Monte Carlo in Atmospheric Optics

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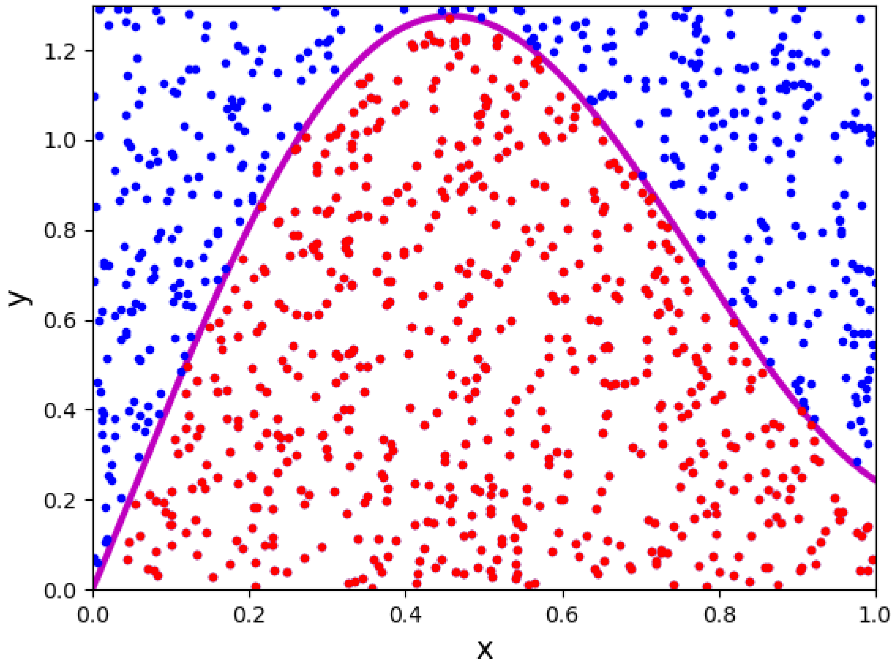
Monte-Carlo: a historical note

- Name of the method – Monte-Carlo – suggested by Nicholas Metropolis after Monte-Carlo casino in Monako
- This method was essential to develop a hydrogen bomb
- The method foundation is to solve a probabilistic problem by sampling associated distributions numerically

Simple application: Integral



Area under curve

$$Area = N_{under} / N_{total} \, Area_{square}$$

Estimation Error:

$$error_{Area} \approx 1/\sqrt{N_{total}}$$

Area	Error	N	$Error\sqrt{N}$
0.892500	6.982%	1e+02	6.98e-01
0.973000	2.142%	1e+03	6.78e-01
0.994875	0.634%	1e+04	6.34e-01
0.999232	0.234%	1e+05	7.39e-01
1.000272	0.068%	1e+06	6.76e-01
1.000010	0.024%	1e+07	7.61e-01

