Levels of Resilience: Moving from Resilience to Resilience Engineering

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Abstract. In order to clarify the concept of resilience in systems, we propose distinguishing among three levels of resilient behaviours: 1) simple, homeostatic response; 2) second order response involving more novel adaptations; and 3) a third order response characterized by learning. This representation is useful in demonstrating how simple first order responses can be ultimately maladaptive (by consuming resources and decreasing the impetus for more fundamental change), and also by suggesting areas where resilience engineering might most productively be focused.

1 INTRODUCTION

The idea of resilient performance, and of engineering work systems to support it, has a strong attractiveness but a definitional imprecision. Woods has illustrated this by outlining 4 common understandings of the term 'resilience' (personal communication). In addition, it has grown increasingly popular in many different contexts (Taleb, 2012; Walker & Salt, 2006; Weick & Sutcliffe, 2007; Zolli, 2012), and this multiplicity has increased its conceptual fuzziness. Although resilient performance seems relatively easy to recognize and describe, moving from resilience to resilience engineering will require a greater clarity not just about what it is, but also how to get, maintain, preserve or enhance it.

In this analysis, we propose a hierarchy of behaviour patterns than can be (and have been) called resilient, and focus on the implications, for research and practice, of clarifying what we mean when we say a system is resilient or (better) acts resiliently.

2 THREE LEVELS OF RESILIENCE

We use causal loop diagrams to illustrate three proposed levels of resilience (Sterman, 2000); although the causal loop notation is convenient and expressive, the fundamental concepts are separable from this representation. In the causal loop notation, arrows indicate the direction of influences among variables; a '+' sign indicates one variable increases the value of another (over what it would have been otherwise) and a '-' sign the reverse.

2.1 Level 1

The simplest level is a simple negative feedback loop (Figure 1), with the system responding to reduce a deviation (*ie*, to mitigate a threat or address an opportunity). We might well label this Level 0 resilience, because many would not consider it resilience at all, at least in the sense commonly used in the resilience engineering community – after all, we would not ordinarily consider a thermostat or a speed governor an exemplar of resilience – but we use the numeral 1 to signify that resilience at this level is essentially a first order response to some disturbance. Using tried and true methods (often but not always codified in formal procedures), actors in a system deal with the 'normal, natural troubles' they encounter in a largely routinised way; they reach their goals in the context of their current mental models, but those models remain unchanged. Much of the work on resilience in ecosystems resides at this level; the feedbacks and systems are much more complex than illustrated abstractly in Figure 1, but are essentially about homeostasis, either as ordinary stability or as stable albeit hysteritic cycles (Bueno, 2009; Gunderson, 1999; Gunderson, Carpenter, Fowlke, Olsson, & Peterson, 2006; Holling, 1973).

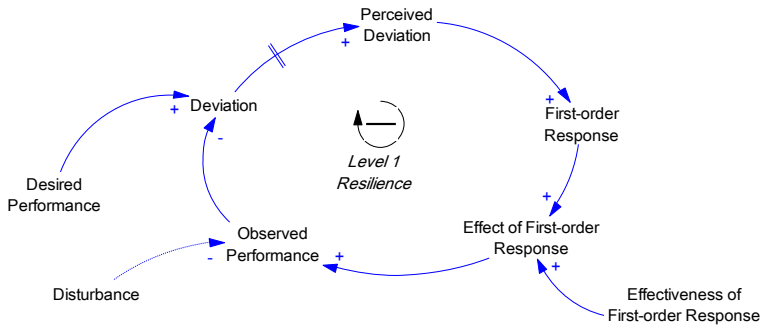

Figure 1. Level 1 resilience, first order responding to counter a perceived deviation.

Figure 1 shows a disturbance decreasing performance, *ie,* increasing deviation; after a time delay (indicated by the double lines) the perceived performance deviation then

leads to increased responses, which if effective tend to improve performance and thus reduce the level of deviation from the desired level of performance. This creates in effect a negative feedback loop, tending to stabilize the system.

