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JSA Action Group 14 Complex Adaptive Systems for Defence: Synthesis Report

Conceptual Framework for Adaptation

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Introduction

It is not the strongest of the species that survives, nor the most intelligent. It is the one that is the most adaptable to change. ~ Charles Galton Darwin

The Problem: Complexity

Complexity results from interdependence of the elements in a situation, and from the fact that there are always important interactions with the broader context in which the situation is embedded. In other words, complex situations are open rather than closed systems.

The interdependence relations can also join up to form loops through which feedback can flow and amplify or suppress some processes, producing very complex behaviours. When the situation contains creative autonomous agents with their own agendas, in other words, adaptive entities, then we can expect even more complex behaviours as the agents strive to pursue their own goals and deal with unexpected events and consequences of their own actions in the complex situation.

These features mean that any attempt to influence one part of the situation inevitably unleashes cascading and interacting consequences in many other aspects of the situation. It is not possible therefore, to precisely determine all the effects that an action will produce, nor what the eventual outcome will be on the selected elements of the situation.

The Solution: Adaptation

What does learning to play the piano have to do with evidence-based management? What do the scientific method, design by genetic algorithms and problem-solving have in common? Does human creative innovation have anything to do with the evolution of species?

The answer is that these apparently diverse phenomena are in fact all instances of adaptation. Moreover, these examples are all achieving complex outcomes in complex systems.

The challenge of working in complex environments is their dynamic, unpredictable and constantly changing nature, including changes brought about by other actors in the environment. Therefore the ability to adapt appropriately is absolutely fundamental to success in coping with those changes.

The essence of an adaptive response to challenges is that the system does not attempt to plan for every eventuality with a predetermined response, but has the capacity to generate new context-appropriate responses to new challenges.

This is essential in the face of complexity because the number and diversity of potential future challenges quickly poses an intractable problem in which planning for all eventualities becomes impossible on any reasonable scale of time, system size, or energy. One must therefore strike a balance between developing particular capabilities which have proved their worth in the past (which amounts to planning on tomorrow being somewhat like yesterday) and investing in the capability to adapt to the unexpected (which amounts to betting on tomorrow springing some surprises). The more complex the environment becomes, the more important is the ability to adapt, and the less reliant we should be on the continued relevance of what worked yesterday – in essence the challenge that underlies any defense transformation.

A defining characteristic of adaptation is that the system 'learns from experience' – by which we mean that information drawn from past successes and failures is somehow incorporated into the system so as to tend to increase its probability of future success.

The fact that there *is* a notion of success (and failure) for the system is another defining characteristic.

Of course, success is never guaranteed – however inability to adapt in the face of significant change is a surefire recipe for failure.

There are many forms that adaptation can take and when it works well, it results in new capabilities, new strategies and new behaviors that improve the system's success. Nevertheless there are still many ways it can fail.

It is very important therefore to understand adaptation, to really explore how it works, how it fails, and how and where we may harness it.

This is the rationale for the Conceptual Framework for Adaptation.

The Conceptual Framework for Adaptation

Overview

Exactly what is adaptation?

It obviously involves change, but it is more than just change in response to a changing environment. A rock that heats up as the day gets warmer is not adaptive. Neither is adaptation just self-initiated change. The breakdown of an unstable molecule is not adaptive. These examples both lack the defining characteristics of a notion of success and failure, and the encoding of information for future use.

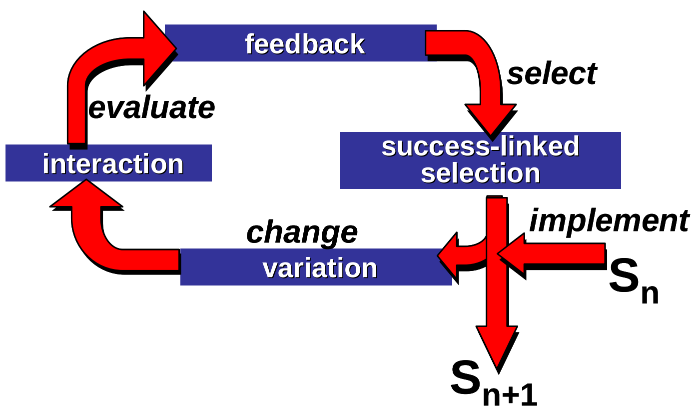

Figure 1: the adaptation cycle. Each cycle experiments with a possible variation of the system (Sn) which, if successful, is retained in the next version of the system (Sn+1). Thus the system tends to become more successful over time.

Adaptation is a powerful underlying fundamental process which at its heart is based on a deceptively simple iterative cycle as shown in Figure 1 above:

> *[change – evaluate – select – implement] repeat*.

such that those variations that tend to increase success (assessed by the feedback from the interaction) are selected (retained) and those that decrease it are selected against (discarded).

The changes that are continuously incorporated into the system amount to encoding information in a way that modifies the future behavior of the system. As a result, an adaptive system has the ability to improve its success in a given context and to maintain success when the context changes.

Fundamentally, adaptation is about change 'for the better' which may encompass improved skills, new knowledge, smoother organisational processes or increased antibiotic resistance in a bacterial strain. Such change, however, implies the need for a means to determine whether that change is going to be beneficial for the system. Beneficial changes are reinforced and becoming part of the system, open new pathways for further adaptation; those deemed otherwise are rejected. The scientist's new knowledge permits better understanding and manipulation of some aspect of the world and opens new lines of research. Greater antibiotic resistance implies that the bacteria can infect more hosts and that new, more resistant strains can evolve. (better for the bacteria, obviously not better for the hosts!)

To adapt means literally to improve the fit of something (the system) to something else (the environment it interacts with). This immediately implies two things: firstly, it must be possible for something to change – either in the system itself, or in its environment, otherwise there cannot be an improvement. Secondly, there must be a way of assessing the fit, or impact on the value function, so that improvement can be recognised.

A third important aspect, also evident in Figure 1 above, is that adaptation is an ongoing cyclic process. There are always more skills to be developed, more problems to be solved, more challenges to be dealt with, and moreover, the environment itself is constantly changing, so that what brought success yesterday may no longer do so today.

Therefore adaptation is not about producing a grand final solution in one step. Rather, the system that is adapting is repeatedly generating and trying out new variations, seeking and considering feedback about whether those variations are an improvement to its fit in the current environment, and so over many cycles of retaining the useful variations and eliminating the harmful ones, the system is continually adjusting and evolving to maintain and improve its success in a changing world.

One can say therefore that the essence of adaptation is that it is:

- ***Value-based:*** Variations are judged by their impact on what matters – success or failure.

- ***Grounded in reality:*** The judgment is based on trying things in the real world and getting objective feedback.

- ***Incremental:*** The system has to remain viable and functioning throughout.

- ***Cyclic:*** It takes many iterative cycles to develop and maintain the level of success needed in an environment which poses many complex and continuously evolving challenges.

Together, these properties make it possible for an adaptive system to 'grow' an effective solution to a complex problem without having to work it all out before engaging.

This is the secret of the power of adaptation in dealing with complexity, since for problems that are complex enough, it is simply not possible to work out a final solution in advance, much as we would wish to be able to. But then inaction is not an option either. Iteration with feedback permits starting with a partial solution and improving it through learning over time. We know that adaptation is a successful strategy for surviving, and indeed thriving in a complex environment. The natural world provides evidence of this success in thousands of examples, from which we can distil these hallmarks of adaptation:

- ***'Intelligent' context-appropriate behaviour*** – discovery and exploitation of advantages available in the system's environment, and recognition and appropriate response to threats

- ***Resilience*** – quick recovery from shocks and damage; core functions are maintained through deeply layered protection and dynamic re-organisation

- ***Robustness to perturbations*** – tolerance to wide ranges of environmental conditions

- ***Flexible responses*** – a range of different strategies for tackling problems

- ***Agility*** – rapid change of tack to more effective behaviours when conditions change

- ***Innovation*** – leading to creation of new strategies and new structures, and

- ***Learning from experience*** – relevant information from past experience is incorporated into the system in such a way that the system's future behaviour is likely to be more effective.

