A Review of Monte Carlo Methods and Their Application in Medical Physics for Simulating Radiation Transport

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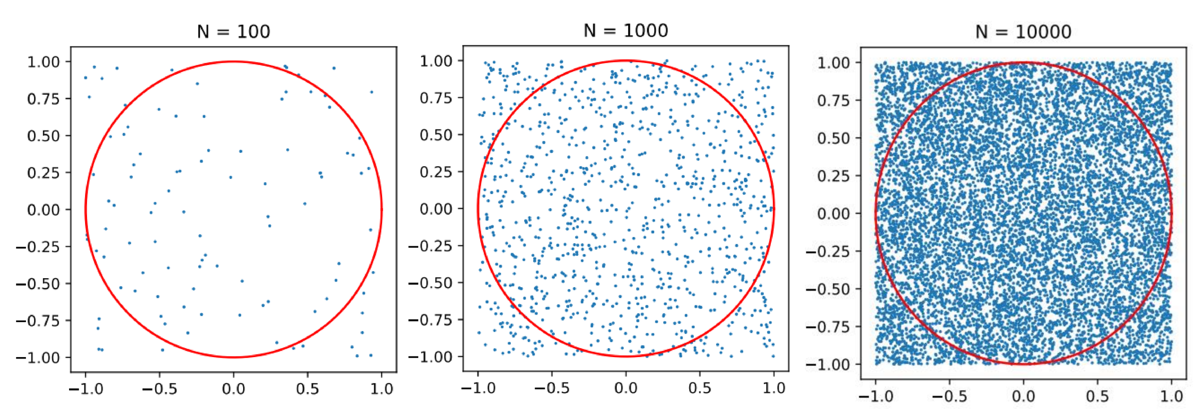
Objectives

The primary goals of this study was to answer the following:

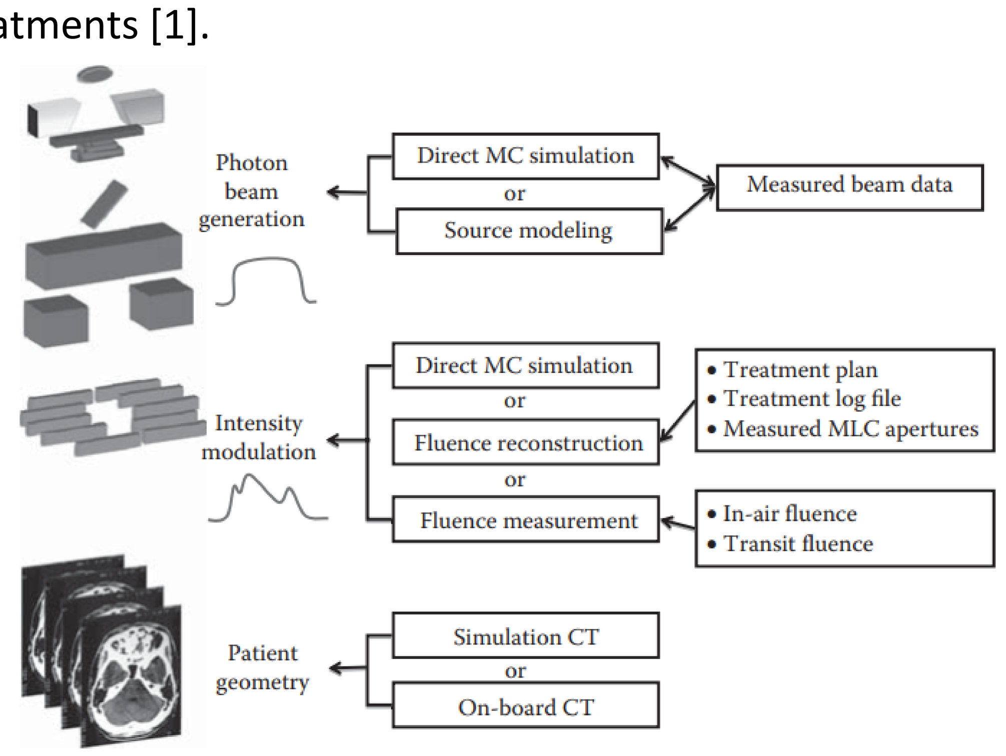
1. What is the underlying physics behind radiation therapy that is carried out through Monte Carlo simulations?
2. What are Monte Carlo methods and how are they implemented in medical physics for use in research and clinical applications.?
3. Perform my own simple Monte Carlo simulation to simulate radiation transport and its interaction with matter.

