Strategic Knowledge Architectures for Agile Threat Response

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Abstract

The synthesis of a new type of information is proposed to enhance the agility of threat response decision making. This form of information consists of strategic knowledge objects whose inter-relationships are represented as a set of integrated architectures across the national strategic, military strategic, and operational levels of decision making. The requirements for computing such knowledge objects are discussed, and methods to satisfy these requirements are proposed.

1. Introduction

With the increasing complexity of Defence systems information processing capabilities are being stressed to critical levels. Getting the right information at the right time cannot simply be assumed, nor can it be assumed that a commander will know that some vital information already exists somewhere in his own Defence organisation. The problem addressed in this paper is the difficulty of combining and condensing the plethora of dynamically changing information for the purpose of strategic decision making; exacerbated recently by rapid technological change that has enabled broader connectivity and increased information supply to decision makers. Accompanying this increased supply of information is the burden of digesting it, especially in critical threat response situations where commanders rely on Staff to provide them with information and situation summaries. This paper proposes a structure of key knowledge variables as abstracted forms of information to facilitate systematic and more effective military decision making. Pertinent application arenas are pre-engagement threat response planning and adaptive post-engagement campaign management.

As used in this paper, the term "knowledge extraction" will refer to the processing of information sets, quantitative or qualitative, and converting the information into more abstracted and condensed forms with compact meaning that provides a foundation for decision making. This *interpretive* process of information condensation and reduction is quite distinct to "knowledge acquisition" which refers to the capture of domain knowledge that inherently exists among the stakeholders in a complex situation. Knowledge acquisition methodologies (such as the well-known "Common KADS") are appropriate for capturing knowledge forms already resident in a system for the purpose of modelling that system. In contrast, the focus of knowledge extraction is on understanding a dynamically changing complex situation. Furthermore, the techniques of machine learning and data mining are a special class of knowledge extraction applicable to dynamic streams of fairly accurate process information, or large reservoirs of stored information that are available to be explored (as in a data warehouse). However, these types of knowledge extraction are not addressed in this paper as they are not so relevant to strategic military decision making.

Initially, it is also important to clarify the intended meanings of the terms “abstractions” and “knowledge” in relation to the usage of the same terms by Rasmussen within his influential work on Cognitive Engineering [Rasmussen *et al.,1994]*. “Abstractions” for Rasmussen are mental models, as conceptual simplifications of reality which enable humans to do tasks and solve problems. In contrast, the meaning applied in this paper is that abstractions are mental objects as cognitive interpretations of information sets which enable humans to make complex decisions. These two slightly different meanings for “abstractions” refer respectively to simpler, more condensed *behavioural models* and simpler, more condensed *information* forms. “Knowledge” for Rasmussen (or prototypical knowledge objects) are thus behavioural chunks of experience used to describe rule-based type action. In contrast, “knowledge” in this paper refers to a chunk of information required to instantiate complex decisions. However, Rasmussen also uses another term “symbols” with a meaning quite similar to “knowledge variables” of this paper. He describes symbols as: “defined by and refer to the internal, conceptual representation that is the basis for reasoning and planning.” These terminology differences relate mainly to the difference in objectives: Rasmussen’s primary objective being to understand complex system behaviour by considering a system and its environmental interactions, while the objective of this paper is efficient and effective knowledge extraction to support more agile decision making for achieving desired end-states. Fundamentally, this distinction is between the behavioural analysis of Rasmussen and the complex situation comprehension of this paper.

A key problem for strategic military decision making is how to condense a confluence of imperfect information into more abstracted information forms describing complex situations such that a strategy and Course of Action (COA) can be decided upon. Traditionally, the evaluation and quantification of highly abstracted variables, such as Threat Level, Preparedness, or Red Vulnerability (Opportunity), has been largely a subjective process open to various kinds of inconsistencies and bias that can present obstacles to the formation of a common operating picture. The notion of formal and standardised architectures of strategic knowledge objects (SKAs) designed for specific categories of military decision making is proposed here to achieve enhanced efficiencies at the knowledge extraction nodes in military information systems. Such SKAs are intended to be multi-tier frameworks of fundamental forms of knowledge that are dynamically updated automatically as any new relevant information becomes available. Generally speaking, the information processes that can occur at military information processing nodes are: input screening for relevance, collation, reinforcement determination, fusion, and finally dissemination. For the SKAs, it is the fusion process that is the critical information processing activity, and the assignment of measures to the abstracted knowledge objects may require subjective fusion of lower-level information, or else, require some type of computational synthesis. With subjective fusion, lower-level information is simply summarised into a qualitative measure, linguistic or numeric. For example: the degree of political stability of Red nation is “high”. However, quantitative fusion of lower level information would require careful scrutiny of the information characteristics. For example: what process should be used to combine measures for military resource availability and deployment state into a military readiness measure. The main objective of this paper is to describe the functionality – the pros and cons - of such predefined structures of knowledge objects with respect to information processing efficiencies. By adopting systematic and appropriate computational procedures, consistency can be maintained at high-levels of information synthesis, responsitivity can be increased and the burden on Staff Officers can be alleviated. In other words, if more automated forms of knowledge extraction can be used to maintain an explicit SKA, the agility of strategic decision

making may be increased with a resulting increase in operational tempo. A secondary objective of this paper is to identify the issues and complexities that must be addressed when synthesising imperfect lower-level information into measures of more abstracted knowledge objects. Although detailed computational methods are not presented in this paper, some recent innovations [Warren, 2000] concerning numerical induction with complex sets of information, address many issues that must be considered when computing such high-level abstracted knowledge measures.

