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PARALLEL ATTACK AND THE ENEMY'S DECISION MAKING PROCESS

by

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14. ABSTRACT
One of the fundamental attributes of air power is its ability to attack a significant number of targets at the same time to effect the ?strategic paralysis? of an enemy?s decision making process. Col John Warden calls this method ?parallel attack.? But how realistic is it to expect parallel attack to achieve strategic paralysis? This paper describes the potential consequences of parallel attack on the enemy?s decision making process and develops new analytical tools to aid planners in planning for parallel attack. Whereas existing parallel attack planning tools focus on the physical features of a command network, the tools developed for this work include both the physical network and the underlying processes. To develop these new tools, a combination of parallel computing theory and decision analysis is used to determine which decision-making processes are most susceptible to parallel disruption. Parallel computing theory forms a large existing body of knowledge on both physical networks and the complexity of performing key processes in parallel. The authors show that certain decision-making models can be significantly disrupted by parallel attack while others may remain relatively intact. A likely progression of decision models is demonstrated as national communications degrade. This research can be used to help future planners target parallel attacks to disable certain high level decision making processes, and more quickly reduce the enemy?s will to resist.

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Preface

I chose this research topic to be unique. While many people have written on parallel attack since the Gulf War, few have addressed new analytical tools to maximize its impact. Parallel attack cannot, in my opinion, be analyzed solely in terms of individual Centers of Gravity. The purpose of parallel attack is not merely to destroy Centers of Gravity quickly, but to produce synergistic effects on the system such that the sum of attacks is greater than individual parts. These synergistic effects cannot be analyzed in isolation. They must be analyzed in terms of damage being done on a system-wide basis.

Similarly, the focus on physical effects only (a.k.a. Warden) is too simplistic. The actual processes that take place in the overall enemy system should be the focus of parallel attack, not merely physical centers of gravity. The approach taken in this paper addresses a small but important subset of decision-making processes from both the physical and process views. Parallel computing provides a large body of well-developed analysis techniques that can be applied to process and physical decision-making. It is my hope that this work may someday be expanded into a robust set of techniques for campaign planners.

My wife Lisa, and daughter Jillian, as always, have been wonderfully supportive of my work. Many thanks to Major Courtney Holmberg, my advisor, as well as Major Mark Devergilio and my classmates for their support.

Abstract

One of the fundamental attributes of air power is its ability to attack a significant number of targets at the same time to effect the "strategic paralysis" of an enemy's decision making process. Col John Warden calls this method "parallel attack." But how realistic is it to expect parallel attack to achieve strategic paralysis? This paper describes the potential consequences of parallel attack on the enemy's decision making process and develops new analytical tools to aid planners in planning for parallel attack. Whereas existing parallel attack planning tools focus on the physical features of a command network, the tools developed for this work include both the physical network and the underlying processes. To develop these new tools, a combination of parallel computing theory and decision analysis is used to determine which decision-making processes are most susceptible to parallel disruption.

Parallel computing theory forms a large existing body of knowledge on both physical networks and the complexity of performing key processes in parallel. The authors show that certain decision-making models can be significantly disrupted by parallel attack while others may remain relatively intact. A likely progression of decision models is demonstrated as national communications degrade. This research can be used to help future planners target parallel attacks to disable certain high level decision making processes, and more quickly reduce the enemy's will to resist.

Chapter 1

Introduction

To subdue an enemy without fighting is the acme of skill.

—Sun Tzu
The Art of War

The use of parallel aerial attack during the Persian Gulf War is credited in large part for the rapid collapse of Iraqi forces, and the subsequent success of the 100-hour ground war. This paper examines the theory of parallel attack when it is directed towards affecting an enemy's leadership and decision-making processes. Specifically, this paper proposes new theoretical tools that may be used by planners to determine the effects of using parallel attack to create strategic paralysis in an enemy.

To properly address strategic paralysis, one must look inside an enemy's decision making process and examine not only the physical mechanisms, but also the underlying processes. Parallel computing theory encompasses both the physical network and the underlying processes used. Using these concepts one can assess not only the physical degradation of enemy C^3I, but also the degradation in ability to perform basic decision making processes. The union of parallel attack theory, decision making theory, and parallel computing theory, therefore, forms a unique contribution for assessing potential strategic paralysis effects.

Background and Significance

Strategic Paralysis

Fadok provides one of the best working definitions when he says that "Strategic Paralysis is a military option with physical, mental and moral dimensions which intends to disable rather than destroy the enemy." [1] Strategic paralysis, also called indirect warfare, has its basis in antiquity. It seeks to avoid costly force-on-force confrontation through indirect means. The Chinese warrior/philosopher Sun Tzu wrote around 340 BC, "Those skilled in war subdue the enemy's army without battle. They capture his cities without assaulting them and overthrow his state without protracted operations." [2] The economy of defeating an enemy using an indirect approach was thus well recognized prior to the birth of Christ. Thousands of military examples of indirect warfare have survived. From the betrayal of Leonidas at Thermopolye in Herodotus[3] to the Cold War and subsequent Soviet collapse, indirect attack is a tried and proven military technique.

JFC Fuller advocated targeting leadership: "Paralyze the brain and the body ceases to operate."[4] Liddell Hart, advocating indirect methods, wrote that:

> A strategist should think in terms of paralyzing, not of killing. Even on the lower plane of warfare a man killed is merely one man less, whereas a man unnerved is a highly infectious carrier of fear, capable of spreading an epidemic of panic.[5]

Early airpower theorists recognized the central role that airpower would play in achieving strategic paralysis. Douhet said, "…the final decision in future wars may be brought about by blows to the morale of the civilian population."[6] Trenchard believed that the airplane "was unmatched in its ability to shatter the will of an enemy country."[7]

Both of these men, along with Mitchell, believed that airpower would eventually be capable of rendering an enemy defenseless.

Parallel Attack

Parallel attack is a specific means for inducing strategic paralysis. Joint Publication 3-0, *Doctrine for Joint Operations,* uses the operational art term **simultaneity and depth** and defines it as bringing "force to bear on the opponent's entire structure in a near simultaneous manner. The goal is to overwhelm and cripple enemy capabilities and enemy will to resist."[8] The contribution airpower could potentially make to parallel attack was realized as early as WWI. US LtCol Gorrell writing during WWI advocated "A general plan of bombardment along the whole of the enemy's front of attack…" using both daytime and nighttime attack to prevent "the enemy's repairing damage already done him." [9] While parallel aerial attacks were exploited at the tactical level as early as WWII, technical limitations in accuracy and payload prevented its success at the operational level of war until Desert Storm. The introduction of large numbers of precision weapons and stealth technology in Desert Storm overcame these limitations, making campaign level parallel attack a reality.