Background

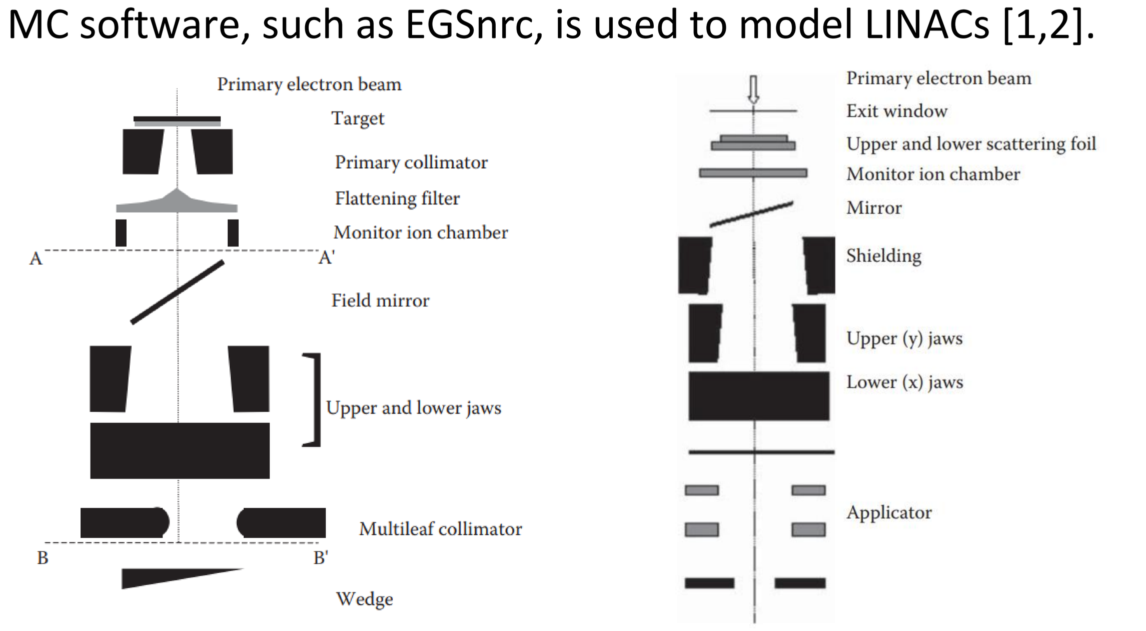
- Monte Carlo (MC) is a numerical method to solve equations or to calculate integrals based on random number sampling.
- MC estimation for pi (figures below): $\pi \approx 4\frac{N_{cir}}{N_{box}}$



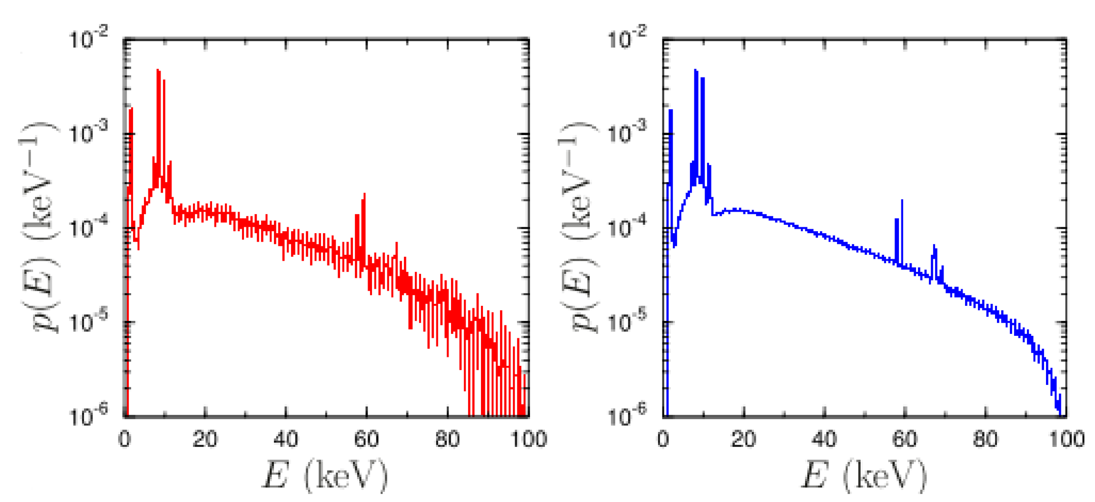
- MC simulations can be used for complex dose calculations.
- Clinical applications of MC simulations include advanced quality analysis (QA) to ensure safe and effective radiotherapy treatments [1].



