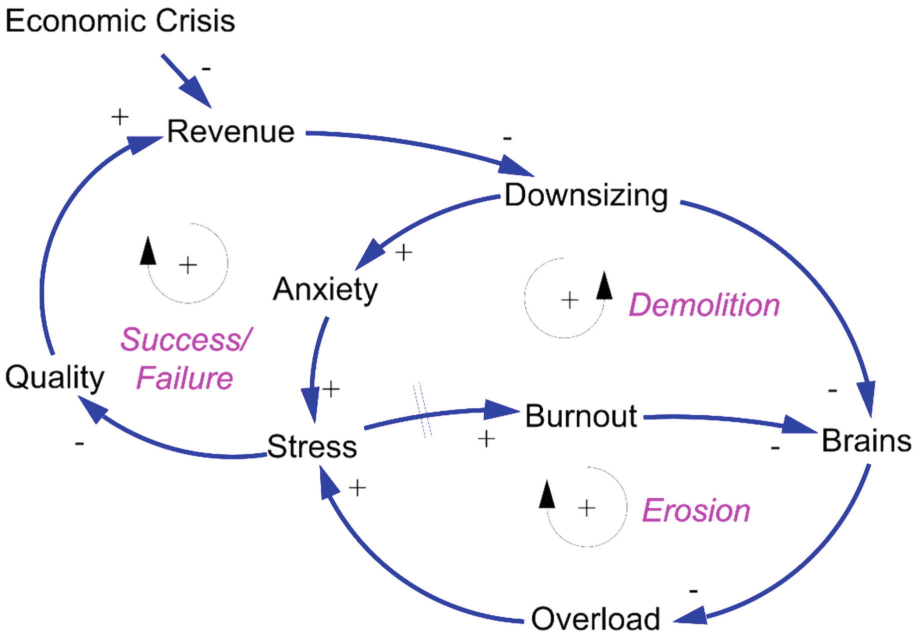

Fig. 4. Economic crisis and culture of fear

For the company in focus, the economic crisis entails a slump in revenue and. The management's prompt response is to downsize, which it hopes will reduce costs and bring the company back into profit. That expectation is not fulfilled. A chain of unintended side-effect emerges: First, the reduction of the workforce means that «brains walk out of the door», - the company loses knowledge and capabilities. Second, the downsizing climate fosters fears with the staff: a culture of anxiety emerges, which induces stress.

Here, a self-reinforcing and therewith destabilizing loop is started: Stress, with a delay (symbolized by two crossbars), leads to burnouts, which tendentially entail losses of people. Having less staff available tends to cause overload, which again results in stress.

From here we start the next self-reinforcing loop: Stress harms quality, particularly product and service quality. Quality is a variable that, if it grows, results in higher revenues; if it decreases revenue will be damaged. That is where we started and where we continue. The overall picture now shows a pattern of decline. An economic decision (downsizing) entails dire consequences at the social level. This worsens and the existence of the company is increasingly threatened.

By the way, the Covid pandemic led to developments which are identical with the situation described here. The pandemic led to economic recessions which were incisive for the hospitality industry, for example in the US, in particular Washington D.C., and in European airline companies, e.g., the Swiss International Airlines AG (SWISS). Early in the crisis, sharp layoffs occurred. One year later, as Covid measures were relaxed and the tourist demand took off, these companies faced severe staff shortages. These resulted in overload, and what has been called « great resignation», and « great quit»:

many employees left their companies and joined other industries. The shortage of skilled workers and higher costs forced companies to save on quality (Kaufmann 2022; Gössling et al. 2020; Dube et al. 2021).

Can the fatal development be overcome? Not, or only gradually, within the structure described. The best solution would be to introduce a new loop. We are only outlining this. As shown in Fig. 5, focused efforts can be made in research and development that produce innovations. This could establish a new, dominant loop, change the dynamics, and increase the revenue. However, there are two difficulties associated with this strategy: First, sufficient resources must be available or raised. Second, delays are to be expected between innovation and yield.

