Improved Ray-Tracing Algorithm for Monte Carlo Simulations

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Monte Carlo (MC) Approach

- Exchange-factors are calculated through ray-tracing the paths of many discrete ‘energy-bundles’.
  - complex geometries can be modelled.
  - but, lengthy computation time to achieve adequate convergence.
- Emitted and reflected directions are selected randomly from probability functions.
- About 75 - 95% of the ray-tracing process is due to ‘intersection calculations’ [1].
- Conventional speed-ups:
  - bounding volumes, graphics hardware, vector/parallel computing.

Discrete Function Monte Carlo (DFMC) Approach

- Change in data structure used for ray-tracing. Remove or reduce the number of intersection calculations.

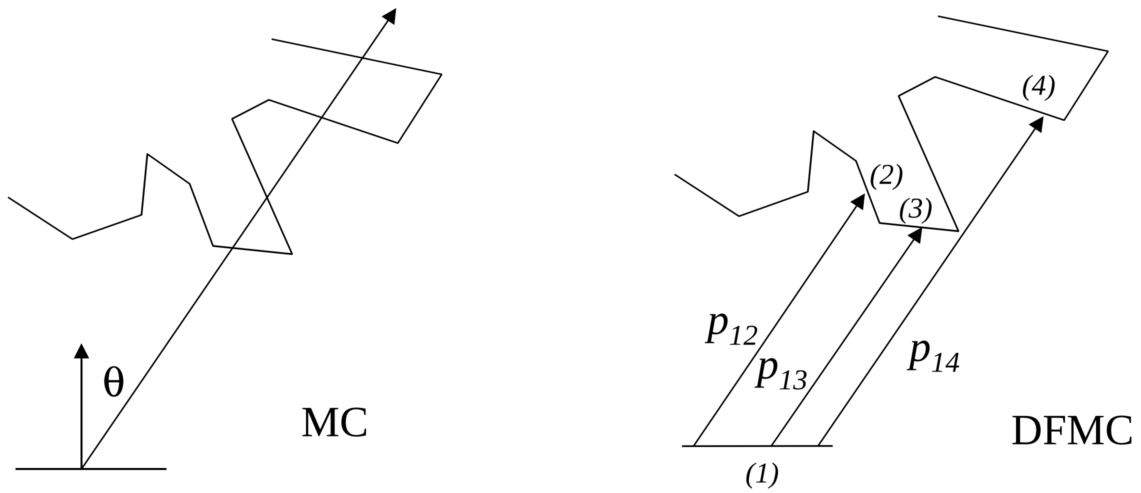
- Discrete functions describe the probability of radiation exchange between each surface.

- Instead of sampling directions, the destination of the ray is sampled.

- Pre-processing is required to evaluate the 'transition probabilities'.
  - Less ray-intersection calculations are required compared with traditional Monte Carlo.
  - Specular/bi-directional reflection:
    - 'n-bounce' approximation.
    - mesh refinement.

- Very fast algorithms can be used to determine the paths of each ray of radiation (ray-intersection calculations are NOT required).

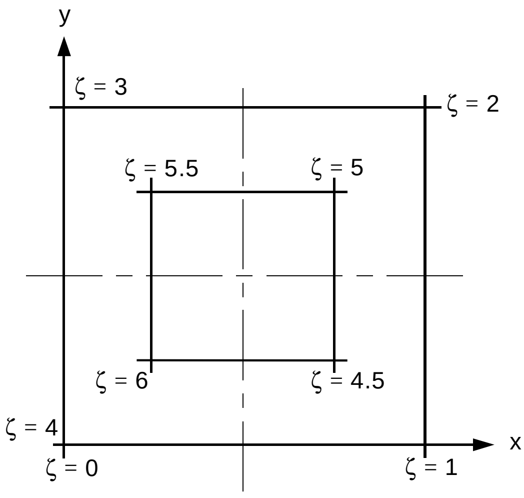
Direction Selection in MC and DFMC



Advantages of the DFMC Approach

- A new way of looking at radiative heat transfer calculations.
- Computational speed improvements.
- Discrete probability functions are independent of (overall) radiative properties.
  - Pre-processing not required if properties are changed.
- Data structure permits rapid updates of the discrete probability functions:
  - Moving geometry.
  - Transient simulations.

