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EXPERT REASONING WITHIN AN OBJECT-ORIENTED FRAMEWORK

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ABSTRACT

A large number of contaminated waste sites across the United States await site remediation efforts. These sites can be physically complex, composed of multiple, possibly interacting, contaminants distributed throughout one or more media. The Remedial Action Assessment System (RAAS) is being designed and developed to support decisions concerning the selection of remediation alternatives. The goal of this system is to broaden the consideration of remediation alternatives, while reducing the time and cost of making these considerations.

The Remedial Action Assessment System was designed and constructed using object-oriented techniques. It is a hybrid system which uses a combination of quantitative and qualitative reasoning to consider and suggest remediation alternatives. The reasoning process that drives this application is centered around an object-oriented organization of remediation technology information. This paper briefly describes the waste remediation problem and then discusses the information structure and organization RAAS utilizes to address it.

INTRODUCTION

Treatment of hazardous waste sites across the United States requires a long and costly commitment. The Remedial Action Assessment System (RAAS) was developed to provide timely and cost effective assistance to experts in choosing treatment technologies to apply to a waste site.

RAAS is a hybrid system designed and constructed using object-oriented tools and techniques. It is a hybrid system because it combines numerical computing (primarily quantitative models) with qualitative reasoning in the generation of its solutions.

PROBLEM DESCRIPTION

A large number of contaminated waste sites across the United States await treatment. Waste sites can be physically complex entities containing multiple, possibly interacting contaminants distributed throughout one or more media. The sites are generally dynamic, with contaminants moving through one or more potential escape paths. When a waste remediation technology is applied, it operates on the site through interaction with the physical characteristics of the medium and contaminant(s).

The overall goal in the application of technologies to a site is to remediate the site according to the requirements established by regulation or agreement. A string or sequence of technologies will be

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linked to accomplish this goal. The technologies are applied in linear sequence, but may interact in a complicated manner through their effects on site parameters.

In computational terms, there are two basic components -- site states and technology operators. The physical site or problem state is identified primarily by geometric dimensions, medium type, and a list of contaminants and relevant physical parameters. Each technology can be viewed as an operator which transforms the current site into a new site. The solution path is a series of operators which successfully transforms an initial site into a goal site.

CURRENT APPROACH

Currently, a professional or team of professionals is assigned the task of developing remediation strategies for each contaminated site. The magnitude of the information which must be considered is great. An expert capable of solving a wide range of remediation problems must be knowledgeable about hundreds of contaminants, scores of treatment technologies and several media types. Considering that new technologies or modifications to old technologies appear with relative frequency, the burden upon professionals in the area of waste remediation is substantial. Another and related difficulty with the current approach is that common or "comfortable" alternatives tend to inhibit the exploration of more innovative solutions.

RAAS APPROACH

The RAAS system implements four basic steps in its computational remediation of a contaminated site. These steps are listed as follows:

1. Receive initial site specification and user goals (goal site).
2. Derive an applicable technology list.
3. Modify site through selection and application of technology.
4. Compare modified site with goal site and return to step three if no match.

The first step is the specification of the site characteristics and the identification of user goals. This step requires the user to describe the site in terms of the media type, contaminants, and his treatment intentions (such as cleanup or containment). Entering this information defines the problem for the RAAS system. The second step, the derivation of an applicable technology list, involves querying a database to determine the technologies which are appropriate to the stated characteristics and goals. The computational use of a technology is the next step and involves the planned selection and application of the applicable technologies to the user specified site. Finally, step four tests the process for completeness (i.e. determines whether or not user goals have been met) and returns to step number three to apply another technology if necessary. Steps three and four are performed in the planner class which selects the technologies and measures their success against the specified user goals. Steps three and four are applied again and again until all viable treatment trains have been identified.

The object-oriented RAAS system defines a class structure to perform the previously defined four step process. There are two primary logical contributors to this object-oriented structure. The first is the physical process of site remediation which suggests such classes as the site, the technology, the contaminant, and the medium. The second logical contributor to the class structure is the decision process which describes the planning of the physical process. The RAAS class structure, a superimposition of both the physical and the decision process, is shown in figure 1. In the figure, the arrowed lines indicate message passing between class instances.

