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Variance Reduction of Monte Carlo Simulation in Nuclear Medicine

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Purpose

A method, which has had a great impact in many different fields of computational science, is called "Monte Carlo". The range of Monte Carlo application is enormous, from the Nuclear medicine, Radiation therapy, Reactor design, Quantum chromo dynamics to Traffic flow and econometrics. One of the difficulties associated with Monte Carlo simulations is the amount of computer time required to obtain results with high precision. To shorten the calculation time and also improve the efficiency, there comes the idea to use the variance reduction techniques.

Method

There are many ways in which a user can improve the precision of a Monte Carlo simulation. These ways known as Variance Reduction techniques. Several of the more widely used variance reduction techniques are summarized as follow:

Splitting/Roulette: In these techniques each region is classified as important and unimportant. If the selected region is unimportant the Russian roulette has been used and in contrary if the important region is selected Splitting is used. The main goal of this technique is to spend more time sampling important spatial cells, and less time sampling unimportant spatial cells.

Energy/ Time cut off: Particles whose energy is out of the range of interest are terminated so that computation time is not spent following them. There are two criteria that should be considered in the simulations for selecting E*cut*: (a) the mean free path (MFP) of photons with energy equal or less than E*cut* should be small in compared with the voxel sizes or (b) the energy fraction carried by photons with energy less than E*cut* is negligible compared with the energy fraction deposited. Time cutoff is Like the energy cutoff but based on time.

Weight window technique/weight window generator: this technique combines Russian roulette and splitting

Implicit capture: When a particle collides, there is a probability that it is absorbed by the nucleus. In analog absorption, the particle is killed with that probability. In implicit absorption, also known as implicit capture or survival biasing, the particle is never killed by absorption; instead, its weight is reduced by the absorption probability at each collision. The implicit capture technique involves launching and tracing packets of particles instead of one by one. At launch, each packet is assigned an initial weight w_0. The packet is traced with a step length distribution determined by the total attenuation coefficient, δ. This technique ensures that a particle always survives a collision It means when a particle reaches the vicinity of the tally region is not absorbed just before a score is made.

Forced collisions: The forced collision method is a variance reduction scheme that increases sampling of collisions in specified regions

Exponential transformation: The exponential transform also called path length stretching is a variance reduction technique designed to enhance efficiency for deep penetration problems or surface problems. It is often used for neutron Monte Carlo simulation and is directly applicable to photons as well.