2.2 Level 2

Level 2 resilience is a second order response to a disturbance that is either unexampled, or not well-managed by first order processes. These responses are often variations on, or novel applications of, well-rehearsed procedures. Here, information from the world not only alters performance, it also alters the framings and mental models that influence performance. Case studies at this level of resilience are common in the resilience engineering literature (Pariès, 2011; Stephens, Woods, Branlat, & Wears, 2011; Wears, Fairbanks, & Perry, 2012; Wears, Perry, Anders, & Woods, 2008; Wears, Perry, & McFauls, 2006). These detailed, technically expert analyses have provided rich insights into the nature of resilience, but often fall short of providing insight into whence come these flashes of brilliance, much less how to enhance them. Resilience at this level typically involves goal tradeoffs, or 'sacrifice decisions'. Partly because of that, resilient activities are often hidden in the interstices of organisational life (since, officially, no goals can ever be admitted to have been sacrificed). This level of performance is roughly related to Argyris' concept of double-loop learning, although not specifically aimed at that notion (Argyris & Schön, 1974).

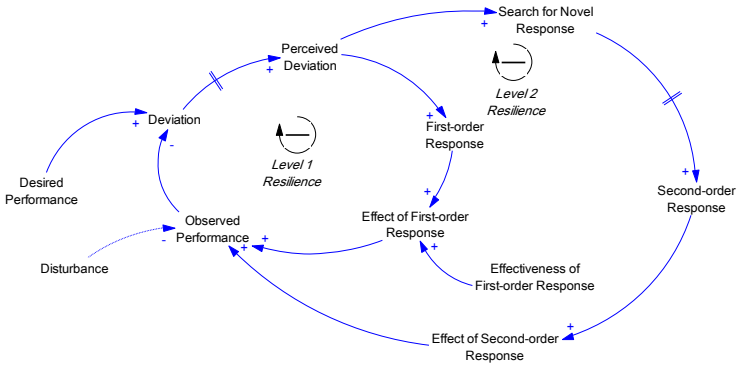

Figure 2. Level 2 resilience. Second order response involves adaption, preparation for future similar disturbances (ie, anticipation and monitoring).

Level 2 involves more than just responding, but also engages the activities of anticipation and monitoring, as a second order response is often aimed at preparing for the recurrence of a similar threat or opportunity. But, Figure 3 reveals a problem at this level (red arrow) – more effective first order responses lead to decreased second order efforts precisely because they are effective, and so reduce the strength of the deviation signal. Thus, fundamental problems tend to persist in the system, because

they seem to be easily mitigated. This pattern can be seen in the common tendency to focus on first order responses (*eg*, fixing 'errors') at the expense of understanding what continues to produce those 'errors' (Dekker, 2011).

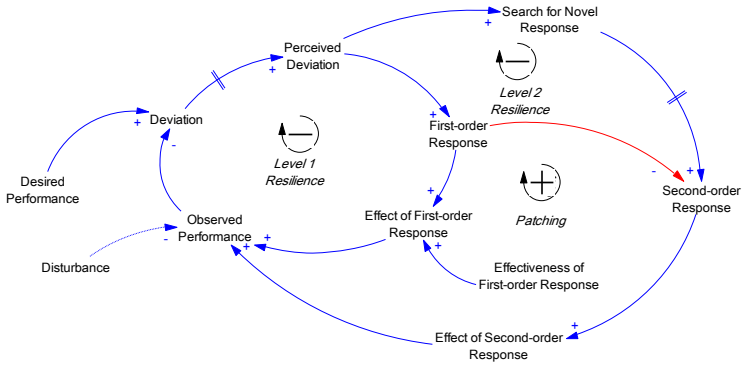

Figure 3. But, effective first-order response reduces second-order response (red arrow).

Figure 3 shows that this behaviour involves both positive and negative feedback loops; this makes the performance of the system hard to predict, as it depends on the relatively strengths of those loops, and on the time delays involved in experiencing their effects.

