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Importance Sampling

(geometrical splitting and Russian roulette)

M. Dressel

IT-API

CERN

Outline

- Introduction
- Example problem of importance sampling
- Concept of importance sampling
- Implementation aspects
- Scoring
- Summary
- Documentation
- Appendix: importance algorithm

introduction

- Variance reduction techniques like "Importance sampling" have been developed to reduce computing time by increasing the efficiency of MC calculations.
- typical or potential users areas of variance reduction:
  - radiation characteristics: LHC detector, space ships, underground experiments
  - deep penetration: shielding, underground experiments
  - dosimetry
  - background: hit rate, occupancy, important damage contributions from tails
  - accelerator studies: radiation environment, beam loss

General v.r. aspects

- Common concept:
  - introduce a statistical particle weight W
  - sample interesting "events" more often than others $\rightarrow$ produces a bias with respect to the physics simulated
  - correct for the change in sampling by adjusting the particle weight W
  - all estimators have to take the weight into account!
- Comparing analog to variance reduced MC for equal computing time:
  - $\overline{x}$: equal (mean value)
  - $v_{\overline{x}}$: reduced (variance of mean value)

figure of merit

A measure of efficiency of the calculation is the figure of merit:

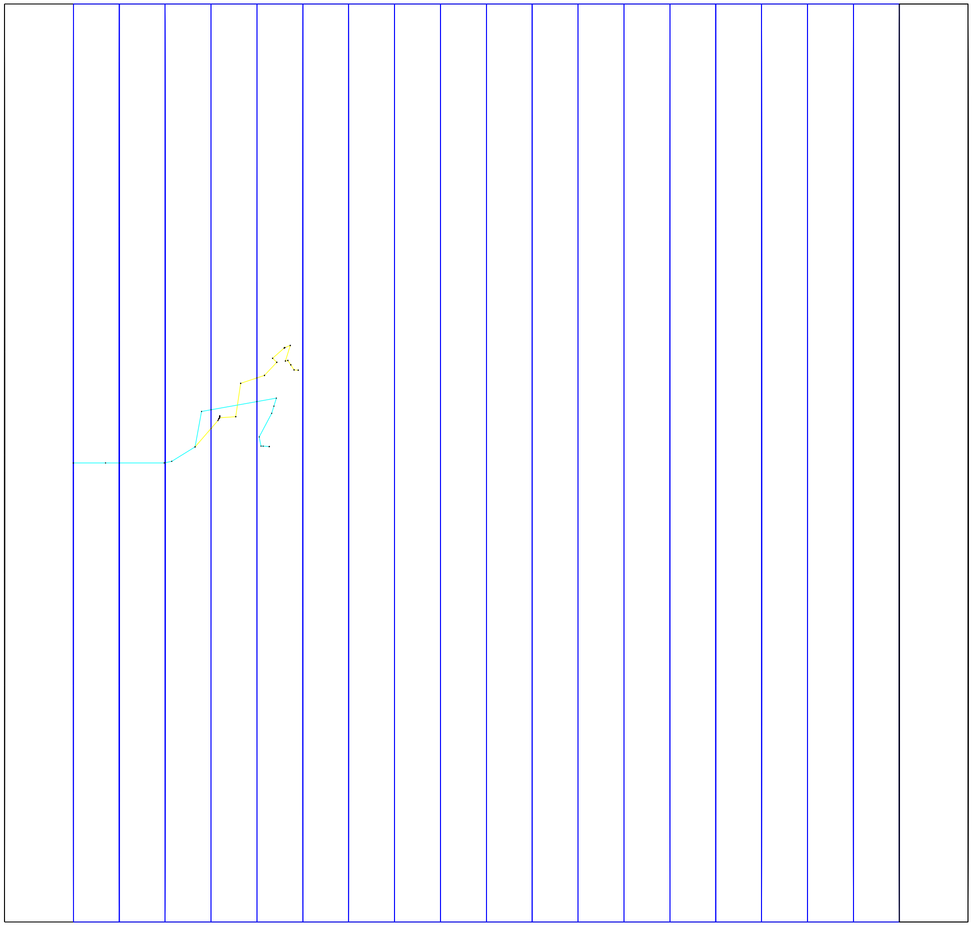
$$FOM = \frac{1}{R^2 T}$$

- $R = \frac{\sigma}{\overline{x}\sqrt{N}}$
  $\overline{x}$ = mean value, σ = standard deviation, N = number of measurements
- T = computing time
- The FOM will be compared to the analogue calculation.
- The larger the FOM the better.

