The Deep Green Concept

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Abstract

The Deep Green concept is an innovative approach to using simulation to support ongoing military operations while they are being conducted. The basic approach is to maintain a state space graph of possible future states. Software agents use information on the trajectory of the ongoing operation, vice *a priori* staff estimates as to how the battle *might* unfold, as well as simulation technologies, to assess the likelihood of reaching some set of possible future states. The likelihood, utility, and flexibility of possible future nodes in the state space graph are computed and evaluated to focus the planning efforts. This notion is called anticipatory planning and involves the generation of options (either automated or semi-automated) ahead of "real time," before the options are needed. In addition, the Deep Green concept provides mechanisms for adaptive execution, which can be described as "late binding," or choosing a branch in the state space graph at the last moment to maintain flexibility. By using information acquired from the ongoing operation, rather than assumptions made during the planning phase, commanders and staffs can make more informed choices and focus on building options for futures that are becoming more likely. This paper will describe the Deep Green concept in detail.

1. OVERALL VISION FOR DEEP GREEN

In a military operational environment the only invariant is constant change, particularly the situation and goals. Under uncertain and time-critical conditions, it is important for commanders to have the ability to rapidly understand the unfolding trajectory of the operation and generate options quickly. More importantly, however, in modern warfare, it is important for the commander to be able to proactively generate options well in advance of when those options are needed rather than generate options reactively as the situation forces him off the plan. In this situation, it is much more important for the commander to have options than to have planned the optimum course of action in fine detail. Robust plans are those that provide not just good outcomes but maximum flexibility to adapt to unforeseen or unexpected situations.

The Defense Advanced Research Projects Agency (DARPA) has recently release a broad area announcement (BAA), 07-56 Solicitation [1] for a battle command technology program, called Deep Green. Going beyond IBM's "Deep Blue"[2] Supercomputer for Chess, Deep Green is meant to be a commander-driven technology, rather than on building technologies to remove the commander. The Deep Green program has the goal of providing tactical commanders a technology to:

- generate and analyze options quickly, including generating the many possible futures that may result from a combination of friendly, enemy, and other courses of action;
- use information from the current operation to assess which futures are becoming more likely in order to focus the development of more branches and sequels; and
- make decisions cognizant of the second- and third-order effects of those decisions.

Deep Green is composed of tools to help the commander rapidly generate courses of action (options) through multimodal sketch and speech recognition technologies. Deep Green will develop technologies to help the commander create courses of action (options), fill in details for the commander, evaluate the options, develop alternatives, and evaluate the impact of decisions on other parts of the plan. (See Figure 1.) The permutations of these option sketches for all sides and forces are assembled and passed to a new kind of combat model which generates many qualitatively different possible futures. These possible futures are organized into a graph-like structure. The commander can explore the space of possible futures, conducting "what-if" drills and generating branch and sequel options. Deep Green will take information from the ongoing, current operation to estimate the likelihood that the various possible futures may occur. Using this information, Deep Green will prune futures that are becoming very improbable and ask the commander to generate options for futures that are becoming more likely. In this way, Deep

Green will ensure that the commander rarely reaches a point in the operation at which he has no options. This will keep the enemy firmly inside our decision cycle.

Figure 1: Operational Concept for Deep Green

The venerable Observe-Orient-Decide-Act (OODA) loops [3] no longer viable for an information-age military. Deep Green creates a new OODA loop paradigm. When something occurs that requires the commander's attention or a decision, options are immediately available. When the planning and execution monitoring components of Deep Green mature, the planning staff will be working with semi-automated tools to generate and analyze courses of action ahead of the operation while the command concentrates on the Decide phase. By focusing on creating options ahead of the real operation rather than repairing the plan, Deep Green will allow commanders to be proactive instead of reactive in dealing with the enemy.

Deep Green was inspired by two concepts: anticipatory planning and adaptive execution. **Anticipatory planning** can be described colloquially as "you know you're going to replay anyway, so why not re-plan ahead of time?" This drives the notion of generating options and futures before they are needed. To some extent Deep Green will trade depth for breadth. Today commanders plan a small number of options very deeply, i.e., all the way to the end of execution in great detail. Most of these deep plans are discarded once the plan goes awry. Sometime the commander and staff are unable to recognize that the plan is broken or is becoming broken. They are often unable to divorce themselves from the plan in order to seek new affordances based on the current state of the operation. By identifying the trajectory of the operation and focusing the commander and staff where to build (perhaps less deep) plans, the commander will have a broader set of options available at any time. This leads to the concept of **adaptive execution[4]**, which is similar to the AI planning concept of late binding. Adaptive execution intends to make decisions at the last moment in order to maintain flexibility to adapt to updated trajectories of the operation.

