A Constraint-Based System for Siting of Air Defense Missile Batteries

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Abstract

Determining optimum locations for a network of air defense missile batteries is currently a time-consuming, man-power intensive task that has to be frequently repeated whenever missiles are deployed to protect allied forces. This paper describes a constraint-based software system for automating the siting of Patriot missile batteries. Solutions are constrained by both probability-of-kill templates and by terrain related factors such as (1) requirements for road access to missile sites, (2) requirements on potential sites related to soil strength, flatness, minimum area, etc., and (3) line-of-sight requirements for both both communications and radar detection. The system combines a Geographic Information System (GIS) and the reasoning system HERMES (Heterogeneous Reasoning and Mediator System), which was developed at the University of Maryland. The GIS is used to screen terrain for potentially usable sites and HERMES is used to compute an optimized solution to siting a network of missile batteries. A route planner is used to plan routes from old sites to new redeployment sites. The system is being extended to also include HAWK missile batteries. This system will be part of a DIS (Distributive Interactive Simulation) system with both 2D and 3D visualizations.

1 Introduction

In a war-time situation, Patriot and Hawk missile batteries are used to protect the front line against enemy attack. If the batteries could simply be positioned and left in place for the duration of the war, then the task of manually siting these batteries would not be onerous. Unfortunately, this is normally not the case during a shooting war. On a battlefront, these weapons systems may be moved several times in one week and there must be several contingency sites available for each battery. In particular, Hawk batteries have strict requirements for locating sites with optimum line-of-sight visibility, and even with current computer-assisted planning systems, siting the batteries is a trial-and-error based, time-consuming task.

Patriot Missile Batteries can be used to defend against either air-breathing threats such as jet aircraft or cruise missiles or against ballistic missile threats such as the Scud missile. Deployment patterns for the two tasks are quite different. In this paper, only the air-breathing case is considered.

The task of siting Patriot and Hawk missile batteries is tremendously simplified by recognizing the existence of several hierarchies in the problem domain. Patriot missile batteries are high cost systems which must be deployed sparingly. They are designed to attack high-altitude targets while they are still remote from the defended targets. These targets are typically high priority assets (command headquarters, ammunition dumps,etc). The Hawk missiles are lower cost systems and are intended to provide area defense and fill in the gaps left after placement of the Patriots. In turn, the Vulcans are positioned to provide close-in defense of the Hawks. As an example, if the Hawks are on a mountain ridge, their radars have a limited capability to look at angles below the horizontal. Vulcans on mountain sides below the Hawk emplacement can be used to defend the Hawks. There is a three-level hierarchy:

1. The Patriot missile batteries are deployed to protect high priority assets without consideration of where Hawk batteries will be sited,
2. The area defense provided by the Hawk batteries is intended to ensure that there are no gaps through which enemy craft can fly without opposition and
3. The Vulcans are positioned to protect the Hawk batteries.

There is a second hierarchy which can be defined in terms of the grid size used to represent the terrain. Given a 100 km by 100 km area that must be defended and terrain data at 100m spacing, the area will be represented by a 1000 x 1000 data array. The 100m spacing is good enough to find *plausible* areas for siting batteries. The detailed analysis of a specific site involves at least 100 rules and the application of several templates and also necessitates a higher resolution grid. A 30m grid spacing is minimally adequate for the detailed analysis of a site. In a hierarchical system, a Knowledge Based System (`KBS`)can be used to delineate plausible candidate areas and a local area `KBS` would be used to find sites that meet the detailed requirements for siting a battery. As an example, such an area might contain 4km^2 while each battery site requires approximate 0.1 km^2. The local area `KBS` could then return a list of satisfactory sites or return nil if no good sites are found. If the local `KBS` fails to find a site, the global `KBS` presents an alternative area to the local `KBS`. This paper will only analyze the global `KBS`.

2 A Knowledge Based Solution

Recent advances have been made in (1) deductive database technology and (2) mediator frameworks[13] that can easily integrate both heterogeneous sources of data and software systems into a coherent whole. Use of HERMES [1, 8, 11] (HEterogeneous Reasoning and Mediator Environment System) will allow the answering of queries that require the interrogation of multiple databases in order to determine the optimum siting of a network of Patriot missile batteries.

The theoryon which HRMES was developed is based on the recent works in Constraint Logic Programming (CLP) by Jaffar and Lassez [6], in Non-monotonic Logic Programming (NMLP), and in Generalized Annotated Logic Programming (GAP) by Kifer and Subrahmanian [7]. Each of these developments allows us to represent and manipulate certain forms of automated reasoning that are critical in hybrid reasoning.

HERMES uses the Hybrid Knowledge Bases (`HKBs`) formalism proposed by Nerode and Subrahmanian that allows the clean integration of multiple paradigms for *representing*, *reasoning*, and manipulating diverse forms of knowledge and data. Lu, Nerode, Remmel and Subrahmanian [8] have developed the mathematical foundations of (`HKBs`), while Subrahmanian [10] has set out the basic ideas behind `HKBs`. In this paper, we report on an ongoing interaction[2, 3], which started in March

1992, that applies the theory and query processing algorithms associated with hybrid knowledge bases to the problem of missile deployment. In particular, we will show how the HKB framework may be used to naturally represent the problem of siting Patriot and Hawk missile batteries in order to protect assets located in a given theater of operations.

