TOWARDS AN OPERATIONALIZEABLE DEFINITION OF RESILIENCE

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Abstract

Background: Often, resilience is being regarded as a homogenous concept, valid to be applied in various domains. This led to rather broad and diffuse definitions that can be difficult to operationalize. There exists a deductive and an inductive understanding of resilience. Unfortunately, there are several drawbacks to the deductive view as it is possible that a non-adaptive system shows a typical resilient response behavior, while a truly adaptive system may show a degrading performance that has nothing in common with a typical resilience performance curve. The inductive view may overcome some of these problems.

Results: Resilience emerges in a state of overload. Overload occurs, as soon as performance requirements exceed the response capabilities of a given system. Resilience is defined as the capability of a system to stay productive in an overload state and to overcome the overload state through adaptation. A resilient reaction can be differentiated into a degrading and an adaptation phase. We've found specific principles, capabilities and mechanisms that enable the emergence of resilience.

Conclusion: The Framework presented could serve as guidance towards an operationalization of resilience in socio-technical systems.

1 INTRODUCTION

The concept of resilience is becoming widely used by many industries where safety and security is crucial for success. Often, resilience is being regarded as a homogenous concept, valid to be applied on individuals [Meredith et al., 2011], projects [Kutsch, Hall & Turner, 2015], organizations [ASIS SPC.1-2009], C2 systems [Pflanz & Levis, 2012], supply chains [Kim, Chen, Linderman, 2015], government [Homeland Security, 2014] or even societies [United Nations, 2017] equally well. This popularity led to rather broad and diffuse definitions that are sometimes difficult to operationalize.

Not only being a term in colloquial language, the term resilience is widely used by the life sciences [Freitas & Downey, 1998], social sciences [Ayling, 2010] as well as management science [Välikangas, 2010], not only with different foci but often with different meanings. Resilience as a concept originated within ecology [Walker & Salt, 2006] and is also applicable in the realm of socio-technical systems. The concept of resilience has a rich history, sometimes with a considerable stretch from its original meaning [Gallopin, 2005].

Principally, there are two different approaches towards a definition of resilience. The typological (or deductive) approach focuses on resilience as a response characteristics to a shock or disturbance and therefore on the "expression" of resilience that can be visualized as typical response curve. It is often referred to because of its easy and rather intuitive accessibility [Prior & Herzog, 2013].

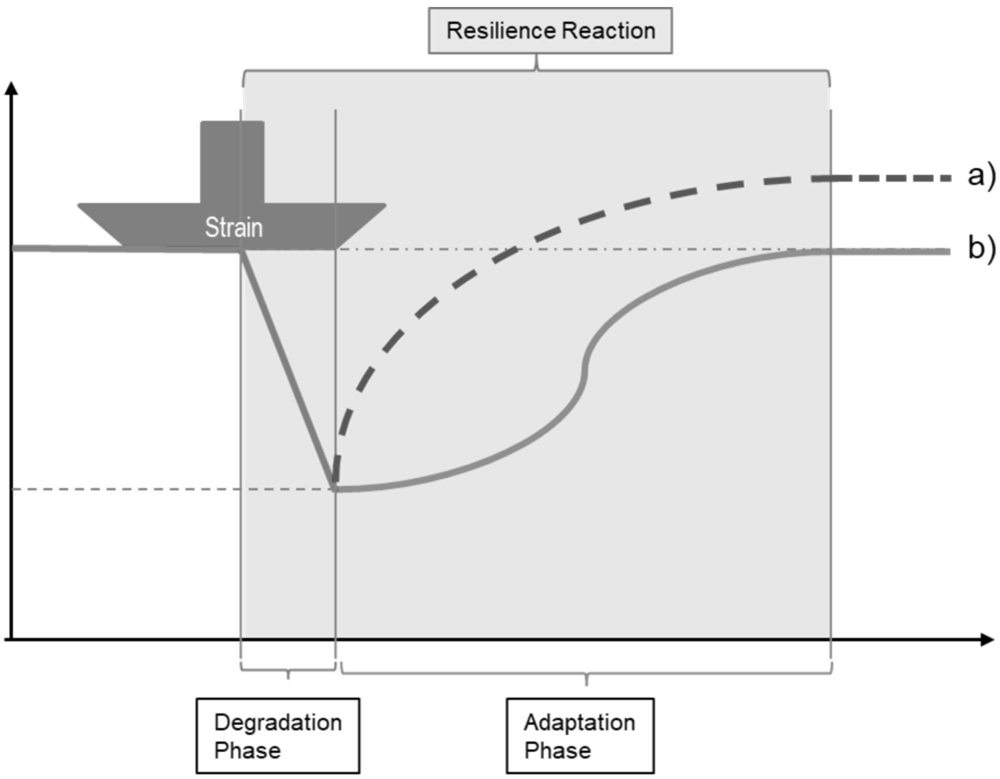

Figure 1. *Expression of resilience: typical response curves: a) "Bounce back" b) Adaptation*