Preview of the Argument

"In essence, air power is targeting, targeting is intelligence, and intelligence is analyzing the effects of air operations."[10] If the essence of airpower is targeting, then all targeting should focus on destroying the enemy's will to resist *over and above* the enemy's physical capability to resist. How does one target an enemy's will and avoid expending precious lives on collateral physical targets?

The first step is to realize that enemy decision-making is not a physical target to be destroyed, but a process to be disrupted. Second, one must also recognize that, in general, the enemy's decisions are not made by a single person in isolation. The decision to fight or give-in is made in parallel by a large number of people tied together by, at times, even the most primitive methods of communication. If the goal of all warfare is to force an enemy to do our will, then all aspects of decision making—both physical and procedural—must be taken into account. Disrupting both the physical and procedural elements of the decision-making system ***in parallel*** is the central focus of this paper. Parallel computing theory will play a central role as it considers the interaction between physical layout and processes conducted in parallel.

The remainder of this paper will proceed as follows. First, a description of three popular decision-making models will be presented, with a focus on both the physical structure and processes involved. Second, relevant concepts from parallel computing will be described. Simple network theory is discussed as a tool to characterize the physical features of parallel decision making. Parallel algorithms are introduced to characterize key decision making processes. Finally, the two key concepts are synthesized to create new analytical tools for characterizing effects of targeting enemy decision making processes. This analysis demonstrates that some decision-making models are easier to disrupt with parallel attack than others. In fact, a *progression* of national decision-making models will be established associated with different levels of enemy disruption. This will help in understanding which decision making models might be present in different stages of conflict, providing a new tool for focused targeting of enemy will.

Notes

[1] Fadok, David S. "John Boyd and John Warden: Air Power's Quest for Strategic Paralysis," School of Advanced Airpower Studies Thesis, Air University Press, Maxwell AFB, Feb 1995, p 10

[2] Sun Tzu, *The Art of War*, Samuel B Griffith translation, Oxford University Press, 1971, p 77-79

[3] Herodotus, *The Histories,* Penguin Classics, England, 1972, p 518

[4] J.F.C. Fuller, *The Foundations of the Science of War,* London, Hutchinson and Company, 1925, p314.

[5] Liddel Hart, Basil H., *Strategy*, Penguin Books, New York, 1991, p 212

[6] Douhet, Giulio, *Command of the Air*, Office of Air Force History, Washington D.C., 1983, p 126

[7] Melinger, Phillip S., "Trenchard and Morale Bombing: The Evolution of Royal Air Force Doctrine Before World War II," War Theory Coursebook, Vol 2, Sept 1997, p 365

[8] Joint Publication 3-0, *Doctrine for Joint Operations*, 1 Feb 1995, p III-11

[9] Gorrell, LtCol Edgar S., "The Future Role of American Bombardment Aviation," War Theory Course Book, Vol 2, Sept 1997 drawn from HRA file 248.222-78, p 253-

[10] Mellinger, Col Phillip S. *10 Propositions Regarding Airpower,* School of Advanced Airpower Studies, Air University, 1995

Chapter 2

Decision-Making Models

> *Machines don't fight wars. Terrain doesn't fight wars. Humans fight wars. You must get into the mind of humans. That's where battles are won.*
>
> —Col John Boyd

Understanding the enemy's decision-making process is a prerequisite for any attack designed to compel an enemy to do our will. The failure to understand the enemy's national decision making structure and process can unnecessarily prolong a war. This can potentially lead to later enemy reversals as seen in Vietnam in 1975 and more recently in the agitation policies of Saddam Hussein in Iraq.

This chapter will describe three models for national-level decision making in terms of physical structure and underlying decision processes. Where appropriate, additional related models are annotated. The three broad models chosen here are the rational, organizational, and bureaucratic decision models based on the work of Graham T. Allison from Harvard University.[1] Though these models are somewhat idyllic, they cover the range of possible decision-making processes a state might use to influence major wartime decisions.

Rational Policy Model

The rational policy model starts with the basic assumption that the state is a unitary decision-maker making calculated, rational decisions. In practice this means that an individual or very small group of people wield most of the power. They make decisions purely on each alternative's relative value, and they consider the risk and possible gains from all outcomes and possible courses of action. In the pure sense, the decision-makers have nearly perfect knowledge of the situation and are able to assess the risks and value of each outcome. They can therefore select the outcome with the greatest risk-adjusted value, optimizing the decision at hand.

A related theory to rational decision making from the field of economics and psychology is Bayesian decision-making.[2] Bayesian decision making is essentially pure rational decision making with the addition of likelihood estimates for outside actions. Here, outcomes are weighted not only by risk, but also by likelihood of outside actions.

Rational Decision Structure

The physical structure dictated by the rational decision-making model is shown in Figure 1. The decision-maker is assumed to be some kind of national command authority, be it a dictator or a small panel such as the US National Security Council. The basic network structure and sub-structures are hierarchical. This national decision-maker has multiple redundant lines of communication to field commanders, intelligence services and other national assets to collect information and transmit actions.

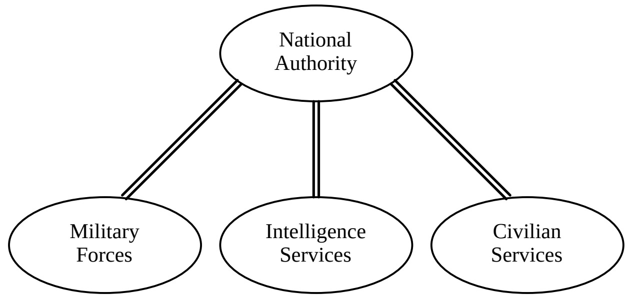

Figure 1. Rational Decision Structure (Hierarchical)

Rational Decision Process

The rational decision process can be summarized in the following steps:

1. Gather information and assess the strategic situation.
2. Generate all possible courses of action (COAs) and assess relative risk and value of outcomes.
3. Select COA with the highest possible risk adjusted value.
4. Execute selected course of action.

The rational decision making process closely mirrors both deliberate and crisis planning processes advocated as part of JOPES.[3] The rational model process is optimizing, since it attempts to choose the highest risk-value option within available information and force constraints.

Bureaucratic Decision Model

The bureaucratic decision-making model is the opposite of the rational model. It assumes that decisions are made as the outcome of a series of overlapping political games.[4] National policy is not a rational consideration of possible alternatives, but a battle between powerful individuals and bureaucracies within the government, each pushing their own personal agenda. The outcome is unpredictable since different elements will dominate at different times.