Similarly, an organisation that seeks to be adaptive in a complex, dynamic world does not attempt to anticipate and plan for every eventuality with a predetermined response. Rather, it focuses on developing its capacity to generate new context-appropriate responses to new challenges when they arise.

As a result, it too displays these hallmarks of adaptation. It is not difficult to see why these characteristics would be appreciated by military organisations, as they prepare for the increasingly complex challenges that can be foreseen.

What organisations do find difficult however, is how to move beyond the general recognition that they need to cultivate more of these characteristics, to actually clarifying what is needed, and where and how it is to be implemented.

Insights into these questions has been gleaned from research into the tremendous power and variety of instances of adaptation in the natural world, and has been incorporated into the conceptual framework discussed here, painting a rich picture of the potential to exploit adaptation in a complex organisation such as a defence force. It also provides detailed insight into how to go about realising that potential, of which only a small fraction is routinely tapped by the natural adaptivity of humans and the organised groups they create.

But while it is clear that inability to adapt in the face of significant change is a sure-fire recipe for failure, we also know that being adaptive is not a guarantee of success. Most piano students do not become concert pianists, many organisations fail, the quest for a unified theory in physics has eluded us for many decades, and evolution has driven many species to extinction. It is not sufficient therefore to just *be* adaptive.

Maximising the chances of success through being adaptive in a complex world requires knowing

- when it is appropriate to use adaptation, and
- how to improve the effectiveness of that adaptation;

which needs

- a detailed understanding of how adaptation works,
- where it can be applied, and
- what specific benefits, costs and risks it entails,

so that good decisions can be made about where to invest in being adaptive, and how to get a good return on that investment. These (in a logically re-arranged form) are therefore the essential issues addressed by the several dimensions of the Conceptual Framework for Adaptation [8,9], or CFA, and are described in the following subsections.

Generic Model of Adaptation

Consider a basic concept of a system as having the capacity to sense, and to act conditionally on its environment as a result of what is sensed. For such a system, a generic model of adaptation, comprises four essential components:

1. a concept of 'fitness' or relative success and failure,
2. a source of variation in some parts of the system,
3. a means of testing the variations produced for their impact on fitness, and
4. a selection process which preferentially retains variations which enhance fitness and discards those decrease it.

Continuous cycling through 2,3 and 4 results in the encoding of information into the system, in a way that tends to increase the relative success of the system.

This generic model implies the following basic properties of adaptation:

[a] the existence of an internal yardstick for judging variations for their impact on success or fitness , and

[b] the encoding of information into the system, i.e. the adaptive changes, as a result of the selected variations.

The encoded information is then used by the system in its subsequent behavior. The changed behavior will tend to increase its success as long as what was learned in the previous environment is still relevant. Because both the system and its environment are dynamic and evolving, there is no guarantee that this will be the case. A successful adaptive system therefore repeatedly seeks evidence to test the continuing utility of its adaptive changes.

In addition, steps 2-4 above require

[c] the ability to produce variations in aspects of the system – this is the raw material for selection to act on;

[d] the ability to produce success-relevant feedback about the variations – required for success-linked selection – usually from real-world, or internally modelled, interaction between the varied system and the environment;

[e] selection – this includes not just using the feedback to assess variations for their potential to aid success, but also the resulting decision and its implementation, i.e. reinforcement and propagation of selected variations and elimination and suppression of discarded variations; and

[f] iteration – this is necessary for two reasons. Firstly, in a complex situation it is not obvious how to be successful, so we have to learn from many adaptive cycles in order to create the adaptive changes that bring about the successful outcomes we seek. Secondly, the environment will keep changing, so to maintain success, an adaptive system can never rest on its laurels.

These are the six basic properties of adaptive processes that we need to look for if we want to recognise adaptation happening in the systems of interest to us, if we want to examine how they are working and look for ways to improve them, and if we want to foster new ones where they are needed.

Examining the various ways in which such a generic model can be instantiated suggests a number of classifications for specific examples of adaptive mechanisms, which are reflected in the other aspects of the CFA as discussed in the following subsections.

But first we need to take a closer look at the difficult problem of defining success.

What is success?

A particularly significant insight has been the realisation of the critical role that the concept of 'fitness' or success plays in adaptation, in defining an axis for the selection process and thereby steering the system through repeated cycles of adaptation towards some parts of the space of possible outcomes and away from others.

What the 'fitness' in fact is for a given adaptive system can be deduced by observing how the selection process actually operates. This may not be the same as what an observer might consider to be the 'ideal' fitness of the system, so we need to distinguish between the fitness implicit in the selection process, and an observer's concept of the fitness of the system in relation to its intended or perceived roles and functions.

This suggests two approaches to understanding success and failure.

In natural systems the measures of success can be inferred by observing how selection actually operates – the best and easiest example to understand is evolution of species where the selection process directly gives the actual measure of 'fitness' – either the individual's genes are passed on to viable offspring and are therefore 'fit' by definition, or they are not.

Another example widespread in natural systems is learning, and here we note a possible divergence between how selection operates, i.e. which learning is reinforced, and how we might conceive of the individual's fitness or success. Since learning generally must operate over a timescale which is much faster than the time it takes for the fitness impact of an action choice to become observable, its selection process uses intermediate proxies for fitness, which we define as:

> *Proxies are observable outcomes which are not themselves measures of fitness, but which correlate well with it in the longer term, and importantly, can be detected over a fast enough timescale to allow an adaptive response.*

Of course the ability to learn is itself a product of evolution, so the selection criteria that shape it are driven by the impact on the learning individuals' success in passing on their genes, including those genes that give rise to the learning ability. One would expect therefore that the proxies align well with impact on actual fitness, however if the environment changes significantly then divergences can arise which evolutionary processes may be slow or even unable to reduce.

The other approach is relevant when we are speaking of designed or engineered systems, or hybrid systems that are at least partly designed. The existence of an external designer implies an independent and usually external notion of success for the system, which may well be, and often is, at variance with the internalised measures of success that are actually being used to drive selection in its adaptive mechanisms.

Here the reason for divergence between the proxies and the 'real' externally defined success is more often the sheer difficulty of articulating sufficiently precise and observable measures of success at the right level of scale. The rich multi-scale and multidimensional nature of the outcome space is one contributing factor to the difficulty. Success and failure are most easily and accurately judged in retrospect when the dust has settled and all the consequences have been played out. Since this is the case, we need to learn from hindsight.

However because of the inherently long latency in arriving at hindsight judgments these measures cannot be used to drive the adaptive processes directly at the action level, although we do propose making use of them to drive the slower higher-level adaptive processes (such as learning-to-learn and defining-success – see below) so that overall our ability to effectively and efficiently develop useful new capability improves with time.

But for faster timescales, the difficult challenge is to identify suitable proxies that can be used for adaptive action and that are good, and improving, approximations to the hindsight measures.

Serial or Parallel?

A fundamental aspect is whether adaptation operates serially on individual systems (as in individual learning) or in parallel on populations (as in evolution of species).

Adaptation processes that work on populations and those that work on individuals have complementary strengths and weaknesses – the former can explore large parameter spaces to produce new design features in the population, while the latter are best at tuning a small number of design parameters within the individual system to produce more effective use of the system's existing capabilities. Evolution is slow, blind and wasteful, whereas learning can be fast, directed and efficient. On the other hand, fitness and the selection process in natural evolution are unambiguously equivalent, whereas the proxies for fitness that evolved for the selection process in learning (i.e. pleasure and pain) can, and in many cases have, become misaligned to current real fitness over time as the environment changes.

The information that is encoded as a result of population-level adaptation resides in not just the adaptive features that arise and are retained in the population, but also in their frequency distributions. That information is transmitted from one generation to the next, albeit with modifications.

Information encoded in individual systems on the other hand, resides within the system itself as changes in capabilities and changes in decision processes. Such individual information can only be transmitted from one individual to another if a capacity to do that exists eg through culture.

It is also possible to conceive of other types of adaptive mechanisms which combine the strengths of the natural types and augment them with features that do not occur in nature. This opens up the possibility of much more powerful adaptation than we have so far tapped.

