9th International Command and Control Research and Technology Symposium

Coalition Transformation: An Evolution of People, Processes and
Technology to Enhance Interoperability

Track: C2 and EBO

A GENERIC FRAMEWORK FOR GENERATING AND EXPLORING C2 CONCEPTS

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Abstract

It is difficult to be truly innovative and generate previously untried and potentially effective concepts. Most 'new' concepts fall into one of two categories: either they arise as a result of trying to solve a problem with the current concept, or as a result of trying to make use of a new possibility. Either way, the new concept is largely constrained by pre-existing structures, paradigms and processes. The agenda of force transformation however challenges us to find new domains of effectiveness in a mostly unknown and hugely complex fitness landscape. This challenge can be broken down into a number of essential phases which can then lead us to a more systematic exploration of the space of possibilities. The first phase is to understand what constitutes 'effectiveness' since this must serve as the compass to guide the exploration. The second is to understand the dimensionality and structure of the concept space we want to explore, and for this we need a generic model of the functionality of the concept that identifies all the degrees of freedom that distinguish different concepts. Thirdly, we need a way of rapidly scanning or segmenting the resulting hyperdimensional space to mark potentially interesting regions for more detailed exploration. And finally we need an accelerated form of co-evolution and effectiveness evaluation to find the local peaks in the marked regions and to explore their breadth and robustness in critical dimensions.

A research program addressing these challenges will be described in the context of a multifaceted force engaged in Effects Based Operations in unpredictable and dynamic non-conventional scenarios. The complexity of the context is required to ensure a commensurate richness in the functionality model, and its structure will be analysed to identify rapid scanning techniques and segmenting filters to focus attention on promising areas. This process yields a number of interesting research questions for further exploration, many of which are amenable to Agent Based Modelling approaches.

1. Introduction

The concept of force effectiveness is a bit like the concept of quality – proverbially difficult to define rigorously, but you know it when you see it. It doesn't matter too much[1] so long as we are operating in familiar territory, because we can use more precise articulations of elements that we 'know' contribute to force effectiveness to provide our compasses to steer by, but it starts to matter terribly when we contemplate the challenge posed for today's western defence forces by the twin prods of exponential growth in technological capabilities and in the range and multiplicity of threats. A natural response by defence planners is to seek to pit the potential advantages of the one against the dangers of the other – hence the successive waves of acronym-ridden initiatives over recent years, currently encapsulated by the various flavours of network-oriented (NCW, NEC, NCO etc) and effects-oriented (EBO, EBP, MDM etc) approaches[2], and the over-riding agenda of force transformation.

Transformation is also an interesting word. It suggests a sweeping and comprehensive change in structure, functions and processes rather than localised improvements in the way things are done. One might expect a transformed force to not just do the same things slightly, or even significantly, better, but to be doing different things altogether, to be performing different roles in the bigger picture. A transformed force might be leaner, more powerful, more aware, more anticipatory, more responsive, more flexible, better able to deal with simultaneity, complexity, diversity, and to do so in effective partnership with a host of other agencies and arms of

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[1] This point is arguable, and only approximately true under very limited conditions, but is not the subject of the present paper.

[2] Network Centric Warfare (US and Australia), Network Enabled Capability (UK), Net Centric Operations (US), Effects Based Operations (US and Australia), Effects Based Planning (US), MultiDimensional Manoeuvre (Australia)

government that may have roles influencing the same action space. The vision invoked by such rhetoric might be inspiring, or daunting, but either way it begs many difficult questions.

If we are talking about changing the game, and moving the goalposts then how do we know in what direction to move them? If we are talking about particular radical changes to some aspects of the force, how can we have reasonable confidence that the necessary complementary changes in other aspects of the force have been identified and can effectively be implemented in parallel? If we are talking about profound transformation, how can it be implemented without taking the force off-line and creating a temporary but tempting vulnerability?

These are important questions, and their difficulty springs from a common thread: in each case we are looking for a needle in a haystack. In the first question, it is not a plain two-dimensional playing field that we are navigating, that can be viewed and appreciated in its entirety by an observer, but a dense fog that we are groping in, in a dimly perceived hyperspace of possibilities that might be aimed for. In the second question, if we have somehow identified a potentially fertile domain to explore in a few dimensions of that space, we are nevertheless still faced with an astronomical number of combinations of settings of the remaining degrees of freedom. In the third question, supposing we have succeeded in the first two gargantuan tasks and have determined a worthwhile objective force construct which is significantly different from today's, we now have to find a viable path through a vast number of intermediate possibilities such that the force retains a necessary level of capability at each step along the way.

This analysis brings to mind the definition[3] of problem or task complexity as the ratio of the number of ways of performing the task incorrectly to the number of ways of doing it right. By this measure, each of these tasks have extremely high levels of complexity.

There are more questions of this nature than there are convincing answers, but two recurring themes emerge in attempts to deal with these issues: experimentation and (co-)evolution.

Experimentation has been a growth industry in defence for the last several years, as if it was a newly developed technology rather than having been the mainstay of scientific research and development for at least a couple of centuries. However, despite the massive resources now channelled into defence experimentation[4] it is the author's contention that that effort is too often misguided in its attempt to apply scientific methodology to what is essentially a complex design challenge, rather than a research program of discovery about how things are in the world. The crucial difference between the two is that science looks for enduring and universal principles by a process of attempting to refute hypotheses through experimentation designed to test all their consequences, whereas in a design problem we are first looking for ways to make things work. As the above concept of task complexity makes clear, there are always a vast number of ways of doing things wrong, and relatively few of getting it right – the challenge is to find the latter. So naïve experimentation that results in 'breaking' a new concept hasn't proved anything except that the experimenter hasn't been smart enough to figure out how to take advantage of the potential utility that might reside in the concept.

This common failing of experimentation methodology in support of concept development is somewhat redressed by the emergence of evolutionary design and evolutionary engineering[5] and the growing emphasis on co-evolution of interdependent aspects of a complex system. These are newer arrivals on the scene but are rapidly gained currency as the limits of conventional systems engineering in dealing with high levels of complexity have become more apparent.