2. Globalisation and Complexity

It is apparent that there is an inexorable trend towards globalisation in process where the diverse cultural, economic and political facets of nations are becoming increasingly interdependent. Although certain aspects of globalisation were investigated several decades ago [Forrester,1968], recent technological advances have accelerated the globalisation process to the point where some potential dangers are becoming more obvious. Several recent observers [Cozien and Colautti,1999][Czerwinski,1998][Mulgan,1997] have noted that there is a danger of chaotic behaviour being induced in a complex world system, and that this is of concern because it is extremely difficult to predict what circumstances may initiate such behaviour. Hence it may be rather difficult to avoid. What this means for Defence is that the historical type of discrete nation conflicts are being superseded by less well defined asymmetric conflicts with indefinite boundaries. Operations other than war and peacekeeping are becoming key Defence activities. In fact, all nations are becoming players in a global economic competitive game where tariffs, treaties, embargos, currency controls, and Information Operations are the preferred response mechanisms. As a result, there is now a permanent and continuous need for complex decisions at the national strategic level to manage a nation's position in the increasingly competitive world order. And furthermore, any strategic decisions for military operations must also be integrated with, and accord with, decisions made at the higher national strategic level (see Figure 1). So the current state of world affairs dictates that military decisions be made with cognisance of a broader context embracing non-military aspects and indirect effects, beyond what was traditionally considered by military commanders. SKAs have been proposed to facilitate this broader type of strategic decision making at both the national and military strategic levels. They are but one tool for increasing the nation's competitive edge in an increasingly dynamic and complex world.

3. What are Strategic Knowledge Architectures?

3.1 The Rationale for Strategic Information Architectures

Defending national security differs from the business activities of commercial organisations in some fundamental ways. Accordingly, these differences require a different approach to the analysis of Defence activities. In commercial or service organisations, activities are driven by customer and market needs, and organisational entities compete to satisfy these needs to accumulate organisational merit or gains. In that world, although requirements may be dynamically changing, stable macro processes can be defined as steps towards the goals. However, in Defence the customer merges with the competitor, and one competes with the customer. Although it may be argued that the customer for Defence is the national population (or government), this is not really the case because the dynamic requirements of the threat scenario drive defence operations while the population needs remain relatively unchanged. In effect, the market for Defence business is the hypothetical threat space – situations that could possibly

eventuate and with which Defence must compete. To be driven by hypothetical situations therefore requires a very different approach to that of business organisations. For the special business world of Defence, the primary focus should *not* be on defining business processes (and tasks), but rather be on the dynamic decision making processes and how to adapt effectively to unknown competitive situations. In principle, defence operations are not unlike playing some lethal sporting match. Rather than using an analytical model based on processes and groups of activities, what should be modelled are the types of decisions, or plays, that re-occur in defence operations. To this end, the key decision categories should be defined along with the knowledge forms upon which they depend. A subsequent consideration would then be how to make the decisions more effectively and improved decision making could be achieved either by better information, better training and skill development, or by better decision support systems. The proposal of this paper is that modelling Defence processes with task and function based formalisms (such as IDEF0) could be made more effective if supplemented with such decision-centric models.

While it is obvious that there is a need for effective information architectures to supply the right information to the right person at the right time, what form these architectures should take is not so obvious. The US DoD has spent considerable effort defining a C4ISR Architecture Framework ([US DoD DISA, 1999)] for example) and producing guidelines for developing product based architectures designed for specific requirements. However, this author feels that the DoD framework does not go far enough and reflects the limitations of focusing primarily on information technology (IT) issues. In other words, the ability to identify and conceptualise all aspects of the C4ISR problem is somewhat hampered by being restricted to IT concepts. For example, the above US DoD framework is based on a tripartite structure of operations, systems, and technical architectures designed to satisfy their respective requirements. In this framework, the product based architecture Development Matrix (Annex B Figure B2) demonstrates that operational architectures are constrained mainly to the level of Mission Requirements – getting battlefield information to the commander and then disseminating his orders. While this is obviously of fundamental importance, it could also be asked *what* is the right information, from the point of enabling more effective decisions.

Strategic Knowledge Architectures are proposed here for the purpose of providing more useful forms of information to decisionmakers, both at the mission level and also to higher strategic levels which must supervise missions in the light of umbrella strategies. SKAs would highlight, and make explicit, the diverse issues that must be considered for each category of military decision making. And while the US framework does commence by defining different objectives, the proposed SKAs go further by including summary *metrics* for a range of considerations that must be combined to arrive at comprehensive strategic evaluations. For example, before the commander's intent can be disseminated through the command architecture, the knowledge requirements architecture is instantiated by operational information produced by possibly diverse systems architectures. With this kind of functionality SKAs would be of most value at the operations level and above, and the explicit definition of SKAs for strategic decision making should include information on the diverse considerations that have previously been deemed, by some consensus, to be relevant. The SKA would be a multi-tier, but not hierarchical, structure of knowledge objects designed to support predefined categories of military decisions such as the decision categories of: Implement Information Operations Response to Threat, Adapt Current Strategy, Evaluate Preparedness, Evaluate Reachback Integrity, or Decide Initial Force

Deployment Plan. Figure 1 illustrates the different levels of information and knowledge architectures and how they should all be integrated. To further demonstrate the SKA concept, Figures 2 and 3 illustrate parts of hypothetical National and Military SKAs, depicting the high-level knowledge objects for which computed metrics [0,1] would be assigned after condensing a vast array of lower-level information. Overall, the basic rationale for proposing the use of SKAs can be summarised as follows:

- Operational decisions should be aligned to an overall strategic plan.
- Strategic decisions are usually made on the basis of highly abstracted forms of information.
- These highly abstracted forms of information are frequently derived in an ad hoc, non-systematic manner that is susceptible to personal inconsistencies, bias, and various idiosyncrasies.
- Standard sets of such high-level variables should be defined explicitly for standard categories of military decision making.
- Multi-tier structures of component information should also be defined.
- Measures for these knowledge objects should be dynamically updated as lower level information changes, or becomes available.
- The instant availability of such measures would minimise inconsistencies and streamline information processing resulting in increased strategic decision agility.