The characteristics of these natural, and hypothesised hybrid or augmented types of adaptation are briefly summarised in the table below:

	EVOLUTIONARY	LEARNING	HYBRID OR AUGMENTED
APPLIES TO	populations	individuals	either
OUTCOME	produces new design features	improves use of fixed design	may be able to do both, or do either better
TIME FOR ONE LOOP TO EXECUTE	period between generations – generally slower	period for one action (OODA) loop, plus associated learning loop – generally faster.	could be accelerated eg through offline simulation
PARALLELISM OF PROCESSING THROUGH INTERACTION	highly parallel – every member of the population is a simultaneous experiment 'evaluating' the fitness of one set of variations	serial – an individual system or organism experiments with one strategy at a time	could use learning mechanism to create directed evolution, and evolutionary strategies to improve learning. Could also parallelise learning through either parallel processing in single individual, or through networking a population of learning systems.
CONTEXT SENSITIVITY	in retrospect only – through some variations turning out to be fitter than others	in anticipation – i.e. before choice of action or response, as well as in retrospect through feedback from consequences of action.	could extend context sensitivity to influence design choices as well as action choices.
ALIGNMENT OF FITNESS AND SELECTION	100%	highly variable	could improve alignment in learning systems by developing better proxies for fitness to drive selection.

Table 1: Types of adaptation and their characteristics

Scales of Adaptation

Being adaptive means having many specific adaptive processes in place, not just a single general purpose one. For example, if a defence force is to maintain a high level of success amidst the stresses and turbulence of its complex environment, many different adaptive processes will be needed to discover how to be more effective, both in solving its difficult problems and in dealing with the wide variety of changes that impact on its operation.

Changes in resources or in strategic factors will call for adaptation of priorities and goals at the organisational level, adaptive logistics are needed to cope with rapidly changing tactical environments at the mission level, and at the individual soldier end of the scale, the need is for each to maintain a heightened sensitivity to indications that the current understanding of the situation may be deficient in some important way so that rapid adaptive changes to the current task can be made when necessary.

There are many more such examples, and the reason it is important to identify them is that each of them has their own requirements for what needs to be monitored, what types of decisions need to be made and what information and services are needed to support those decisions. Those information feeds, support services and decision responsibilities and authorities need to be tightly connected in each case to create the adaptive process that is needed.

So, the many adaptive processes that are needed differ from each other in the scale at which they operate (individual, small unit, up through the command level to the entire organisation) and in the functional dimensions that they address (logistics, strategic policy, manning, task objective, etc).

Furthermore, the very fact that a large complex organisation must have so many adaptive processes in place, creates an additional requirement for adaptive cycles spanning across those scales and dimensions in order to maintain overall alignment of intent.

Obviously these scales are not insulated from each other. They interact generally through adjoining scales, and while the details may vary widely, it is often the case that the properties of the scale below a given level determine the capability than can be exercised there, while the scale above sets constraints and roles. Tuning these aspects requires adaptive mechanisms that operate across multiple scales, while effective action generally requires adaptive mechanisms within a singlescale.

A highly effective and adaptive overall system then will have a coherent and smoothly integrated set of adaptive mechanisms that operate both 'vertically' and 'horizontally' – what we might term an *adaptation architecture*.

The bottom line from this discussion is that we cannot afford to focus on a single scale of operation when we address effectiveness and adaptivity. In fact when problems arising from complexity are raised, they are often presented in a way that conflates several scales – symptoms of the problem may reside at one scale, contributing mechanisms at another, while the most effective levers of intervention for resolving the problem may in fact be at different scales again. This is all the more reason to consciously address and think about what scales are present, what is happening in each one, and how they interact.

Finally we must acknowledge that the scales discussed here (focusing on composition) are just one example of the essentially multi-dimensional and multi-scale nature of complex adaptive systems, and that we could as well address scales through a functional decomposition, or through nested scales of effects, or of time-scales over which relevant contextual changes, system adaptation and action, and their consequences unfold.

Because of the interactions between scales, and between these various dimensions, different conceptualizations of scale are not perfectly correlated, but neither are they independent, as quickly becomes evident in any real world application.

The Black-box Perspective: Classes of Adaptation

Another aspect of the CFA helps identify the many instances where adaptation may be needed by considering what kinds of outcome are sought.

Firstly, there is the basic and obvious adaptive cycle of always looking for ways to increase effectiveness in every function at every scale, from better tactics in the field to better asset management in the barracks. These are the <u>continuous improvement processes</u> which most defence organisations have long practised.

In addition to these internally-driven processes, an adaptive organisation has the capacity to respond appropriately to various kinds of <u>dynamic drivers</u> – significant and unexpected changes that could impact effectiveness, especially those arising in or from the strategic and operational environments. These changes become apparent on different timescales and ranges of effect, and require different kinds of adaptive response.

The CFA identifies four broad classes of such changes. These are described below, together with the kind of adaptive response that is called for.

1. Responsiveness:

Unexpected threats and opportunities can occur within short time-frames and over short ranges. An appropriate adaptive response exploits opportunities and meets threat in a timely manner. This implies the capacity to recognise and respond to these threats as effectively as if there had been ample time to plan and prepare for them.

2. Resilience:

Losses and damage to capabilities are internal changes over short time-frames with a broad range of effects. Resilience implies the ability to recover from or adjust to such misfortunes, and to degrade gracefully under attack or as a result of partial failure. In other words, core functions continue to achieve essential levels of capability when individual elements are disabled one or more at a time.

3. Agility:

A strategy or course of action and its underpinning concept of engagement depend on many conjectures and assumptions concerning a given situation. New information or new developments on any time scale might challenge the validity of these assumptions and affect the feasibility and likelihood of success of courses of action. Agility implies the ability to rapidly recognise when to shift from one strategy or course of action to another and do so smoothly while managing cost and risk.

4. Flexibility:

External changes over longer time-frames and larger scale effects will create different and perhaps unexpected future operational contexts. An appropriate adaptation ensures continued effectiveness across a range of unanticipated tasks, situations, and conditions, for example by reconfiguring the structure and capabilities of the organisation in different ways to perform different tasks under different sets of conditions.

	How responsiveness is perceived	*How resilience is perceived*	*How agility is perceived*	*How flexibility is perceived*
Adversary perspective	The system seems to be 'context-aware'. It discovers and pursues vulnerabilities. It finds and uses resources. It recognises intent and foils attempts to surprise and deceive it.	The system seems unbreakable. The amount of effort required to damage it is disproportionately large compared to its impact.	The system can counter all options. It slips out of our fingers like water. Opponents' initiative cannot be maintained.	The system seems to morph effortlessly from one form to another. The system maintains a consistently high level of potency and effectively checkmates hostile intent. The system is fluid and shifts its strength to the targeted area.
Stakeholder perspective	The system displays a degree of intelligent autonomy even in a hostile environment.	The system provides a high degree of assurance that it will continue to deliver its essential role even in a hostile environment.	The system can deal with an unpredictable, hostile, changing environment. The system will not lose sight of how well its tasks are contributing to intended overall outcomes. It will adapt whenever necessary.	The system is a flexible and powerful tool of government power. It offers a sufficient range of options in any situation. It rapidly generates customised force packages for emerging situations.
Ally perspective	The system is an intelligent partner. It can find valuable new resources, provide valuable information on threat and provide prompt protection and support.	The system will continue playing its essential roles in a hostile environment. Roles of lesser overall value may be shed, which may impact on allies.	The system will adapt to significant changes in the environment in a timely manner. It can be counted on not to become stuck in an ineffective posture.	The system is resourceful and can assume many different roles in a coalition operation. It has a 'can do' posture. It is able to effectively negotiate distribution of roles, resources, and responsibilities with its partners.
Commander or soldier perspective	I am able to recognise and deal appropriately with unexpected events. I can count on my team to do the same.	I am able to rely on the continuing operation of essential functions. I have the means to continue delivering my own critical roles.	I am able to change my approach and course of action in a timely manner as required by significant changes in the environment. I am confident that this happens in a coherent way across the force.	I can rapidly create tailored teams of force elements to deal with any emerging situation.

Table 2: Classes of adaptation and how they are perceived from various perspectives

The value of successfully implementing each of these four classes of adaptation is summarised in Table 2, from several perspectives: an adversary, a stakeholder, an ally and a soldier or commander within the system.