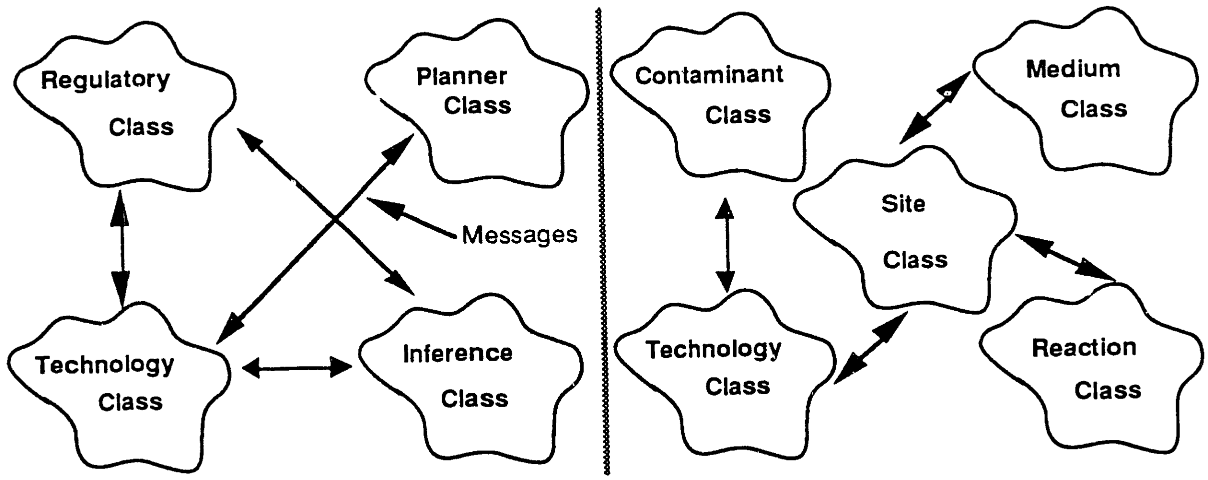

FIGURE 1.0 Decision and Physical Classes

The following paragraphs provide a detailed description of the four main steps listed previously and the object structure which implements them.

SITE CHARACTERIZATION

A RAAS user will characterize the site as his initial step in the use of the application. A site is characterized by the selection of a contaminated medium, and a list of contaminants. In addition to the medium and constituents, the user must specify treatment goals. Treatment goals in reality are dictated by a host of regulations which are accessible to the RAAS user for perusal. The user is allowed to select cleanup levels directly from the relevant regulations or choose his own treatment goals independent of the regulations.

The newly characterized site, the initial site, is the first state from which all solutions will stem. This site and all sites generated are instances of the site class. The site class creates instances which are used as interim solutions during the search for viable treatment alternatives. As each technology is applied to a specific site instance, the values of the data items of that site change depending on the effects of the technology, and on the unique combination of technologies which have been applied before. For example, hydraulic conductivity, which is one of the parameters of a soil medium, is a measure of how easily water may move through soil. The initial site specified by the user contains the beginning value for hydraulic conductivity. In-situ vitrification, a treatment technology which "glassifies" the soil by sending a very strong current between two electrodes, may have a dramatic effect on hydraulic conductivity, in effect zeroing out the parameter. Any technology applied after the in situ vitrification process will have to operate on a site with a very low hydraulic conductivity. It is the role of a site object to keep current parameter values, as well as contaminant concentrations and containment levels, and location of medium (in situ or ex situ).

SELECTION OF APPLICABLE TECHNOLOGIES

After the site has been characterized, a list of applicable technologies must be generated from a query to a database which contains information about 10 media types, 399 unique contaminants, and approximately 90 treatment technologies. The applicable technologies will be used as the building blocks for the sequences of treatment trains. The applicability of a technology at this point in time is a static database entry which actually represents the general conclusion that there is at least one circumstance when the technology of interest will be effective on a particular set of contaminants located within a particular medium to accomplish a selected goal.