In light of the increasing flood of information, several other authors [Anken,1998][Arens *et al.*,1998][Ballard,1999][Beers,1997] have also noted the need for structures of more intelligent information for military decision making. Applications such as the Warfighter's Information Packager [Arens *et al.*,1998] and the Intelligent Hierarchical Decision Architecture [Beers,1997] are currently being developed to service this need. The Information Technology Office of DARPA also has the special Information Management Program [DARPA Information Technology Office,1999] which "..strives for major advances in acquiring and effectively using vertically integrated, as well as horizontally distributed information resources to provide the defence analyst with a comprehensive ability to assess a rapidly changing situation". Relevancy filtering and visualising abstract information spaces are key capabilities in these types of applications. However, the functionality of the SKA is slightly different to these types of applications. Rather than focusing on data mechanisms to supply information forms requested by decisionmakers, (as for inferencing, temporal reasoning, or activation and change analysis), SKAs are intended to be a maintained network of specially synthesised high-level knowledge objects with links to their component information sources. Decisions would be facilitated by the instantaneous availability of highly abstracted forms of information (or knowledge), which can also be presented visually on a dynamically updated map. Another concept that has also been proposed recently is quite similar to SKAs, and this has been presented as an extension to the Rasmussian type of Cognitive Task Analysis (CTA). Roth et al. [Roth *et al.*, 2000] have identified a limitation of CTA for the design of decision support systems, and to address this weakness they have identified the need to make explicit the domain relationships (as "functional abstraction hierarchies") to first understand the abstracted problem space. Then, in relation to this, the critical decisions and their information requirements should be defined and information visualisation techniques used to provide users the appropriate information. However, the difference from SKAs is that Roth et al. do not synthesise abstracted measures, focusing more on supplying relevant but *unprocessed* information for critical decisions. Thus, the complexities of numerical synthesis discussed in this paper are not addressed and more emphasis is placed on the

visualisation techniques used to facilitate the absorption by the decisionmaker of a greater range of lower-level information.

3.2 Some Benefits of Strategic Knowledge Architectures

The potential benefits that should arise from the use of SKAs can be summarised as follows. Strategic Knowledge Architectures would:

- Enable the elicitation of an agreed upon decision support knowledge-base which could aid distributed communications about complex situations.
- Alleviate the information processing demands on the commander's Staff.
- Enable systematic integration of diverse forms of information.
- Reduce the effects of personal bias when rationalising tradeoffs.
- Enable more rapid and agile updating of key knowledge variables due to well defined relationships.
- Be on-line all the time, so significant changes in particular knowledge variables can more clearly be identified and alerted.
- Enable changes to strategy caused by changing contextual circumstances to be expedited, since changes in key knowledge objects are highlighted.
- Provide the potential for tactical information at lower operational levels to be captured in similar architectures to prevent the loss of such information.

3.3 Potential Criticisms of Strategic Information Architectures

Some potential criticisms of the SKA concept will now be discussed. The first is that the "fog of war" makes the definition of such SKAs designed for strategic decision making rather unrealistic. In other words, high level military decision making is unique and cannot be standardised. One reply might be that it is feasible to define categories of strategic decisions and then for these general categories, define the types of knowledge that would be desirable. Based on these general categories of decisions, sets of knowledge variables could be mixed and matched from the predefined knowledge structures to fit any new types of decisions as they arise. A further criticism could arise from the Naturalistic Decision Making (NDM) school [Klein,1998], which avoids information-based analytical decisions in favour of an intuitive process of matching cognitive perceptions of a situation with stored patterns of experience. From that viewpoint, it could be argued that basing decisions on numbers which are the end result of computational processes is foolhardy, to say the least. The reply to this might be that while NDM is very suitable for more tangible tactical decisions, higher decision levels where more intangible considerations need to be considered, would be hard to fit to previous strategic situations due to the abstract and vague nature of the situation characteristics. Furthermore, the existence of a human knowledge base of all abstract strategic situations that could arise in the future is hard to imagine. Even if a match could be made, any historical or prior Course of Action must have been based on some sort of subjective rationalisation of tradeoffs which cannot be recalled at a later date. Ultimately, for single recognition fits where a similar complex situation (and effective response) can be found in past experience, no comparative Course of Action performance evaluations could be made. Nevertheless, a degree of scepticism about the meaningfulness of any numerical knowledge metric is very justified, and can only be defused if careful attention is paid both to the modelling of uncertainties in the component information, and to the integration procedures used to combine the diverse forms of information. Experience, intuition, and innate skills would still be the basis of decision making, and the strategic knowledge objects would

simply provide a new form of support information. Perhaps the most justifiable criticism of the SKA concept is simply that making explicit such important high-level decision variables is dangerous because it introduces a form of traceability which is not always politically desirable.

4. Defining the Strategic Knowledge Space

The requirements for defining a meaningful knowledge space to assist the strategic evaluation of complex situations will now be discussed.

4.1 The Strategic Knowledge Objects

To commence, it is postulated that the strategic evaluation of complex situations or problems usually proceeds through the informal use of highly abstracted forms of information called here strategic knowledge objects. In the military domain, threat response initiatives or modification to existing game plans, could thus be determined on the basis of some structure of decision variables similar to that shown in Figure 3. While such a structure may seem simplistic, it is suggested that evaluations, and the extraction of such high-level information is axiomatic to strategic decision making, and always takes place across the various levels of decision makers, albeit in an informal or subjective manner. In order to arrive at an evaluation of these high-level variables, a multitude of diverse lower level information must be successively combined. And while formal methods such as data and information fusion are used in certain areas of situation awareness, in general, the methods used for information synthesis are far less formal. The multiple levels of knowledge objects, as demonstrated in Figure 3, represent the multiple tiers of informal information synthesis that usually occurs. For any given complex situation a set of critical knowledge objects that are essential to making skilful decisions must first be agreed upon. It is suggested that such SKAs need to be defined by the domain experts for a set of standardised threat situations, and these would comprise the basic knowledge base that would be instantiated as threat information becomes available. The objective is not to try to define every situation that could eventuate, but initially to conceive of the range of complex situation categories that the nation and Defence may need to respond to in the future.