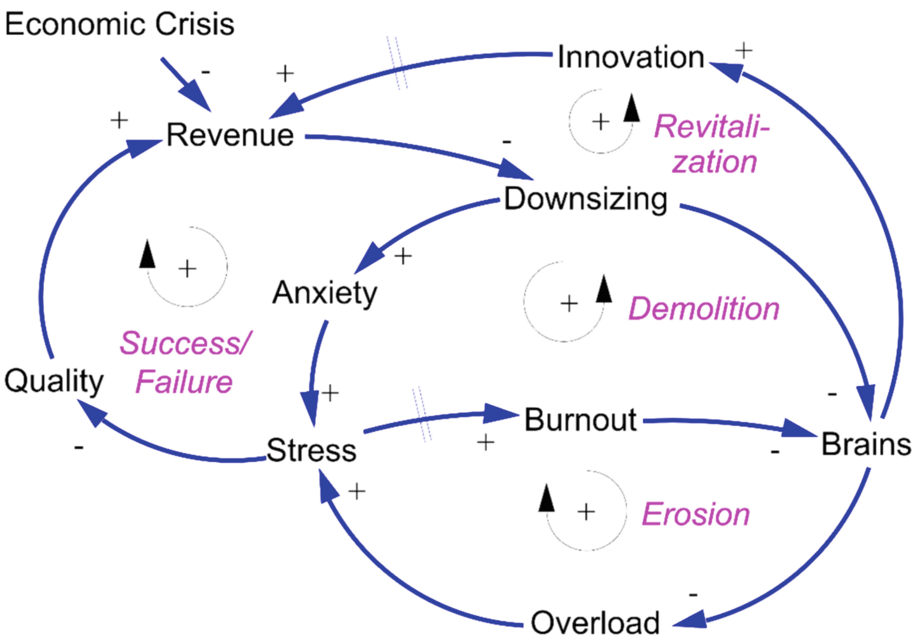

Fig. 5. Revitalizing the System

The eigen-variety (internal variety) VE of the company, in the first phase heads toward Zero: Due to self-reinforcing negative cycles, revenues decrease more and more and thus the space of possibilities increasingly disappears. In contrast, innovation in the second phase sets a positive development in motion, which expands the space of opportunities to one or more:

$$VE_1 \rightarrow 0 \tag{3}$$

$$VE_2 \geq 1 \tag{4}$$

4 The Economic Dimension of Sustainability

CASE C: Designing Business Systems
The design of a business system involves multiple decisions; the complexity is often overwhelming. How can a decision-maker master[4] this complexity?

A heuristic device for that purpose is The Generic Structure of Business Systems, as shown in Fig. 6. The variables are logically connected to form a loop.