The salient principle of co-evolution here is that of multi-dimensional exploration of the effectiveness landscape within a targeted domain in order to find (co-evolve) specific

[3] http://necsi.org/projects/yaneer/SSG_NECSI_2_E3_2.pdf

[4] *The Code of Best Practice for Experimentation*, Alberts, Hayes, Kirzl, Leedom, and Maxwell, CCRP; *Delivering Innovation, The Joint Concept Development and Experimentation Campaign Plan FY2004-2011* http://horizontalfusion.dtic.mil/docs/warfighter/CPLAN04JFCOMCdr.pdf

[5] http://necsi.org/projects/yaneer/SSG_NECSI_2_E3_2.pdf

combinations of the characteristics represented by those dimensions, which work well together and result in acceptable[6] levels of utility. Measurement of the utility clearly requires experimentation, but what is less widely appreciated is that the design process itself in the form of constructive exploration also requires experimentation.

The challenge of force transformation requires us to develop strategies for addressing these difficult questions, and in this paper we will concentrate on the first of them, the ‘where to look’ issue.

But first, the sceptical reader may need convincing of the scale of the problem.

2. Transformation Problem 1: Where do we look?

Adopting a goal of force transformation carries an implicit assumption that where we are now is not good enough, or soon wont be, and that somewhere else is much better. But what is this metaphorical space in which we posit our present force and imagine others?

The familiar 3-d fitness landscape diagram of a hilly terrain laid out over a finite rectangular grid, where height indicates fitness, and the two horizontal axes represent the degrees of freedom of the system whose fitness is represented, is deeply misleading because it conceals a number of serious problems:

1. ***How do we define fitness?*** The picture suggests that ‘fitness’ is a well-defined function, overlooking the thorny problem of articulating what constitutes fitness in a way which is meaningful relative to the government’s intent for the force, i.e. defining the success criteria by which the government might judge the value of its defence capability, and actionable by those charged with defence development. In reality, there will be multiple conflicting and shifting requirements and the combination of these into a single fitness metric can only be done by imposing value judgments on relative weights – essentially policy judgments, which are notoriously ephemeral.

2. ***How big is the space of possibilities?*** The two dimensions and the convenient sized grid suggest a very tractable search space, but in reality we are dealing with a vast number of dimensions, some of them with ranges spanning many orders of magnitude, or perhaps even unbounded. There are various ways of estimating the dimensionality of the space, but when one considers that describing a force construct includes not just the technical performance parameters of the equipment, but also organisational structure, doctrine and procedures, human roles and capabilities, and supporting infrastructure, then even a crude quantisation of all these aspects leads to a combinatorial explosion of possible constructs. Granted that few of them would represent viable constructs worth exploring, the problem remains that there is no possibility of exhaustively and systematically searching the space for regions of potential novel utility.

3. ***How does fitness depend on design choices?*** The picture also suggests that fitness is a single-valued and smoothly-varying function of the system’s degrees of freedom, or design parameters. Not only is this not the case in general, but capturing the dependence of the fitness metric on system design parameters is far from trivial.

   When we consider a high level effectiveness metric which is relevant to government intent there will necessarily be a large number of interacting causal and influence factors contributing to the final outcome, and these cannot be untangled as if they operated independently and could be aggregated linearly.

   In general, force fitness depends on not only the design degrees of freedom in the force (what capabilities we have and how we organise, manage and use them, including C2 and operational concepts), but also on the agreed success criteria, on what other

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[6] when a threshold of complexity is crossed we have to abandon notions of optimisation – evolutionary systems never optimise – they can only seek a transient competitive edge.

cooperative and opposing agencies choose to do, and on a range of contextual and environmental parameters.

Therefore it becomes very difficult to attribute unambiguous ‘value’ to a proposed new C2 concept – any estimate of the impact on fitness will depend on a host of these other contingent factors which might have been chosen differently or over which we have no control. In other words, the value of each design choice may depend critically on what other design choices have been made, and on other uncontrollable factors. This is significant if we want to undertake comparative evaluation of different design choices since the ranking that emerges may depend dramatically on the contingent factors.

Even if we agree to a test scenario in order to provide a fixed context for comparative evaluation of competing design choices, the overall fitness will still depend in a highly non-linear way on other aspects of the total force construct, so the bottom line is that a realistic fitness landscape will be neither single-valued nor smoothly-varying.

4. ***How can we ‘see’ the peaks?*** In the fitness landscape picture, the current operating point is generally identified as a medium size hill in the foreground, while an *evidently* higher peak in the background is earmarked as the target, trivialising the problem of finding out where higher fitness regions may be. But we cannot ‘see’ the fitness landscape in any real problem domain, because as discussed above, fitness is a highly non-analytic function of a huge number of factors, and can only be ‘discovered’, in one small region at a time, by careful experimentation-supported co-evolution of a small selected subset of those factors. So there is a significant problem hidden in the question: if we are seeking transformation, where should we look?

5. ***What strategy should we follow in exploring this space?*** If, as a consequence of its hyperdimensionality, we cannot traverse the entire space in a systematic way, then how should we choose a tractable and useful subset of dimensions to explore in? In other words, what do we ignore (keep fixed) and what do we explore (permit to vary)? This is another non-trivial problem, and the way in which it is answered will foreclose possibly interesting options which will not be considered. A more sophisticated formulation of the question would instead ask how to select a search trajectory in the space – allowing for the selected variables to be scanned in a correlated way.

   Proponents of the 3-d fitness landscape view might argue that it represents an approach where, having somehow chosen the variable parameters, everything else is held fixed while fitness variation with those parameters is explored, but this ignores the interactivity of the many factors influencing fitness and would generally fail to capture the true potential impact the choice of those parameters might have. In other words, the complexity of the system we are dealing with will generally require many other aspects of the system to be ‘tuned’, possibly undergoing quite radical rethinking, in order to reap the potential benefits of any particular proposed innovation in the targetted parameters. The results of the ‘tuning’ will in general vary along the range of the parameters we are explicitly exploring. This makes a nonsense of the notion of a few-dimensional fitness landscape with ‘everything else fixed’. If the shape of the fitness distribution as the target parameters are varied is to be a useful indicator of the potential utility of those parameter ranges, then ‘everything else’ should not be fixed, but tuned accordingly in each sample region.