2. BASIC SYSTEM ARCHITECTURE

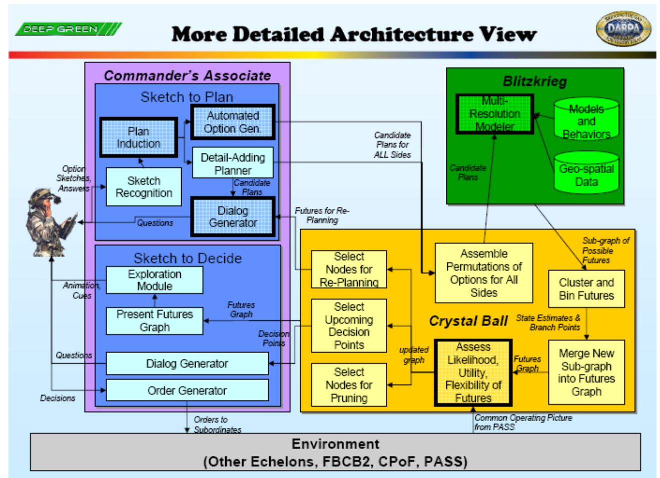

Figure 2: Architectural Overview of Deep Green

2.1. Commander's Associate

The Commander's Associate has two major sub-components, Sketch to Plan and Sketch to Decide. (See Figure 2.) The two components are discussed separately because in an open, modular architecture, it is envisioned that one or the other must be able to be replaced with new technologies over time without disrupting the entire system. A goal of the Deep Green program is to develop and apply computer software technologies to develop a Commander's Associate that automatically converts the commander's hand-drawn sketch with accompanying speech of his intent into a Course of Action (COA) at the brigade level. The Commander's Associate must facilitate option generation, "what-if" drills, and rapid decision making.

Sketch to Plan

This component provides the commander the ability to generate quickly qualitative, coarse-grained COA sketches that the computer can interpret. Sketch to Plan will be multi-modal (both sketching and speech) and interactive. The computer will watch the sketch being drawn and listen for key words that indicate sequence, time, intent, etc. as the commander is creating the sketch. Sketch to Plan will induce both a plan and the commander's intent from the sketch and speech. Unlike other approaches that are optimized around machine interpretations [5] (i.e. constraining the sketching method to drag-and-drop modalities, forcing the human to learn the computer's 'language' to some extent), Sketch to Plan is optimized around the user free-hand sketching options over a map. In addition, the Sketch to Plan component must be imbued with enough domain knowledge that it knows what it doesn't know and can ask the user a small set of clarifying questions until it understands the sketch and can use it to initialize a combat model.

The sketch Recognizer converts a free-hand set of strokes, combined with speech, into a set of military objects, such as units and graphical control measures (MIL STD 2525b [6] and STANAG 2019 APP-6A [7]). The plan inducer has the challenge of inducing the commander's plan and intent for the recognized "bag of symbols." We envision a detail adding planner within Sketch of Plan that adds details to the commander-generated option so that it can be modeled by Blitzkrieg. Finally, the dialog generator helps Sketch to Plan understand the commander's option by formulating clarifying questions when necessary.

Sketch to Decide

When the commander is asked for a decision, Sketch to Decide will allow him/her to explore the future space to gain an appreciation for the ramifications of a choice. It is envisioned as similar to a comic strip with branch points that correspond to branch points in the futures graph. Scott McCloud [8] asserts that the idea of a comic in which the readers get to make a choice at the branch points is today "exotic" but may well become common in the future. Since the 1970s (and perhaps earlier), there have been novels and game books in which the reader is asked to make a decision and then is directed to a different page or paragraph, depending on the choice made, such as the 1980's children's <u>Choose Your Own Adventure</u> gamebook series or the DVD movie <u>Clue</u> based on the board game <u>Clue</u> as examples . Recently Forbus has explored the idea of a comic graph [9]. The idea here is the same: the user gets to choose which path to follow at a branch point. One can imagine the commander exploring the future space to understand how his courses of action may play out and identifying the critical branch (decision) points.

