Machine Learning for acceleration of Monte Carlo transport

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What is Nuclear Engineering Monte Carlo Neutral Particle Transport?

Nuclear engineers are interested in how neutrons transport in some materials. Monte Carlo simulation is a stochastic method invented to simulate neutron transport.

Possible interesting events for neutrons:

- Elastic Scattering (neutron loses energy, changes angle)
- Inelastic Scattering (kinetic energy not conserved)
- (n, γ) reaction, emits a photon
- (n, 2n) reaction, kicks out 2 neutrons
- Fission

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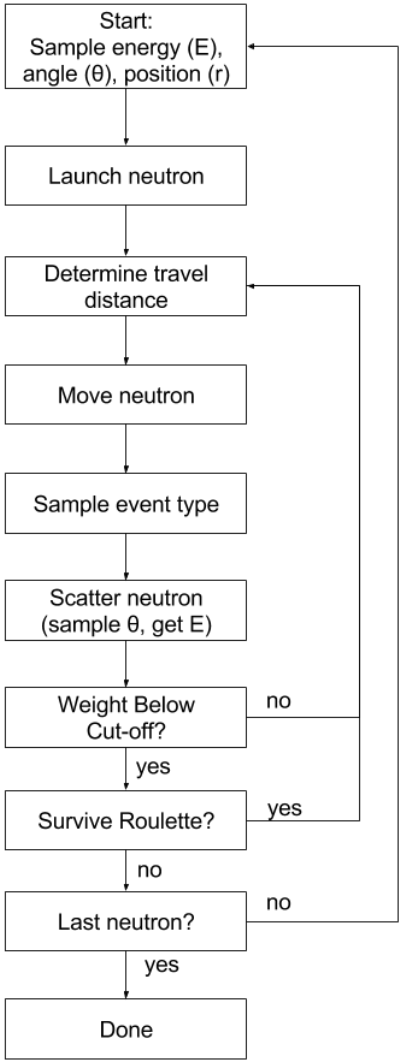
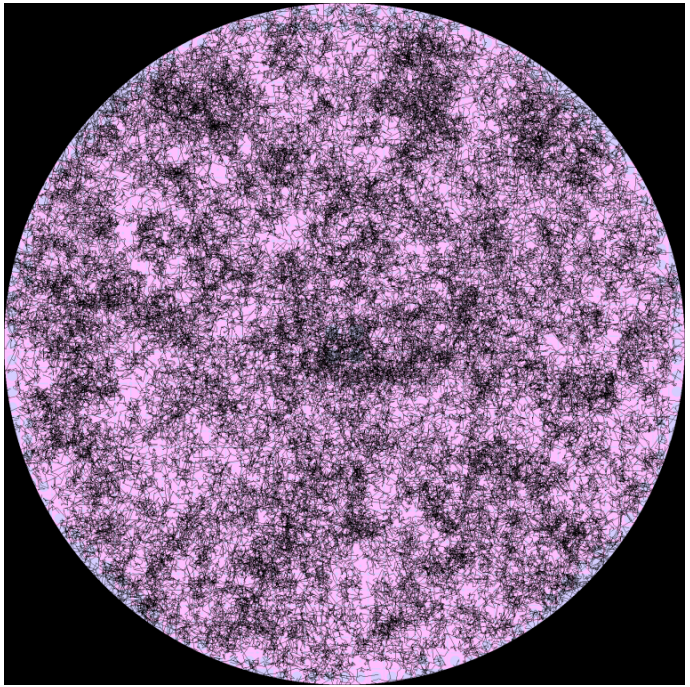


Procedure

Run histories for each neutron

1. Sample Neutron's energy and angle
2. Neutron proceeds until absorption or escape



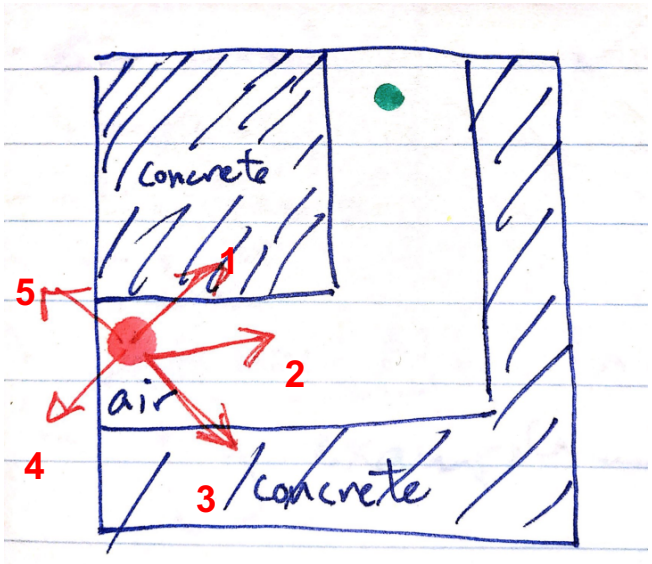
Neutron Transport simulation of 2000 neutrons
Credit to: Andrei Rykhlevskii