6. ***What should we do at each point of the search trajectory?*** Obviously we should estimate the fitness at each point, which requires some kind of experimentation environment in which outcomes can be generated to populate effectiveness metrics, but furthermore, as discussed above, in order to be useful this requires ‘tuning’ of the other aspects of the system, which itself poses major problems. There is no unique, exhaustive nor simple way to do this except in the most trivial cases. The best way known to the author is through co-evolution of the other aspects in iterative experimentation, but this will generally be expensive and slow, and in any case will produce fitness estimates that depend on the details of how the tuning is done.

7. ***But the space is not static!*** A further complication not apparent in this picture is that the context in which our system is operating is reactive and proactive – any perceived shift in our operating region is likely to trigger a countering shift in adversary posture which will impact on the resulting fitness of our system. In other words, it is not a static landscape in which we can meander about and stake out the higher ground, but a dynamic responsive one in which a hill may melt away as fast as we invest resources in climbing it, and the holy grail of a supposed distant peak may always appear to be just that – out of reach.

Of course the difficulty of the transformation challenge does not constitute a reason for declining it, but while there is much effort going on within western nations to address it, truly transformational insights or outcomes have been elusive.

If one examines the 'new' concepts that have been proposed, they generally fall into two categories: they arise either as a result of trying to solve a problem with a current concept, or as a result of trying to make use of a new possibility. Either way, the new concept is largely constrained by pre-existing structures, paradigms and processes, and generally amounts to doing the same things somewhat better or faster – which may be useful as long as those same things are still relevant, but which can hardly be considered transformational. In the language of our conceptual space of possibilities, these categories of approaches are likely to perform limited exploration in the vicinity of familiar operating regions, but are unlikely to suggest radically different operating regions.

3. A Solution Strategy

If we wish to break through this logjam we need to develop a systematic strategy which addresses the difficulties discussed above.

We propose here an outline of such a strategy, based on breaking down the problem into a number of relatively tractable phases tackling each of the seven major problems above in turn, which can then lead us to a more systematic exploration of the space of possibilities.

The first phase is to tackle problem 1 – understanding what constitutes 'effectiveness' since this must serve as the compass to guide the exploration. The second phase addresses problem 2 – understanding the dimensionality and structure of the concept space we want to explore, and for this we need a generic model of the functionality of the concept that identifies all the degrees of freedom that distinguish different concepts. Thirdly, we need a way of rapidly scanning or segmenting the resulting hyperdimensional space to mark potentially interesting regions for more detailed exploration. This entails making some progress with problems 3, 4 and 5. And finally problems 6 and 7 teach us that we need an accelerated form of co-evolution and effectiveness evaluation to find the local peaks in the marked regions and to explore their breadth and robustness in critical dimensions, and their dynamical behaviour in a reactive context.

A successful implementation of this strategy would yield a rich harvest of promising new concepts as candidates for force transformation. Obviously this is an ambitious agenda, and we will only overview the process here, and point to some of the further work that needs to be done. Furthermore, we will restrict ourselves here to C2 concepts rather than the broader force construct space, but this does not imply much reduction in difficulty nor significance since C2 is at the heart of transformation, and represents both its greatest challenge and its greatest opportunity.

4. Phase 1: Understanding Defence Effectiveness

In some ways this is the most important problem to solve since the consequences of getting it wrong are potentially the most catastrophic. It is also the interface between the defence domain and the larger world within which defence is just one agent. Effectiveness is not to be judged internally but externally by the authority which provides the mandate and resources for the existence of defence. That mandate generally comes with a statement of purpose or mission for defence, but in language too vague to serve as anchors for measurable or estimable benchmarks of effectiveness. Defence planners therefore typically adopt more concrete scenario-based capability goals. But there is a danger in jumping too glibly from the general to the specific here, and that is of losing sight of the many implicit aspects of the defence purpose and thereby producing a force which can do certain things very well, but whose role in the bigger picture is not so well thought through. Since that bigger picture is necessarily impacted by agencies other than defence, and their actions necessarily interact with those of defence, the high level measures of effectiveness for defence must be developed in concert between them all[7], through an extensive and ongoing dialogue between defence, its source of authority, and the other relevant agencies. These will be couched in terms of outcomes that are produced in the world, such as for example: the "*goal is to … deter a crisis with knowledge and application of D.I.M.E.*[8] *effects; but if deterrence fails … compel or defeat the adversary rapidly and decisively*"[9]. But such statements raise more uncertainties than they dispel – what kinds of crises? At what acceptable cost? What constitutes 'defeat'? how do we judge how 'decisively' defence has acted? and then there are the unstated (but even more important) requirements such as for example not to solve one crisis by undertaking actions which ultimately cause a more serious one later[10]. Elaborating answers to such questions entails an exploration of what we might call the 'space of possible futures' and the assignation of value (from 'very desirable' to 'avoid at all costs') to different parts of that space, and then the identification of the roles that defence must or might play and the outcomes it should produce or avoid in its contribution to the generation or prevention of the preferred or dangerous futures.

The first part of that process belongs to the broader forum to which defence is answerable, but the second part, understanding the outcome space – how it relates upwards to the strategic directions sought in the futures space, and ensuring it is reflected downwards into how defence operates, sits squarely in our remit.

At first sight, the outcome space may seem discouragingly complicated with vast numbers of parameters spanning the physical, cognitive, social and informational domains[11], but on reflection there are structured ways to think about it which help us to focus on the essential features. The simplification comes about if we start from the observation that ultimately armed conflict is about a clash of wills, and that the objectives of each party are to exert a shaping influence on the will of the other parties[12], i.e. to create an outcome in the cognitive domain. The reason we seek outcomes in the other domains is that that is how we can influence the will or commitment of other parties to their values and objectives. The reason we identify the will of the other parties as the primary target is that it is the single most powerful locus of control determining they what will or wont do.

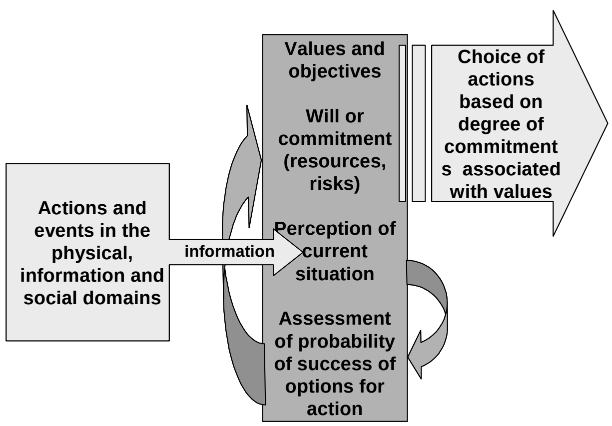

Figure 1 *Information about events in the world influence perceptions of the current situation, which affects assessment of the probability of success of different action options, in turn influencing commitment to pursuing objectives, and hence choice of actions.*

This is illustrated in the simplified influence diagram of Figure 1. The

[7] The need to do this is is at the heart of the EBO concept in the US, but is more focused on the context of operational planning, rather than on the context of defence capability planning.