Sketch to Decide is designed to allow the user to "see the future," but this capability must be developed with care to prevent confusing the decision space. Humans are notoriously bad at thinking through probabilistic choices and even more so when there are competing outcome utilities. At each branch point, there are multiple decision dimensions/utilities that have to be considered, such as likelihood, risk, utility, resource usage, etc. In addition, the abstract nature of the state and the uncertainty of predictions, locations of units, etc. must be portrayed intuitively. Therefore, at any "frame" in the Sketch to Decide graph, the user can perform Sketch to Plan actions, allowing the commander to conduct "what-if" drills wherever he wants in the future space. The user is going to need a lot of help in evaluating these options, especially because they are probabilistically weighted. By presenting decisions early and allowing the commander to explore the future space, Sketch to Decide supports adaptive execution, allowing the commander to make decisions when they are needed, rather than committing too early.

2.2. Blitzkrieg

Blitzkrieg is the simulation component of Deep Green. It is used to generate the possible futures that result from a set of plans (one plan for each side/force in the operation). Besides being very fast (the *blitz* in Blitzkrieg), it is designed to generate a broad set of possible futures. These futures should be feasible, even if not expected by human users. Over time, Blitzkrieg should learn to be a better predictor of possible futures, based on presented options. Blitzkrieg identifies branch points, predicts the range of possible outcomes, predicts the likelihood of each outcome, and then continues to simulate along each path/trajectory. Gilmer and Sullivan provide an example of a possible implementation of this idea [10] in which they determine branch points and continue to simulate along multiple paths. Blitzkrieg should reflect out-of-the-box thinking, rather than merely generating hundreds or thousands of "Monte Carlo" runs of a stochastic model and binning the outputs [11]. This will require an innovative hybrid of qualitative and quantitative technologies.

As an example, two forces may collide with each other. The collision may be predicted with some sort of analytical model that accounts for non-determinism in rate of march of the forces. Qualitatively there are a number of possible outcomes of this collision: one side or the other may get quickly defeated, one side may begin to lose and withdraw, the two forces might avoid each other and continue on their way, both sides may choose not to engage each other, or both sides may become involved in an attrition slug-fest, etc. Quantitative models, such as Lanchester equations [12] or the Qualitative Judgment Model [13] might then be used to determine the relative likelihood of these various outcomes. Perhaps heuristic methods might be used instead of or in addition to these quantitative models. For instance, a fuzzy rule base might be used that takes into account aggressiveness of the opponents, their relative strengths, etc.

In warfare, all the players can be potentially moving at the same time, so predicting when these forces will meet, separate, etc. is challenging. The conditions of these meetings may, in fact, also impact the prediction of outcomes described in the previous paragraph. Continuing with this scenario, due to the non-deterministic nature of each side's movement, speeds could indicate some likelihood that one side or the other would reach a key piece of terrain first. In this case, the force that arrived first might have an advantage in the ensuing engagement. If, on the other hand, the force that arrives first is in an exposed position, such as being in the middle of a river crossing or out in the open, the other side might have an advantage.

The Army and the Marine Corps, if not the nation, are at war. The current war has many non-kinetic aspects and involves paramilitary forces, terrorists, and masses of civilians on the "battlefield." Blitzkrieg, and in fact all of Deep Green, must support the full spectrum of military operations, from mid-intensity combat to operations other than war, perhaps all occurring simultaneously in a three-block war context [14]. We believe that the combination of these qualitative and quantitative methods will allow Blitzkrieg and Deep Green to better support full spectrum operations. The impacts of medics and food distribution in local villages, the destruction of culturally significant sites, morale, leadership, and cohesion perhaps are best represented qualitatively, rather than quantitatively.

Today's class of combat models requires detailed terrain databases in order to function properly. Blitzkrieg will use more qualitative terrain representations. Commanders do not reason on the stem spacing and diameter of trees at breast height, vertical cone index of soil, or whether a particular area is composed of sandy clay loam. They reason about maneuver corridors, key terrain, and points of dominance. Of course, we do not want to "dumb down" Blitzkrieg to the extent that it provides little additional rigor than would an average human, but the right balance needs to be struck. At the same time, the creation of the abstract, qualitative terrain representation should be based on the same detailed terrain representation used in our current class of simulations, such as the OneSAF Objective System [15] Objective Terrain Format [16], and generate the more abstract terrain needed by Blitzkrieg in an automated fashion.

2.3. Crystal Ball

Crystal Ball serves several functions. First, it controls the operation of Blitzkrieg in generating futures. Second, it takes information from the ongoing operation and updates the likelihood metrics associated with possible futures. Third, it uses those updated likelihood metrics to prune parts of the futures graph and nominate futures at which the commander should generate additional options and invokes Sketch to Plan. Finally, it identifies upcoming decision points and invokes Sketch to Decide. While Crystal Ball has a moderate role prior to execution, it is the backbone of the system during execution.