However, there are several drawbacks to this perspective of which the inherent ambiguity is probably the most significant one. Following the typological approach, it is well possible that a completely non-adaptive system shows a typical resilient response behavior, while, on the other hand, a truly adaptive system may show a degrading performance that has nothing in common with a typical resilience performance curve. Therefore, this a posteriori definition is not necessarily useful for an a priori model to build up resilience from first hand. The second approach is the taxonomic (or inductive) approach which may overcome some of these problems but is not as intuitively accessible as the typological one [Gibson & Tarrant, 2010]. However, for this paper we will focus on the taxonomic approach and limit the scope of our work to emergence of resilience in socio-technical systems.

2 METHODS

The goal of our work is to provide a framework that supports the execution of experiments in the spirit of concept development and experimentation (CD&E). With the intention to get there, we will use the term resilience rather as a technical term than as general concept. We put our focus on drawing the margins of the framework tightly around the core of the resilience concept, leaving everything aside that might be covered by other related concepts as robustness, resistance or sustainability. Furthermore, we will take a performance driven perspective on resilience covering aspects as safety and organizational performance.

To begin with, we need an operationalizable definition of resilience. In favor to get there, we will refer to resilience as a property of systems only to emerge in a state of overload. Overload occurs, as soon as performance requirements (R) exceed the response capabilities (C) of a given socio-technical system. Therefore, overload can be formalized as $C/R<1$. Continuing from this definition we suggest a resilience framework consisting of four elements: 1) phases; 2) principles; 3) capabilities and 4) mechanisms.

2.1 Phases

Resilience emerges dynamically as the system is entering the state of overload. In response to this evolution the system may experience timely separated phases.

2.2 Principles

Principles are strategies to be followed to enable the emergence of a resilient reaction when the system is entering a state of overload. The principles require specific abilities to generate this response.

2.3 Capabilities

Capabilities emerge from successful application of a single mechanism or a set of specific mechanisms.

2.4 Mechanisms

Mechanisms are the means by which actions and reactions can be carried out. Mechanisms are based on tangible, intangible as well as human resources, such as specific tools or rules for example.

3 Results

As stated before, we regard resilience as an emergent property of a system under strain and not as a capability by itself. As requirements exceed a systems nominal performance, it starts to mobilize all available resources and reserves to withstand the strain mobilizing maximum performance. If maximum performance exceeds a critical time frame or requirements further increase, the system enters the state of overload and resilience may emerge in a dynamic response of the system to the strain it is exposed to. This reaction evolves in two phases, the degradation and the adaptation phase. Based on successful adaptation, new system capabilities are developed and implemented until system capabilities exceed the situation requirements ($C_{New}/R>1$) and the system completes the resilience cycle by returning to normal operation.