[8] Diplomatic, Information, Military and Economic

[9] Brig Gen James B. Smith, US Deputy Commander for Joint Training and Doctrine in http://www.dtic.mil/ndia/2001testing/smith.pdf

[10] for an insightful discussion of how such errors commonly arise in complex situations see *The Logic of Failure,* Dietrich Dörner, New York 1996

[11] as identified in numerous CCRP publications.

[12] Each party also seeks to align the will of the various levels in their own force.

central box lists the four elements of an actor's cognitive domain which we are interested in here. The influence flow we are highlighting is shown by the four arrows.

It is interesting to note that information is the medium whereby actions in the physical world influence perceptions and ultimately the commitment or will to act.

Information is derived form the physical world, but is manipulated by various parties along the way. It purports to describe what has happened, is happening, might happen or will happen, but it may be deliberately or accidentally inaccurate. The information is distributed in inhomogeneous ways to people and affects their perceptions, and ultimately their decisions to act. A very direct way of influencing outcomes therefore is through information operations to control information content and flows.

But overall, the avenue to influencing what outcomes unfold is through the lens of the perceptions of the major players, i.e. all the social, informational and physical outcomes of defence actions need to be seen in the context of a causal network[13] whose target endpoints are the commitments of the relevant parties to pursuing their objectives.

On the other side of the lens, those commitments together with a host of other contingent factors will determine through another causal network the unfolding course of events which we seek to influence. We can of course choose to target some critical points further downstream in the causal chain, for example by direct attack on an adversary action already in train, but if our first preference is to deter such actions we can only do so through targetting the adversary's commitments to them.

Granted that we have no direct access to others' perceptions and will, we can still identify clear measures of success and exit conditions in terms of observable outcomes resulting from the choices they make (such as 'adversary forces retreat from X', 'frequency of violent incidents in AOR decreases', etc...). But those observable outcomes are not sufficient in themselves for our purposes because they dont give us insight into what to do, whereas acknowledging that perceptions are the key to the outcomes we seek allows us to reason about what is going on. These understandings should help us to identify the most precise (i.e. with no significant unwanted effects) cost-effective way of achieving our objectives. From this point of view, the challenge of C2 then, is to choose and cause to happen those actions which will give us an overall adequate set of outcomes in the cognitive domain. We will return to this thread in the next section.

The above quoted example of a defence objective is drawn from the operational planning domain (EBO in fact) and it should be acknowledged that there is an important difference between that domain and the capability development domain.

When one is planning operations in the face of an actual impending crisis the questions raised above become much more focused, and the options, issues, impacts, possible players and so on are much clearer, although they may still be tough to quantify or reach consensus on. By contrast, the difficulty for capability planners is that what types of crises their future capabilities will be called on to address, their extent and concurrency requirements, and the timescales over which they will unfold can only be guessed at, and the span of possibilities is wider than it has ever been before.

What this means is that even if we cant be sure of what kinds of operations we will have to perform, we can be sure of one thing: the realtime dynamics of *deciding* what defence is going to do and *raising* an appropriate force package to do it are going to be of comparable importance with the ability to produce or prevent particular outcomes.

This is essentially a command and control issue, but at a level above that of the command and control of the operation itself. In other words we will need a force which is not particularly

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[13] We talk about a causal network rather than a causal chain to capture the highly interactive and multiple sources of influence on unfolding events. In particular, causal networks may exhibit complex properties such as attractor states, criticality, etc which are important to understand and exploit if we want to focus on effectiveness.

structured or optimised to do a known fixed number of things extremely well, but rather a fluid flexible force construct which can engage and negotiate with a diverse range of stakeholders, and rapidly mount whatever specialised operations are required, in partnership with other agencies.

Thus if the effectiveness measures of the force are to address the extent to which the outcomes created contribute effectively to the strategic steering of our course through the space of possible futures, they must also embrace at the next level down not only the conventional measures of mission outcomes, but also the dynamical properties, of how the higher level decisions about what missions to undertake are made and implemented.

Note that the requirements for the dynamical properties of the defence enterprise as a whole will never emerge from a mission-based perspective of what defence is required to do. It is only by considering the spectrum of contingencies that may arise over time, the need to modify current operations in order to respond to new situations or to accommodate changes in policy or revised situation assessments, the challenges of rapidly creating yet another new force package out of an exhausted and depleted force that has been engaged in multiple continuous operations for some time, and the types of options that defence needs to be able to bring to the negotiating table at the whole-of-government policy level, that one can start to appreciate the full impact of this dimension.

Dealing any further with the issues and complexities of defining defence effectiveness in this way is beyond the scope of the current paper, so we will move on assuming that we have a sufficient articulation to create a fitness concept embodying the actual criteria by which defence success will be judged.

However before we close this discussion we re-iterate that the importance of going through such a process comprehensively can not be overstated. If we fail to do so, we risk investing a massive fraction of our countries' resources in an enterprise which is built on a foundation of sand and which may, in the name of protecting certain of our interests and values, place others that we hold even more dearly in serious jeopardy.

5. Phase 2: Creating the Space - Developing a Generic Framework for C2

Suppose we now have a clear set of effectiveness measures describing the outcomes by which defence will be judged, and hence the roles and functions which it must perform, and the dynamical properties of the defence enterprise.

For the purpose of discussing the subsequent phases of our proposed solution stategy, we take the following as an illustrative example.