4.2 Strategic Knowledge Relationships

After defining the desired set of knowledge objects, their relationships must be defined. In this context, it should be noted that the SKAs are not hierarchical as there can be information shared between similar level variables, or from other levels. The importance of individual input elements must also be defined in their various combinations, within identical levels, as well as between different levels. When combining a piece of information upward it can have different importance levels for the different higher-level variables of which it is a component. And when defining the relative importance levels for variables on the same level, they need not be restricted to *additive* preference ratings, as usually derived by the common practice of pairwise factor comparisions; this constraint is relaxed since component information *interdependencies* preclude additivity. These requirements also distinguish the information integration procedures required in strategic information aggregation from the additive weighted aggregation operation that permeates most decision theoretic methods in multicriteria or multi-attribute decision analysis. After such an architecture of relationships has been defined, a general consensus has been reached on the relevant information for each particular category of strategic decision. Such consensus could be considered to have reduced uncertainty by eliminating the multiplicity of personal patterns of information usage existing before the SKA definition.

5. Measuring Strategic Knowledge Objects

5.1 Measures as Evaluations of Strategic Concepts

With any form of information-based decision making, ordinal relationships are established between choices. Although information inputs may be words or linguistic ratings, or even feelings, they may be used to establish a set of ordinal relationships for the key considerations. So the knowledge measurement problem in strategic decision making is how to synthesise and combine a diversity of information into meaningful ratings, as opposed to ratings of spurious or inadequate derivation. The necessity then is for explicable, rational, systematic, and traceable procedures for information synthesis that are not based on simplistic assumptions or methods.

Initially, the strategic knowledge measures will be placed in the broader context of measures of performance (MOPs) and measures of effectiveness(MOEs). For military operations MOEs may be applied to evaluate the correctness of operational decisions and lower level tactical MOEs are relatively easy to define. But less easy to define are higher level MOEs, as well as how to synthesise them. When discussing performance evaluation of complex systems there may be different understandings for the related terms so some definitions follow. Complex systems of information are those in which information relates to a variety of fundamentally different issues or facets, some or all of which are inter-related in a virtual or real system. MOPs are simply ratings (absolute or relative) for an issue, behavioural facet, or group of facets, in relation to defined value scales. In this respect, MOP is a general term that simply refers to a performance rating, normalised or not, but based on a value scale for a system facet. MOPs may be of several types depending on their intended function: effectiveness or efficiency, each being based on quantitative or qualitative behavioural characteristics. Efficiency MOPs relate to the conversion of quantitative inputs or resources to outputs. Effectiveness MOPs relate to the achievement of expected performance levels of behavioural facets. All are determined by relating observable behaviour to datum levels. However, accompanying systems engineering developments in the 1970's much discussion focused on how to evaluate overall system effectiveness. Subsequent to this period, MOEs for many people came to be associated with total system performance, leaving MOPs to be identified with performance evaluation of the sub-aspects and their facets. According to this understanding, MOEs relate to defined datums of overall system performance and goals. Although this convention is quite common, it is arbitrary and the terms do not always convey this meaning. Simply speaking there are only MOPs at various levels of systemic abstraction, the core problem being how to synthesise MOPs through various levels. While a common understanding is that MOPs refer to parts of the system and MOEs refer to the whole system goals, it may not always be possible to find a single characteristic by which to evaluate the whole system. Thus, complex systems are frequently evaluated by developing a global MOP from various lower level MOPs and lower-level performance characteristics.

It should be noted that measures for the knowledge objects within SKAs are not equivalent to MOEs for the following reasons. Firstly, MOEs when treated as total system MOPs are based on datums for overall system performance (or target end-states) rather than by the integration of subsystem MOPs. In this context, knowledge variables are not system aspects whose behaviour can be observed and measured because they represent abstract concepts. Another distinction to be made is when MOEs are treated as dependent outcomes, determined by distinctly different decision variables (as for evaluating military operations planning by quantitative mission characteristics). Knowledge object synthesis does not coincide with this interpretation either

because the input information set does not actually cause the output meta-variable state. Rather, it is the mutual associations between the inputs that induces the higher-level knowledge metric. This is the same as saying that it is the input *associations* rather than their aggregate sum that determines the knowledge output. In other words, knowledge metrics provide an overview of relevant input information rather than being statistical measures of typicality or simple weighted averages. Notably, it is the extra information embedded regarding consistency, conflict, or reinforcement, that distinguishes high-level meta-knowledge measures from statistical measures of typicality, or hierarchical aggregates. While a variety of MOEs and MOPs have been defined for military operations, some fundamental information complexities, that must be addressed when integrating a variety of MOPs to form an overall cognitive understanding of a complex situation, are usually ignored. When deriving measures or evaluations for knowledge objects in SKAs, sometimes it may only be feasible to use subjective judgment. For other knowledge objects, computational synthesis may be feasible and the requirements for adequate methods will now be discussed.