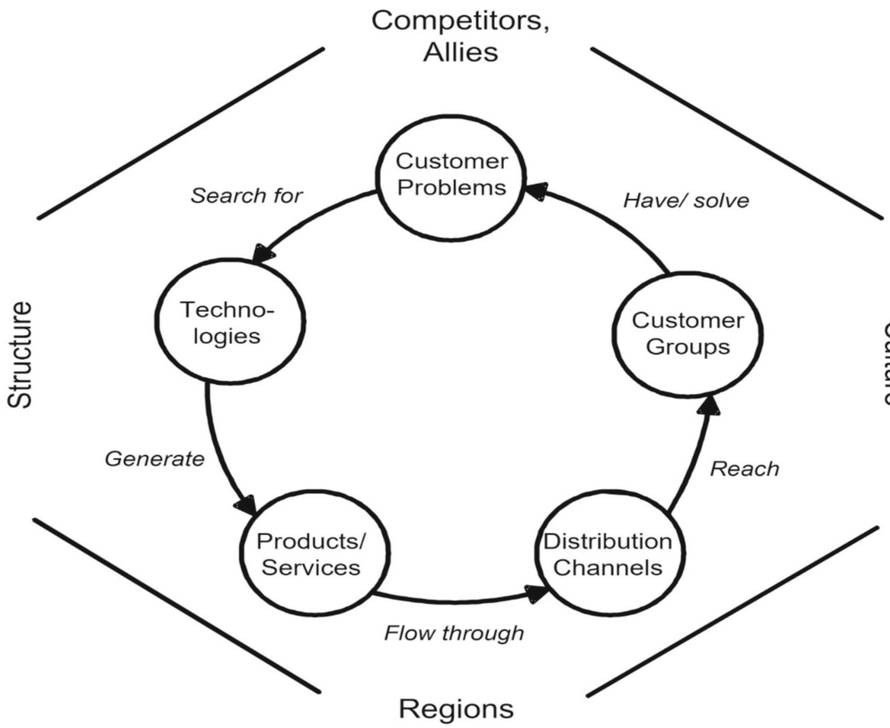

Fig. 6. Generic Structure of Business Systems (after Schwaninger 2009)

The diagram exhibits a structure that is generic in the sense that the dimensions and variables constituting the circuit can be identified in any business system. What varies for each dimension is its concrete design, which must be decided specifically. For example, in a catering business, the concrete design could include options such as:

– For the dimension *products*: complete menus, single dishes, dishes without garnish, garnishes
– For the dimension *distribution channels*: direct distribution, franchise, specialized retail chains, wholesalers

[4] Normally, in organizational contexts, "mastering complexity" can only be achieved to a limited extent.

– Etc.

What is the variety in this design spectrum? If we take a rough approach, defining m as the number of dimensions of design (e.g., $m = 5$ as in our example of the generic business system structure), and n as the average number of variants per dimension of design[5], then:

$$\mathrm{VH} = n^m \tag{5}$$

$$\mathrm{VH} = 4^5 = 1'024 \tag{6}$$

In case the dimensions show different numbers of variants $(n_1, n_2, \ldots, n_m)$ the variety could be calculated similarly:

$$\mathrm{VH} = n_1 \cdot n_2 \cdot \ldots \cdot n_m \tag{7}$$

For $n = 4$ (on average) and $m = 5$ the hetero-variety then equals $1'024$ different states of the system in focus, i.e. the potential offers. This number illustrates that the business under study is complex. Also, the size of the variables cannot be reduced with ease. In this situation the analytical approach taken with the calculation needs a complement: a more intuitive method of variety attenuation.

One such method is known as *Morphology*. Figure 7 shows a mode of mapping the business system. We take Catering as example and extend the number of dimensions, by differentiating some of those shown in Fig. 6. For example, the dimension Product, in Fig. 7, is subdivided in three categories (PP, PS, PL). Technologies is subdivided in three categories as well (TS, TT, TP), etc. In addition, the dimensions of competitors/allies and regions are added. In sum, now n remains 4 (on average) and m is 11. The application of the above formula (5) to the extended version of dimensions leads to a huge amount of potential states:

$$\begin{aligned}\mathrm{VH} = 4^{11} = 4\prime 194\prime 304 (&\text{hetero} - \text{variety, because these are the variants} \\ &\text{confronting the manager})\end{aligned} \tag{8}$$

After a vertiginous, exponential growth, the variety of the business system in this case amounts to more than four million different states. This is a potential variety which could handle large complexities in the market. However, it would only be effective if the company could manage it. This is doubtful: a company that wants to offer anything to anybody is doomed. It is then necessary to find a level of eigen-complexity that can be handled effectively. What happens if we reduce some dimensions of the business system to one variant only? This would be equivalent to a powerful reduction of eigen-variety. For example, the four dimensions of price level, sales channels, region, and competition could each be reduced to one variant. This would shrink the inherent variety of the system by a factor of 256 to $16'384$ potential states (approximately 4^7 instead of 4^{11} as

[5] VH in this case is the complexity of the possible designs of the business system (or potential offers) confronted by the manager, whose VE is his or her behavioral repertory for coping with that complexity. The gap between the two is huge.

four of the dimensions are reduced to one state only). This would improve the ability of the company to handle the business. However, on the one hand, this reduction still would not be enough, on the other hand such restrictions could subsequently be found to be infeasible. Here, the morphology is helpful.