Each of these classes of adaptation can be applied at every scale of the organisation from the highest strategic level of decision-making to the individual. The details of implementation apply variously to each situation depending on its scale and context of application.

An agile platoon commander, for example, constantly looks for any evidence that the platoon's current task is unlikely to achieve its intended effect or that a better option is possible. This may be because important aspects of the situation have changed or were not previously understood. The commander then chooses and implements more appropriate tasks for achieving the higher intent.

Similarly, at the scale of a joint task force, an agile command team not only understands all of the conditions and assumptions which underpin the current operational design, but also ensures that surveillance and monitoring capabilities are tasked to look for any evidence that those conditions no longer apply. Furthermore, when a significant departure from expected conditions is observed, the operational design is rapidly adjusted, triggering a cascade of subordinate adaptations. The result is an agile force that is highly attuned to learning about critical aspects of the operational situation and to adjusting its operation based on what is being learned in order to achieve and maintain a high level of effectiveness.

While the four classes are clearly important at every scale of action in an operational context, they are equally relevant to the business aspects of raising, developing and maintaining the parent organisation which produces and fields operational units. The open boundaries of this larger system and the interdependence of its components make it an equally complex decision-making environment. An organisation that adopts a similar 'adaptive stance' (defined and discussed on p34) at every relevant scale and in every aspect of its functioning, cultivates the adaptive capabilities that will position it to attain and sustain high performance in a constantly changing and high risk environment.

Identifying these four classes is valuable because each has different capability requirements, for example on the kind of continuous monitoring of the relevant circumstances, as well as on the types of adaptive changes to be made. Choices made in the development and generation of forces can thus enable or constrain the extent to which these classes of adaptivity can be exercised.

In particular, decisions that influence flexibility [16] will directly impact on the extent of the other classes of adaptivity that can be realised, so flexibility is an enabler for the other three classes.

Stimulated, Anticipatory or Free-Cycling

Another aspect of adaptation which the discussion of classes clarifies is that an adaptive cycle may or may not be triggered by a stimulus.

Continuous improvement adaptation would likely be a free-cycling process, although feedback about the impact of improvements from previous cycles could certainly affect the next cycle.

The four classes on the other hand, will by definition be reacting to information (the stimulus) about something unexpected and possibly dangerous, happening in the real world.

Responding to well-understood and predictable trends of environmental change can also benefit from an adaptive approach.

This is the third possibility – an adaptive cycle may be initiated in anticipation of some developments in the real world. The triggering information in this instance could for example, be generated by running a 'model' of some sort which represents some aspects of the world, and predicts developments or opportunities that could be exploited. To count as an instance of adaptation of course, feedback about the actual versus expected consequences must be sought and used to inform subsequent cycles of adaptation.

The Bootstrapping Perspective: Levels of Adaptation

Becoming better at adapting

The black-box perspective focused on an outsider's view of the outcomes of the effective use of adaptation. But to exploit adaptation, we also need to take the lid off the black box and look inside at how it works. This complementary element of the CFA addresses what aspect of our system is being adaptively changed. It turns out that this leads naturally to a nested hierarchy of levels of adaptivity, with each successive level operating on all the previous levels and adding more power to them.

Level 1 – the action level.

Adaptation at this level is focused how existing sense, decide and act capabilities are employed from one moment to the next. This level includes most of the tasks performed on operations.

Level 2 – the capability improvement level.

Here adaptation is used to change the sense, decide and act capabilities themselves in ways that increase potential effectiveness. Such changes result in improved outcomes at the 'action' level. Examples of Level 2 adaptation include training, capability development, rapid technology insertion and the creation and dissemination of operational lessons.

Level 3 – the learning-to-learn system level.

The targets for adaptation at this level are the adaptive processes at the previous two levels. The way in which they operate improves as a result, and accelerates the improvement in outcomes at the 'action' level. This level includes adaptive improvements to how training is conducted, to how operational lessons are collected and processed, and to how new capabilities are developed..

To get to the next (fourth) level, we need to take a step back. Implicit in the descriptions of the first three levels is the existence of an internal yardstick for the selection process which determines whether the variations being considered are likely to improve eventual success. Within each cycle of adaptation, feedback is needed about the impact on success of the variation being tried. However since real success or failure can take too long to become apparent, in practice proxies for success or failure are used instead. These are internal yardsticks which can be assessed quickly enough rather than measures of actual success or failure. Examples include performance targets for training, and for new capabilities and course-of-action objectives in operations.

The danger in employing proxies is that they may not be good enough indicators of the impact of each variation on real success and failure. Although accurate feedback about the real impact is usually only possible over much longer timescales, it is important to make use of it in a slower adaptive cycle that aims to improve the proxies themselves, since this will ultimately improve the utility of the first three levels. So we add:

Level 4 – the defining success level.

> At this level the targets for adaptation are the proxies used at levels 1 – 3 and the aim is the development of sufficiently precise and actionable proxies for success and failure which can better steer the lower level cycles towards ultimate success and away from failure.

Finally, when we consider that at every scale of application, from individuals acting alone or in small teams to national forces acting within broad coalitions, there are always many other adaptive systems operating in the same space, we recognise a fifth level, which takes account of how these other systems will adapt in response to the changes we make.

Level 5 – the co-adaptation level.

> The targets for adaptation at this level may include both relationships to other systems in the one organisation, and to other systems outside the organisation. Over time an adaptive system can improve its own effectiveness by gauging the likely responses of others, adapting its actions as a result and then observing the outcomes and learning from them.

Note that each successive level described here operates over a slower time-frame, but adds more adaptational power to deal with the challenges of the complex situation by improving the quality of action possible. Ultimately the impact of all the levels is evident in improved outcomes at the 'action' level, Level 1, which changes what the system is doing in its interaction with its environment. This is where success or failure outcomes are generated.

Decisions made at this level are action decisions – their primary intent is to influence the development of the situation.

Levels 2-5 on the other hand can be thought of as addressing aspects of the design of the system. The intent of decisions made at these levels is to improve Level 1 outcomes by impacting on what future action and design decisions are going to be possible, or how they are made.

Level 2 directly changes the system's design by changing its sensing, decision and action capabilities, while Levels 3 and 4 target the system's adaptive properties. Level 5 targets the design of the larger system within which the system of interest is embedded, and its 'internal model' of other adaptive entities in its environment. Level 5 can also directly or indirectly target aspects of others' adaptive processes (whether friend, foe or neutral) in order to shape their adaptive behaviour towards advancing the system's goals.

In summary, if we think of *action level* adaptation as tuning a given system, and *capability improvement level* adaptation as changing the system, then *learning-to-learn level* adaptation seeks to improve the ability to change the system. Together, these three levels enable the system to drive towards regions of higher success (as internalized by the selection criteria) in a generalized fitness landscape, while the *defining success level* of adaptation calibrates the direction-setting mechanisms – the internalized fitness criteria – by which the system is steered. Finally, depending on whether we are talking about systems that we own, or systems that are owned by others, we can think of the *co-adaptation level* as on the one hand, changing the way we use our systems, and on the other hand, taking account of the fact that the systems with which our systems are interacting are also adaptive, and anticipating the more complex and intelligently reactive and adaptive context that our systems have to deal with.

Implementation Issues

Revisiting Measures of Success and Failure and Proxies for them.

Level 4 adaptation introduced the need for proxies. Often what are described as measures of success are actually proxies—objectives that have been chosen based on the conjecture that achieving these will bring real (often implicit) goals closer.

It is important to be clear about whether goals are real goals or proxies. If they are proxies, then the underlying conjectures need to be made explicit and subjected to critical testing.

The important issue is whether the proxies are actually serving the real goals. This is the process of adaptation which underpins the agility class, and which is therefore vital for ensuring that battles are not won at the cost of losing the war.