5.2 General Considerations for Computational Synthesis

At the lower-levels of information processing the activities of relevance determination [Boykin and Merlino, 2000] and textual summarisation [Endres-Niggemeyer, 1998] are especially important. At higher-levels, the computation of abstracted knowledge metrics poses some different challenges: how to combine a variety of heterogeneous information forms where any single input form can be a combination of different uncertainty types, how to decide what combination operator is most appropriate, and how to rationalise the tradeoffs between different lower-level facets. While relevance and collation are preliminary operations at all knowledge extraction nodes, fusion and reinforcement are key processes for abstracting knowledge at the higher-levels and these two processes are frequently subjective and ad hoc. In essence, the computation and assignment of a measure to the knowledge objects is a unique type of *summarising* process based on a collection of numerical input information. Using the metaphor of different types of fruit in a basket, it is more like a summary of the states of the fruit in the basket. The relevant input information may also be qualitative or quantitative, numerical or lexical, embodying different forms of uncertainty. To maximise the knowledge extracted from the input information, careful attention must be paid to the management of these diverse uncertainties in the information synthesis process. However, the special techniques required for the management of hybrid uncertainties in information integration are beyond the scope of this paper and a separate work by the author [Warren, 2000] has proposed a system of information semantics to address this topic and allow more rigorous uncertainty management in information synthesis.

5.3 Knowledge Relationship Implications for Computations

Input information at knowledge extraction nodes may represent lower-level aspects which are largely uncoupled, or represent lower-level aspects which are parts of a system with fairly obvious aspect interdependencies.

5.3.1 Non-Linearities in Systemic Inputs

For systemic information inputs, there are certain non-linear information associations that need to be addressed. This situation applies when there are fairly obvious interdependencies between the information elements, although these may be unquantifiable. One example of such systemic information integration is when buying a car is based on the three quantitative variables: cost,

power and interior size; these variables are obviously interdependent to some degree. Another very common example, but perhaps less obvious, are decisions for complex projects based on lifecycle cost, benefit and risk aggregates, which are also interdependent aspects of a problem. Similarly, it is highly desirable that the management of joint military operations be based on a set of systemic knowledge measures [Ballard 1999]. Systemic interdependencies compound the difficulty of developing high-level aggregate measures because simple weighted averaging should not be applied, although it frequently is. Overall, perhaps the most commonly used measure structures are hierarchical that aggregate by weighted averaging. The problem is that they cannot capture synergies, or different types of information redundancies, because they do not treat the collection of aspects as a system. This point can be simply illustrated as follows.

Assume that numerical measures are normalised [0,1] and the problem is to aggregate two equally important lower-level measures: M1=0.9 and M2=0.1. Linear averaging, as used in hierarchical aggregation, simply yields the value 0.5 (neglecting certain types of knowledge objects discussed later that require Max or Min operations). This form of compensatory aggregation, where the high value fully compensates for the low value is inherent in the standard averaging operators. Alternatively, a non-linear operator could be used which would then need to be justified by some non-linear process existing in the real-world situation. For example, in traditional multi-attribute decision analysis non-linear operators are frequently used to model bias in the human decisionmakers, such as pessimism or optimism. But, the non-linearity associated with combining different facets of system performance, or different pieces of strategic information, is of a completely different nature. In fact, what is important is non-additivity, not non-linearity, and the multiplicative aggregation operators commonly encountered in decision analysis are but one type of non-linear operator. The key question is whether compensatory aggregation is justifiable, or are there synergies or redundancies embedded in the input information. Simply speaking, in systems of inter-related measures, low values represent windows of weakness that may bring the *whole system* down, so they should not be compensated for by higher values elsewhere. For this reason, the synthesis of systemic information should be sensitive to the consistency of the information components (or measures for aspects). Furthermore, when positive or negative synergy exists between a set of inputs, the integration procedure must also be able to capture those features. Although the limitations of weighted averaging (or weighted hierarchical aggregation) for the cognitive synthesis of information was identified several years ago [Zeleny,1991], as yet no satisfactory solution has appeared in the opinion of this author. What is required is some form of non-additive aggregation operator that models this non-compensatory behaviour and is also sensitive to patterns in the input numerical sets. For the example above, the combined value using non-additive aggregation should then be above, or below, the (weighted) average (0.5) according to the type of synergy or redundancy inherent in the input information set. Since numerical consistency is a critical issue, a heuristic procedure called Globular Knowledge Fusion (GKF) has been developed by the author [Warren: 1997,1999,2000] which is a partially compensatory algorithm that is a function of the consistency within the input information set. Consequently, it enables a range of systemic aggregation non-linearities to be captured in the information integration process.

5.3.2 Tradeoffs Between Non-Systemic Inputs

For the situation where the input information at a knowledge extraction node does not represent a lower-level system, but simply represents discretely different aspects to be considered, the question then is what rationale to use when synthesising the different aspect values into a single

global meta-value. An example of this is when buying a car is based on the three variables: cost, colour range available, and fuel economy. Although there may be some interdependency between these variables, they are less tightly coupled than in the previous car example. For other problems there may be no connection at all between the inputs. With this type of input information, whatever form the input information takes, qualitative or quantitative, it can be reduced to a numerical rating scale expressing proximity relationships based on a defined value system. Given that a satisfactory method has been selected, the problem is again how to combine several (and usually a fairly small number for strategic information) pieces of information into a meta-value. One example of a high-level military knowledge object that cannot be derived from directly measurable inputs is Force Preparedness, derived from Readiness and Sustainability states (as in Figure 3). Measures (e.g. 0.7, 0.4) for each of these discrete sub-variables would be developed from lower levels of information, and the question is what rationale should be used for combining them into the Force Preparedness summary meta-variable. If all input metrics were the same value (for example, 0.7) then it seems reasonable that the meta-variable would be that value (0.7). But what to do when they are different? Is the node synthesis a tradeoff evaluation, or does the meta-variable concern primarily a proposition evaluation, rather than a complex state evaluation? When synthesising intelligence information, for example, a higher value than the Max may even be appropriate if values are very similar with a high degree of proposition affirmation. (This reinforcement problem will be discussed in the following section.) Basically, there are three types of combination that may be appropriate at any knowledge extraction node: Extreme value (Max or Min), tradeoff rationalisation, or reinforcement. The nature of the meta-variable alone determines which is the most appropriate type of operation. It is proposed that a suitable approach to rationalise tradeoffs between independent aspect measures should also be based on the disparity between them. Increasing disparity should be reflected in the meta-value such that increasing disparity lowers the meta-value below the weighted-average. By so doing the meta-value would be penalised for increasing disparity (basing measures on an increasing monotonic measurement scale) i.e. the tradeoff rationale is to lower the global value for more inconsistent sets of values. The GKF algorithm, previously proposed for capturing systemic non-linearities in information integration, is again proposed for rationalising tradeoffs on the basis of numerical disparities within the input sets. In effect, the input information representing tradeoffs is a virtual system where the overall problem is the system.