Bureaucratic Decision Structure

The physical structure for the informal part of the bureaucratic decision making is shown in Figure 2. This informal network acts in concert with the formal hierarchy discussed in Figure 1. Political games are ultimately played out both within and without formal lines of authority. Players may form alliances both inside and outside the formal government structure to increase their power and status in the national policy game. The network is very nearly a star or all-to-all network.

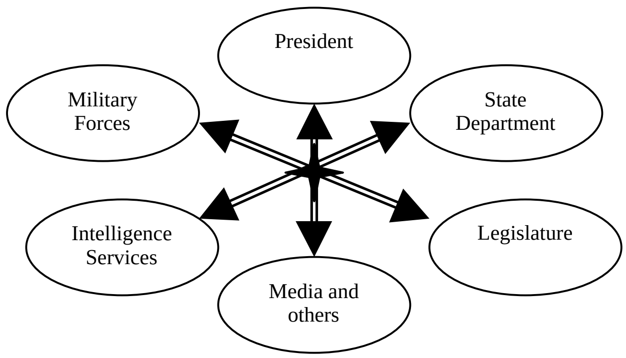

Figure 2. Bureaucratic Decision Structure

Bureaucratic Decision Process

The bureaucratic decision process is initiated at the lower bureaucratic level. Essentially each player in the national policy game performs the following process independently.

1. Gather information from formal and informal sources.
2. Formulate COAs not only to achieve national objectives, but to enhance the player's bureaucratic power and influence.
3. Choose the COA that maximizes power and influence.
4. Begin active campaigning and brokering to garner outside support for the player's own own COA.

Since all players in the national policy game make a power-rational choice at their level, decisions are often locally but not nationally optimized. The criterion for decisions is extension of personal power rather than national interests, causing additional inefficiency. Further, since the decision frequently depends on the relative strength and power of the personalities involved, the final outcome is very difficult to predict. Of the three models, this process is potentially the most inefficient and most likely to produce a course of action that may be far from optimal.

Organizational Process Model

The organizational process model sees policy decisions as the output of limited organizational processes and structure. In essence, the structure of organizations limits their action to pre-existing routines, and these routines form the narrow constraints in which leaders must operate.

A related theory asserts that organizations have limited *mental models* within which they have to operate.[5] Absent an institutionalized policy of organizational learning, these mental models become the only acceptable courses of action, regardless of the crisis at hand.

Organizational Process Model Structure

The physical decision structure for the organizational process model is, like the rational model, hierarchical (Figure 1). At each level in the organization, behaviors are selected from a limited set of pre-programmed behaviors. As options travel up the hierarchy to the national policy level they are reduced at each level so that only a few may ultimately be considered.

Organizational Decision Process

The organizational decision model process is perhaps the simplest of all. At each level in the hierarchy, possible pre-programmed actions are compared to the current situation. The "best fit" course of action is passed up to the next level for consideration. The process might appear as follows:

1. Gather information on the current situation, primarily within this organization.
2. Compare the current situation to available behaviors within this organization and recommendations from lower levels in the organization.
3. Choose the COA that best fits the current situation and this organization, even if the fit is not particularly good.
4. Recommend this COA up to the next higher level in the hierarchy.

The organizational model is unique in that it considers an organizationally limited number of options. As a result, decisions can be made quickly based on limited information but may be far from optimal.

Reviewing the three decision models, the rational model is capable of creating the best decisions, though it requires near perfect information and consideration of a large number of COAs. The organizational process model is second in effectiveness because it is capable of producing a reasonably good solution with little time and information. Finally, the bureaucratic decision model has the potential to make some of the worst possible decisions, and can take a long time to do so. The chapters to follow will examine how these models map to parallel computing structures and processes for more detailed analysis.

Notes

[1] Allison, Graham T., Conceptual Models and the Cuban Missile Crisis," *American Political Science*, Vol LXII, no 3, Sept 1969

[2] "Are People Bayesian? Uncovering Behavioral Strategies," *Journal of the American Statistical Association*, Vol 90, Issue 432, December, 1995, p1137

[3] Joint Publication 5-0, *Doctrine for Planning Joint Operations*, 13 April 1995, p III-2

[4] Allison, Graham T., "Conceptual Models and the Cuban Missile Crisis," *American Political Science*, Vol LXII, no 3, Sept 1969

[5] Senge, Peter, *The Fifth Discipline*, Doubleday books, New York, 1990

Chapter 3

Parallel Computing

The object of parallel warfare is effective control of the enemy's strategic activity.

—William Head and Earl Telford
The Eagle in the Desert

What is parallel computing theory and how does it relate to parallel attack and decision making? Parallel computing is a complete body of theory relating the physical structure of computers with more than one brain to the processes that are performed on them. Since this theory encompasses both networks and their processes, it allows us to analyze the effects of degradation of the overall decision-making system as it is disrupted by parallel attack. This author has uncovered no other well-developed theory can account for both the inherent parallelism of an organization's decision-making process and the simultaneous degradation of points in the process from parallel attack. By combining the basics of parallel computing theory with decision-making theory, one can focus parallel attacks to maximize their impact.

Network Theory

Like the pioneers of ACTS developing their industrial web theory, the pioneers of parallel computing theory focused on networks first. The earliest parallel computers were special purpose computers with processors arranged in arrays. The output of one processor would feed into the input of another in *assembly line* fashion.[1] Later, as more complex layouts were developed, a body of formal processor network theory was also developed to characterize various networks.

Since it would be impossible in limited space to cover the entire body of parallel network theory, we will try here to introduce some of the basic terms and concepts. For a more complete discussion the reader is referred to Leighton.[2] Let us begin with some definitions, and expand upon them with a few examples.

Node. A node is a processing element. This can be thought of as a separate computer with one or more network connections.

Tree. A hierarchical network as shown in Figure 3.

Edge. An edge is a network connection. Nodes are connected together by one or more edges. All edges are assumed to have the same data-carrying capacity.

Link. Synonym for an edge. The term link is often used to denote an edge connecting two units or command centers.

Root. The topmost node in a tree.

Leaf. A leaf node is the lowest node in a hierarchy or tree.

Height. The height or depth of a tree. It measures the distance from the highest (root) node to the bottom leaf nodes. The number of nodes from the root to the leaves in the tree.

Parent and Children Nodes. For hierarchical networks like trees, the higher of two connected nodes is called the parent and the lower is called the child.

Degree. The number of edges that a node has. For example, a node with two network connections has degree two.

Bisection Width. The minimum number of edges that must be cut to sever the network into two pieces.

Diameter. The maximum distance between any pair of processors expressed in terms of the number of edges to be traversed.