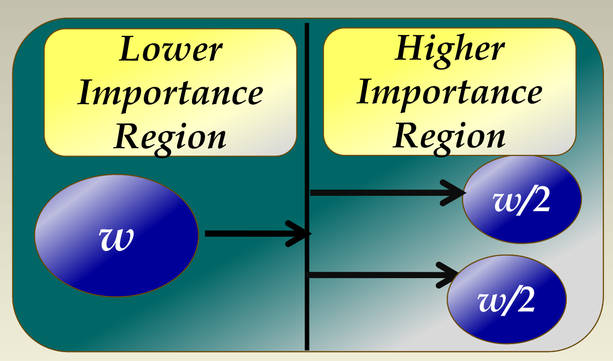

Fig. 1. **The Splitting process**

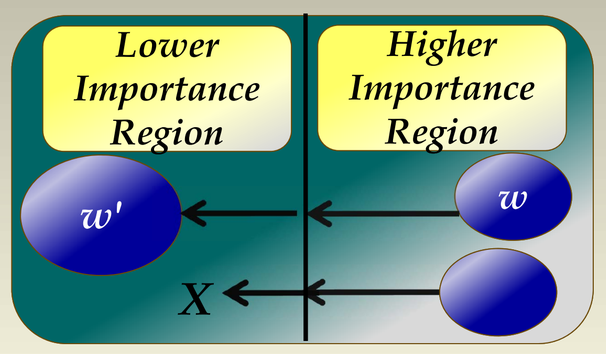

Fig. 2. **The Russian Roulette process**

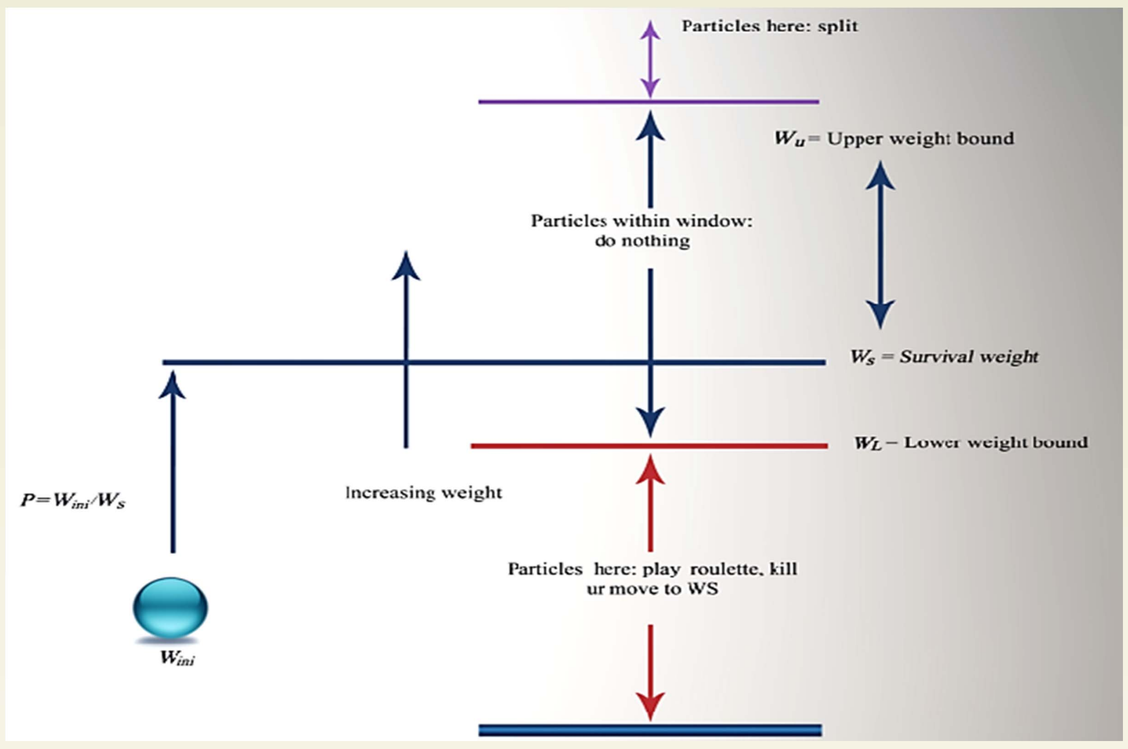

Fig.3. **Schematic of the weight window technique**

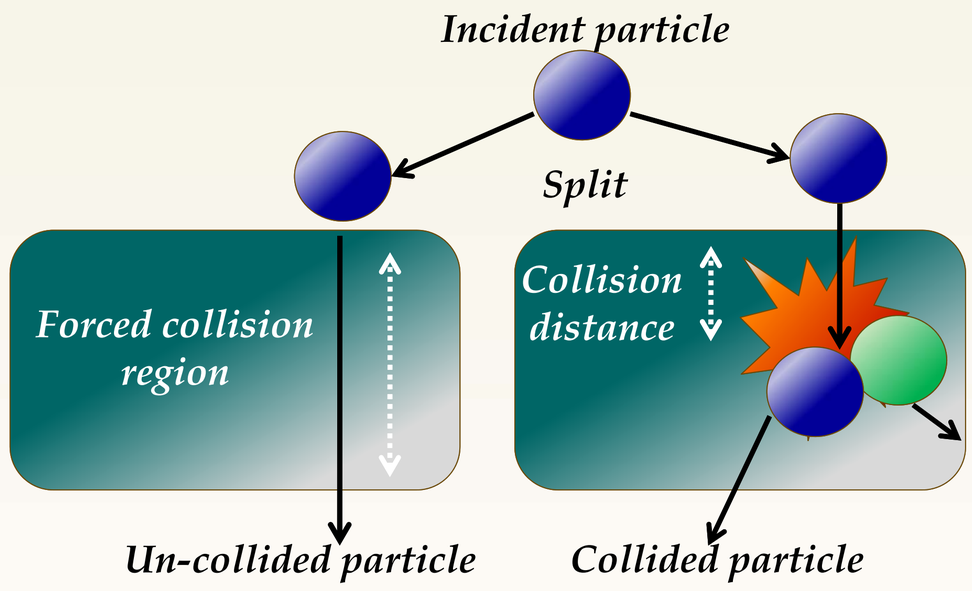

Fig. 4. **Schematic diagram of the forced collision**

Results

In *Splitting/ Russian roulette* technique each region is classified as important and unimportant. If the selected region is unimportant the Russian roulette has been used and in contrary if the important region is selected Splitting is used. The main goal of this technique is to spend more time sampling important spatial cells, and less time sampling unimportant spatial cells. The *energy/ time cutoff* are similar but more caution is needed in energy cut off because low energy particles can produce high energy particles. The *weight window* technique is space energy dependent and can control weight fluctuation by define upper and lower energy bounds. Weight window technique is used to avoid following very low weight particles which causes reasonable computer timer during the simulation. The main advantage of *implicit capture* is that a particle always survives a collision. It means when a particle reaches the vicinity of the tally region is not absorbed just before a score is made. The *exponential transformation* is designed to enhance efficiency for deep penetration problems, but it should be noted that due to the large weight fluctuation that can be produced by this technique, it should be used accompanied by weight controls.