5.3.3 Reinforcement Modelling

For some special types of knowledge objects, for example those required for INTEL threat ratings, a special type of synergy called “reinforcement” may be appropriate whereby a meta-metric is beyond the range of the input metrics or evaluations. In the opinion of this author, some approaches (as in [Yager and Rybalov,1998]) to the reinforcement problem have been hampered by complexity and the lack of a clear rationale. It is proposed that a modification to the GKF method developed to capture systemic non-linearities, can provide an adequate and rational procedure for modelling reinforcement. The key determinant in the reinforcement process is the consistency (or lack of conflict) between the input metrics, given that the values fall within the extremal bands defining high affirmation or negation (e.g. > 0.7 or < 0.3 for normalised metrics). When values are grouped within these extreme regions there may be sufficient reason to extend the meta-value beyond their individual values (higher or lower), especially when the meta-variable concept refers to a binary variable. When values do not fall into the extreme regions, reinforcement is not required and the partial compensatory GKF method would again be

suitable. As an example where reinforcement is appropriate, the knowledge object "Threat Level" may be based on information evaluating the proposition: "unknown object has attacking intentions", which must be YES or NO if perfect information were available. It would seem reasonable to base the amount of reinforcement in the combined value on the degree of consistency between the inputs: more consistent, then more reinforcement forcing the combined value closer to YES or NO. Since the GKF method mentioned previously does reflect the consistency of the input set of metrics, a consistency parameter can be extracted and used in a separate non-linear function which has been selected to yield a suitable pattern of sensitivity beyond the Max or Min. (Examples of this reinforcement procedure can be found in [Warren,1999].) For the reasons that have been described in this section, the GKF algorithm provides the basis for modelling the primary types of information synthesis non-linearities when computing metrics for the abstracted knowledge objects.

6. Summary and Conclusions

A smarter Defence force must rest on several pillars: smarter weapons, smarter logistic support systems, smarter operational systems, smarter decision making processes, smarter decisionmakers, and smarter information. This paper has focused on developing smarter forms of information for strategic decision making. The proposal is that standardised architectures of strategic knowledge objects need to be elicited and maintained in times of threat or conflict. But it is also feasible that some of these SKAs should be maintained permanently to facilitate the continuous monitoring of a nation's global context. Overall, the focus has been on decisionmaker needs rather than how, or by what standardised process, strategic military decisions are made. This shift of focus towards the ultimate forms of information strategic decisions are based upon could even be called a paradigm shift because any analysis of the dynamic business processes of the military, from that viewpoint, would not start by decomposing activities. Rather, the analysis would start by decomposing the knowledge requirements for key categories of military decisions. This may also serve to disenfranchise the stranglehold that technology has had on the analysis of military decision processes. When the spotlight is kept on the relevant knowledge objects, any technology that can generate them is valid and the search for uniformity in process technology, or in computer or operational architectures, becomes less critical. Even though interoperability standards must be complied with across sections of the overall military system of systems, an all-pervasive uniformity is not necessary, nor even desirable for vulnerability reasons. So while the SKA concept may appear to be naïve, or too simple a form of information to present to serious decisionmakers, they represent forms of information which are often generated and used informally in strategic decision making. Zuboff [Zuboff,1988] has introduced the "informating" concept after observing the implementation of information systems to provide new forms of information within commercial enterprises. Zuboff (and subsequently others) observed that when more pertinent information was directly available, via the medium of an information system, decision effectiveness increased far beyond the levels explicable simply by automation effects due to increased connectivity and availability of information. These observations have given credibility to the rather obvious assertion that the provision of information which more directly supports decisions helps the decisionmaker make better decisions. But how to systematically synthesise more relevant forms of information has been the difficulty since the evolutionary path of information systems has mainly focused on increasing analytical capabilities with respect to large volumes of stored information. This is exemplified by the On-line Analytic Processing(OLAP) and Data Mining boom in the early 1990's. While such

dynamic information analysis capabilities have been developed to high degrees, processes for the synthesis of diverse information have been studied far less, and primarily from the perspective of object inheritance structures in software engineering. Unlike business organisations, military situations are not usually accompanied by a vast data warehouse covering many years. More commonly, only limited amounts of dynamically changing imperfect information with high levels of uncertainties are available for a given situation. Even the field of information fusion, which is highly developed for certain military applications, focuses mainly on proposition evaluation rather than the synthesis of abstracted decision information. Nor do other powerful process modelling formalisms, such as UML, address the abstraction process required for synthesising strategic measures. In essence, the embedded meaning required in each knowledge object, that has been deemed important when defining a specific SKA, must be carefully scrutinised to determine how a measure should be derived. This may require examining the value systems used to normalise or scale metrics, as well as determining what is the most appropriate information integration procedure. Moreover, the various forms of uncertainty in the source information and their hybrid combinations must also be carefully modelled if the abstracted knowledge measures are to be meaningful and useful. In summary, the integrated architectures of knowledge objects have been proposed to aid rapid comprehension of an increasingly complex world where the dimensionality and density of the information space can be overwhelming.