N. The number of nodes in the network. For a tree, **N** may also denote the number of leaves in the network.

O(N). Asymptotic notation - a function describing the upper bound limit of a network characteristic or process running time in terms of the number of inputs N. See Appendix A for a formal definition of asymptotic notation.

Bandwidth. The amount of information that can be transmitted from one point to another. For our purposes bandwidth will be expressed simply in terms of the number of edges, with each edge capable of carrying the same amount of information.

The terms above are best explained using an example. Let us consider first a simple hierarchical (**tree**) network, consisting of four **leaves** shown in Figure 3. **Nodes** are displayed as circles, and **edges** as lines. This network has seven total nodes, and six edges. The **bisection width** of the network is only one, since cutting either of the top-level edges divides the network approximately in two. The **diameter** of the network is four, since any node can reach any other by crossing at most four edges. The **degree** of nodes is one for the leaves, two for the root, and three for the two middle level nodes. The **height** of the tree is three.

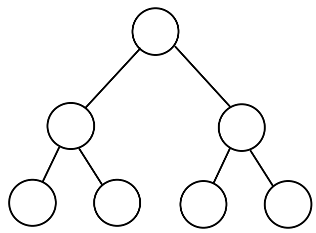

Figure 3. A Binary Tree

The tree shown in Figure 3 is called a **binary tree**, because each parent node has exactly two children. For a general binary tree with N leaves, the height will be $log\ N+1$ or $O(logN)$, the diameter will be $2\ log\ N$, and the bisection width will remain one.[3] The bisection width is the limiting factor in processing on a binary tree, because information tends to have limited flow at the root node. For example, consider a process in which all leaf nodes might need to exchange data freely. The leaf nodes pass their data to the center nodes over four edges. Next the data must pass through only two links to the root node and then be distributed out from the top over the same two links. Effectively the bandwidth is cut in half as one travels up each level in the tree, forming serious bottlenecks at the top levels in the tree.

A less vulnerable hierarchical network is the *fat tree*. A fat tree is a tree with one edge at the leaves, two at the next level, four at the next, and so on up to the highest level. A simple example with eight leaves is shown in Figure 4. The fat tree has the same basic characteristics as a binary tree, but its bisection width is always *N/2* for a tree with *N* leaves. This can be thought of in practical terms as having increasing redundancy in communications for higher levels of responsibility in a hierarchical organization.

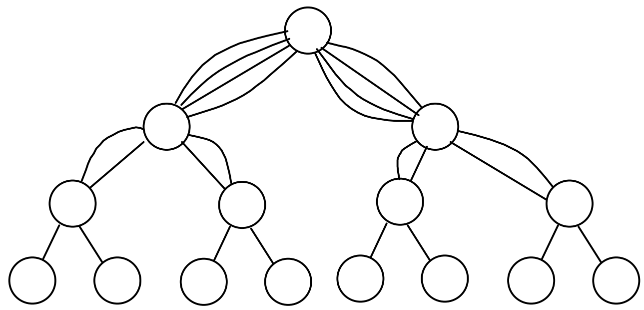

Figure 4. A Fat Tree

The relationship between networks and the physical structure of an organization will be covered in detail in Chapter 4. Let us now examine the other half of the parallel computing theory: algorithms.

Algorithmic Theory

An algorithm is a series of steps used to complete a given task. The bulk of algorithmic theory in parallel computing focuses on how many steps it takes to complete a task given a certain input size. The minimum number of steps, in rough terms, is called the complexity of the algorithm. The complexity is expressed in terms of the input size *N*. For example, sorting a list of size *N* on a regular desktop computer will take O(*N log N)* steps using the best algorithm.[4]

For a parallel computer, both the number of steps performed by a processor and the number of communications that take place between processors are summed. For simplicity, communicating between processors along any edge is assumed to take one step.[5] Since all of the processors can each execute a step in parallel, the complexity of a parallel algorithm measures the time it takes to complete a task using all of the processors. For some tasks, it will take almost as much time to complete a task in parallel as it would on a single computer. For others the time to complete the task can be significantly reduced by computing it in parallel. For example, it is possible to complete the sorting problem above in parallel using O(*log N)* time on *N* processors.[6]

The complexity of completing a task in parallel is tied closely to the characteristics of the network.[7] The trees from Figure 3 and Figure 4 are good examples. While most parallel algorithms can be efficiently implemented on the fat tree, the limited bisection width of the binary tree will significantly slow the processing of many of the same algorithms. The complexity of a given task can be evaluated analytically for a given network, and further, one can analytically determine degradation of the process as links are severed in the network. This makes parallel computing applicable and, potentially, important to parallel attack, strategic paralysis, and the operational art of war.

An example is illustrative. Consider the consolidation of information in a hierarchical network such as that shown in Figure 3. For simplicity, suppose the consolidation is simply adding up the number of enemy tanks. Each of the units at the lowest part of the hierarchy has seen a certain number of tanks, and one wishes to know the total number at the highest level in the hierarchy. The process used is to have each node add the numbers from its two children and then pass the total to the parent. One can trivially see that for a hierarchy with *N* leaves, the number of operations to consolidate the information will be the same as the height of the tree. Since the height of a binary tree is *O(log N)*, it will take at most *O(log N)* time to consolidate the total sum at the highest level in the tree. Thus, totaling the tanks will take *O(log N)* time for a simple hierarchy with *N* leaves. It can be shown that the consolidation operation need not be limited to addition. Any simple operation where the order of the operation does not matter will take *O(log N)* time on such a tree.[8] This type of operation is called a *reduction* operation, because the amount of data is reduced or consolidated at each step independently. Interestingly, performing a reduction operation in parallel is faster than performing it serially. To add *N* numbers serially it clearly takes *N-1* time steps, which is substantially larger than *O(log N)*.

Next, if one damages one or more links in the binary tree from Figure 3, it is easy to see that the entire process suffers. If any link in the binary tree is eliminated, an entire branch of the tree will be cut off resulting in the wrong sum being computed. If edges are degraded, the process suffers in proportion to the degradation at each level. For example, halving the speed of a link will double the time for data to traverse that link. If one damages only one link in each level of the hierarchy with a parallel attack, the time for the reduction operation to be completed overall will be effectively doubled. In contrast, damaging two links on the same level is no better than damaging one at that level, since both are used to transmit data at the same time. For maximum impact on this type of network and process, then, it would be better to mount a parallel attack at multiple levels in the hierarchy than to focus on any single level.

Having laid the foundations for parallel analysis in this chapter, the next chapter will move to bring all of the pieces together by analyzing the decision processes from Chapter 2 using parallel computing theory.

