Variance Reduction in Monte Carlo $k_{\text{eff}}$ calculations: state-of-play

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New Method to Use Variance Reduction within Monte Carlo Eigenvalue Calculations

OPTIMIZING VARIANCE REDUCTION IN MONTE CARLO EIGENVALUE CALCULATIONS THAT EMPLOY THE SOURCE ITERATION APPROACH

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ABSTRACT

The question of variance reduction within the source–iteration scheme of a Monte Carlo eigenvalue calculation is tackled. The trade–off point between improving the statistics of a local response and simultaneously not damaging the fundamental mode, the source for the calculation of the local response in the next fission cycle, is found. It is realized that applying less normalizations, i.e. employing superhistories, is advantageous. Realistic test problems, both fast and thermal fission, with in– and ex–core local responses, are treated. There is a good agreement between the predicted and actual gain in efficiency. A single comparison with the classic formalism, based purely on $\Phi^2$, shows large differences.

(submitted to Annals of Nuclear Energy; Sept. 2013)
Since then:


K.W. Burn, “Estimating Local In- and Ex-Core Responses within Monte Carlo Source Iteration Eigenvalue Calculations”, Proc. of PHYSOR-2014 (Oct. 2014) and JAERI-Conf 2014-003


K.W. Burn, P. Console Camprini, “Radiation transport out from the reactor core: to decouple or not to decouple?”, to be submitted to ICRS-13, Paris, Sept. 2016

Other relevant references:


Three types of problem:

1. “Local” response(s) within or outside criticality safety configurations.
2. “Local” response(s) within a reactor core.
3. “Local” response(s) outside a reactor core.

We took our innovative variance reduction tool (*), developed up to that point for fixed source problems (**), and modified it for the source-iteration scheme.

So far we have tested it on reactor in- and ex-core problems. We are just beginning to test it on criticality safety problems.

(*) The DSA (Direct Statistical Approach): optimizes splitting / Russian roulette parameters at phase space surfaces, independent of, or dependent on, the weight of the progenitor. It is 2\textsuperscript{nd} moment-based.

1. “Local” response(s) within or outside a criticality safety configuration:
2. “Local” response(s) within a reactor core:
3. “Local” response(s) outside a reactor core:
How is the DSA applied to eigenvalue calculations?

We are dealing with the source-iteration approach: at the end of each normalization cycle (usually the same as a fission cycle), we renormalize the fission source. This cancels any effect brought about by variance reduction.

Anyway, if VR is applied, then we shall be distorting the fundamental mode and there will be a trade-off between such distortion (minimize it) and the tracks at the local detector (maximize them).

→ Firstly treat it is a multi-response problem: the local detector(s) + a sufficient number of spatial bins to mock-up the fundamental mode (as the fundamental mode is the source for the next cycle).

→ Secondly treat it like a fixed source problem and assume each cycle is independent.
A cycle: we mean between fission source normalizations.

→ Usually a cycle is a fission generation.

We should like to give the neutrons more “time” to get to the local detector before we renormalize the fission source.

→ Renormalize every $n$ fission generations: superhistories (*)

→ Allow to vary the VR parameters according to the fission generation within the superhistory.

The rest is as for fixed source problems, including the necessary approximations to estimate a reasonable 2\textsuperscript{nd} moment function (the “EPS” algorithm).

It is interesting to note that with superhistories, there are many volumetric branchings (in-superhistory fissions). These give a substantial contribution to the 2\textsuperscript{nd} moment (and are taken into account).

That is the DSA for source-iteration eigenvalue problems (*),(**),(***).

Does it work?

It has been tested so far on some PWR and LFR in-core and PWR ex-core problems:


(**) K.W. Burn, “Estimating Local In- and Ex-Core Responses within Monte Carlo Source Iteration Eigenvalue Calculations”, Proc. of PHYSOR-2014 (Oct. 2014) and JAERI-Conf 2014-003

• There is a good agreement between the functional value and direct estimate of the 2\textsuperscript{nd} moment for in-core problems, as expected.

• The agreement is less good for ex-core problems, as expected.

• Allowing a number of fission generations between normalizations of the fission source (i.e. superhistories) allows a greater skewing of the track population to calculate a local in-core detector, compared with a single fission generation.

• However if VR parameters are employed that are independent of the fission generation, variance is introduced between fission generations.

• Allowing the VR parameters to vary according to the fission generation (or group of fission generations), as well as reducing the above variance by softening the RR between generations, allows the neutron population to be fitted better to the local detector at later fission generations within the superhistory.

• However allowing such dependence of the VR parameters on the fission generation yields an increase in efficiency of only around 2 for an in-core local detector. This factor looked surprisingly problem-independent. Instead it was much less than 2 for ex-core detectors, as expected, because transport between fission sites counts little (fission in the external pins of the outer assemblies gives the main contribution).
• For a large PWR problem with ex-core local detectors, it was found that whilst the DSA calculated well the ex-core detectors, there was too much axial fluctuation in the fundamental mode (see next slide).

• The problem of stability of the fundamental mode is state-of-the art. (There is no reason to expect that it will not occur for in-core local responses or for criticality safety problems with in- or ex-core responses.)
One standard deviation error bars are reported but are virtually invisible. It looks as if the fundamental mode is distorted in the VR case.
Results of the axial profiles of the core leakage neutron flux with variance reduction directed at an ex-core neutron detector in the pressure vessel well, employing a superhistory of 1 fission generation and (separately) of 10 fission generations, show that in both DSA cases the fundamental mode is fluctuating too much.

1. Such fluctuations mask the effect that we are looking for (the approximations intrinsic to the normal decoupled case).

2. Such fluctuations, having a large wavelength, are often not apparent in the statistical error.

This is where we are now.
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