APPLICATION OF A TECHNOLOGY

The technology class is the foundation of RAAS. The instances of the class, the individual treatment technologies, are hybrid decision makers, utilizing numerical models as well as expert rules of thumb to arrive at decisions about their own usage. The application of a technology to a site is performed in two phases: the first is a qualitative evaluation of relevant parameters and the second a numerical estimate of how the relevant parameters are altered numerically by the technology. After the qualitative reasoning has been applied, the quantitative models within the technologies are engaged to alter site parameter values accordingly. The numerical effect of a technology depends on the specific technology chosen and the specific site to which it is applied. Figure 2.0 displays the step-by-step process of applying a technology.

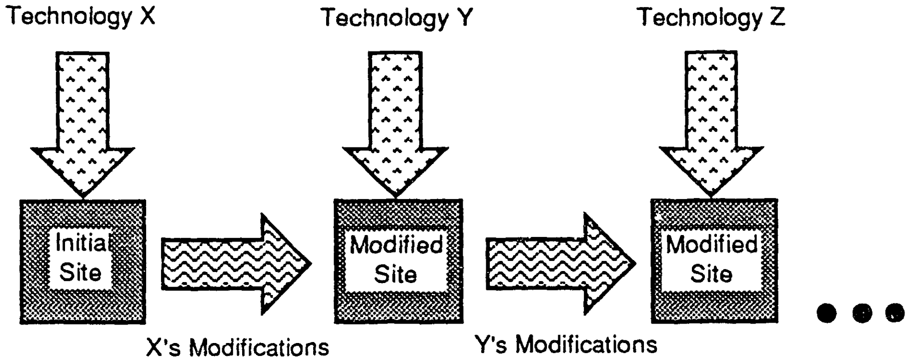

FIGURE 2.0 Application of Technologies to Changing Sites.

There are several general effects a technology might have upon a site in our model of technology operation. Each of these effects gives rise to a subclass of the main technology class in our object-oriented design. RAAS has seven different types of technology operators shown in figure 3.

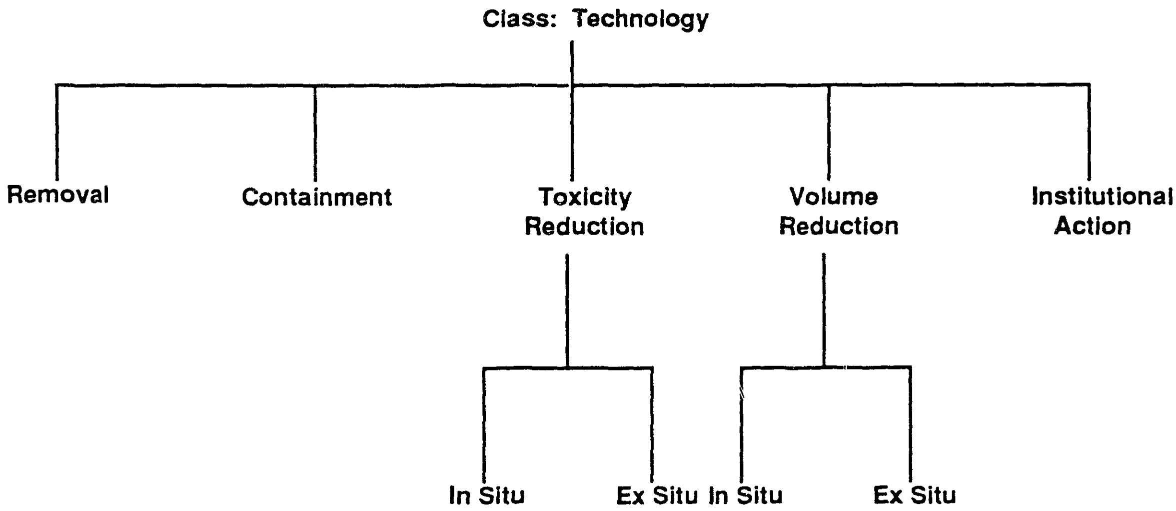

FIGURE 3.0 Treatment Types

The classes above generate site effects reminiscent of their names. For example, the removal technology class listed above might reduce the level of contaminants in a hot cell, thereby reducing the danger of contamination. Other classes perform other necessary remedial functions, and they numerically alter the site object according to the nature of this function.

The nature of qualitative decision making within the technologies consists of two rule types. The first rule type describes disabling conditions. Any number of disabling conditions may exist at a site which prevent the application of individual technologies. Individual site characteristics or combinations of site characteristics may establish such unfavorable conditions. If the inferencing of the technology deems this to be the case, the technology disqualifies itself or seeks help from other technologies to alter the constraining characteristics. The second rule type is functional permitting or promoting the operation of the technology on the site.