There is no way of making sense here in an analytical way. An intuitive approach is to define profiles of combinations across the dimensions.

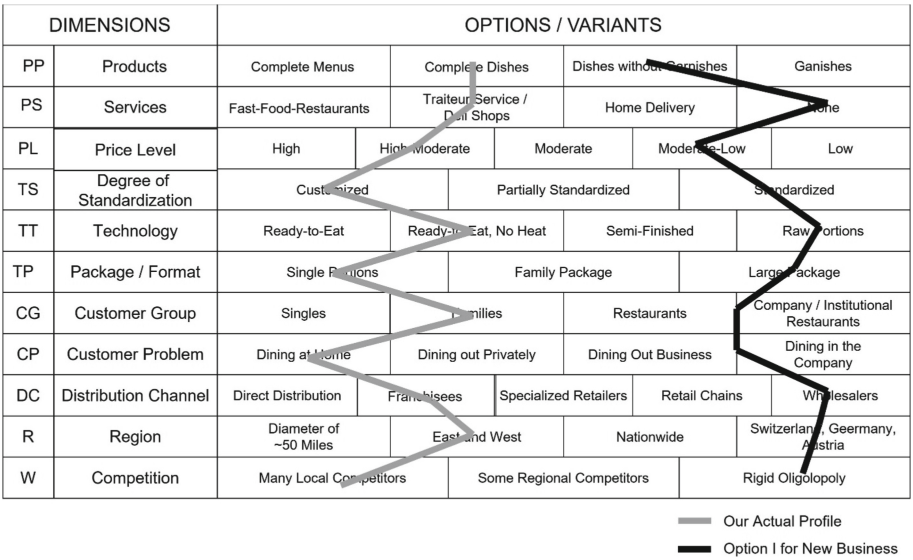

Fig. 7. Example of the morphological method

Human cognition is powerful in discerning or establishing patterns. In Fig. 7 to the left, a profile is shown of the actual configuration of a business system of the company in focus. Now it is the task of human imagination to invent and consider other profiles. The current profile of the business is more of the high quality/low standardization type. Alternatives such as a higher standardized/industrialized profile are different options, which might be examined.

In Fig. 7 to the right, one strategic option is distinguished[6]. The complexity of the business system in these cases has been reduced to the extreme. Each dimension of the business system commits to a single manifestation. For example, the profile on the left defines the Complete Dishes as “the” product. The variety of this dimension is therefore 1, no longer 4. If we continue this logic, VH will be equivalent to Eq. (9):

$$VH = 1^7 = 1 \tag{9}$$

The potential variety VH_{pot} has been reduced from roughly four million (see Eq. 6, above) to an actual variety VH_{act} of 1, i.e., by 99.99998 percent. This value is merely

[6] One could equally compare profiles of competitors.

theoretical. In reality, one could hardly uphold a business system with such a narrow profile successfully, however the rationale of the case shows the impressive difference that can be achieved between potential and actual variety (Eq. 10).

Practically, the reduction of variety will be an iterative approach, starting with the numbers of options for each dimension $(n_1, n_2, \ldots, n_m)$. Step by step, these could be reduced significantly, resulting in new numbers of options $\tilde{n}_i \ll n_i$ (for all dimensions $i = 1, \ldots m$), with $\mathrm{VH}_{\mathrm{act}} = \tilde{n}_1 \cdot \tilde{n}_2 cdot \cdots \tilde{n}_m$ and

$$\mathrm{VH}_{\mathrm{pot}} \gg \mathrm{VH}_{\mathrm{act}} \tag{10}$$

As shown, the human intuition is able to reduce the complexity of the number of states radically, to a level that can then be handled analytically. Another way of pursuing a drastic variety reduction would be Machine Learning.[7]

We have to call attention to the potential downside of variety attenuation. If this goes too far, then the possible consequences can be fatal, for example, when a product range is too narrow. The ultimate case of variety attenuation is « sheer ignorance» (Beer 1979: 40).