Wiederhold and his colleagues [12, 13, 14, 15] have proposed the important concept of a *mediator* between heterogeneous databases. Intuitively, a mediator is a program that accesses different data and knowledge representation paradigms and works with *existing* implementations of those paradigms. Mediators typically express methods to resolve conflicts, unify mismatches in measurement units (e.g. data expressed in centimeters and inches), and generate sophisticated conclusions based on information contained in a variety of data structures and data repositories. Till recently, mediators have primarily been developed on an ad-hoc basis, with large amounts of C-like code being written to implement them. Maintaining such software is almost impossible because reading any large body of C code is a formidable task. In this paper, we propose a formalism called *hybrid knowledge bases* (HKBs, for short) that has the capability of expressing and reasoning with a variety of information represented in various ways. The language of HKBs is completely declarative, and hence, maintaining and understanding the rules in an HKB is relatively easy. HKBs form a simple theoretical framework within which mediators can be expressed.

Before explaining how HKBs can be used to solve terrain reasoning problems, we briefly explain the syntax and semantics. The language in which the mediator is written is a simple rule-based language with certain specific constructs, and with a special compiler that can be used to implement these special constructs. A rule is a statement of the form.

$$\begin{aligned} A : [u_0, t_0] \quad \leftarrow \quad & \Xi_1 \,\&\, \ldots \,\&\, \Xi_k \mid\mid B_1 : [u_1, t_1] \,\&\, \ldots \,\&\, B_n : [u_n, t_n] \,\& \\ & \mathbf{not}(B_{n+1} : [u_{n+1}, t_{n+1}]) \,\&\, \ldots \,\&\, \mathbf{not}(B_{n+m} : [u_{n+m}, t_{n+m}]). \end{aligned}$$

where $A, B_1, \ldots, B_{n+m}$ are atoms ,in the sense of logic (cf. Shoenfield [9]), and $\Xi_1, \ldots, \Xi_k$ are constraints over domains $\Sigma_1, \ldots, \Sigma_k$, respectively. Ξ_k are constraints over domains $\Sigma_1, \ldots, \Sigma_k$, respectively.

The u's are either constants (real numbers between $[0, 1]$), or variables ranging over $[0, 1]$, or complex evaluable function terms that evaluate to values in $[0, 1]$. The t's are either sets of time points (non-negative integers), or variables ranging over sets of time points, or complex evaluable terms that evaluate to a set of time points. The above clause may be informally read as: "If each of the B_i's, $1 \leq i \leq n$, has certainty at least u_i at all time points in the set t_i, and, for each B_j, $(n+1) \leq j \leq (n+m)$, it is not provable that B_j has certainty at least u_j at all time points in the set t_j, and each of the Ξ_e's, $1 \leq e \leq k$, are solvable over their respective domains, Σ_e, then conclude that A has certainty at least u_0 at all time points in the set t_0." Examples of domains for Σ_e's include the real numbers with arbitrary linear and/or nonlinear functions and functionals, the domain of integers, the domain of quadtrees, the domain of binary trees having nodes possessing a certain structure, flat files, raster representations of maps, to name a few.

3 Missile Siting System

In this section, we present a description of our system for siting missile batteries. Figure 3.1 shows the data flow. Section 3.1 describes the required data, Section 3.2 discusses how we we determine the regions which meet minimal requirements for siting batteries, Section 3.3 describes how we narrow down possible sites to selected sites, Section 3.4 describes the algorithms used to optimize the movement from one network of batteries to a new network of batteries and Section 3.5 descibes our objective of being able to run a simulation of the the movements from the old sites to the new sites.

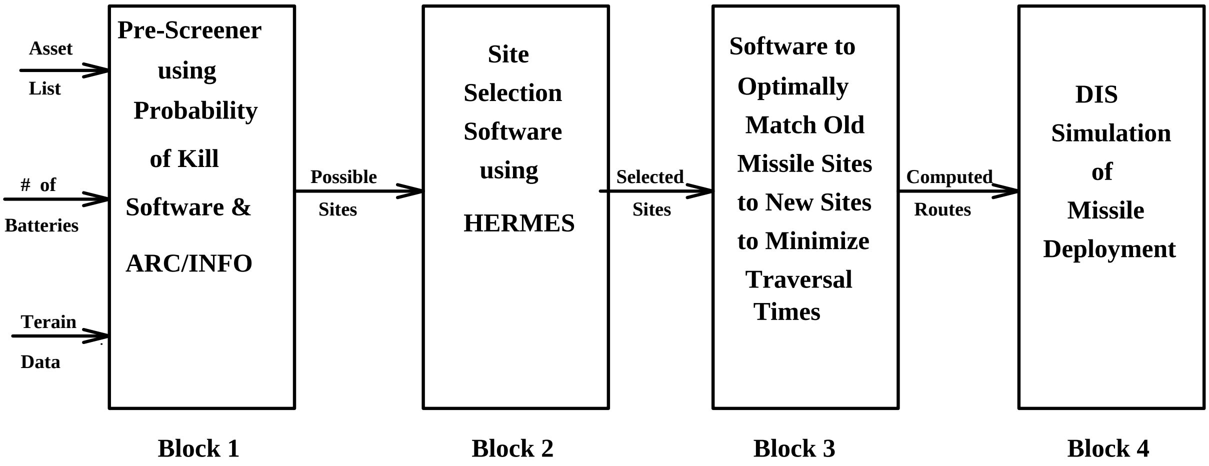

Figure 1: Data Flow For Siting of Air Defense Missile Batteries

3.1 Data

3.2 Pre-screening

3.3 Site Selection

3.4 Traversal Optimization

3.5 Simulation of Missile Deployment

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