Multi-scale Frameworks of Measures

The principle of developing proxies for outcomes that are too slow to materialise or difficult to observe can be applied repeatedly and lead to a multi-scale framework of measures. In each case the new proxies represent conjectures about what has to happen or be achieved in order to progress towards fulfilling the previous ones. Thus the proxies become increasingly detailed, local and short-term, essentially mirroring the operational design from overall strategy, through plans, courses of action, tasks and down to procedures. Monitoring proxies provides information on the extent to which the targeted outcome is occurring. More importantly, however, when considered in conjunction with the proxy or measure of success at the next higher level, it supports testing of the underlying conjecture and therefore both learning about the complex situation and adapting the operational design at the relevant level of detail.

Measures of failure (and their consequent multi-scale proxies) are perhaps even more necessary to clarify than measures of success. Monitoring measures of failure not only supports important learning about the dynamics of the complex situation, but also provides early warning of undesirable developments that need to be mitigated through invoking an adaptive response.

A multi-scale set of measures of success and failure also communicates the purpose and principles of an organisation to its members, thus guiding their behavioural choices. A very useful principle is to reward the achievement of desired outcomes rather than just blind adherence to process.

Multiple Instances of Adaptation in an Organisational Context

There is another important aspect to being adaptive as an organisation. The complex structure of an organisation includes many individuals, dynamic teams and groups with different roles and powers. Furthermore, the organisation also acts as an entity within its environment while interacting with other organisations. The problem is that if the need to be adaptive is embraced by every individual, team and group at every scale and pursued independently, there is significant potential for divergence and fragmentation. The key concept that enables constructive resolution of this dilemma is the development of intent, capability and constraints through deliberate and connected design processes.

Operational design (what is going to be done) and system design (what is going to do it) together create the dynamic coherence to harness the creative power of adaptation while also focusing it effectively on the organisation's challenges. Design is itself a process of adaptation. The link between design and adopting an 'adaptive stance' at every scale of the organisation lies in mission command.

Implementing Level 3: How are Success or Failure of Adaptation Defined?

To implement Level 3 we need to be able to measure improvements (or not) in the success of the targeted adaptive process. So that begs the question of what the success of adaptation (as distinct from the success of the system that owns it) actually means. What can adaptation do for us? And how might it fail us?

To answer these important questions it is helpful to think in terms of a visual aid or metaphor - the 'fitness landscape' [5] – illustrated in Figure 2.

Imagine a landscape where each position in the horizontal plane represents a different variation of the system, and the elevation at each position is proportional to the success or fitness of that version of the system in a given environment.

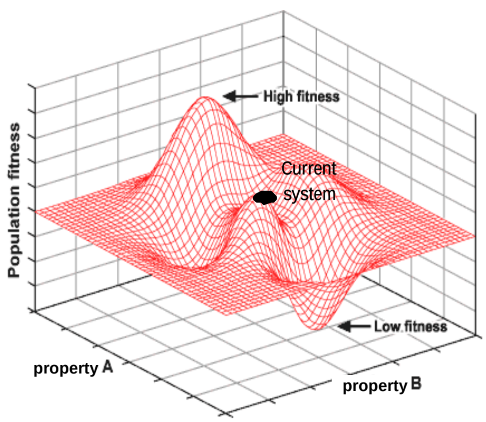

Figure 2: Example of a 'fitness landscape'. The current system occupies one peak in the 'fitness landscape' which means that small changes in system properties (A and B) will decrease its success—it can only move 'downhill'. The landscape also contains both higher peaks and dangerous 'low fitness' traps. Since a system cannot 'see' across the landscape, a fundamental question is how it should move (adapt).

The current version of the system then is just one point in the landscape, and its height represents how successful it is in its current environment. Significant changes in the environment would change the landscape – some areas might get higher, other lower, since success depends not only on the properties of the system but also on those of the environment, in other words, how well-fitted this particular system is to that particular environment.

Now, since height equals success in this metaphor, the question is: how can the system get higher? As the system goes through various changes it is moving in this metaphorical landscape – and if a new version of the system is more successful in the current environment, then that means it has moved to higher ground compared to its previous position.

This is what adaptation does – it enables the system to move in this virtual space, and it does so in a way which is always seeking the higher ground – greater success. Of course we cannot expect the environment to remain static – and when and if it does change, so does the potential success of every version of our system – in other words, the landscape itself is changing shape even as we manoeuvre on it, seeking to improve our success. The system can also seek to shape and harness environmental change to increase its own fitness, without having to change itself.

Like every metaphor, this picture is greatly over-simplified, but it is good enough to convey a sense of what adaptation has to do: either 'move' the system to higher ground, or raise the height of the landscape in the area where the system already is. The former is about changing the system and the latter is about changing the environment, but both are about getting "better", or increasing success.

So this suggests that the important properties of adaptation are:

a. how quickly it can move the system in this landscape
b. how well it can pick the right direction to move in i.e. towards greater success and away from failure or decreasing success, and
c. how well it can modify the environment to
    - increase the success of the current system or
    - counter environmental changes that would lower it, and
    - foster the emergence of high-fitness regions elsewhere to which the system might move.

In addition there are some potentially harmful things we would like it to not do:

d. keep changing things that work well and on which many other things depend
e. decrease the system's ability to move eg by overspecialisation or getting set in its ways;
f. lose useful information – allow the system to forget what it has learnt;
g. modify the environment in ways that decrease current or anticipated future success, eg by prioritising short-term gains over longer-term consequences.

These desirable and undesirable properties of adaptation [10] imply clear objective measures of success and measures of failure for how well adaptation serves the interests of the system doing the adapting.

Notice that some of them are in tension. For example, picking the right direction to move in requires the ability to evaluate how fitness changes in different directions of system change, but this takes time, since we have to try out variations and get success-relevant feedback, so the faster we try to move in the fitness landscape, i.e. improve the first property above, the less time is available for doing the second one well. Attempts to speed the process up in order to move the system faster in the 'fitness landscape', must therefore come at the cost of how well the direction of movement is chosen.

Another example of conflict can be seen between specialisation and agility. Specialisation is the result of adaptive changes that are focused on improving the system's ability to perform certain functions. The danger here is that as the system accumulates changes that make it better at those functions it becomes more difficult to reverse those changes and shift to significantly different capability profiles if environmental changes suddenly require it.

Similarly, the continual churn of testing the utility of variations in current systems becomes difficult to justify and maintain if they experience a long period of relative stability in their environment. They are prone then to stop exercising their adaptive processes and lock in the current successful designs – in other words, get set in their ways. This improves efficiency in the short term, since they are no longer 'wasting resources' on those processes – however they are now at risk of catastrophic failure since they may not detect significant environmental changes until it is too late to adapt successfully to them.

There is also an implicit tension between short-term and long-term benefits. This tension does not exist in natural evolution since evolution has no way of anticipating long-term outcomes. But it is an issue for adaptation in human systems since we do have the capacity to choose our value functions, and to estimate outcomes over different timescales. We must ensure sufficient weight is given to longer-term consequences.

The Independent Design Parameters of an Adaptive Process

We have discussed a generic concept of adaptation as creating variations, testing the suitability of those variations, receiving feedback and evaluating it against the internal yardsticks (the proxies) and, as a result, selecting whether to retain or reject the variation. Each of these functions can be implemented in a variety of ways, and they are all legitimate targets for adaptation. Variations in these will affect the way in which the adaptation operates and therefore the extent of its desirable and undesirable properties. However, the relationship between the targets for change and the resulting impact on properties is far from simple.

Moreover, this implies that there are a very large number of independent design parameters for an adaptive process, and therefore the design space is vast. Yet only an infinitesimal fraction of those possible designs are potentially useful. Adaptive processes with randomly chosen design parameters are almost certain to be useless. Even intelligent and careful human choices are likely to be problematic because although we can in principle make independent choices about how to implement each design parameter, in practice they interact in complex ways to produce the emergent properties of adaptation.

However evolution - itself an adaptive process - is capable of overcoming these odds and developing adaptive mechanisms that are effective, through incremental improvements in design over many generations of large populations.