Also, the other side of variety engineering needs to be emphasized, if VH is the variety of the market and VE the variety of the firm or business. The amplification of VE can be a powerful strategy for conquering customers or markets. In principle, it would not be difficult to enhance the variety of a business system, e.g., by adding additional products to the offering. The danger of this strategy would be logistical complexity. A balance should then be sought by other means, for example by segmenting or restricting the target market.

Such an expansion of eigen-variety very soon becomes a logistic challenge. Many firms have not mastered that contest. They suffocated in the complexity of their business systems.[8] On the other hand, huge successes exist, of companies that found ways of handling the complexities of the logistics in marketing and distribution. Examples range from Amazon to Ebay, Zalando, and smaller specialists (Jeong et al. 2022).

5 Integral Governance and Control of Organizations

For coping with complexity, experts advocate holistic and integrative concepts of governance and management (e.g., Beer 1988; Espinosa and Walker 2011; Bleicher and Abegglen 2021). All three dimensions of sustainability covered at this point – ecological, social, economic – will be covered in CASE D, under the attribute "integral".

CASE D: Corporate Governance and Management

The governance of organizations of any kind, corporations in particular, aims at their viability, sustainability, and evolution. Two cybernetic models have been developed

[7] As we learnt from Machine Learning experts, there are methods that accomplish such complexity reductions. What algorithms are good at is finding correlation patterns that are useful for navigating the complex space. In the solution of the problem in focus here, techniques of dimension reduction, reinforcement learning, and natural language processing would play a major role. See also: James et al. (2021).

[8] One strategy to limit logistical complexification would be to seek a balance by other means, for example by segmenting, restricting, or redefining the target market.

to support organizational governance. The Viable System Model (Beer 1981, 1984, 1985) was designed for structural diagnosis and design. The Model of Systemic Control (Schwaninger 2000, 2001, 2009) has been developed for orientating control in the context of governance and management in general. In the following we shall draw on the second model.

The Model of Systemic Control discerns a logical hierarchy of control levels, - the levels of operative, strategic and normative management (Fig. 8).

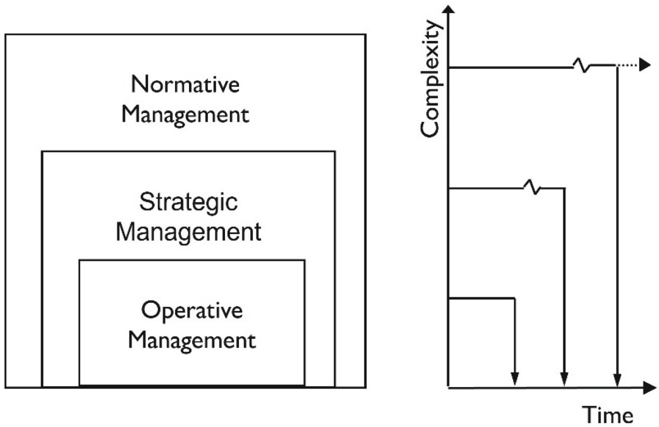

Fig. 8. Logical levels of management in the Model of Systemic Control (The Model of Systemic Control (Schwaninger 2000, 2001, 2009) has utility at all levels of management, including corporate governance, which it subsumes: that is the system of rules, practices, and processes by which a firm is directed. It involves balancing the interests of a company's many stakeholders (Chen 2021). Corporate Governance is mainly located at the level of normative management, and for the organization as a whole.)