Prior to Execution

During pre-operations planning, Crystal Ball receives options from Sketch to Plan for all sides and forces. These options are generated by humans. Crystal ball assembles the permutations of plans and sends them to Blitzkrieg to generate the possible futures that result from each permutation. If the commander uses Sketch to Decide to inject branches and sequels into this process, Blitzkrieg will make additional runs. Blitzkrieg returns sub-graphs of possible futures and branch points to Crystal Ball with annotations as to Blitzkrieg's *a priori* estimate of the likelihood of these options. Another function of Crystal Ball is to merge these sub-graphs so the futures that are qualitatively the same (regardless of which permutation of options generated them) are combined. This reduces the complexity of the future space, helps refine the list of critical branch points in the future space, and makes Crystal Ball's during-execution job easier.

Crystal Ball also generates two additional metrics associated with the possible futures: value/utility and flexibility. Utility is a rating of how good the future is with respect to the goal of the operation. Utility cannot be based completely on some *a priori* estimate of "board position," casualty rates, etc. "Board positions" are really a measure of the location of entities with respect to key terrain, the objective, etc., but what constitutes key terrain can often be a function of the mission. Flexibility is a measure of how many branches from a future lead toward better utility. Most commanders would rather have choices than only one good path. If the battle is moving toward nodes with little flexibility, this indicates that the plan is "brittle" and perhaps can be easily derailed by enemy action – or our own mis-actions.

During Execution

Once the operation is underway, Crystal Ball will get information about the ongoing operation from the battle command systems, such as FBCB2 [17], CPoF [18], or the publish and subscribe services (PASS) [19] of ABCS 6.4+. For forces other than BLUE, this information is largely location and perhaps strength information fused from various intelligence sources. (This information fusion is not a part of Deep Green's objectives; Deep Green assumes the information it gets is the best available.) For BLUE forces this information will include information about location and strength, but also potentially information about logistics status, velocity, etc. Crystal Ball uses this information about the current operation to update the likelihood estimates of the many possible futures. Having done that, Crystal Ball can compare the likelihood, utility, and flexibility and estimate which futures are likely to occur that have little value or flexibility. Crystal Ball will use this estimate to nominate to the commander futures at which he/she should focus some planning effort to build additional options/branches. If the commander reaches a future for which no options have been developed, he/she has been surprised and the enemy is now operating inside his/her decision cycle. Crystal Ball will identify the trajectory of the operation in time to allow the commander to generate options before they are needed. Crystal Ball will also use this information and additional heuristics to nominate futures for pruning from the graph and to identify decision points to send to Sketch to Decide. Pruning, however, will not be based purely on likelihood, but also on attributes such as risk to the operation.

2.4. Automated Option Generation

The focus of Deep Green is on tools to help the commander (and staff) generate options quickly. Leaders from the field generally do not want machine-generated courses of action. Nevertheless, under Deep Green, we intend to sponsor a small set of modest efforts to generate options automatically. The long-term vision of Deep Green is for options to be generated by both the commander and the computer. Initially we expect the machine generation of options to be centered on making clever "mutations" of the human-generated options to increase the breadth of the futures generated. This highlights the need for Sketch to Plan to induce the commander's intent from the free-hand sketches. Any options generated by the computer should feasibly meet the commander's intent.

2.5. State Space Graph

Throughout this discussion of Deep Green we have mentioned the "state space graph." We are still very early in the development of Deep Green; in fact, by the time this paper is published we will have just selected performers for Deep Green. We envision the collaboration of Blitzkrieg and Crystal Ball creating and maintaining a graph of possible futures. The tasks assigned to Crystal Ball sound like a hybrid of Markov technologies, such as hidden Markov models, Markov Chain Monte Carlo, Markov and Partially Observable Markov Decision Processes, and Bayesian technologies, such as continuous bayes networks, Gaussian, Inference, and Clustering/Join Trees [20]. We, therefore, envision the data structure of the state space graph also being a hybrid of these representations. One can envision Blitzkrieg adding nodes to the graph and Crystal Ball updating, and in some cases pruning, the graph. Conceptually, this would appear like the movement of an amoeba, where the human-generated options cause Blitzkrieg to shoot out pseudopodia. In preparation for initiating Deep Green, we commissioned a study to look at existing planning languages in the AI community and the military and identify the necessary and sufficient data elements for this state space graph. That report will be published in the future.