<u>Outcome</u>: in the context of preventing adversaries from bringing about outcomes judged to be detrimental to the nation's interests, defence through its posture and operations, whether alone or in cooperation with other agencies, causes the adversary to perceive that it is checkmated in every direction which we wish to prevent, while not impeding those courses of action whose consequences we prefer. In other words, the outcome of defence's actions is that in the adversary's estimation, every Course of Action (CoA) we wish to deter is costly, dangerous and has a low probability of success. Conversely, we always have sufficient freedom of action to achieve our required objectives (i.e. the adversary is not able to constrain our ability to pursue our interests). In particular:

- When the adversary is considering a CoA which threatens our values, we always have sufficient time to select and implement appropriate deterrent actions (i.e. to stop adversary from seeing it as a viable option)
- Response time to threat detection is fast enough to pre-empt threat (i.e. if an adversary CoA is actually embarked on then it is effectively thwarted before any real damage is done)
- Response time to attack is fast enough and effective enough to deny adversary any advantage from attack (i.e. if an attack does occur then even if some damage is done, our response actions successfully counter their intended impact, cf civic authorities cleaning up graffiti immediately to deny gratification to the perpetrators)

- We always have sufficient ‘depth’ to maintain superiority in face of escalation.

The defence roles and functions required to achieve this will include for example, ensuring that our surveillance and intelligence capability is adequate to provide the lead times we need for action, that our response times are fast enough, and ensuring that every own Centre of Gravity is not worth attacking because the cost of doing so is not commensurate with its value, in other words we have effective multilayered defences and our capabilities are so decentralised and robust that no single element has sufficient value to warrant the cost of an attack.

The dynamical properties of the defence enterprise that are required to continuously achieve these outcomes no matter what other operations may be in train, can be inferred from the above in the context of a wider spectrum of operations.

Now that we supposedly have a clear articulation of what we have to achieve, the next phase is to explore the dimensionality and structure of the space of possible ways we might address the C2 aspects of doing it. This raises the obvious question: what exactly is C2 about?

In the preceding section we argued that the challenge of C2 is to choose and cause to happen those actions which, through shifting perceptions and assessments in the cognitive domain, bring about outcomes which contribute effectively to shaping the future that unfolds. This suggests the following primary roles for the command and control of defence:

C2 Role 1 having understood the higher strategic intent in the space of possible futures, negotiating the defence role in implementing that intent,

C2 Role 2 determining the outcomes defence needs to produce or avoid to implement that role, alone or in cooperation with other agencies

C2 Role 3 choosing defence actions to undertake to produce or avoid those outcomes,

C2 Role 4 causing those actions to happen, and

C2 Role 5 monitoring and continuously re-assessing all of the above in the light of unfolding events.

We note that there is an implied logical flow from C2 Role 1 through to C2 Role 4, but that we have to be careful not to build in to our generic framework any constraining assumptions about how these roles are performed and interact. For example, some aspects might in the future be handled indirectly by setting some global or local parameters which affect how the entire defence enterprise, or some part of it, behaves, rather than deliberately and explicitly handled.

We also note that the C2 Roles above are recursive in nature, and can be applied at any level of scale. This raises the issue of how the levels interact. We know how the levels relate in a traditional C2 construct, but again we would seek to not bias a generic framework according to any particular model of how that occurs so as to be open to considering radically different concepts that may arise.

C2 Roles 1 and 2 have been discussed in the preceding section in the context of understanding how outcomes generated (or contributed to) by defence can in turn contribute to shaping the strategically-defined desired future through the lens of impact on the perceptions of the major players and the consequent impact on their decisions propagating through the causal network that produces the future.

C2 Role 3 is essentially a planning role, and requires a similar understanding of the causal network operating on the other side of the cognitive and perceptual realm of the major players – in other words, understanding how the actions that defence might undertake, or contribute to, will impact on the targetted perceptions. The other aspect of choosing action options is understanding their feasibility, costs and risks as well as their expected benefits, and being able to make the appropriate tradeoffs to arrive at a decision. Yet again, we will seek to keep the articulation general enough to not imply any constraint on how actions are chosen. The ‘understandings’ required may be explicitly sought and developed by individual agents (human or not), or they may be implicitly evolved and refined by the system as a whole, or some combination thereof.

We focus now on C2 Role 4, and consider how actions come about, leaving aside for the moment how to choose the actions required. In general, we'd like to understand the causal influences that lead to actions, so that we can think better about how, from a command and control point of view, to bring about the actions we want. In this context we take the most general interpretation of action as anything which generates an observable consequence in the world, including for example the creation or dissemination of information.

The causes and initiation of a (military, but also more more general) action are not as clean to define as we might like but we can identify the several elements or conditions that have to be in place before an action occurs. In no particular order, we propose there are

[i] objective (for action),

[ii] will to act,

[iii] opportunity to act, and

[iv] capability to act, comprising authority to act, and the means (physical and informational), and competence required to act.

So for example the objective, the means and the competence may be there for particular kinds of actions such as destroying some kinds of target, but it wont happen until authority is given and an opportunity arises. On the other hand the authority may be given and the opportunity arise, but the action doesnt get initiated because of a failure of will or of competence. Note that this is not about what it takes for successful action, rather it is about the necessary conditions for an action to happen at all, so it includes poorly chosen or executed actions - even those must have each of the elements to some degree, although people may act without sufficient authority, means or competence, may misread the opportunities presented, may pursue ill-framed or conflicting objectives, may have low levels of commitment and be easily discouraged, and so on.

Clearly these are also recursive functions that occurs at all levels of scale from whole-of-government, big picture, long timeframe, down to individual, local, moment-by-moment, and there are different choices that can be made about how those functions are handled. Depending on what C2 structure and philosophy is in place, those charged with creating actions might get everything they need 'on a plate', or they may need to engage in significant effort themselves to shape the conditions for action.

For example, they may receive objectives and allocated capability which is:

- so specific that the actual action required is clear, or
- specific enough to determine an obvious set of possible actions so that the choice of opportunities to pursue and means to employ is straightforward, or
- broad enough to require further analysis to develop options, evaluate, select and implement them, or
- so broad that significant negotiation is required with higher levels and with flanking entities to create the conditions for actions.

Nevertheless, the functions required are the same in every case, what changes is the distribution of responsibility for performing them.

So, from this point of view, if one of the roles of C2 is to choose and cause appropriate actions that will succeed in bringing about the precise outcomes sought, then we suggest it does so by

[i] determining objectives (ultimately specific enough to act on)

[ii] fostering 'will' to act,

[iii] ensuring that opportunities to act are sought, shaped and recognised, and

[iv] building capability (in slow time) and allocating it (in faster time), or more specifically: delegating authority, with constraints such as ROEs, derived from the defence mandate,

acquiring and developing means and competence (in slow time) and allocating them (in faster time).