Notes

[1] Leighton, F Thomson, Introduction to Parallel Algorithms and Architectures, Arrays, Trees, Hypercubes, Morgan-Kaufmann Publishers, 1992

Notes

[2] Ibid, p 103, p 280, p 730

[3] All logarithms in this paper are base two. For the generalized *k*-tree where each parent node has *k* children, the logarithm would be base *k*.

[4] Cormen, Thomas H., Leiserson, Charles and Rivest, Ronald L, *Algorithms,* McGraw-Hill, 1992, p 153

[5] The assumption that each task and communications step takes one step is a theoretical simplification. In practice, a real communication step usually takes longer than a single processing step. The purpose, however, is to evaluate the relative performance of different algorithms on networks. The actual performance will differ from the theoretic by only a constant multiplier (i.e., the time for a communications or processing step). See Appendix A for a formal definition of this asymptotic notation.

[6] JaJa, Joseph, *An Introduction to Parallel Algorithms*, Addison-Wesley, 1992, p 158

[7] Ibid, Chapter 1

[8] Baker, Louis and Smith, Bradley, *Parallel Programming*, McGraw-Hill, 1996, p 10

Chapter 4

Effects of Parallel Attack on Decision-Making

The Gulf War began with more targets in one day's attack plan than the total number of targets hit by the entire Eighth Air Force during the years 1942 and 1943 combined.

—William Head and Earl Tilford
The Eagle in the Desert

This chapter will synthesize the three main concepts from the previous chapters: parallel attack, decision-making models, and parallel computing theory. The real-world effects of parallel attack on decision-making systems are not absolute. With the proliferation of modern communications systems, it is nearly impossible to completely cut off all communications. Even after the extensive air campaign and land offensive during the Gulf War, leaders in Baghdad maintained enough command and control capability to sound a general retreat up the Euphrates valley.[1] With increasing redundancy at higher levels of Iraqi command, their communications network approaches a fat tree hierarchy, which has a large bisection width. Yet the capability to sound a general retreat is far different from the information dominance enjoyed by the coalition in the Gulf War. The ability to collect and process vast amounts of information and effectively incorporate it into the decision-making process in large part determines success in modern warfare. This chapter will therefore examine how a decision-making process might degrade under parallel attack, and how the three decision models from Chapter 2 can be used to characterize this degradation.

The Rational Policy Model

Recall that the rational policy model attempts to choose the optimal course of action by assessing the risk adjusted value of each alternative based on near-perfect information. It uses a hierarchical tree network that is probably semi-redundant at higher levels, similar to the fat tree shown in Figure 4. The final decision is made by a relatively small number of people acting rationally as the national command authority. The rational model is somewhat idealistic, since no organization has perfect information or is completely rational.

If one were to implement the rational policy model in practice, it might look something like a top-down deliberate planning process. It would be time consuming to gather all of the information affecting a decision, to generate and assess all possible courses of action, and choose the best. Let us examine the complexity of performing these operations on an ideal hierarchical fat-tree network with *N* leaves and no damage shown in Figure 4. Let us assume that the root of the tree represents the national command authority (NCA) and the leaves of the tree are the lowest level units in the hierarchy. The theoretical time to execute the underlying steps for *O(N)* pieces of information and as many as *O(N)* COA's is shown in Table 1 and detailed in Appendix B. This may seem to be a small complexity, but in terms of parallel computing, a process that takes *O(N)* time is very poor. Recall that to serially process *O(N)* pieces of information it also takes *O(N)* steps. Therefore the rational process model achieves no speedup versus having all information directly sent to the NCA. If the size of the organization *N* is very large, generating a rational decision will take a very long time.

Table 1. Rational Process Complexity

Operation	Undamaged Network	Parallel Damage
Gather Information	*O(log N)*	*O(N)*
Generate/Assess COAs	*O(log N)*	*O(N)*
Select COA	*O(N)*	*O(N)*
Execute COA	*O(log N)*	*O(log N)*

The fact that the rational model needs nearly perfect information and requires consideration of all possible COAs at the decision-making level is its Achilles heel. While such a process might be practical for peacetime planning where time is plentiful, it will not last long in crisis or wartime.

The situation becomes even worse if one considers the effects of parallel attack shown in the third column of Table 1. Here let us assume that a parallel attack focused on leadership has reduced the redundancy in the decision tree from a fat tree (Figure 4) to a binary tree (Figure 3). This type of attack might mirror the results achieved in the Gulf War where command and control system effectiveness was significantly reduced but not completely eliminated. Connectivity is retained, but bandwidth is more limited at the higher levels. This means that the *O(N)* pieces of data take progressively longer at each level in the hierarchy, getting bottlenecked at the top. This effectively slows the information flow from *O(log N)* time to *O(N).* For a large organization, this type of slowdown would be staggering. The organization would be forced to move to a different model to maintain its decisiveness in a wartime situation.

How could one target a rational decision process to maximize impact? Consider the impact of eliminating *log N* communications links using a parallel attack. This is equivalent to removing *log N* edges from the tree. First, lets consider an attack on a single level in the hierarchy. As long as no branch in the tree is completely cut off, we will still be passing *N* pieces of information over at worst *(N - log N)* remaining links. This will only double the amount of transmission time at the targeted level, assuming the damage is randomly distributed. Since this doubling is only at one level, this will have a marginal effect on the overall time to transfer information. In contrast, if an attack is focused on multiple levels along the same path from top to bottom in the organization, eliminating only *log N* links could double the time to gather information at each level. By doubling the time at each of *log N* levels, one effectively slows the entire process by *log N* time, doubling the overall transmission time. Thus, one could cause maximum impact at minimum cost by disrupting communications at multiple levels in the organization, rather than focusing on a single level.

How would the quality of rational decision-making be impacted? As Table 1 shows, the most costly part of the process is the collection and consideration of *N* potential pieces of information and COAs. As the network feeding the NCA degrades under parallel attack, less information will be forwarded, fewer COAs will be considered. Decisions will be made without full knowledge of the situation, and with fewer alternatives being considered. Since subordinates will no longer be able to keep their leaders fully informed, they will likely filter both the flow of information and suggested alternatives. The quality of the decisions will be significantly affected by the methods subordinates use to filter information and behaviors. As will be shown shortly, this *degraded* rational process will closely parallel the bureaucratic and organizational process models described in Chapter 2. The rational process may ultimately give way to bureaucratic or organizational decision making in the face of parallel attack.