Operative Management has a short-term horizon. In short, it oversees the current business which aims at delivering value, in terms of quality and economic success. Strategic Management acts in a long-term horizon. Its task is building and cultivating value potential, i.e., the prerequisites of future success. Finally, Normative Management is the locus of the identity and the ethos of the organization. This includes the values and supreme norms governing it. The horizon is very long, almost timeless. In the diagram (Fig. 8), from below to above, complexity rises. Each one of the logical levels has specific control variables (for details, see Schwaninger 2009:48ff.). An integral governance or management implies that the control parameters of all three logical levels are under control simultaneously, even if contradictions arise.

The eigen-variety of the management system is defined as:

$$VE_t = VE_o \cdot VE_s \cdot VE_n, \tag{11}$$

where the partial eigen-varieties for the levels o operative, s strategic, and n normative, of management, multiply up to a total eigen-variety VE_t. If we assume that each one of the levels has five options of state or behavior, the potential variety is:

$$VE_t = 5 \cdot 5 \cdot 5 = 125 \tag{12}$$

To put this in practical terms, such options could be, for example:

– At the operative level: increase production efficiency, raise marketing budget, strengthen sales effort, streamline logistics
– At the strategic level: Investment in R&D, redesign of business system, new distribution strategy
– At the normative level: Commitment to sustainability, reorientation of focus from products to customer lifestyles
– In principle, it would be relatively easy to raise the variety of the company, by increasing any one of these partial varieties. Enhancing the partial variety at only one level, e.g., the operative plane, would result in a linear growth of VE_t (in Fig. 9, from operations O_1 to O_3). In case of an increase of more than one partial variety, the growth of VE_t would be polynomial (e.g., from O_3 to O_5). In case of losses of partial varieties, VE_t would decrease in a similar manner (Fig. 9). The variation of eigen-varieties with factors k_o, k_s and k_n for the operational, strategic and normative levels leads to a modification of the total eigen-variety:

$$VE_t = VE_o, k_o, VE_s, k_s, VE_n, k_n, \tag{13}$$

In Fig. 9, e.g., we have $k_o = 1.2$ (for VE_o between O_1 and O_2 for the increasing scenario) and $k_o = 0.8$ (for VE_o between O_1 and O_2 for the decreasing scenario). Equation (13) shows that the modification of variety on one level only leads to a linear change, the modification on two levels to a quadratic change. In practical terms: concerted simultaneous increases of variety, i.e., of the respective number of choices, at more than one level, enable an exponentially stronger radius of action. One must keep in mind that the changes of numbers on the different logical levels (operative, strategic, normative) can also compensate each other with respect to VE_t in case there is an increase on one and a reduction on another level.

	O_1	O_2	O_3	O_4	O_5	O_6
VEo	5	6	7	7	7	7
VEs	3	3	3	4	5	5
VEn	2	2	2	2	3	4
VE_t	30	36	42	56	105	140
VEo	5	4	3	3	3	3
VEs	3	3	3	2	1	1
VEn	2	2	2	2	1	0
VE_t	30	24	18	12	3	0

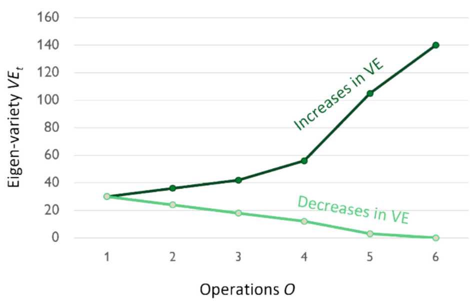

Fig. 9. Changes of total variety as a function of changes in partial varieties (Upper half: increasing partial varieties; lower half: decreasing partial varieties)

To summarize: considering the three management levels (operative, strategic, normative) and their options for action (eigen-varieties) in an overall view, then the total variety VE_t is the product of the partial varieties, since these are combinations in the sense of combinatorics. A change of the partial variety in only one dimension has a linear effect on the total variety, since only one variable is affected. An increase in more than one dimension typically leads to a super proportional increase of the total variety (amplification); a decrease in more than one dimension leads to a sub proportional decrease of the total variety.

The data and the picture indicate that variety engineering has a nonlinear tendency (in case of an increase in variety of more than one level), whereby amplification deviates more from linearity than attenuation, which remains closer to a linear behavior.