Importance sampling motivation

- a prime example application for importance sampling is: shielding against neutrons of a few MeV energy
- example exercise: interrogate on neutron related quantities behind a thick concrete shield:
  - 180 cm thick concrete cylinder with radius 100 cm
  - 10 MeV neutrons entering along the cylinder axis
  - estimate neutron energy "cell flux" in the last 10 cm

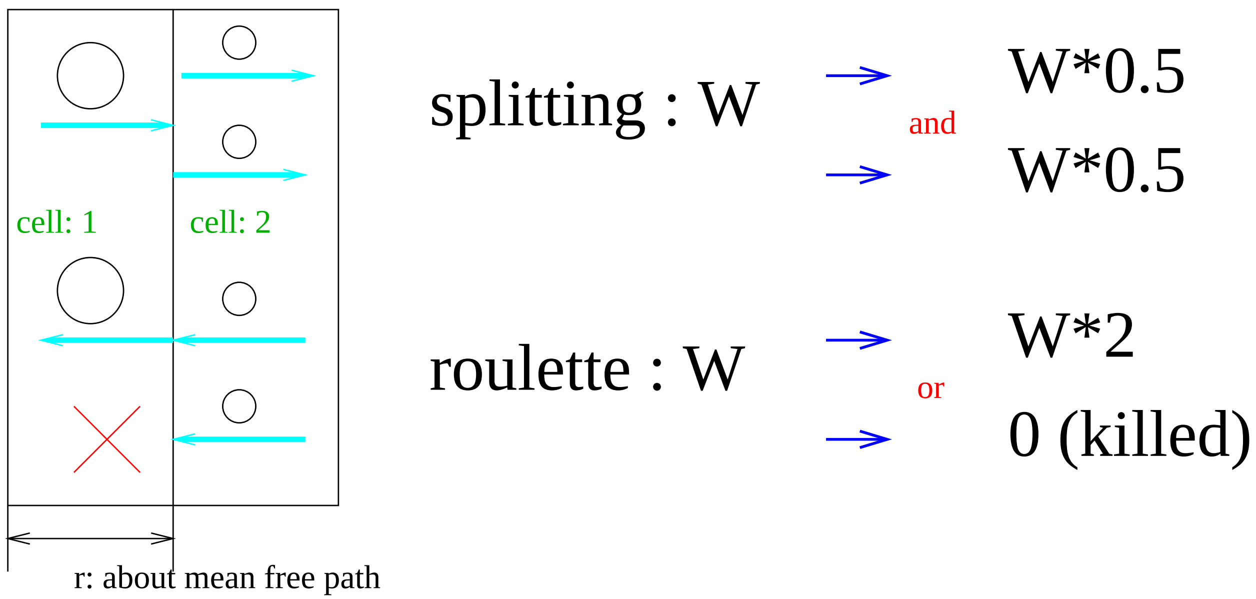
Analogue simulation



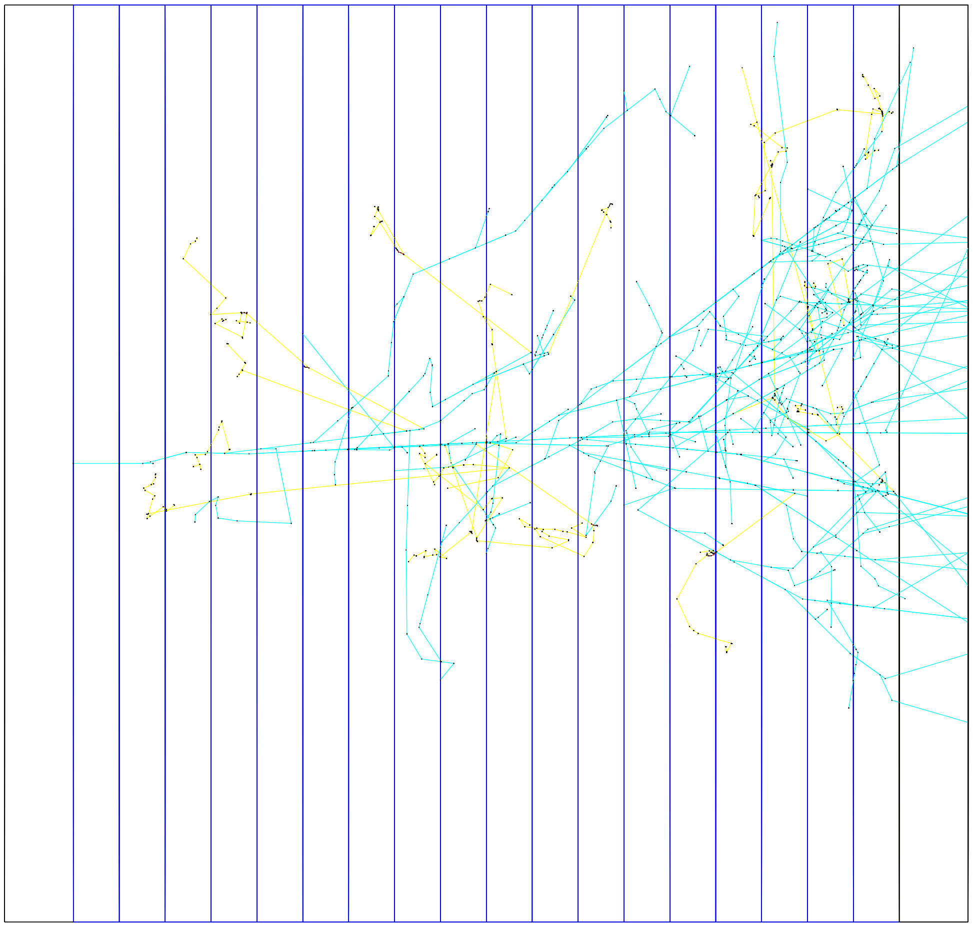
imp. samp. concept

- example with two cells with importance values $I_1 = 1$ and $I_2 = 2$

example: two cells with $I_2 = 2*I_1$



Importance sampled



Example energy flux

Φ_E the energy flux per starting neutron:

- flux: $\Phi(\vec{r}, E, t) = vN(\vec{r}, E, t)$
  v = velocity, N = particle density = $\frac{\textit{particle weight}}{\textit{unit volume}}$
- integrated: $\int \int \int \Phi(\vec{r}, E, t) dE dt \frac{dV}{V}$ using $ds = v\, dt$
- $\int \int \int N(\vec{r}, E, t) ds dE \frac{dV}{V} = WT_l/V$ (track length estimator for flux)
  W = particle weight, T_l = track length, V = volume

Φ_E is estimated by $\sum E * WT_l/V$ per starting neutron

Result energy flux

- equal amount of computing time

Analogue calculation:

$\Phi_E = 1.52 \times 10^{-8} MeV/cm^2,\ R_a = 0.24,\ FOM_a = 18$

Importance sampled calculation:

$\Phi_E = 1.37 \times 10^{-8} MeV/cm^2,\ R_i = 0.016,\ FOM_i = 4033$

Interpretation of normalized FOM:

Time to run analog calculation to have $R_a = R_i$:

$T_a = \frac{FOM_i}{FOM_a} * T_i = 224 * T_i$

Analog calculation would have to be repeated 224 times!

Note: "R's" are statistical errors, related to precision not to accuracy!

Implementation basics

General: Importance sampling:

- is done particle type wise.
- is only supported for field free applications and neutral particles.

Geometries

Definition of cells:

- cells are physical volumes or simple replicas identified by *G4GeometryCell*

Two kinds of geometries may be used to define cells:

- The mass geometry used for tracking (normal geometry).
- A parallel geometry to be designed by the user for importance sampling.