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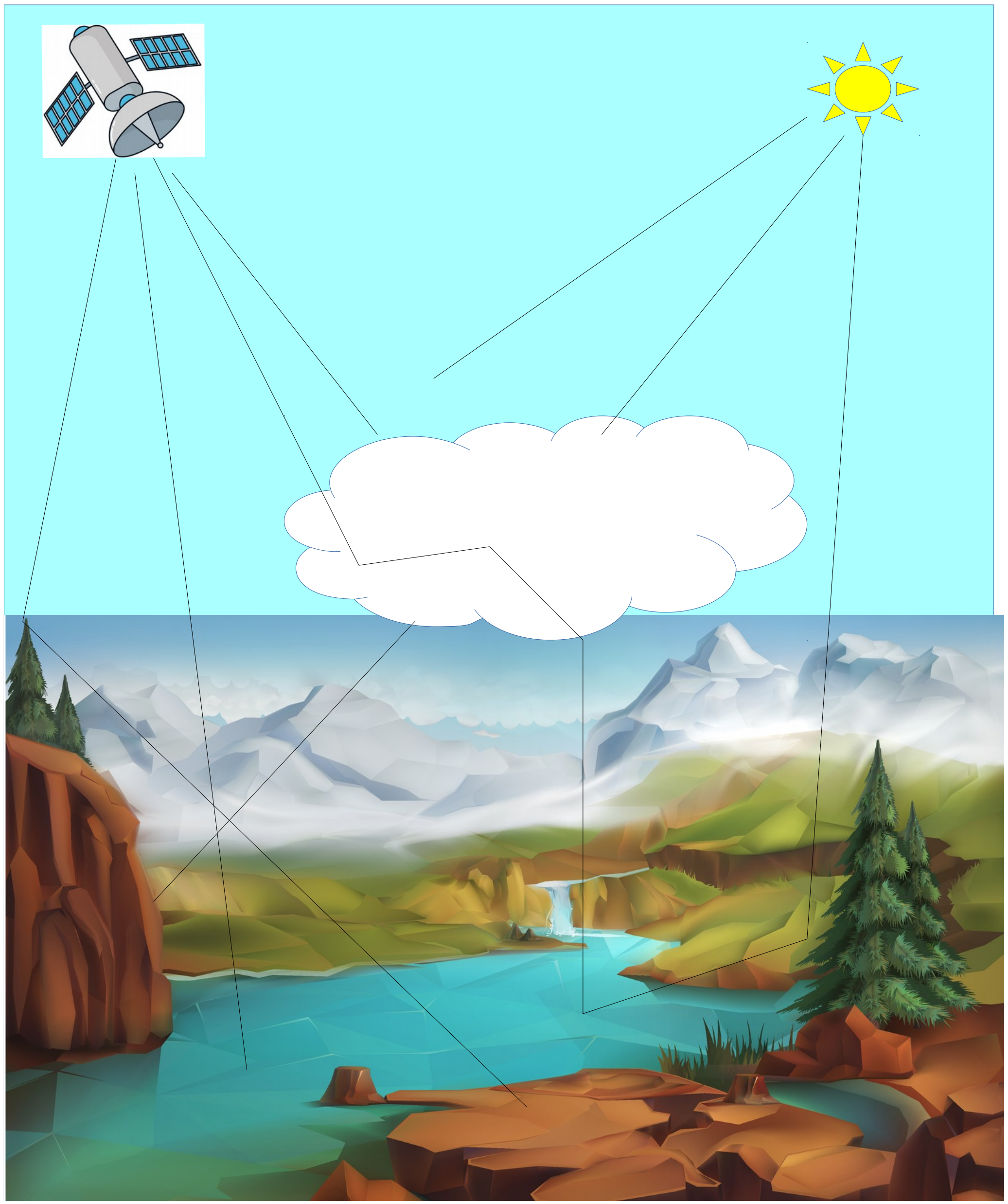

Sun plays roulette with Earth by sending photons and on a quantum level all processes are random: both scattering and absorption.

Thus, a trivial implementation should just follows the photon random path inside the atmosphere and accounts for all effects, including:

Emission

Absorption

Scattering

Refraction

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Monte-Carlo:

1. Implementation seems to be straightforward – just sample all probability distributions required:
   - Anything related to photon propagation and emission
2. Monte-Carlo algorithm:
   - Start a photon
   - Trace until it either absorbed, escaped atmosphere or entered the instrument
   - Tracing must account for the boundary condition complexity and atmospheric properties variability both spectral and spatial as well as temporal if required.