The Bureaucratic Decision Model

Recall from Chapter 2 that the bureaucratic decision model asserts that decisions are made in an overlapping hierarchical set of political games, played out to maximize the power of individual players rather than organizational goals. The communications network in this model has two components: the formal hierarchy and the informal, cross-hierarchy political network. The process used to make decisions is much more distributed, since each political player filters both the information and recommended alternatives before forwarding that information up in the hierarchy. Far less information and far fewer alternatives are therefore considered when making a decision.

The hierarchical portion of the network is similar to the fat tree network seen in Figure 4 and used in the rational decision making process. The cross-political bureaucratic network is less formalized and closer to the star network shown in Figure 2, Chapter 2. The hierarchical communications network may be redundant at the highest levels to assure survivability in wartime. Interestingly, the less formal bureaucratic network may be more vulnerable to attack, since it depends on telephones, civilian computer networks and fixed organizational sites. Since the informal bureaucratic network is not a recognized part of the process, it is not as well protected as the formal wartime chain of command.

Table 2. Bureaucratic Process Complexity

Operation	Undamaged Network	Parallel Damage
Gather Information	*O(log N)*	*O(log N)*
Generate/Assess COAs	*O(log N)*	*O(log N)*
Select COA	*Constant*	*Constant*
Execute COA	*O(log N)*	*O(log N)*

The time complexity for the hierarchical portion of the bureaucratic decision making is summarized in Table 2 and detailed in Appendix B. This table focuses on the formal hierarchy, not the informal bureaucratic network. Compared to the rational decision model, bureaucratic decision making within the hierarchy is much more efficient. This is due to the fact that only a limited amount of information is passed up by players to their superiors in the hierarchy. Similarly, only a small number of alternatives are considered for execution at each level in the hierarchy. While this filtering saves time, it does not necessarily increase the quality of decisions made. In column three, degradation is shown for parallel attacks that focus on reducing the fat tree (Figure 4) to a binary tree (Figure 3). As shown, as long as parallel attacks do not completely cut off communications, the hierarchical portion of the network will continue to function normally. This is again due to the filtering that takes place at each level that reduces the number of alternatives and information considered.

Let us now consider the informal bureaucratic network of the decision making process. The cross-bureaucratic network can be seen as a telephone network, where virtually any player can talk to any other to gather information and form advantageous alliances based on shared political interests. Since virtually all cross-bureaucracy communication takes place over telephones, unclassified networks, or in formal fixed office buildings in the capitol, it is more vulnerable than the formal hierarchy to attack. Because this network is fixed, loosely organized and not as redundant, damage done generally creates a proportional reduction in cross-bureaucratic communications. Reducing this network by 50% would therefore reduce cross-bureaucratic communications by 50%. Eliminating a few key systems such as power, telephones and top government buildings could potentially cripple the cross-bureaucratic power game.

How will the quality of decisions be affected by parallel attack? As described above, decisions in the bureaucratic decision model are made by players primarily to maximize personal power. The source of this power can be either from the strength of personalities or the strength of alliance with other players. The cross-bureaucratic flow of information most directly impacts alliances and the coordination. Without cross-bureaucratic information and alliances, players will likely become entrenched in promoting their own organization's agenda. In the worst case, the bureaucratic model may degrade to resemble the organizational decision model described in Chapter 2. Lacking cross-bureaucratic information and alliances, players in the political game may fall back on what their portion of the organization does best as the only viable course of action.

How should one target the bureaucratic decision process with a parallel attack? As shown above, the focus should be on the informal cross-bureaucratic flow of information. Players in the bureaucracy rely heavily on these relatively vulnerable channels as the source of personal power. Key telephone, electrical and central government office buildings are poorly protected and do not have the redundancy of the formal command hierarchy. A single parallel strike on these systems may paralyze the bureaucracy, reducing overall effectiveness. Eliminating these key informal lines of communication will throw major government players out of their normal mode of operations, likely injuring their effectiveness as bureaucratic leaders. Subsequent entrenchment of leaders along organizational lines may reduce the ability to build consensus, particularly if the President or Prime Minister of the enemy country is not a strong executive leader.

The Organizational Process Model

The organizational process model outlined in Chapter 2 was based on the premise that organizations tend to focus on the behaviors that they have used before. In essence, any organization has a very limited set of behaviors or *mental models* that they are accustomed to performing. Given a choice, elements within the organization will tend to fit a given situation to its known set of behaviors rather than adapt its behavior. The organization therefore tends to repeat itself—it will do the same now as it did in the past.

Analyzed from a parallel point of view, the organizational process model is very efficient. At each level in the hierarchy, the current situation is analyzed against a very small number of possible behaviors, and only a limited number of possible courses of action are presented to the next higher level. Information is processed and filtered at each level as well, largely using organizational criteria. The parallel efficiency of these operations is summarized in Table 3 and detailed in Appendix B. For the undamaged and damaged network, we again assume the fat tree structure from Figure 4 degrading to the simple hierarchy from Figure 3. Because of the processing of information at each level and consideration of a small number of options, the organizational process model performs well even if damaged.

Table 3. Organizational Process Complexity

Operation	Undamaged Network	Parallel Damage
Gather Information	*O(log N)*	*O(log N)*
Generate/Assess COAs	*O(log N)*	*O(log N)*
Select COA	*Constant*	*Constant*
Execute COA	*O(log N)*	*O(log N)*

Given that the organizational process model is efficient, even with a degraded communications network, how can one use parallel attack to affect the process? The answer, obviously, is not to focus on the communications network but rather the potential behaviors of the enemy. In terms of military action in particular, potential adversaries frequently have experience and training for only a very limited number of courses of action. They will likely revert to those they have trained for and executed before. This knowledge can be used to tailor our own actions in an attempt to take the enemy outside of his comfortable mental models. Any action that takes a trained force beyond the actions, doctrine, environment and mental models they are trained for will reduce their effectiveness as long as they use this decision model.

What is the potential qualitative effect of parallel attack on organizational decision making? This depends entirely on the ability of a parallel attack to take the enemy outside of his organizational mental models. Organizational decision making is effective only so long as the current situation lies within reach of pre-programmed organizational actions. If parallel attack effectively takes an enemy beyond previously trained-for experiences, the entire process breaks down and the enemy will be likely to select a poor COA.

A Progression of Decision Models

The presentation order of the three models may represent a succession order for national level decision-making. An organization may begin with a rational decision-making process in peacetime, reflecting the most efficient use of plentiful time and peacetime communications bandwidth. After substantial wartime damage has been inflicted on an enemy's system, rational decision making will be unsustainable, and likely be replaced by a process that resembles either bureaucratic or organizational decision models. If individual players in the government retain sufficient personal power and inter-agency communications, the move to a bureaucratic model is likely. Once internal government communications have broken down, various government departments are likely to retain semi-autonomous action using the organizational model. In the final stages, organizations revert to the behavior they were organized and trained to demonstrate. In absence of a central functioning government, separate units may act autonomously on their own internal mental models until overcome by the enemy.