As we have noted repeatedly, there is a recursive nature to all of these, i.e. they can be applied at different scales of action (which roughly corresponds to the traditional strategic to tactical continuum).

Obviously there needs to be coherence in the many actions that are generated if they are to bring about the outcomes we want in an efficient and effective way. Because we know that effects of actions will combine non-linearly, a traditional view of C2 would imply that the coordination function needs to be operating on the big picture most of the time, rather than on a segmented battlespace which treats each piece as if it is independent of what is happening elsewhere. This view poses a challenge for the decentralisation of command authority. How will responsibility for the outcomes at various levels of aggregation or detail be shared? Should we aspire to ensure that there are no conflicting/overlapping areas of responsibility, and that responsibility is always accompanied by commensurate authority and means? If so then how do we handle the big picture elements that span the domains of responsibility of several players? And if not then how do we resolve conflicts, tune coordination and improve (not 'optimise' because generally we cant do that) overall outcomes, while maintaining tempo? Either way a degree of interaction and collaboration is required to rapidly identify and iron out conflicts, to iteratively refine action concepts and achieve consistency in the light of the whole context of actions. What needs to be negotiated is the assignment of objectives, resources, constraints, responsibilities, authority and information between the various elements. In complex warfare these functions are not second order perturbations on an otherwise smooth hierarchical C2 structure - rather they are critical aspects of handling complex situations on which success or failure may hinge quite dramatically and non-linearly. Once again this is a recursive concept which applies at all levels of decisionmaking, and may belong in the C2 world up to a point (where that point is set is another parameter of our C2 concept), and beyond that reside in the competence of the actors.

But there is another view about how coherent large scale action can be generated, emerging from the world of the science of complex systems, in particular Complex Adaptive Systems (CAS). This is too big a topic to delve into in the present paper, but suffice to say that it does not require centralisation of control or oversight, and that if we are really seeking to explore transformational C2 concepts we need to keep these options open. The implication for our present purpose of developing a generic framework to generate and explore such concepts is that we have to beware their inadvertent preclusion.

So far, our framework is very general and doesnt say anything about where or how or when all these C2 functions are performed or by who, or even to what extent the functions are performed at all. All these should be free parameters in our framework so that a particular C2 structure and philosophy will correspond to a set of choices as to how these C2 functions are performed, distributed and linked. The framework discussed here is rich enough to generate many different such sets of choices since the permutations of possibilities is huge even for a relatively simple model force.

Some examples:

- one can have a hierarchical command structure in which each level receives objectives, constraints, authority, and resources to allocate from the level above, and is responsible for interpreting and developing them into similar products for the levels below.
- alternatively the distribution of responsibility for defining (and subsequently modifying) objectives, constraints, authority and resources might be devolved to the level of action very rapidly through only one or two layers of interpretation from the external source of authority. Such a devolution might be facilitated by separating these functional elements, or by providing only broad guidance and bounds from above, and creating a marketplace of bottom-up initiated actions which have to compete for resources.
- Constraints have the function of reducing the risk of unwanted outcomes (whether collateral damage and fratricide through ROEs and battlespace coordination, erosion of

future capability through limits on acceptable risk or on consumption, etc). The application of constraints are usually linked with the delegation of authority, but do they have to be?

- Fostering 'will' for the required actions might be primarily the responsibility of the higher levels of command or might be more evenly distributed.
- At higher levels of decisionmaking, the 'will' that needs to be fostered is also to commit the resources required
- Identifying opportunities for action might be a distributed function in a well-integrated system-of-systems, or might be left to individuals.
- Authority for action might be assigned on a case by case basis or semi-permanently, or by rules, or negotiated, or a base level might be always associated with functional roles, and additional authority levels assigned temporarily with allocated objectives and means.
- The means (equipment) and competence (people) might be semi-permanently teamed (eg artillery battery) and assigned to units of action that are more or less transitory or enduring, or the people might be more multiskilled (implying that competence is more widely distributed), assisted by more automation, decision support and intuitive interfaces while the means might be pooled and dynamically allocated.
- many of these functional elements of C2 could be either automated or supported by a higher degree of automation.

Wherever we can identify a number of ways of handling some aspect of C2, we also have the option of deciding whether the choices to be made should be built-in, applied uniformly throughout the force and enduring in time, or whether they should be more dynamic and flexible in time and locally across the force. These meta-decisions have significant implications for the requirements on the way the force is organised, equipped, trained and supported, and for the resulting dynamical properties of the force.

In general, all else being equal, one would prefer to maintain flexibility rather than hardwire such choices and constrain future options. However, all else is not equal usually - in particular costs and risks, and there may be further tradeoffs in capability as well - i.e. structuring for flexibility rather than optimising for a limited range of tasks.

Finally C2 Role 5 covers the traditional control role, but also the growing understanding that complex enterprises cannot be effectively led or managed through ‘ballistic’ behaviour[14] or fire-and-forget processes. Tactical military leaders have always understood this and it has been reflected in their control practices, but strangely perhaps, the insight has not always been equally taken up in the loftier realms of decisionmaking, possibly because of the inevitable inertia that accompanies the scale of decisions at those levels.

For the purposes of our generic framework, the degrees of freedom we have in how this role is implemented are to do with the key parameters of adaptation, addressed in an accompanying paper[15], but in brief, include such aspects as the selection of indicators to monitor, and how well they correlate with the likelihood of producing the preferred outcomes, the frequency of monitoring relative to the timescale of change in the indicators, and how tight the control loops are.