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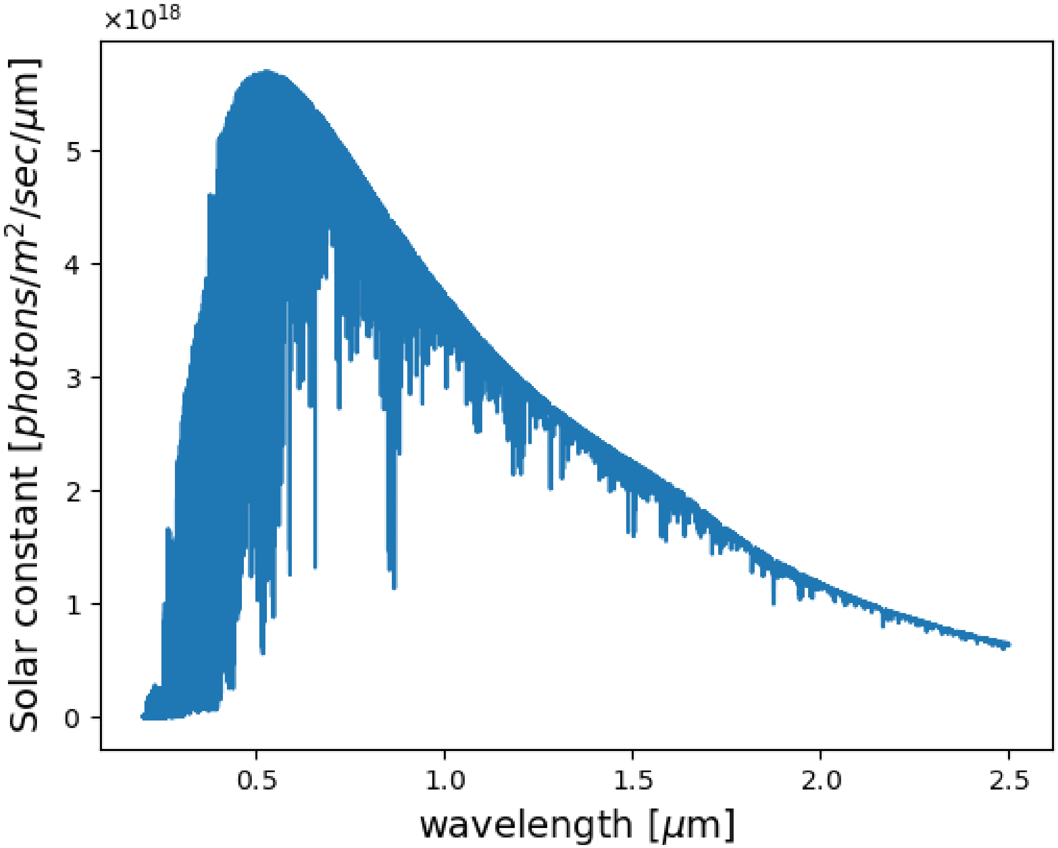

Computer simulation uses <10^8 photons that is 10^{10} less than the Sun does.

- Random number generators produce limited number of random numbers (called period)
- Typical simulation can use a few HUNDREDS random numbers per a single photon trace
- Use only tested random number generator never system

Monte-Carlo: Local estimate

- The efficiency of the direct Monte-Carlo methods are non adequate due to the wast majority of the photons included into simulations are missing the sensor aperture
- Local estimation:
  - Assign a weight to a photon
  - Absorption leads to the weight modification
  - At any point evaluate a potion of the photon that can reach a detector

Monte-Carlo: Jacobian

- Correlative sampling
  - For base and perturbed problem the same random numbers chains for all photons involved should be used
  - Trace base problem, use two weights one for base and the other for perturbed case, entering perturbed area compute weights associated with both base and perturbed problems

Free codes: 1D

- SMART-G Monte Carlo GPU Radiative Transfer
  https://www.hygeos.com/smartg
- Maybe there is more, did not found

Free codes: 3D

- I3RC Monte Carlo community model of 3D radiative transfer

  https://i3rc.gsfc.nasa.gov/I3RC_community_model_new.htm

- ARTS: The Atmospheric Radiative Transfer Simulation

  https://www.radiativetransfer.org/

- GRIMALDI: 3D Monte Carlo codes for visible, infrared, and microwave radiation. The site also features codes for calculating ice crystal single scattering properties

  https://tools.tropos.de/

- MCARaTS: 3D radiative transfer model based on forward-propagating Monte Carlo photon transport algorithm

  https://sites.google.com/site/mcarats/home

References

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- Dupree, S.A, and S.K. Fraley, 2002: Monte Carlo primer: A practical approach to radiation transport, Kluwer Academic, 342 pp
- Deutschmann et al, 2011: The Monte Carlo atmospheric radiative transfer model McArtim: Introduction and validation of Jacobians and 3D features, JQSRT, 112, 1119-1137, https://doi.org/10.1016/j.jqsrt.2010.12.009
- **Many others**