The progression follows the communications requirements and vulnerability of the models. Our analysis showed that rational decision making was the most time consuming and potentially most vulnerable to parallel attack. The bureaucratic decision model was second in terms of communications and physical vulnerability. Its dependence on relatively vulnerable cross-bureaucratic relationships made it a prime target for coordinated parallel attack. Finally, the organizational model has the least communication requirements and is least vulnerable physically to parallel attack. Individual units can continue to execute their mental models even in absence of communications with superiors. Together, these models form a potential progression in enemy decision-making. An enemy may start making rational decisions, revert to bureaucratic decisions at the outset of war and eventually degrade to organizational decision making if the battle progresses poorly.

Notes

[1] Gordon, Michael and Trainor, Bernard, *The General's War*, Little Brown and Company, 1995

Chapter 5

Conclusions

This work started with the thesis that parallel computing constructs could be used to analyze the effects of parallel attack on the decision making process. It focused on three different national decision-making models, in an attempt to show some of the strengths and weaknesses of this analysis method. For example, parallel analysis was adept at analyzing the relatively structured rational process model, but less effective at analyzing the unstructured cross-bureaucratic network of the bureaucratic models. This is due in part to the difficulty of characterizing a bureaucracy's network and processes.

In many ways this paper has only just begun to scratch the surface on the analysis that could be performed using these techniques. Idealized decision models as well as simple networks and algorithms were selected to demonstrate the principles involved. In practice a real enemy might have several parallel decision networks with varying degrees of vulnerability, both in the network itself and the decision processes used. More complex networks and processes can be divided into key sub-networks and steps, much as was done with the sample decision models above. By applying parallel computing theory to systems and processes, one can arrive at an understanding of which steps are most costly and which elements of the network are most vulnerable. Equally important, one can quantify the impact on the process when parallel damage is assessed on the system as a whole.

Lower level networks and processes could potentially be analyzed using the same techniques. Consider, for example, an operational objective of paralyzing an Integrated Air Defense (IADS) network. Traditional nodal analysis might attempt to identify key physical nodes and links in the network to disrupt the IADS system. Yet if the IADS has sufficient redundancy it might survive a nodal attack. In contrast, applying parallel computing analysis to the network, one can attack both the physical relationships and the processes performed within the IADS. This may result in an attack that accomplishes the same level of disruption with fewer sorties. For example, it may be possible to stop the IADS from operating effectively by disrupting the underlying process rather than physically destroying its C^2 centers.

One of the most interesting ideas that evolved during the writing of this paper is the possibility of parallel attack causing a progression of decision process models from a rational to a bureaucratic to an organizational model. The rational model is most vulnerable to attack, while organizational mental models can continue to operate even in a severely damaged organization. This may explain, in part, why enemies throughout history have continued to fight well beyond the point where any rational gain was possible.

For example, WWII began with centralized control firmly in the hands of Hitler and his General staff. Except for a few significant blunders made by Hitler himself (decision to invade Russia, genocide, and decision to declare war on the US), Hitler and his core group of Generals made relatively *rational* decisions. As the war progressed, various *players* in the Reich like Speer, Goering, Himmler, started to assert more power. Though Hitler still wielded a great deal of power, key members within the Reich started filtering information and recommending courses of action designed to maximize their own personal power. Finally, as the Reich began to fall under the allied advance in 1944, these players revolted. Himmler secretly negotiated with the allies, Speer disobeyed Hitler's *scorched earth* order, and the 20th of July movement attempted to assassinate Hitler himself.[1] This was the death knell of the bureaucratic organization. Once Hitler hung the traitors and any hope of defending the Reich was gone, Germany continued to fight in an autonomous organizational mode until the bitter end.

In WWII, then, Germany passed through all three organizational models. What started as a centralized rational decision-making, gave way to bureaucratic decision making after Germany's blitzkrieg expansion. When the bureaucrats were finally defrocked and the bureaucracy dismantled by advancing allies, the German war machine continued executing its mental models using organizational templates until Berlin itself was taken. This analysis would apply equally as well to the difficulties Japan had in WWII.

This leads to another interesting possibility that one might want to leave intact certain lines of communication to facilitate a rational and orderly surrender rather than completely destroy an enemy's command and control system. We may not be able to control the shift from rational to bureaucratic decision making, particularly if the enemy is rapidly expanding government along with territory and forces. One can, however, try to delay the shift from bureaucratic to organizational decision making. By identifying key "doves" and "hawks" in the process and targeting the power base and systems of the "hawks," one could potentially draw conflict to more rapid conclusion. Further, by maintaining limited enemy communications capability in the face of defeat one may facilitate a rapid and orderly surrender.

In summary, this paper presents a number of new ideas. Parallel computing techniques can be used to assess both systems and the underlying processes that take place within them. These techniques can be used to assess the impact of parallel damage on the speed and quality of processing within the system. The techniques could potentially be used on any well-defined system, whether at the national or much lower level to identify process vulnerabilities and assess potential parallel attack damage. In detail, we analyzed three national level decision-making models using this method and found that there may be a progressive relationship from rational to bureaucratic to organizational decision making as communication capabilities degrade. This analysis revealed strategies for shaping national decision making using parallel attack, as well as the need to maintain some national-level enemy communications capability to facilitate an orderly surrender. These results open new avenues for potential research including formalization of parallel analysis targeting and assessment theories, national decision-making analysis, revised conflict termination strategies, and potential automated tools to aid in analysis. Though this work has only scratched the surface, we hope it will provide some food for creative thought in future parallel attack planning.

Notes

[1] Ikle, Fred Charles, *Every War Must End*, Columbia University Press, New York, 1991, p 72

Appendix A

Asymptotic Notation

In the field of computing, the complexity of an algorithm is generally expressed in *asymptotic notation*. This notation expresses the running time of the algorithm in terms of the set of natural numbers $N=\{0, 1, 2,\ldots\}$. Since computational theory is primarily concerned with what happens for large N, the complexity of algorithms is expressed in asymptotic terms. For large N, the constants and lower-order terms are overcome by the effects of high order terms. In addition, different computer implementations may introduce differences in run time constants. For all of these reasons, run time is expressed in the asymptotic limit as the input size N gets large.