Primarily, the qualitative rules will inhibit technologies from being applied because one or more parameters have exceeded an operational range. For example, the utilization of the technology ex-situ bio-treatment is partially dependent on the moisture content of the soil. If the moisture content is above or below the active range of this parameter, the technology is disqualified. The rules that the technology utilizes are similar to the rules a technology expert would use to make the decision, and the single outcome of the inferencing is a decision to apply the technology or not.

During the application of the individual technologies, the technology instances will often need additional information and calculations from other classes. Among the classes which may be called to supply additional data are the contaminants class and the reaction class.

PLANNING TREATMENT TRAINS

This section discusses the coordination of individual technology decisions into a global solution. A global solution must address the global goal of site remediation as specified by the user of the system, and therefore requires a decision strategy which uses the individual technologies as pieces in the solution. Three major complications - the decomposition of user defined goals into a series of subgoals, the subsearches for support technologies, and the construction of associated problems through alternate contaminant pathways - arise in the depth first search for a complete list of technology alternatives.

It is the duty of the RAAS planner class to specify the control of treatment train development. A remediation alternative or sequence specifies a complete solution. If the user has decided that the goal is to restrict access to the area, then a single technology such as fencing is appropriate. However, the goal of the user may be much more complicated, such as the collection, treatment, and disposal of the multiple contaminants, each to a different level, depending on its long term risk to the neighboring community. Whatever the defined goal, the search through technology objects within the RAAS application will attempt to yield the treatment alternative to satisfy it. Figure 4 illustrates the search with links as technologies and site states as nodes. Darkened nodes represents altered sites due to the successful application of a technology.

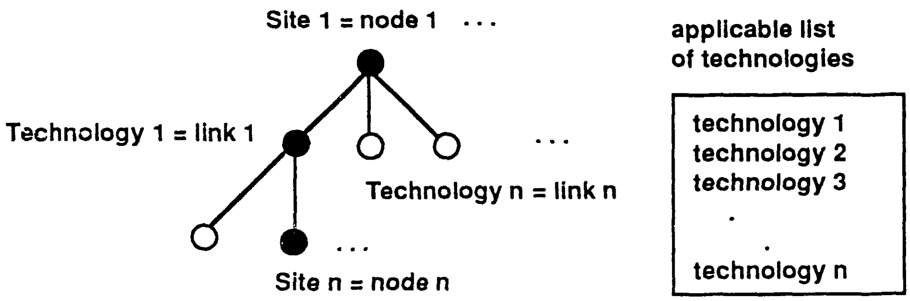

FIGURE 4.0 Search for Solutions

The active search for combinations of technologies which satisfy user goals at a site is a numerically driven depth first search that uncovers nonmonotonic paths of reasoning from the initial site state to the goal state. The reasoning is nonmonotonic because the application of technologies is not based solely on whether the remediation technology addresses the goal of the site (such as contaminant removal), but is based instead on whether the technology has any effect at all on site parameters. Therefore, a technology can actually worsen the conditions at a site and still be included as an effective technology because of its potential side effects.

An important concern is the necessity to include all constraints satisfying solutions to a problem. Many paths lead belatedly to dead ends, but the extra search, unchecked by heuristics, is necessary because one of the primary objectives of the search is to discover unusual alternatives that could easily be overlooked by professionals who may look only for the more standard solutions.

CONCLUSION

RAAS was funded to assist in the costly process of specifying treatment alternatives for remediation of hazardous waste sites across the United States. RAAS is a true object-oriented application which relies on the close cooperation between coarse numerical models of the physical process and rule-based or qualitative models of expert decision making. It utilizes the strengths of object-oriented analysis and object-oriented design in the modelling process. This methodology has at least two primary benefits. First, the creation of multiple expert objects provides a more direct mapping from the actual process to a software system, making the system easier to build. Second, the distribution for the inferencing among a number of loosely connected expert objects allows for a more robust and maintainable final product. It is also anticipated that other advantages of object-oriented systems, namely maintainability and extendibility, will be important to future versions of the RAAS product.

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