2.3 Level 3

If a system has gone through enough second order experiences with appropriate and relevant feedback (March, Sproull, & Tamuz, 1991), it may then begin to learn how to do second order response well. This not only increases the effectiveness of second order responses, but also contributes to building 'margin' (Stephens, 2010) – a collection of informal buffers, resources, short-cuts, tradeoffs and procedures – a 'bag of tricks' – that can be called on in either impromptu or extemporaneous ways. We postulate that resilient systems are characterized by their skill at capturing and learning from these experiences; which, paradoxically, may be dependent on their relatively frequently experiencing them (Farjoun, 2010). Figure 4 illustrates this more complex system, with an additional negative feedback loop.

3 DISCUSSION

3.1 Implications

This analysis of resilient performance indicates where we should be focusing attention, where resilience can become resilience engineering. We can certainly learn from Level 2 events, but they are not common, present some risk, and are often trivialized in heroic (*deus ex machina)* narratives. Resilience engineering should be about more than celebrating or understanding level 2 successes, important as that is. Rather, it should be focusing on Level 3 – understanding how build adaptive capacity; how and when to trigger it; how to control it, and by what types of control architectures; and how to husband it for future use (as opposed to squandering it on the everyday).

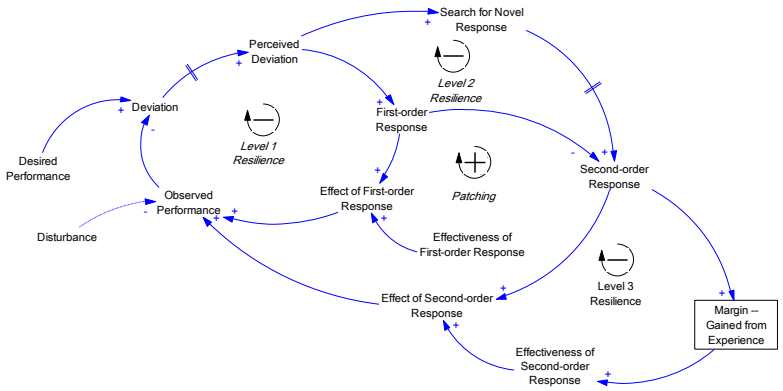

Figure 4. Level 3 resilience, learning how to respond better; increasing the repertoire of possible responses.

Figure 4 also identifies points at which specific resilience engineering efforts might be targeted in order to improve the system's overall ability to respond, to build the 'margin for manoeuvre' that can be called on against unexpected events. Note that the effectiveness of local, first order response negatively influences the 2nd order effort. This suggests that organised efforts to enhance second order response even when the local response is successful are not only useful but necessary to keep a system from getting trapped in a vicious cycle of temporary success from first order response that hides its growing vulnerability due to inadequate margin.

It is important to note in this analysis that the negative feedback is not always desirable, nor positive feedback always undesirable. Rather, they are rather dampening or amplifying, respectively; positive feedback is important to amplifying novel, desirable adaptation, especially after severe disruptions.

3.2 Tradeoffs

Finally, this analysis suggests that systems contain internal tradeoffs regarding the sorts of issues to which their control structures should attend. Given that attention is limited, there will be a tension among focusing on level 1, 2, or 3 responses. Level 1 responses are immediate and demanding, and so tend to dominate, in particular, reducing through their apparent success attention to level 2 responses. But for the system to be able to adapt and thrive over a long time, some attention must be shifted to level 3 responses, even though that must inevitably decrease attention and effort at levels 1 and 2.

3.3 Limitations

These levels of activity may roughly correspond to structural levels in an organisation, but there is no necessity that they do so. The value in this conception comes from looking at multiple levels simultaneously, and particularly how they relate to one another. Similarly, although the three levels tend to emphasize particular sets of the cardinal resilience activities (Level 1, responding; Level 2, monitoring and anticipating; and Level 3, learning), there is no presumption that they are so clearly separable.

4 CONCLUSION

By more specifically articulating the level of resilient behaviour that is the focus of a given discussion, we should be able to communicate more precisely, and to more directly identify opportunities for system design and improvement; that is, to move from simply describing resilience to engineering resilience.

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