What this means in practice is that if we wish to learn to be adaptive in new ways, or to greater extents than previously, we cannot expect to simply decide how we think it should be done, put it in place and expect it to work well. In most cases, we will also have to use an adaptive process to develop our new adaptive abilities to the level of effectiveness that we seek. This is the rationale behind Level 3 of adaptation (learning-to-learn, or evolving the ability to adapt)

Variation

One obvious precondition for being adaptive is that the targets for variation must be variable . Conversely, when considering the potential for adaptation, one of the first questions to consider is what degrees of freedom exist for variation and whether they are sufficient. Sometimes all that is required is to remove organisational barriers to variation (subject to risk management). Choosing what to vary need not be random, it can be informed by an understanding of how the variable aspects influence the outcomes. In general, one should not vary too many things at once (unless within a disciplined design process) because it will not be possible to draw unambiguous conclusions about the utility of any particular variation.

Fostering diversity is healthy, however, as it increases the potential for adaptation. However, since there is a tension between diversity and efficiency, current effectiveness (which calls for efficiency) and situation unpredictability (which calls for adaptation) should both be monitored in order to gauge how much diversity to allow.

Interaction and feedback

The utility of variations is assessed by feedback from interaction with the environment, although this can potentially expose the system to great risk. Sophisticated systems such as humans and their organisations make use of models for low-risk experimentation, albeit at the cost of confidence in the outcome. Feedback needs to be both rapid and informative—a problem in itself as rapid feedback is often insufficiently informative. One way to counter such difficulties is to make better use of the 'free' experiments that are continuously generated in any large organisation of humans undertaking complex challenges—the inevitable 'near misses' and errors which largely go unreported in a risk-averse and zero-defect culture. This is further discussed below.

Selection

Selection is the process of deciding which variations are adopted and disseminated in the system; thus it relies heavily on the choice of proxies and the quality of feedback. Selection also involves decisions about how strict or tolerant the selection should be (which will impact on the potential for adaptation retained in the system and its current effectiveness) and how broad or targeted the dissemination policy should be for those variations which are retained.

In general, random variations are much more likely to be neutral or harmful than beneficial and even intelligently targeted variations cannot be expected to have a very high success rate. Thus selection will primarily involve rejecting variations or correcting errors and failures and, consequently, how well those rejections are implemented and enforced is also an issue.

Health of Adaptation

Each element of an adaptive mechanism needs to be just right in order for adaptation to be successful at improving fitness, and maintaining it in the face of environmental change, both with respect to its own functioning and in its relationship to the other elements. If any one element is defective or not properly linked to the others, the adaptation will fail in various ways, for example:

- if there is not enough variation (both in scope – what gets varied, and extent – how much it gets varied), the system may not be able to find new strategies or structures which would maintain or improve its fitness relative to competitors; however if there is too much variation it may not get to recognise the value offered by a new variation before it gets replaced by yet another version;

- if the variations that do arise are not experimented with through fitness-relevant interactions that create feedback then the adaptive mechanism is not able to distinguish between those that enhance fitness and those that dont; timeliness of feedback is in tension with comprehensiveness here – fast specialisation may miss some downsides, but the compromises forced by robustness to many stresses may reduce some benefits;

- if the feedback from the interactions is not correctly linked in to the selection process then the system may fail to retain the winners and discard the losers; and

- if the selection process is not well-aligned with the system's fitness then it may incorrectly label the winners and losers.

- Moreover, adaptation is a dynamic process and the various timescales need to be well-matched. The total cycle time is the sum of the times needed for each step, and in order for the adaptation to cope with changes in the environment, this cycle time needs to be much faster than the time constant of change in the environment – how much faster depends on other parameters that determine the difficulty of finding areas of greater fitness, the topology of the fitness landscape, and the rate at which it can be traversed.

These are some of the factors that can impact on the effectiveness of an adaptive mechanism at producing context-appropriate system behaviour and outcomes. Analysing all of them in a systematic way and developing diagnostic tools to assess the health of an adaptive mechanism is a current active area of research, but a quick 'health check' for monitoring the process of adaptation and assessing its need for improvement should incorporate the following guidelines:

- Align feedback (I know what happened) with responsibility (I care) and authority (I can act on it).

- Make sure the loops are closed, e.g. ensure that when adaptation occurs (at any level or in any class) that the consequences are monitored and fed back to those with the responsibility and authority.

- Look for and pay attention to informal processes of adaptation—what actually gets rewarded or sanctioned in the organisation, rather than what is said to be valued. These are sometimes at odds.

- Where several actors are involved in an adaptive process, check for and remove any conflict of interest with the success criteria for the adaptive process.

- Ensure that those empowered to make decisions on adaptation are also sufficiently supported to do so, especially with action options and relevant information to identify and evaluate action options.

- Consider the relevant time-frames of the cycle of adaptation and of the development of desired and unwanted consequences in the target system. Ideally, a number of cycles of adaptation should be possible in the time it takes consequences to develop.

What influences the success of adaptation?

The previous subsection concentrated or easily identified problems with adaptation. But if the goal is to really enhance the success of adaptation, we need some more detailed insight. We have already discussed a very large number of independent design parameters for any instance of adaptation, and in an earlier subsection, also some broad emergent properties of adaptation which constitute potential measures of success and failure for adaptation. So what is needed is an understanding of how the design parameters influence them.

For a real instance of adaptation, it should be possible to judge the outcomes of those emergent properties, assess their relative priorities and identify where the adaptation is judged to be insufficient. In such a case, understanding those influence relationships will be very helpful in implementing Level 3 adaptation to improve it, since it will indicate where to tinker.

Study of natural adaptation in biological systems has once again been a very fruitful source for insights into this complex web of relationships.

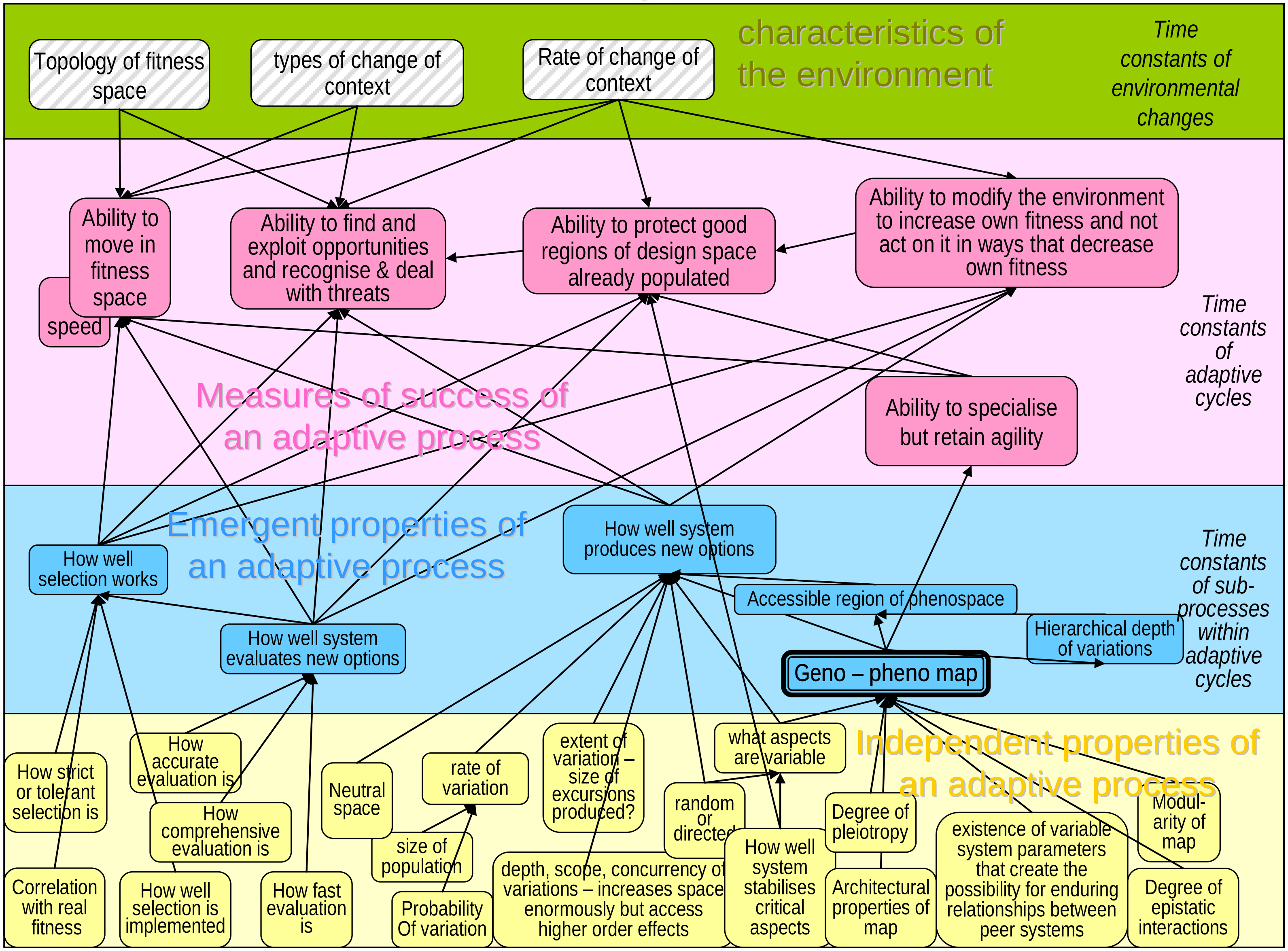

Figure 3: Influence diagram of relationships between independent properties of an adaptive process and its measures of success (see text for details)