Some neutrons are more interesting than others

Neutrons with larger energy and right direction have greater possibility to hit the “point of interest” (green point), where you want to know neutron flux.

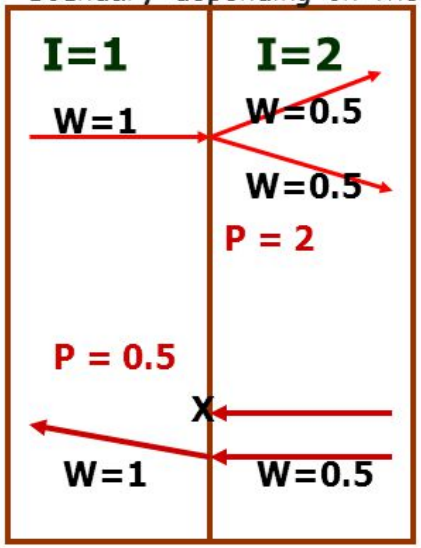
So it’s more meaningful to sample neutron 1,2,3 than 4,5

Solution: Using **survival biasing** and **russian rouletting** based on importance map



Importance sampling technique

- Importance sampling acts on particles crossing boundaries between "importance cells".
- The action taken depends on the importance value assigned to the cell.
- In general, a track is either split or plays Russian roulette at the geometrical boundary depending on the importance value assigned to the cell.



- Survival probability (P) is defined by the ratio of importance value.
  $P = I_{post} / I_{pre}$
- The track weight is changed to W/P.

- Splitting a track (P > 1)
  - E.g. creating two particles with half the 'weight' if it moves into volume with double importance value.

- Russian-roulette (P < 1) in opposite direction
  - E.g. Kill particles according to the survival probability (1 - P).

Monte Carlo is slow ...

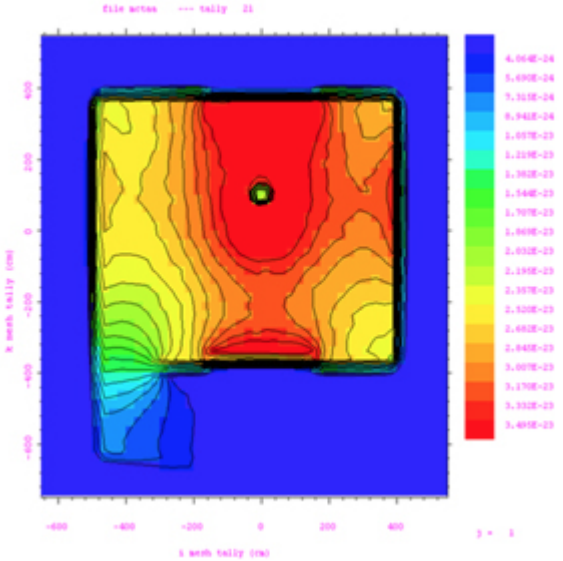
Some researchers speed it up using Hybrid methods.

Hybrid method in Monte Carlo method

Hybrid MC solves the deterministic equations to get a coarse estimate of the importance map of neutrons.

This avoids spending computational time on neutron histories which don't contribute to the solution.

But solving the deterministic equation is extra work.



Importance map example.
Monte Carlo methods, S Green, Z Ghani and F Fiorini, September 2017.

Our Solution: Machine Learning Monte Carlo acceleration

In Machine Learning Monte Carlo, we build the importance map *without the effort* of solving the deterministic equation.

Instead, we *learn* from an initial set of Monte Carlo histories and update iteratively, on the fly, during the simulation.

This avoids calculating deterministic equations and we expect to get similar results in similar computational time with less user effort.

Steps taken

- Read papers and learn basic ideas in nuclear transport
- Set up OpenMC on Virtual Machine
- Ran examples
- Understood how MC sampling is implemented in OpenMC

Future work

- Seek an appropriate unsupervised learning method
- Alter OpenMC sampling procedure
- Alter sampling based on prior runs
- Add Machine Learning to the procedure

Thank you !