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[14] So-called ‘ballistic’ behaviour, coined by F.Reither in *Sprache und Kognition* 4, part 1 (1985), 21-27, describes the phenomenon of setting a course of action in train and then, as for a ballistic projectile, not paying attention to how it unfolds, or exercising any further control. As Dörner points out (*ibid*) in the context of managing complex enterprises: “Because our grasp of reality can only be partial, we have to be able to adjust the course of our actions after we have launched them; analyzing the consequences of our behavior is crucial for making these *ex post facto* adjustments”

[15] *What Do Natural Complex Adaptive Systems Teach Us About Creating A Robustly Adaptive Force?* AM Grisogono, 9th ICCRTS, Copenhagen, 2004

This analysis would not be complete without a discussion of the role of information in all of the above. Information has been a primary focus of US initiatives to transform defence, and a centrepiece of network-centric theory[16]. Clearly the control and use of information is key, and we have already acknowledged for example its role in bridging the world of events and the world of perceptions which influence future actions. Information also features prominently in our postulated conditions for action: objectives are a class of information, as are responsibility, authority and constraints, notwithstanding their simultaneous standing as politico-legal instruments. The judicious use of information plays a role in fostering will, and it is the means whereby opportunities for action are sought, identified and communicated. But it is as a critical element of capability that the role of information is pre-eminent, whether to support situation awareness for decisions, targetting and battle damage information for response systems, or as the medium for collaboration, negotiation and coordination of cooperative actions. The control function also depends on high quality timely and accurate feedback. These are mostly realtime or near-realtime classes of information, but then there are the slowtime classes of information: doctrine, MGI, databases and so on. There are so many types and roles for information that we are in danger of losing sight of the salient in a forest of detail.

Recalling that we are seeking to identify parameters that can capture the range of ways in which C2 can be exercised, and in this instance, how information is handled, we can find our way out of the woods by adopting an approach based on decomposing the structure of the information space rather than treating it all as an amorphous infospace, which doesnt easily allow the posing and answering of questions about how much information is enough, and what dissemination policies should be invoked under what circumstances. By identifying different classes of information, and allowing for their differential distribution, we can discriminate between the requirements for how the various classes of information should be managed, disseminated and exploited in the light of the different functions they support.

For example, some classes of information might be managed and deconflicted centrally, and disseminated in a controlled way - such as objectives, intent, authority and constraints. Other classes of information might be better handled in a more decentralised way, ambiguous and conflicting information may need to be retained to support competing but plausible hypotheses until the uncertainties are resolved by further information.

As a first cut we propose the following classes:

- I1. information about own force,
- I2. information about adversary forces,
- I3. higher intent, objectives, orders, plans, ROEs, etc
- I4. information about the environment and infrastructure, and
- I5. information about other players.

A useful and orthogonal classification of information might address scale as proposed by Bar-Yam[17]. He has also discussed locality-based measures of information relevance[18], and we would add other non-geospatial measures of proximity which might be used as additional discriminants, in other words attributing relevance not just to information about the local environment but also to information that would reduce a critical uncertainty, cause revision of previous decisions, impact the assessment of the effects expected from planned actions, alter expected costs and /or risks, or change the assessment of the current mode[19] the system is or should be operating in.

[16] See for example *Information Age Transformation* David S. Alberts, CCRP, Washington, 1996, revised 2002

[17] http://necsi.org/projects/yaneer/SSG_NECSI_1_CROP.pdf , http://necsi.org/projects/yaneer/SSG_NECSI_3_Litt.pdf

[18] relevance of course needs to be defined with respect to a role or function.

[19] Mode here means a CAS-type of recognisable pattern of interactions in the whole system, a concept we are in the process of exploring in current research. Switching mode would entail a synchronised set of decisions about meta-levels of control, eg changing the aim point on many tradeoff scales, changing dissemination priorities etc.

There are a number of degrees of freedom characterising how the processes of seeking, processing, managing, storing, disseminating and exploiting information are distributed, performed and prioritised in the whole defence enterprise, and we should allow for their conditional dependence on a suitably refined structural decomposition of information as discussed above, including appropriately defined relevance measures. Our generic framework therefore should include a set of parameters to capture the degrees of freedom implied in this discussion.

Such suggestions may not be well received by hardline proponents of the NCW tenets who may argue that the only way forward is to adopt a seamless high-bandwidth all-informed post-before-process information policy. From our point of view this is a hypothesis, and represents just one possible set of choices. It might well produce high fitness domains under some circumstances, but we are interested in identifying other useful choices as well, and in understanding the conditions under which they are effective. We would claim that the NCW thesis should emerge as a region of potential utility on its own merits from a disciplined application of the solution strategy proposed here, and could constitute one of a set of test cases for refining the strategy.

In conclusion, a generic framework describing the essential features of command and control of a defence force will have two classes of free parameters which characterise the functions discussed in this section, and whose ranges are wide enough to cover all the conceivable ways choices about how they are handled could be made.

At the simplest level, think of the defence enterprise as a black box that the government can use. It feeds in a set of objectives, resources, authority and constraints and a set of effectiveness measures against which defence will be held accountable, and modifies them from time to time, sometimes very frequently. Without peering in to see what happens in the black box, one can observe its output:- over time, defence executes a number of actions that influence outcomes, and its level of performance against the effectiveness measures can be monitored.

If we now lift the lid of the black box, we see a command and control system whirring away processing the inputs and ultimately creating the conditions for actions. One set of parameters will describe how the input stream is transformed into the conditions that produce the actions. It will include for example how, not just information as described above, but also access to resources, responsibilities for objectives and authority, are processed and distributed throughout the complex network that constitutes a defence force, and what types of interactions exist between the nodes of the network. A particular set of values of these parameters will correspond to a particular C2 concept.

The other set of parameters will be the dynamical ones which describe the meta-properties of the command and control system, which of the first set of parameters are not fixed, what their ranges are, how their values are chosen, how long they endure, how homogeneous or otherwise their distribution is, under what conditions they change and what indicators are monitored to trigger such changes. Some of the second set of parameters may also be dynamical, so a meta-meta-level may be required.

We now have an outline of our space. It is indeed very large.

6. Phases 3 and 4: Planning and Executing a Mission in the Space of Possibilities

We present here some initial and immature thoughts about how to tackle the challenge of exploring in this space, hoping that others may be stimulated to join the effort.

It would be useful to find ways of rapidly scanning or segmenting the space to mark potentially interesting regions for more detailed exploration, but in order to think about how to do this we need to first understand the space a little better. All we have done so far is to discuss the possible C2-related dimensions of the space, whereas there are of course many more dimensions required to describe the rest of the aspects of the force other than C2, and what we are actually interested in is a function that describes the fitness of the force construct represented by that point in the space.