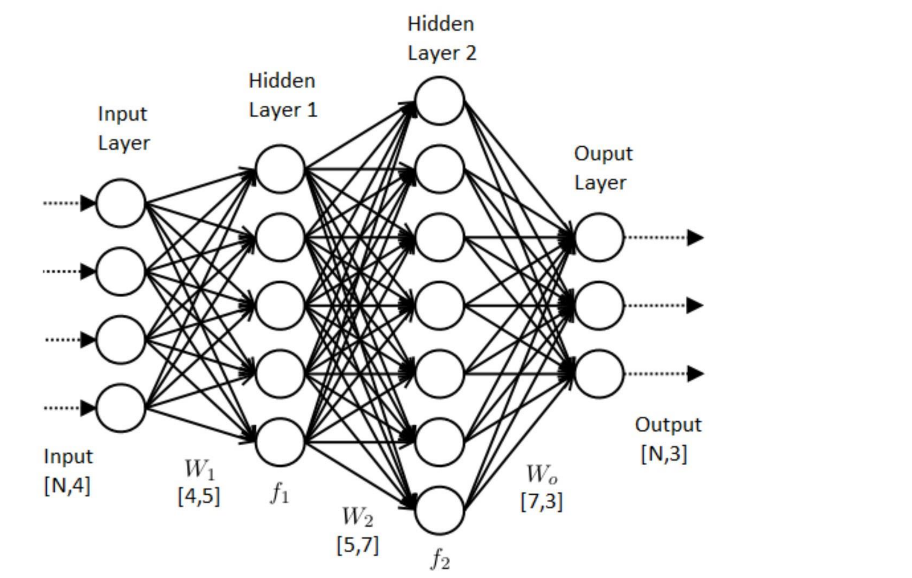
- MC software, such as EGSnrc, is used to model LINACs [1,2].



Current Research

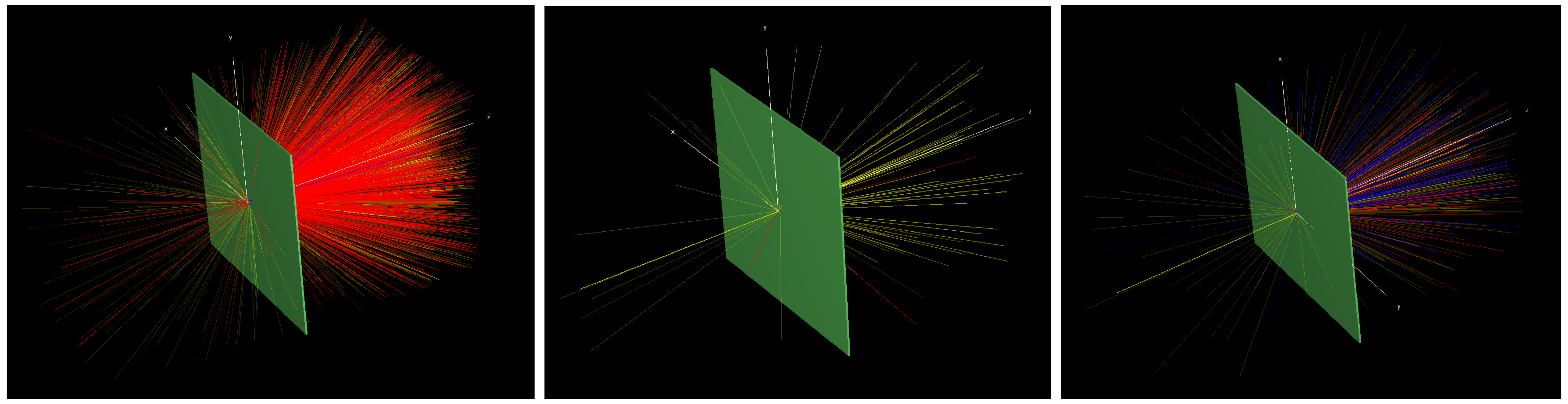


- The figure above, produced by Garcia-Pareja et al. [3], show x-ray emission spectra from a tungsten target being bombarded by 100keV electrons at normal incidence.
- Their work explores the use of various variance reduction techniques (VRT) that can be used to reduce computation time.
- These various VRTs, were shown to effectively reduce computation time.