While not claiming to be either complete or exact, Figure 3 provides a usable view of those relationships. The dynamic properties of the environment also influence the effectiveness of the adaptive process. Obviously if environmental change is too fast or chaotic, adaptation will not be very useful and therefore not successful. It has also proven to be useful to identify some intermediate emergent properties of the adaptive process between those parameters that are in principle, independently settable (in the yellow band at the bottom of the diagram) and the desired emergent properties. These intermediate properties can serve as proxies for the desired properties that they lead to.

Some of the terminology used in the diagram betrays its origin in current biological theory. These include:

- neutral space (encoded information which does not (currently) affect functionality),
- geno-pheno map (the relationships between encoded information and the actual properties of instantiated systems),
- phenospace (the space of possible instantiated systems),
- pleiotropy (the condition of one piece of encoded information affecting multiple features of an instantiated system) and
- epistatic interactions (whereby the impact of some encoded information on the features of the instantiated system depends on the level of activation of certain other encoded information)

In evolutionary theory, these and other related concepts are of great importance in understanding how new design features arise through adaptation, but they are not at present readily translatable into defence terms, or indeed even interpretable given current ways of thinking.

This suggests that these important concepts in the biological domain may have potential to offer new insights to analogous complex design problems in defence. Further development of this influence diagram and naturalising it into defence language is a task for the future.

Final comment

In this brief overview of the CFA, we have to acknowledge that the real world is generally messier than theory. In practice neither the levels nor the classes described here are quite as disjoint as the framework implies. But we should bear in mind that the intent of the framework is not to provide a rigid or exclusive description of what is possible, but simply to guide a more systematic appreciation of existing and possible adaptive mechanisms.

The real issue is not so much to police the boundaries between these categories but to explore what else is made possible or illuminated through addressing them.

The space of possibilities for exploitation of adaptation to enhance success is much larger than most people realise. Figure 4 illustrates the space defined by just three of the aspects of the CFA, classes, levels and scale

From Theory Into Practice

Too hard or too easy?

There are three common responses to hearing about adaptive approaches to dealing with complexity. The first (*It's impossible!!*) is one of feeling overwhelmed by the apparent difficulties and scepticism that the science can be usefully applied. By contrast, the second response (*It's trivial!!*) dismisses the science as unnecessary because adaptivity is a natural human ability. The third response (*Hmmm… tell me more!*) sees both the challenge and the possibilities and is therefore interested in learning about it.

The first two responses are not helpful if we wish to more fully exploit the potential benefits of increased adaptivity, so we need to address them. Although they seem to be in contradiction, there is a grain of truth in both positions. We acknowledge that fully exploiting adaptation is hard, and we also agree that adaptation is a property of all living systems, and it therefore comes naturally and easily to us. In many ways, human beings are adaptive par excellence, as evidenced in countless ways by human histories and cultures.

But there is no contradiction here because these two responses are focusing on adaptation at different scales of complexity. The adaptive properties that living organisms evolve are those that are possible for them to evolve and that sufficiently enhance their success in their environment. So humans are very successfully adaptive at the scales of complexity that characterised the environments we inhabited until very recently – relatively isolated and independent communities of up to a few hundred individuals.

However, our recent global interconnection implies that the scale of adaptivity that we now need to exercise is far greater. In a sense, human organisations arose as an adaptation to deal with complexity that was beyond the cognitive and action span of individuals, but they too have been challenged well beyond their limits now. There is no shortage of examples of massively complex regional and global problems which we struggle unsuccessfully to deal with, even when goodwill and resources are plentiful.

So humans do have a fundamentally adaptive nature and this is a strength that we must recognise, foster and build on. At the same time, we need to go much further in developing adaptive capabilities for individuals, for teams, and for organisations.

Is it too hard? It is too early to be pessimistic because we can identify a vast range of possibilities for being more adaptive which could be, but has not yet been, exploited.

Moreover, our understanding of the scientific basis of adaptation helps us to analyse the factors that influence how successful adaptation is (i.e. the extents of the desirable and undesirable properties listed above), and this will be very valuable when we need to improve the way in which our adaptive processes are working.

The Adaptive Stance

The foregoing sections are quite abstract, and become even more opaque for the non-specialist at the next level of detail about actual parameters and the complex relationships between them. If we hope to produce insights that are practical and can be confidently applied by large organisations such as our defence forces we need to convey the key insights in a way that is readily appreciated and implemented by a broad audience.

The Adaptive Stance is an attempt to operationalize the imperative to be adaptive and to embed it in a familiar military context, where the many existing strengths of military thought can be acknowledged and built upon, and new ideas can be understood in relation to them.

The Adaptive Stance represents a convergence of thinking from two very different origins – one is the detailed conceptual understanding of adaptation sketched out here, and the other is several decades of empirically-based6 and theoretically-grounded work on complex decision-making by Professor Dietrich Dörner at the University of Bamberg in Germany. Dörner's work will be discussed in the following section, where it will be evident how his discoveries and insights are incorporated into the Adaptive Stance. Here we just acknowledge his work as a key source of insight and empirical support.

Basically, the Adaptive Stance is an intellectual stance that creates the preconditions for being adaptive for individuals, teams, and larger groups throughout an organization such as a defense force. In a very important sense, the Adaptive Stance is the necessary complement of Mission Command . What we mean by this is that it both depends on, and is essential for, Mission Command. Neither will work without the other. Mission Command describes how orders should be given to enable those on the receiving end to use their capabilities, initiative, and local knowledge to advance command intent. Conversely, the Adaptive Stance describes how Mission Command should be received and how to make best use of the autonomy and responsibility it confers.

<u>At an individual scale</u>, the Adaptive Stance embodies the military ideals of initiative, flexibility, resilience, integrity, mental toughness, cool-headedness, and objectivity and includes the following personal qualities:

- Ambiguity tolerance – the ability to resist the urge for closure and certainty;
- Openness to learning:
    - accepting the possibility of being wrong, letting go of having to be right;
    - resistance to loss aversion and commitment bias : not falling in love with one's own ideas;
    - accurate persistent awareness of one's assumptions and hypotheses;
    - simultaneously entertaining the possibility of alternate versions of one's assumptions and hypotheses;
    - continuously seeking ways to test them and being prepared to revise them as a result;

- willingness to try new ideas;
- whenever an explicit prediction is made, being willing to observe the real outcome when it transpires and to objectively assess what can be learned in order to improve future predictions and to gain a more accurate sense of the quality of one's predictive ability; and
- doing the same with implicit predictions, by realizing that every decision or action taken contains an implicit prediction, and making those predictions explicit;

- An ingrained habit of thoughtful self-reflection about the effectiveness and appropriateness of one's beliefs, actions and decisions, and ever-present consideration of the question: "how would I know if I was wrong about this?"
- Supporting others' learning by appreciating that it is much more important for them to be prepared to be wrong so as to be open to learning, than to feel that they always have to be right (which would require them to either be risk-averse or in denial); therefore 'decriminalising' others being wrong, making it ok for them to acknowledge when they make mistakes or are proved wrong.