At the beginning of the preceding section, we postulated an example set of aspirational outcomes to serve as a vehicle for discussing the phases of the proposed solution strategy. We could apply these in the context of one or more suitably challenging scenarios, bearing in mind the need to exercise the dynamical properties of the force construct as well as its static capabilities. At a given point in the space, in a given scenario where contingent factors are controlled, the fitness, or extent to which these outcomes are achieved by a force whose C2 systems are described by the values of the parameters at that point, will depend on the actual capabilities of the other aspects of the force, including the range of operational concepts available to it. Once again a bewildering array of choices presents itself. We could proceed in two ways. We could work with a fixed array of physical capabilities and investigate the potential fitness of C2 options, tuning operational and logistical concepts for example, to see how in the given scenario those fixed physical capabilities are best exploited. Or we could take the view that we are confident that a particular C2 concept has high potential fitness and explore how to best equip and position the force to exploit that concept. These represent two different search trajectories in the space.

But we still have to address the two key problems:

- how can we reduce the number of regions we have to explore? and
- how can we rapidly estimate the outcomes in those regions without having to mount time-consuming and expensive experiments?

For the first problem, we are seeking ways of reducing the dimensionality and complexity of the problem. The challenge is reminiscent of similarly daunting problems in understanding how natural evolution through random shuffling of genetic material can produce such dazzlingly complex, varied and successful lifeforms, and how human intelligence can leap to insights about a chess problem which defy algorithmic solution. These are examples of the needle-in-a-haystack problem in other guises. The existence of successful outcomes to such problems in the natural world should give us a glimmer of hope that progress can be made, although one would hope that the eons of time that evolution has required to find its needles might be offset by leveraging today's high speed and highly parallel supercomputing haystack-processing capability.

As it turns out, there is a key principle[20] operating in both evolution and intelligence which reduces the complexity hugely, and which we could tap for our transformation problem.

The principle hinges on the exploitation of the building block hierarchy that always exists in complex systems. Simple elements interacting in simple ways produce patterns of behaviour which become the elements operating at the next level up of complexity. Interactions of these patterns then generate higher order patterns which in turn become the emergent entities at the level above, and so on. The search problem for useful new functions at one level then is reduced in complexity to searching through the permutations of the relatively few emergent entities at the level below, rather than the impossible search through all the permutations of the vast number of elements at the base level.

This is the secret behind the success of evolution (selection based on permutations of proven successful clusters of genes through recombination in sexual reproduction rather than random reorderings of the entire base sequence), of human intelligence operating on very slow wetware (heuristic searches through limited spaces of high level cognitive concepts which can be recombined in novel ways), and behind the richness and power of language itself.

It is also the principle underpinning Rodney Brooks' very successful Subsumption Architecture[21] approach to building intelligent machines. Brooks reasons that the Artificial Intelligence community need not attempt to build "human level" intelligence into machines directly from

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[20] see for example John Holland *Hidden Order: How Adaptation Builds Complexity*, Perseus, 1996; Laird, J.E., Newell, A., & P.S. Rosenbloom. (1987*) Soar: An architecture for general intelligence*. Artificial Intelligence, 33, 1-64; Steven Pinker (1997) *How the Mind Works,* New York, Norton ; Steven Pinker (1994)*The Language Instinct, How the Mind creates Language*, New York, Harper Collins. For a simple overview see *Complexity*, M Mitchell Waldrop, Penguin 1992.

[21] Brooks, R.A., "*How to build complete creatures rather than isolated cognitive simulators*," in K. VanLehn (ed.), Architectures for Intelligence, pp. 225-239, Lawrence Erlbaum Assosiates, Hillsdale, NJ, 1991.

scratch. Citing evolution as an example, he claims that we can first create simpler intelligences, and gradually build on the lessons learned from these to work our way up to more complex behaviors.

These examples offer tantalising possibilities which are beyond the scope of the present paper to explore in depth, but we can see that an application of this principle would require further structural analysis of the concept space and the identification of the right building blocks and emergent concepts at each level. As Holland describes it: *the cut and try of evolution isnt just to build a good animal, but to find good building blocks that can be put together to make many good animals.*[22]

This is surely not so different from our own challenge.

The other question posed in this section is how to rapidly assess utility as we traverse whatever search trajectory we end up with. There is hope here too. A successful application of a subsumption approach would imply a number of successive sweeps through a set of nested, but each hugely simpler search spaces with a corresponding reduction in complexity of the fitness function being considered at each stage. We hasten to add that this is not the same as factorising the battlespace into a number of disconnected segments and optimising local tasks in each – which suffers from the inability to deal with coherence and integration in the big picture. The decomposition we are talking about here is in an orthogonal dimension and should foster the natural emergence of large scale coherence as happens in the natural examples which inspires it.

If it all starts to seem too easy, there is still the remaining challenge of dealing with a dynamic reactive context. But this is also true of evolution and of human intelligence. We will have to return to this point in future research.

8. Concluding Remarks

We have attempted in this paper to lay out a possible strategy for tackling the hard problems of innovation and transformation, and in the process have identified a great deal of work that has to be done to even establish how feasible, let alone how productive, the strategy might be.

The tasks include further structural analysis of the outcome space, and its relationship with the futures space, defining useful measures of defence effectiveness, mapping out the causal networks operating on each side of the cognitive domain of the major players, (we have glibly skipped over the issue of better understanding that domain itself, but no doubt that would also yield powerful and deeper insights), further development of the C2 parameter space and its extension to cover other defence functions, structural analysis of that space into a generic building block hierarchy, the corresponding decomposition of the effectiveness measures into a hierarchical structure, and the development of techniques for their rapid assessment, and finally, the application of the subsumption principle to spawning promising concepts for a more targetted search through the space of possibilities.

This is admittedly a high risk and speculative agenda, and there is a modest long range research program in train addressing parts of it, but the scale of the challenge and of the possible payoffs warrants a more concerted effort. The author will welcome interest in collaboration.

9. Acknowledgments

While retaining responsibility for the views expressed here and any errors of fact or interpretation, the author is grateful to a number of people for stimulating discussion and debate: Alex Ryan, Jennie Clothier, John O'Neill, Yaneer Bar-Yam, Rodney Brooks, Derek Abbott, and the members of the NATO SAS050 Panel in particular David Alberts, Dick Hayes; Dan Maxwell, Jim Moffat, Graham Mathieson, Gary Horne and Reiner Huber. The author is also appreciative of the on-going support of the Defence Science and Technology Organisation.

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[22] Quoted in *Complexity*, M Mitchell Waldrop, Penguin 1992.