3. FUNDAMENTAL SHIFT AWAY FROM THE TRADITIONAL OODA PARADIGM

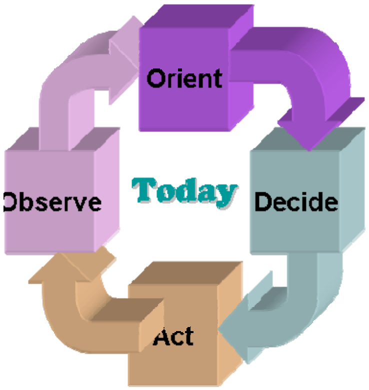

Figure 3: The OODA Loop

The OODA loop concept [21] was first introduced by Col John Boyd, U.S. Air Force fighter pilot ace, in 1986 in his presentation entitled "Patterns of Conflict" (POC). (See Figure 3) Since then there have been many variations of this process. The venerable Observe-Orient-Decide-Act (OODA) loop is no longer viable for an information-age military. Previous work has centered on speeding up the overall loop or developing technologies that work within a single phase of that loop. Today, when the plan goes awry, we go into a reactive mode, in which we create courses of action, analyze them, and then choose.

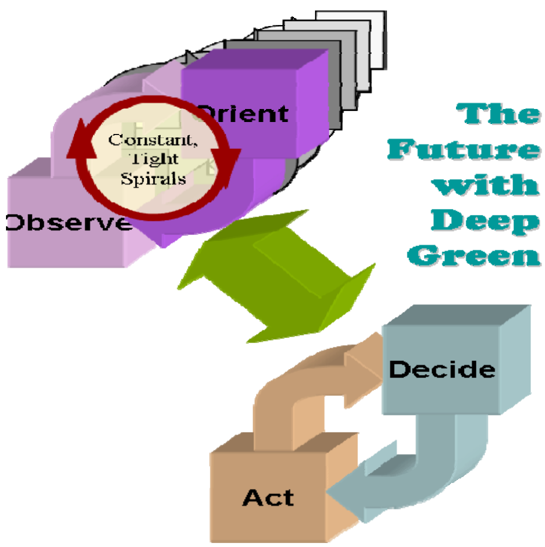

Figure 4: Multiple OO's, One DA Loop Processes

Deep Green creates a new OODA loop paradigm. (See Figure 4) Observe (execution monitoring) and Orient (options generation and analysis) phases run continuously and are constantly building options based on the current operation and making predictions as to the direction the operation is taking. When something occurs that requires the commander's attention or a decision, proactive options are immediately available. Ideally, the OO part of OODA is done many times prior to the time when the commander must decide. When the planning and execution monitoring components of Deep Green mature, the planning staff will be working with semi-automated tools to generate and analyze courses of action ahead of the operation while the command concentrates on the Decide phase. By focusing on creating options ahead of the real operation rather than repairing the plan, Deep Green will allow commanders to be proactive instead of reactive in dealing with the enemy.

4. SUMMARY

We are just getting started! Deep Green will provide technology to break the OODA paradigm. Deep Green enables the rapid construction of sophisticated planning and execution systems using existing technologies. The overall objective will be an open and scalable battle command decision support architecture that interleaves anticipatory planning and adaptive execution to stay inside the enemy's decision cycle. Deep Green will provide an implementation framework to enable rapid technology insertion into battle command systems today and in the future. When successful, we will build a revolutionary decision support system that will allow us to defeat peer competitors in the future. So long and thanks for all the fish.

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Biography

COL John R. Surdu, Ph.D., U.S. ARMY, Program Manager, DARPA Information Processing Technology Office. COL “Buck” Surdu was commissioned a second lieutenant of infantry after graduating from the United States Military Academy in (1985).

COL Surdu has worked as a research scientist and team leader at the Army Research Laboratory, focusing on unique uses for virtual reality technologies for command and control applications. As a senior research scientist at the Information Technology and Operations Center, he directed several applied research efforts. From 2003-2006 COL Surdu has been the Product Manager for the One SAF program office.

In addition to a Bachelor of Science degree in computer science from the United States Military Academy, in (1985) COL Surdu earned a Master of Business Administration degree from Columbus State University. In (1990), COL Surdu earned Master of Science degree in computer science from Florida State University (focusing on artificial intelligence in 1995). He finalized his formal education with a doctoral degree in computer science from Texas A&M University in (2000) (focusing on simulation technology and its applications to command and control).

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