These qualities and behaviours massively increase the quantity and quality of learning by leveraging the opportunities inherent in every action and decision.

Although we have described the Adaptive Stance at an individual level, it is clearly a stance that would be difficult for an individual to cultivate in an organizational culture which was punitive and blame-oriented, and which insisted on unattainable standards of performance. To empower the individuals in an organization to adopt the Adaptive Stance it is necessary for their senior leaders to lead the way by example, thus demonstrating that the organization really does value adaptivity and learning for tomorrow more than it values a perfect score for today.

It is also a stance that requires some autonomy – clearly it would be difficult to practise it in an organization which demanded conformity and used prescriptive command. Such an organization would be incapable of utilising the vast learning and adaptive potential of its members.

Similarly Mission Command would be disabled by the absence of an Adaptive Stance, which equates to a stance of waiting to be told what to do, following orders without question, assuming others know what they're doing, and not taking responsibility.

<u>At higher scales</u>: the Adaptive Stance can also be adopted at higher scales than an individual. For example, an organization that adopted an Adaptive Stance would be open to the possibility that any element of its hardwon and prized codified knowledge (in the form of rules, procedures, tactics, doctrine etc) and its operational knowledge (objectives, plans, situation awareness pictures etc) might be wrong in some ways, or in some circumstances. If it was important to know, it would then deliberately use some of its resources to look for evidence of being wrong, and revise its knowledge as a result. It is not easy for a larger entity like an organization to cultivate the corresponding Adaptive Stance qualities at the scale of that entity. Effectiveness in pursuing a given course of action may partly depend on the level of commitment to it, which constant questioning may undermine. It may be better in that case to dissociate responsibility for execution, from responsibility for questioning and looking for contrary evidence.

<u>Across different scales</u>: We cannot fully discuss nor resolve all the issues in taking an organizational Adaptive Stance here, but there is one example where the adaptation and learning of the individual and the organization intersect, and considerable learning potential results for both.

Table 3 below illustrates all the possible combinations of an individual's action or decision and the apparent outcome. Assume that the 'rightness' of the decision or action in the circumstances can be judged by a Subject Matter Expert who is familiar with all the organization's codified and operational knowledge. The outcome can similarly be judged as catastrophic, not what was sought (wrong), or what was in fact sought (right). Of course the individual's action is not the sole determinant of the outcome so we expect all the boxes to be populated

The boxes on the diagonal represent those cases where the organization's expectation is met – so the individual's behavior is not creating a learning opportunity for the organization here (this is an oversimplification for the sake of the point being made). However the center and upper left boxes do represent learning opportunities for the individual – the organization will teach him what they expect of him. The bottom right hand box reassures both the individual that he did the right thing, and the organization that its judgment of the correctness of his action is also correct

Outcome \ Individual decision or action	"Unacceptably" wrong	"Acceptably" wrong	Right
Catastrophe	**Sanctions or punitive Measures**	**Learn about context.** Learn about the boundaries of what is/isn't acceptable	**DON'T SCAPEGOAT!!** Review boundaries between "wrong" and "right". **LEARN RESILIENCE** Learn about complex dynamics that led to outcome
Wrong	**Sanctions or punitive Measures**	**Corrective measures** **(individual learning)**	**DON'T SCAPEGOAT!!** Review boundaries between "wrong" and "right". Improve decision process and support. Learn about complex dynamics that led to outcome
Right	**Review how 'unacceptable' is defined.** **Sanctions or punitive measures**	**STOP BLAME GAME** **"near misses"** Learn about tolerances, and robustness of processes. Learn about complex dynamics that led to outcome	**Confirm what is already known, or guessed**

Table 3 An individual action or decision can be judged by the organization according to its codified knowledge, as having been the right choice in the circumstances, or not (either 'acceptably' or 'unacceptably' so, in the latter case implying serious consequences such as court-martial). The consequences of the decision or action can be catastrophic, wrong (not what was wanted), or right (what was wanted). Because the individual's action is generally not the sole determinant of the outcome in a complex situation, every box in the matrix can be populated. See text for discussion.

The interesting boxes are the yellow-shaded off-diagonal ones because here the outcome does not match the organization's expectations, so there is the possibility of organizational learning.

When the individual has done the 'right' thing according to the organization's knowledge at the time, it should not turn around and pillory him if the outcomes turn out to be unsatisfactory or worse. Blaming the individual is a natural reaction, but very damaging for all concerned because it precludes organizational learning, and erodes personal confidence, goodwill and trust in the organization. The learning opportunities relate to why the unwanted outcomes were produced and how with hindsight, they might have been avoided, and whether the codified knowledge that judged that action as 'right' before the outcomes were produced, needs revision in the light of what happened. These are rich and valuable learning opportunities for the organization in both operational knowledge and codified knowledge. These opportunities are denied to an organization that has a scapegoating culture.

The bottom left box is an interesting case. If a successful outcome results from an individual's action that is deemed unacceptable, the organization has to decide if the judgment of "unacceptable" still stands because it is based on fundamental values or principles, or whether it was based on a more pragmatic criterion which might be revised in the light of what happened.

Finally, the most important box is the middle of the bottom row. This is the case where the individual has not completely observed the organization's expectations but nevertheless a good outcome has been obtained. These are the near misses, where mistakes were made but there was no serious price to pay.

We expect that there will be large numbers of such incidents throughout an organization, for the simple reason that humans make mistakes. Near misses are a hugely valuable learning opportunity both because there are so many of them (and therefore they collectively explore a very large space of possibilities), and because they are in a sense 'free experiments' which carry potentially valuable information about tolerances and robustness of processes, and failure modes of our systems.

But these lessons are not available to an organization which does not foster an Adaptive Stance culture because if no adverse consequences force them to, individuals will not be motivated to report a near miss and incur blame and criticism for what they did wrong, when they can instead bask in their successful outcomes.

Finally there is another important cross-scale opportunity for individual and organisational learning in complex operations such as our forces are currently engaged in. These situations involve a great number of diverse individual agents and groupings at various scales, and it is very difficult to identify them all, and establish the connections between them, and their multiple and shifting allegiances and networks.

Understanding this complex human terrain is crucial for successful interventions, be they peacekeeping, reconstruction, counterinsurgency or humanitarian missions, but it is simply too complex, too dynamic, and generally too obscure for the traditional approach reliant on a small number of individuals in the S2 and S3/S5 roles, supported by intelligence, surveillance and reconnaissance systems.

A complex systems perspective suggests that the development of sufficient understanding of this complex human terrain calls for an approach with a commensurate degree of diversity – a far greater degree of diversity than is available in the traditional approach.

But the needed diversity can be found in the many individuals that comprise the deployed force. This diversity needs to be harnessed more effectively to support the necessary organizational learning about the situation. Each individual will observe a different small part of the total situation and will filter and interpret it differently based on his unique history and knowledge.

The organization needs to learn how to learn from all these individual learnings. There are of course a number of challenges in achieving this, not least, the challenge of learning to not just tolerate diversity in the force, but to foster and embrace it as a precious resource.

Proposed Future Research

It is generally the case with scientific research, that every insight won raises new questions, and while knowledge of a small domain grows slowly, awareness of the size of ignorance grows faster. This work has been no exception.

The application of the CFA to various defence problems [6, 11-15] has so far been an effective way of driving its development. More case studies and applied studies would be helpful to develop more workable techniques and tools to operationalise the framework.

The big challenge is to tackle a general theory of interacting adaptive processes, as also identified in the Causal and Influence Networks thrust, and the Complex Operations thrust. Having the detailed CFA for an isolated instance of adaptation provided here is a good starting point for this problem. There are several important aspects of this challenge – multi-level selection, interaction between different inheritance pathways, interaction between self-organisation (S-O) and adaptation, how robust functions emerge from networks of noisy interacting adaptive and S-O processes, and so on. The theoretical biology field has been in ferment for the last several years and there is a wealth of new ideas to explore.

It would also be useful to extend the framework to encompass other processes that produce, maintain or modify structure in complex systems, such as S-O, autopoeisis, and homeostasis.

Irrespective of how rapidly progress might be made in extending understanding of this domain, the CFA as it now stands is mature enough to be usefully applied to many existing problems.

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