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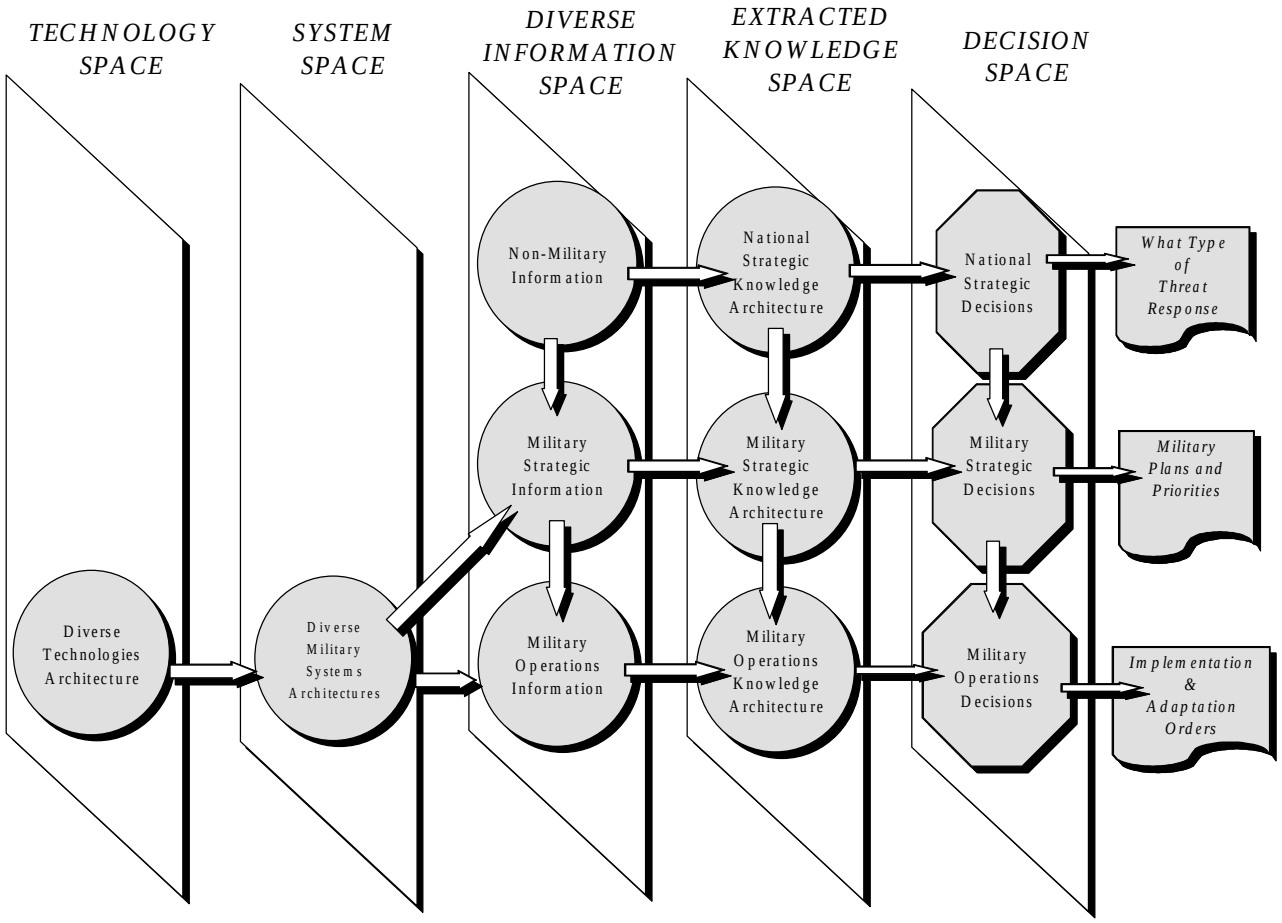