6 The Concept of Residual Variety

At this point it makes sense to introduce a conceptual distinction between three entities that cope with complexity and interdepend at the same time (Fig. 10).

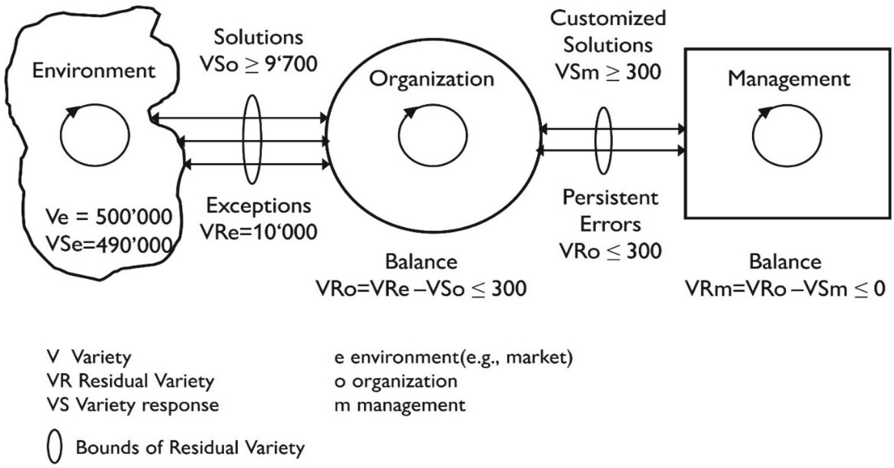

Fig. 10. Stages of residual variety (He concept of Residual Variety and the diagram go back to Espejo (1989). The equations come from the authors.)

The three entities are Environment, Organization, Management. Each one of these entities copes with the specific complexities it is confronted with. Each one of them absorbs complexity by means of self-organization. There is a remnant complexity it cannot take care of. This Residual Variety has to be absorbed by an upstream unit, the organization for the environment, and the management for the organization. To illustrate that principle, we draw on a somewhat abstracted practical example.

We refer to a firm running an online business in its market. The market shows a complexity of $Ve = 500'000$ transactions. Most of these transactions are realized within the market itself and without any interference by the organization. This self-organizing property is represented by the loop icon in Fig. 10, indicating the variety response $VSe = 490'000$. 2% of the variety –$10'000$ standardized transactions - is not attended inside the market and needs special attention by the organization, which equals the residual variety $\text{VRe} = \text{Ve} - \text{VSe} = 10'000$. The organization needs to take care of these exceptions and is successful in 97% of the cases ($\text{VSo} = 9'700$), while the rest – 300 cases of persistent errors, which cannot be attended by the organization - needs the attention of the management, which, again, equals the residual variety $\text{VRo} = \text{VRe} - \text{VSo} = 300$. The management is supposed to come up with customized solutions, which often imply some sort of (partial) redesign of procedures, changes in the product range, etc. The management is successful if it can offer at least these 300 solutions, i.e., $\text{VSm} \geq 300$, which means $\text{VRm} = \text{VRo} - \text{VSm} \leq 0$ and no problem remains unsolved. The equations in Fig. 10 contain inequality operators. This expresses the fact that the balance can assume a negative value when a variety surplus occurs. If, for example, the variable VSm is, let us assume $\text{VSm} = 350$ (instead of 300), then the balance $\text{VRm} = -50$. This result indicates a redundancy of potential command (McCulloch 1989; Beer 1981).

7 Conclusion

The goal of this paper is to elucidate ways of dealing with complexity through variety engineering. We defined the concept and explored the role of variety engineering. In addition, we demonstrated how it works by means of examples of attenuation and amplification as strategies for coping with complexity. The substantive horizon has covered the different dimensions of sustainability, - ecological, social and economic, as well as the overarching aspect of an integral governance, which covers all of these dimensions.

