**Calculation of Monte Carlo Importance
Functions for Use in Nuclear-Well Logging Calculations***

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Importance sampling is essential to the timely solution of Monte Carlo nuclear-logging computer simulations. Achieving minimum variance (maximum precision) of a response in minimum computation time is one criteria for the choice of an importance function. Various methods for calculating importance functions will be presented, new methods investigated, and comparisons with porosity and density tools will be shown.

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Introduction

Variance-reduction or biasing techniques are required in Monte Carlo calculations to reduce the computational time required to obtain results of sufficient precision. There are many Monte Carlo biasing techniques that require approximate importance information. Similarly, there are a number of Monte Carlo techniques that can be used to provide importance/biasing information. Monte Carlo importance generators often produce poor estimates in regions of poor sampling or in regions of low importance. Two newly developed techniques, a quasi-deterministic¹ and an integral transport² solution, are investigated as alternatives to stochastically generated importance functions.

Discussion

The efficiency of a Monte Carlo calculation is affected by the type of tally and the random walk sampling. The tally choice tries to obtain the best results from the random walks sampled. Random walk sampling amounts to preferentially sampling important random walks at the expense of unimportant random walks. Analog Monte Carlo simply samples events according to their natural physical probabilities. Analog calculations estimate the number of physical particles executing any given random walk. Nonanalog techniques do not directly simulate natural physical probabilities. Nonanalog techniques are free to do anything as long as the particle density is preserved. Preservation is accomplished by adjusting the weight of the particles. There are three basic types of nonanalog games: (1) splitting, (2) Russian roulette, and (3) sampling from nonanalog probability density functions.

Successful use of variance reduction techniques is often more art than science. After the techniques are selected, the user has to supply parameters. Parameter choices are important since the user is trying to minimize the product of the variance and the computer time usage. Parameters are chosen based on experience from similar problems, guessing, or generation. One widely used method is the importance generator³. Although this generator has been successful in many logging problems, it is a statistical method that can produce poor or no estimates in regions of poor sampling or low importance. Failure results when very few particles enter a region, and when even fewer of the entering particles subsequently score.

The quasi-deterministic method attacks these deficiencies by sourcing particles into all regions and only requiring a particle undergo one step in the transport process

before making an estimate of the particle's average score. The integral transport method calculates the multigroup adjoint fluxes based on a diffusion approximation to the integral transport method. Both methods provide a deterministic calculation of importance functions in complex geometries. The value of these techniques is that some of the "art" is removed from variance reduction and the user interface is significantly simplified.

Using the neutron benchmark porosity tool proposed by Gardner⁴, several calculations were performed for a 20 porosity unit limestone formation using the MCNP code⁵. (Similar calculations have been performed for a gamma-ray density tool.) Table 1 illustrates the calculational efficiency, on a Cray X/MP for both the near and the far detector.

Table 1
FOM for Various Variance Reduction Techniques
($FOM = 1/(\text{relative error}^2 \cdot \text{cpu time})$)

Case	Model	FOM	Description
1	Implicit	0.2	All importances 1
2	Wgt Window	0.9	Starting with unity importances
3	Int. Trans	10	1431 cells, 9 neutron groups
4	Wgt Window	18	Initialize with Case 3 parameters (two separate runs)
5	Wgt Window	12	Initialize with Case 3 parameters both detectors
6	Quasi-deter	9	Optimize for near detector

The problem is difficult because: there is considerable neutron thermalization; the near and far detectors are 30cm apart; and a low variance response is sought at each detector. Optimization of the near detector response causes the far detector response to suffer and vice versa. Cases 2, 4, and 5 require considerable user intervention, whereas 3 and 6 do not. Case 1 places all spatial cells in the problem at unity, which is a reasonable starting point for generation. Next, weight windows are generated starting with all cells having importance of 1. In most cases, a user would "bootstrap" case 2 to a level where the FOM was reasonable. Case 4 illustrates optimizing the near and far detector, making two (2) calculations, and combining the results. Finally, case 5 is an attempt at a near/far optimization by forcing a percentage of the neutrons to both the near and far detector during the generation stage.

Conclusion

The quasi-deterministic and integral transport methods have advantages over current stochastic methods. With both methods there is no problem getting particles into every region because they are either sourced in or determined from an adjoint solution. Each method provides importance estimates which yield calculational efficiency greater than stochastic methods. Also, the user is relieved of having to choose initial biasing and of adjusting the function in the poor statistics regions for stochastic generators.

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