Figure 1: Integrated Knowledge Architectures for Threat Response Decisions

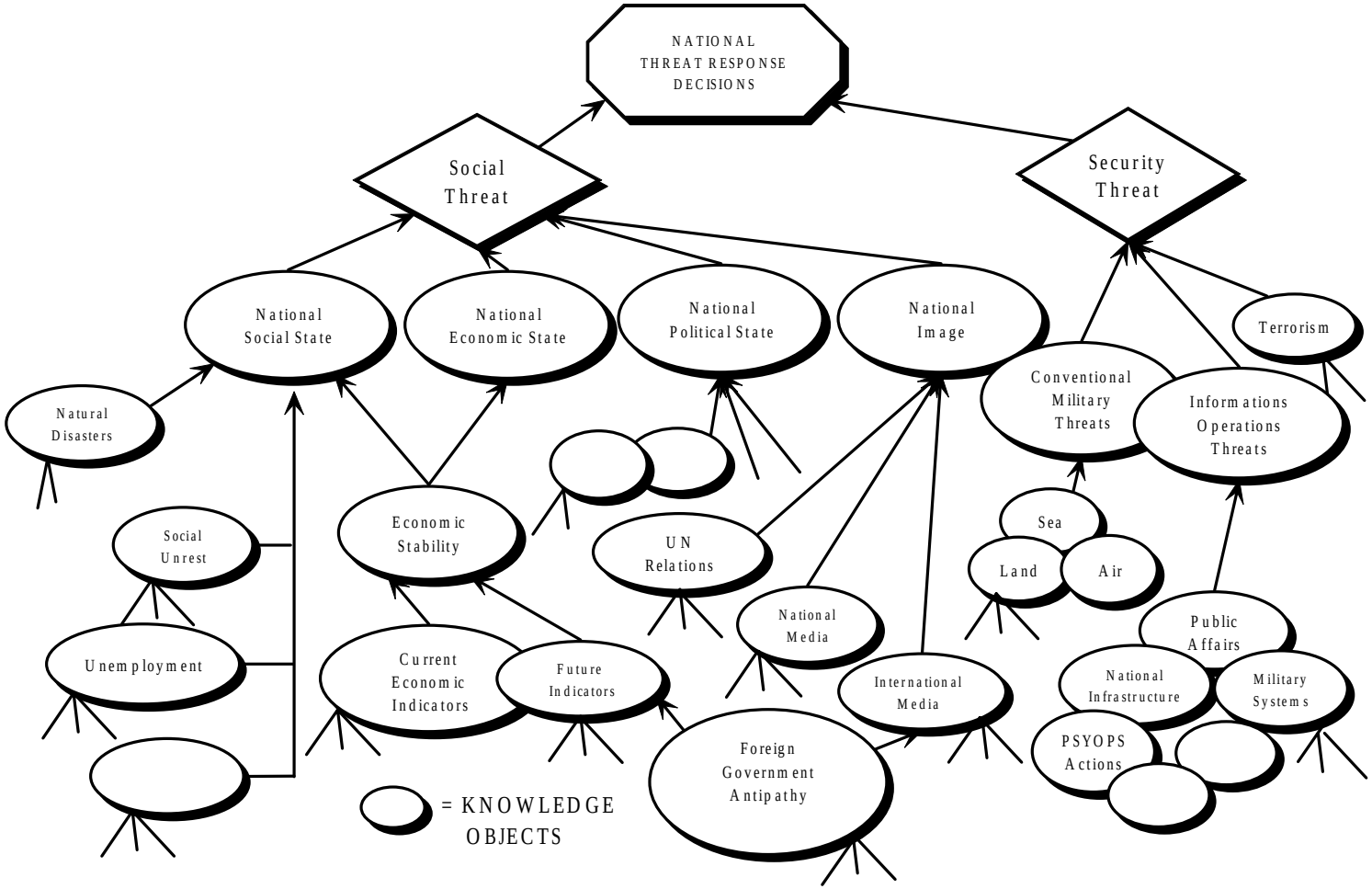

Figure 2: Example National Strategic Knowledge Architecture

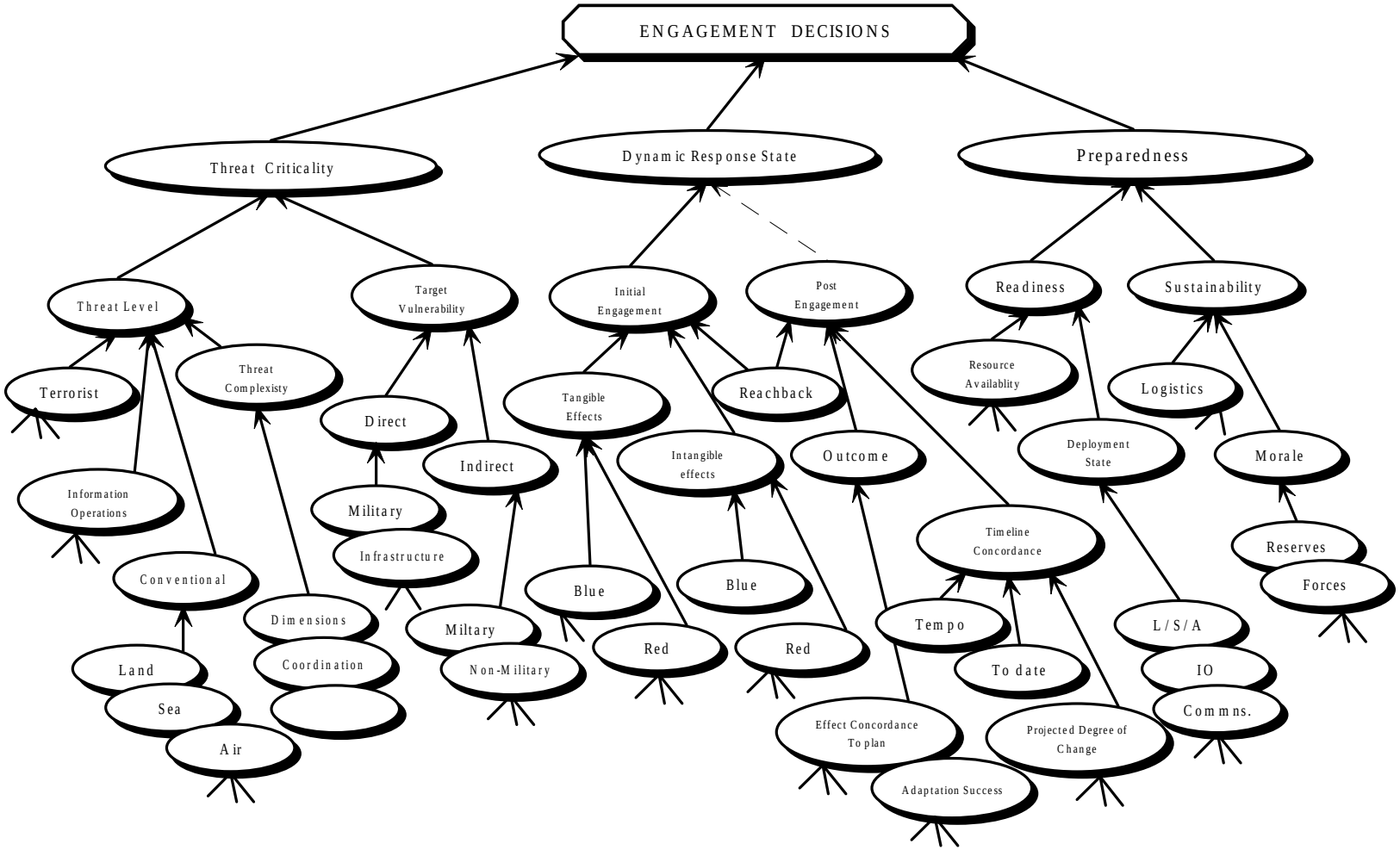

Figure 3: Example Military Strategic Knowledge Architecture