Analysis Case



- 'North' enclosure wall ($2 \leq \xi \leq 3$) at 320 K.
- Rest of geometry at 300 K.
- Emissivity:
  - $\varepsilon_{enclosure} = 0.1$
  - $\varepsilon_{obstruction} = 0.9$
- Reflections ('one-bounce' approximation):
  - Specular.
  - Bidirectional:

$$f(\theta_I, \theta_R) = \frac{(s^2+1)\cos(\theta_R)e^{-s|\theta_I+\theta_R|}}{2s\cos(\theta_I) + e^{-s(\pi/2+\theta_I)} + e^{-s(\pi/2-\theta_I)}}$$

$$-\pi/2 \geq \theta \geq \pi/2$$

Computational Speed Improvements

Convergence criteria	Simulation time relative to Monte Carlo, %		Reference
	Specular case	Bi-directional case	
±5% (99% conf.)	13	17	[2]
±10% (95% conf.)	33	50	[3]

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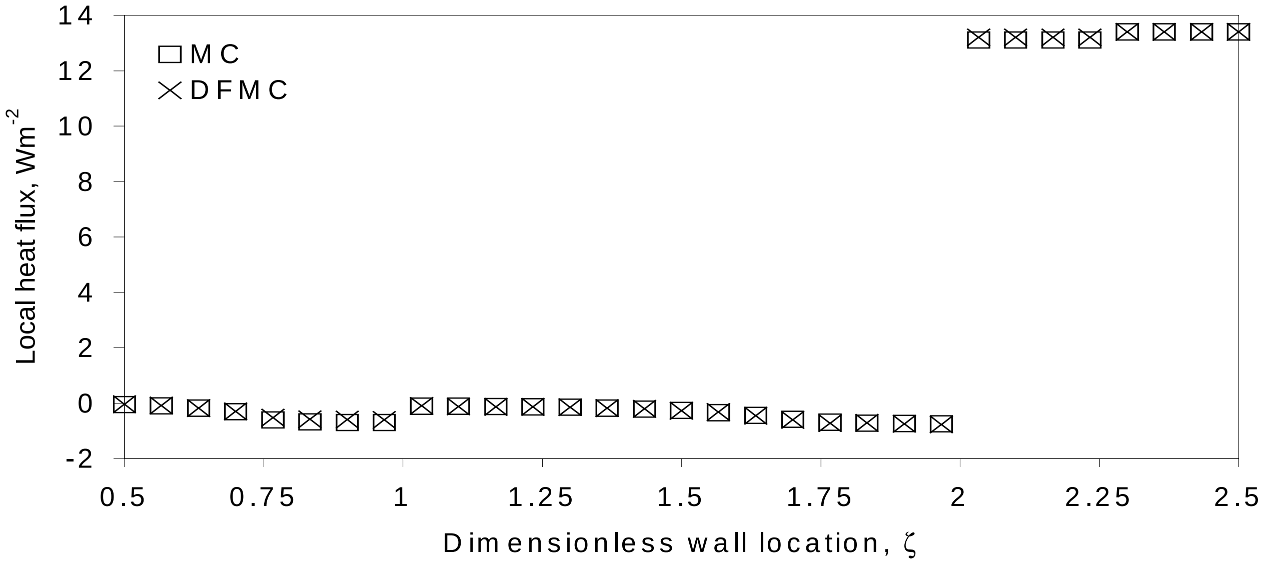
Comparison of Local Heat Fluxes for Specular Case



Conclusion

- A very fast ray-tracing algorithm for Monte Carlo simulations has been presented.
- Initial simulations have indicated that speed-ups to a factor of 8 are possible.
- Suited to high-reflectivity geometries.
- The data structure:
  - permits changes to the radiative model to be assessed quickly.
  - offers many possibilities with respect to numerical methods.
- Starting point for developing a new improved radiation simulation technique.

References

[1] Plunkett, D. J., and Bailey, M. J., 1985, "The Vectorization of a Ray-Tracing Algorithm for Improved Execution Speed," *IEEE Computer Graphics and Applications*, Vol. 5, No. 8, pp. 53-60.

[2] Shaughnessy, B. M., and Newborough, M., 1998, "A New Method for Tracking Radiative Paths in Monte Carlo Simulations," *ASME Journal of Heat Transfer*, Vol. 120, No. 3, pp. 792-795.

[3] Shaughnessy, B. M., and Newborough, M., 1999, "Calculating the Reflected Paths of Radiation in High Reflectivity Enclosures," 5th *ASME/JSME Joint Thermal Engineering Conference, March 15-19, San Diego, California*.