- The *G4GeometryCell* and importance value pairs are stored in a importance store (*G4VIStore*, *G4IStore*).

The user has to assign importance values to all cells of the geometry.

Multiple particle types

Sampling multiple particle types:

- A geometry may be used to importance sample one or more particle types.
- And multiple parallel geometries may be used for different particle types.

Scoring

The scoring of some quantities helpful to check the importance sampling is supported. The scoring:

- may be particle type specific or it may integrate over several particle types.
- is related to the cells described above.
- may also apply to the mass or parallel geometries.
- may also be used without importance sampling.

Summary

- importance sampling and scoring updated for version 5.0
- mass and parallel geometry supported
- large performance improvement for neutron shielding to be expected

Other variance reduction techniques:

- weight roulette and implicit capture (prototypes for both exist)
- weight window biasing (has been looked into)

Documentation

For Geant4 version 5.0

- Slides:
  http://dressel.home.cern.ch/dressel/biasscore/u02.pdf

- Description under development:
  http://dressel.home.cern.ch/dressel/biasscore/Sampling.html
  (will move to Geant4 home page with releasing version 5.0)

- Examples: "$G4INSTALL/examples/extended/biasing"

Appendix: Imp. samp. algorithm

- The use of customized algorithms is supported.
  - A customized algorithm derives from *G4VImportanceAlgorithm*
- A default algorithm is implemented in *G4ImportanceAlgorithm*

Default algorithm

- divide geometry into cells
- assign importance values to the cells
- when crossing from cell m to cell n: $r = I_n/I_m$
  1. if $r = 1$: continue transport
  2. if $r < 1$: play Russian roulette
  3. if $r > 1$: split into r tracks
- real numbers possible for importance values:
  change in $r > 1$: two values for number of particles after splitting:
  - $int(r) + 1$ particles with probability $p = r - int(r)$
  - $int(r)$ particles with probability $1 - p$
- particle weight $W \rightarrow W/r$ "expected value splitting"