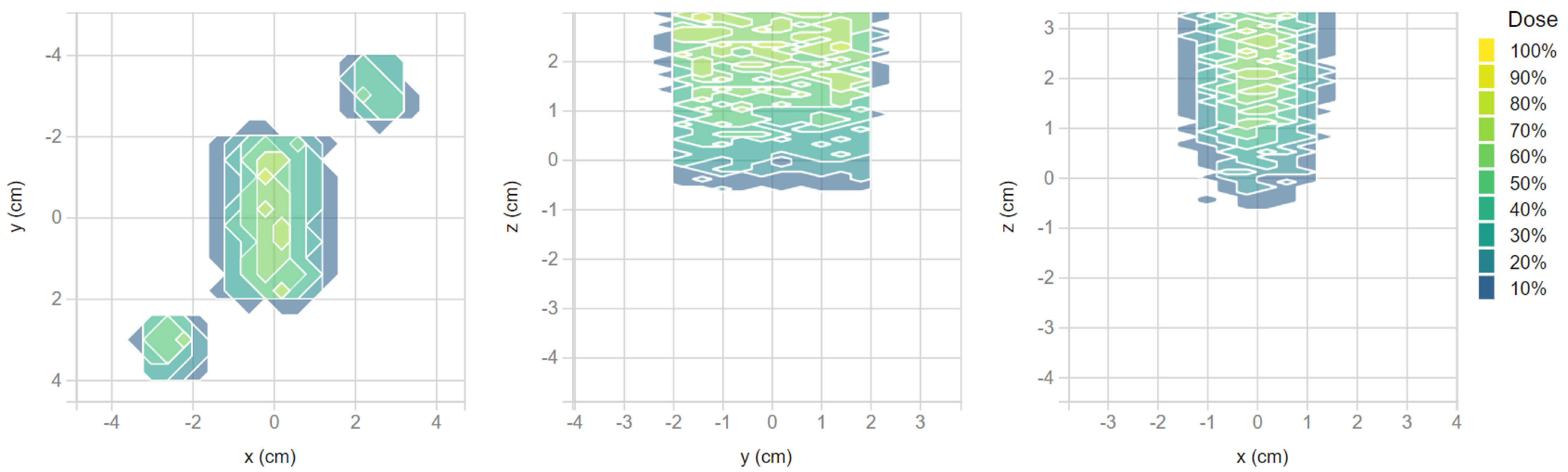


- The work of Sarrut et al. [4] explores the use of neural networks for applications in MC simulations. The figure above shows a schematic of a simple neural network.
- General Adversial Networks (GAN) were used to try and produce phase space files generated by standard MC simulations, hoping to increase computational speed.
- GANs used as a phase space generator were shown to produce strong dosimetric accuracy but were shown to be notoriously difficult to train.

Monte Carlo Simulations using EGSnrc



- A pencil beam source of particles (electrons on the left, photons in middle and right) is incident on a tantalum slab. Incident energies left to right 20 MeV, 1 MeV, and 20 MeV.
- The dose on the slab was calculated and the simulations were repeated for water and copper slabs.



- A photon LINAC was simulated and compiled using BEAMnrc.
- Using CT DICOM data, the dose on a patient phantom was scored.

Results

Summary of region dosimetry (per particle)

Medium	ρ [g/cm^3]	V [cm^3]	E_{dep} [MeV]	D [Gy]
Ta	16.654	10.0	3.3692e-1 ± 12.104%	3.2409e-13 ± 12.104%
Pb	11.350	10.0	1.2804e-1 ± 15.469%	1.8072e-13 ± 15.469%
H_2O	1.0	10.0	4.6386e-4 ± 53.390%	7.4310e-15 ± 53.390%

Summary of region dosimetry (per particle)

Medium	ρ [g/cm^3]	V [cm^3]	E_{dep} [MeV]	D [Gy]
Ta	16.654	10.0	2.5699e0 ± 1.578%	2.4720e-12 ± 1.578%
Pb	11.350	10.0	1.6328e0 ± 1.901%	2.304e-12 ± 1.901%
H_2O	1.0	10.0	1.7423e-1 ± 1.140%	2.7912e-12 ± 1.140%

- Shown are the dose of the 20 MeV incident photons (top) and 20 MeV incident electrons (bottom).
- The dose of the photons were roughly 10x lower, indicating photons have less interaction with matter.
- The dose distribution on the patient phantom is of expected 2cm x 2cm shape.

Conclusions

- Monte Carlo simulations are pervasively used in in research and technology development.
- To make Monte Carlo simulations practical for clinical use, current research is exploring techniques to reduce computation time.
- EGSnrc software is a robust tool that can be used to model radiation transport and LINACs.

References

1. Hendee William R. Monte Carlo Techniques in Radiotherapy. Taylor and Francis Group, 2013
2. R Townson, F Tessier, E Mainegra, and B Walters. Getting Started with EGSnrc. National Research Council of Canada, Ottawa, 8(May):1–72, 2005
3. Salvador García-pareja, Antonio M Lallena, and Francesc Salvat. Variance-Reduction Methods for Monte Carlo Simulation of Radiation Transport. 9(October):1–13, 2021.
4. David Sarrut, Ane Etxebeste, Enrique Muñoz, Nils Krah, and Jean Michel Létang. Artificial Intelligence for Monte Carlo Simulation in Medical Physics. 9(October):1–13, 2021.