We have demonstrated that both approaches, attenuation and amplification can be a blessing: they can lead to an equilibrium of varieties between competing or conflicting agents. At the same time, we have indicated that any one of these strategies can also lead to failure.

Our emphasis has been on the enhancement of eigen-variety and the attenuation of hetero-variety, but we have also considered the other two options: attenuation of eigen-variety and amplification of hetero-variety. An overview is given in Table 1.

We do not claim completeness for the successes and failures listed in the Table. The cases presented are only some examples from the universe of manifestations of variety engineering. But these are typical for the topic, lending themselves to a modest generalization.

The enhancement of eigen-variety can lead to remarkable successes. The most powerful approach in that category is reframing/redesign of structures or strategies. The main failure we have referred to is the collapse of eigen-variety of a business when the complexity of the offering was overstretched.

Raising eigen-variety is often achieved by focusing, specializing, or shrinking the business. In these cases, a change of variety is implied for both sides of the equation, VH and VE. VE, seen superficially, may be reduced as a function of a loss of "mass", as is the case in downsizing. However, the main point is that the environment is redefined. It becomes smaller and less complex. Henceforth, the relative variety VE/VH shifts in favor of the business, which then has a better grip on the market.

Successful attenuation of hetero-variety hinges on an understanding of the structures inherent in the system of interaction. Building and implementing good models here is

Table 1. Summary of the outcomes of different strategies of variety engineering

	Success	Failure
Amplify Eigen-Variety	Reframing/Redesign of strategies and structures, Strategic focus, Innovate (CASE B), Increase power of marketing through new products (CASE C), Flexible management (CASE D)	Overstretch amplitude of product range (CASE C), Become dominant in a way that jeopardizes the relationship with the environment
Attenuate Eigen-Variety	Keep the set of strategic and structural options focused (CASE C)	Lack of flexibility in management (CASE D)
Amplify Hetero-Variety	Understand drivers of complexification in the environment (market, regulation, etc.)	Inability to cope with variety proliferation in the environment
Attenuate Hetero-Variety	Modeling and structuring the environment and the organization, reframing/redesign of strategy and structure (CASE A)	Limitation of co-evolution of the interacting agents

key; reframing/redesign of strategy and structure probably being the most powerful lever. Excessive damping can lead to failure if strong resistance to the dominant party arises from the environment, respectively if the coevolution of the actors involved is made impossible.

The most powerful lever with both approaches – enhancement of eigen-variety and attenuation of hetero-variety – is framing/redesign.

The potential variety of a complex system does and cannot be materialized fully, with all its states or behaviors. Management is the process by which the desirable states and behaviors of a system are enabled while the undesirable ones are prevented. As we have shown, variety engineering is a powerful yet subtle vehicle for accomplishing this delicate endeavor.

What would need further elaboration to complement the cases treated here, is the dynamics of variety engineering in organizational processes. The equations and numbers used until now are very abstract and would be insufficient to describe these processes in a qualitative sense. Variety amplification and attenuation in organizations are the product of communication and conversations.[9] We can think, for example, of conversations for reflection and conversations for action. These dynamics of variety engineering are an important topic in need of further investigation.

In addition to the demonstration of how it works, it is necessary to emphasize in this conclusion what variety engineering can mean in the future. It is an unorthodox conceptual approach that is effective in confronting complexities. It can, for example, guide decisions and actions in conflict situations. Its working principle may seem too simple.

[9] For the distinction between the concepts of communication and conversation according to Shannon & Weaver and Pask, see Dubberly & Pangaro (2009:1f.). The relevance of these concepts from the stance of the "new" Cybernetics, e.g., Maturana, Winograd & Flores, Luhmann, is analyzed in Vásquez & Benavente (2016).

However, this principle is a platform for inciting innovation. It can stimulate inventive, and sometimes radical, design of complex systems - when it comes to reframing or transformation. And it can foster the resilience needed for dealing with the ubiquitous uncertainty. Variety engineering has great potential!

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