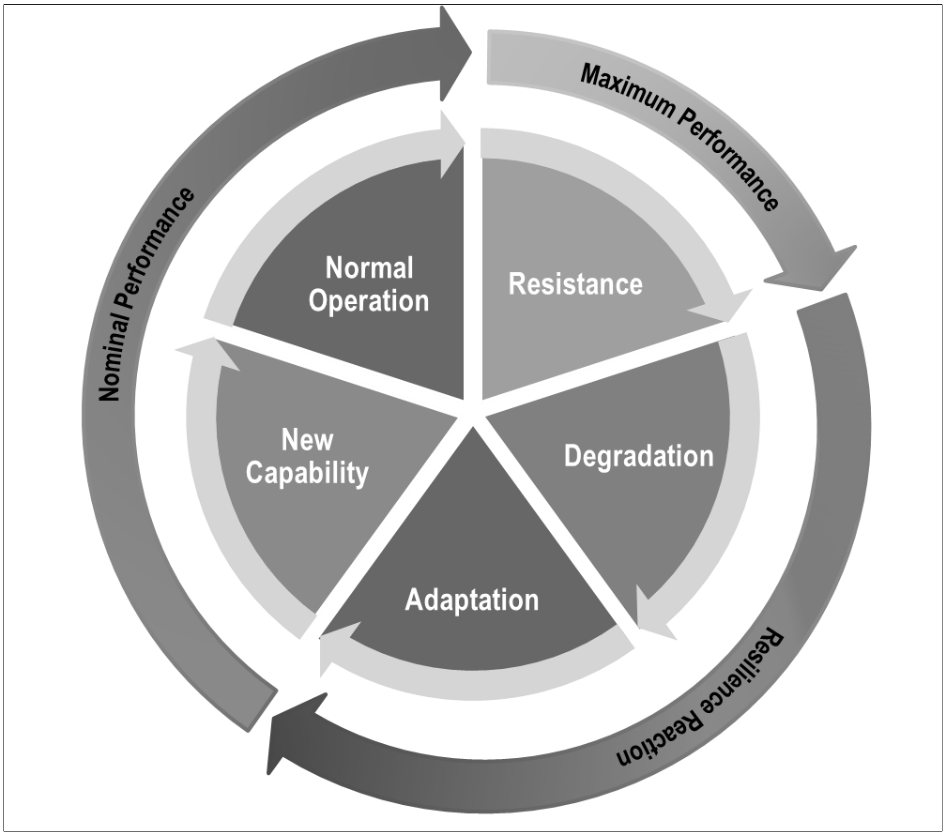

Figure 2. *Resilience cycle*

3.1 Degradation Phase

As the maximum performance of a system is exceeded it starts to degrade over time as overstressed parts and functions fail and losses occur. To be able to degrade, three principles proved to be important. These are the principles of 1A) autonomy, 1B) fractality and 1C) compatibility.

The *1A) principle of autonomy* refers to the locus of control, which must stay with the acting and deciding entities to enable timely and (hierarchy-)independent decisions based on the knowledge and experience of the involved entities. This will foster the use of local intelligence as an important prerequisite for the capability of self-synchronization to evolve.

The *1B) principle of fractality* enables organizational stability during the degradation of the system, when teams and units are constantly breaking up and reconfiguring to keep up a functional organization, hence producing a scalable organization. A functional organization is crucial to keep up a significant system output in the state of degradation [Danner-Schroeder & Geiger, 2016].

The *1C) principle of compatibility* enables the recombination of system parts in a different way than they were designed for. Hence, such parts can be used as replacement for failing but crucial other system parts and the system may serve as its own spare parts stock. This is true for organizational structures as well as for infrastructure, hard-, soft- or liveware.

3.2 Adaptation Phase

The degradation phase blends over into the adaptation phase and vice versa. This means that there is a constant overlap of the two phases at any given time during a resilience reaction, but the ratio significantly changes over time in a directed manner. Three principles are crucial to enable adaptation. These are the principles of 2A) diversity, 2B) selection and 2C) standardization.

The *2A) principle of diversity* is addressing the fact, that adaptation depends up on a minimal level of variance in the system. Either, there is a sufficient level of diversity already in the system or it should be created by introducing variance into the system, for example by accepting deviations from rules and SOPs and by letting people solve problems by trial-and-error tactics. At this point, one important thing to keep in mind is to carefully control the level of variance introduced into the system to avoid that the system is shifting to a chaotic state. Hence, if variance is introduced into a system it should happen in a controlled manor.

Once promising solutions to problems have been found, *2B) selection* starts and the solutions are undergoing a testing phase. As soon as a workable solution is selected, it is going to be implemented in the system.

The *2C) principle of standardization* is addressing the process of implementing a new capability or problem solution into an organization. So, standardization is a manifestation of learning in an organization, ensuring the system-wide application of the new capabilities and their application in the most effective and efficient way.

3.3 Capabilities & Mechanisms

As stated above, capabilities emerge from successful application of a single mechanism or a set of specific mechanisms. So, if we are going to assess a system regarding its resilience potential, it all comes down to the identification and evaluation of the resilience enabling mechanisms present in the system. The mechanisms might vary between different organizations. Some of them might have a more universal and generic character such that they reappear constantly in resilient systems albeit in changing appearance. Examples for this could be generic rule-sets, role-based organization, modularity, standardization, improvisation or selection by trial-and-error tactics.

Table 1. *Element-structure of the resilience framework*

Phase	Principle	Capability	Mechanism (examples)
Degradation Phase	1A) Autonomy	- Timely Decision Making - Use of Local Intelligence	- Involved and Acting Entities Decide for Themselves
	1B) Fractality	- Self-synchronization - Scalable Organization	- Generic Rules - Role-Based Organization
	1C) Compatibility	- Recombinability	- Modularity - Standardization
Adaptation Phase	2A) Diversity	- Creativity	- T-Shapes (Polyvalence) - Improvisation
	2B) Selection	- Testing	- Trial & Error
	2C) Standardization	- Learning & Implementation	- Adaptive SOP

4 Conclusions

When planning for a resilience experiment, we may follow the guidance provided by the definition of resilience and the four elements of the resilience listed in the framework. First, we would probably like to check for the presence of resilience. As discussed above, resilience is a system property to emerge in an overloaded system. Hence, if the condition C/R<1 is not met, we are not looking at resilience. Second, we may specifically check for the presence of core principles, capabilities and mechanisms. Third, we could also want to look at the system performance. In some particular cases, we might detect a typical resilience performance curve, as an exemplary expression of resilience. This will most probably be the case in a situation, where a timely limited disturbance, like a shock, occurs. This could typically be the case after an isolated event like an earthquake, flooding or power failure for example. It will be less probable, if the disturbance persists or even progresses over time as it would be the case in a war situation for example.

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