In more formal terms, one can express the upper bound limit of an algorithm's performance, denoted $O(N)$ in terms of its exact running time $g(N)$ as:[1]

$O(N) = O(g(N)) = \{f(N)$: there exists positive constants c and n such that $0 \le f(N) \le cg(N)$ for all $N \ge n$ }

In other words, the simplified limit $O(N)=f(N)$ and the exact function $g(N)$ differ only by a constant factor c for large N. In practice, taking the asymptotic limit of the run time eliminates the lower order terms and constants from the exact expression. This provides the order of doing a calculation, but not its exact cost. Since the constants differ depending on the computer used, this is an acceptable analytic method for computing.

Further, by focusing this paper on national level decision making, *N* is guaranteed to be large. The most common asymptotic functions used in this paper are as follows:

- ***Constant*** - formally denoted *O(1)* - A process that can be completed in a constant amount of time that does not depend on the size of *N*.
- ***O(log N)*** - The process can be completed in a number of steps that vary as the logarithm (base 2) of *N*. This is typically the lower bound for non-trivial parallel processes, because the best networks known have a diameter that is *O(log N)*. Since the diameter determines the minimum transit time between nodes in the network, *O(log N)* cannot be exceeded when shared information or results are required.
- ***O(N)*** - This process takes *N* steps to process an input of size *N*.

Notes

[1] Cormen, Thomas H., Leiserson, Charles and Rivest, Ronald L, *Algorithms*, McGraw-Hill, 1992, p 24

Appendix B

Algorithm Run Times

Rationale for the run times used in the analysis in Chapter four (Table 1,Table 2 and Table 3) will be detailed here. The purpose is not to detail the complete algorithms used, but only to outline the basic rationale for the parallel run times quoted.

Rational Process Model

Table 1 represents cost of performing steps in the rational process model on an undamaged fat tree network and a damaged binary tree network. The overriding assumption with the rational process model is that there are potentially as many as $O(N)$ possible pieces of data to be collected and $O(N)$ courses of action to be considered. This information is processed by the central national decision making authority, which considers all the facts and COAs before making a decision.

The first two steps in the undamaged network column of Table 1 each take $O(\log N)$ time. It takes $O(\log N)$ time, which is the tree height, to pass the $O(N)$ pieces of information from the leaves of the tree to the root on a fat tree. The rationale is simply that there are $O(N)$ edges between any two levels in the tree hierarchy to transmit the $O(N)$ pieces of data. The third step, selection of the COA, occurs at the root of the tree, where all $O(N)$ possible COAs are considered. This takes $O(N)$ time, since the root must consider each serially. Finally, when one COA is selected by the central decision makers, it must be transmitted from the root of the hierarchy to the trees, which takes *O(log N)* time, because the height of the tree is *O(log N)*. Overall, the rational decision making process takes *O(N+log N)* time on the undamaged network. This is dominated by the time it takes the central rational decision maker to consider the *O(N)* pieces of information and possible COAs available.

Moving to the column two (parallel damage) of Table 1, communications now become an equal consideration. Since the root of the tree no longer has *O(N)* edges, the communications time for *N* pieces of information in the first two steps is *N/2* at the top level, *N/4* at the next and so on. This can be expressed as the sum *N/2+N/4+N/8+…+1* which can be simplified to *O(N).* Therefore, the steps to gather information and COA's both take *O(N)* time. The time for the central decision maker to consider all information and COAs serially remains *O(N).* Finally, once a decision is made, it will take *O(log N)* time, the height of the tree, to transmit it down the hierarchy from the root to the leaves. The overall process is still *O(N)*, though in practice the damaged network will take *O(N)* time to gather *N* pieces of information versus only *O(log N)* time on the undamaged network.

Bureaucratic Process Model

The run times for steps in the bureaucratic decision model are summarized in Table 2. For this decision model, they key assumption is that not all of the information available to a decision-maker at each level is passed up to the next higher level. Instead, each player carefully filters the information available to suit his or her personal agenda and maximize personal power. Each boss in the hierarchy therefore receives an extract of the information and possible courses of action available to each subordinate.

For the analysis of the first two steps in Table 2, let us assume that the size of the summary report that each subordinate passes to their boss can be bounded by a constant (example: all reports are less than 100 pages). At each level in the hierarchy, the boss effectively consolidates the information and COAs from the two subordinate reports into a new report to pass to its boss. Computationally, this is a classic parallel reduction operation, since *N* reports at the leaf are reduced to a single report at the highest level[1]. This takes only *O(log N)* time, since each of the *O(log N*) levels in the hierarchy each assess and consolidate a constant amount of information. The steps to gather information and generate/assess COA's both use this process, each taking *O(log N)* time. The third step, selecting a COA, takes a constant amount of time because the root level decision maker has only a small number of COA's to consider. Lower level bureaucrats have already filtered out alternative COAs. The final step, execution, takes only the height of the tree, or *O(log N)* time to transmit this decision from the root to leaves.

In examining the parallel damage (binary tree) column of Table 2, one can see that all of the steps take the same amount of time as in the undamaged (fat tree) case. This is due to the fact that the reduction operations from steps one and two remain the same whether the network is a fat tree or binary tree. In the binary tree case (the worst case examined), each boss in the hierarchy still goes through the process of summarizing its subordinate's report into a new report bounded by a constant size. Effectively, this reduces the amount of information by a factor of two as one moves a level up the tree. This matches the reduction in bandwidth as one moves up the tree. At the leaf level, *N* reports are generated and transmitted over *N* edges. At the next higher level, *N/2* reports are generated and transmitted over *N/2* edges. This pattern continues until the highest level is reached where only two reports are transmitted over two links to the root level decision authority. Thus, the time to perform our parallel reduction is *O(log N)* steps on the binary tree as well as the fat tree. The final two steps, COA selection and execution remain the same as well, so effectively the hierarchical portion of the bureaucratic decision model takes the same amount of time whether the network is a binary tree or fat tree.

Organizational Process Model

First, note that Table 2 depicting the run times for the hierarchical portion of the bureaucratic process model and Table 3, depicting run times for the organizational process model contain the same values. This is due to the fact that both processes use the same parallel reduction operation to reduce or limit the amount of information that a subordinate provides to a superior. The only difference in the formal hierarchy is that the bureaucratic model filters information based on personal power and gain, while the organizational model filters information based on pre-programmed organizational behavior. It is the criteria used to filter information that differs, but not the underlying process. Since the criteria is applied to the limited (constant amount) information received from subordinates in both cases, the criteria used to filter information does not affect the asymptotic run time for any of the steps in either. Therefore, the processes within the hierarchy for the bureaucratic and organizational process models take the same amount of computational time.

Notes

[1] JaJa, Joseph, *An Introduction to Parallel Algorithms*, Addison-Wesley, 1992, Figure 1.1, p 8

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