Integration of Monte Carlo Methods with TMG's Suite of Radiation Analysis Tools

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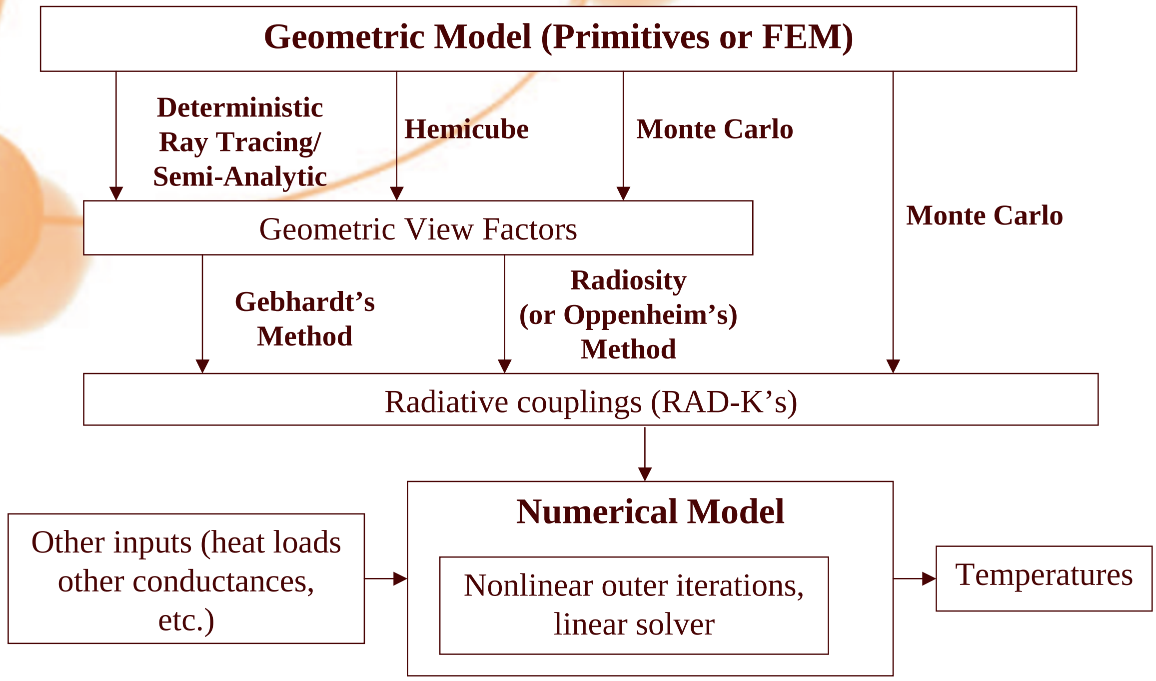
Overview

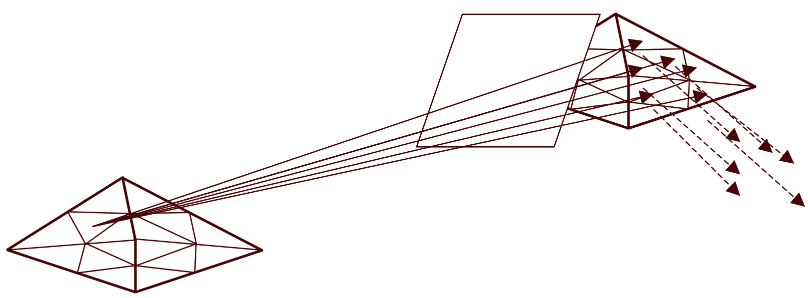
- In spacecraft radiation analysis there are generally two main tasks:
  - Determine the effects of IR exchange between components of the spacecraft
  - Determine heat loads from the environment (solar, albedo, planetary IR)
- Solution of both of these problems is complicated by the reflection of radiation within the spacecraft
  - Without reflections (and transmissions), this task would be simple
- Most of the techniques in S/C radiative thermal analysis are differentiated by the way reflections are accounted for
- We review these techniques as they are implemented in TMG, focussing on the recent integration of Monte Carlo methods with TMG

IR interchange between surfaces



Geometric View Factors

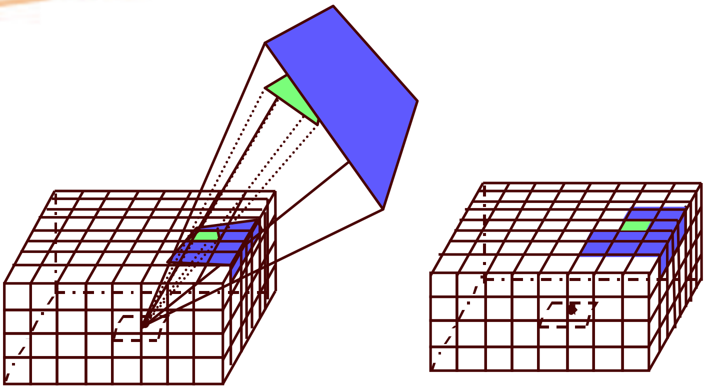
- Deterministic Ray Tracing / Semi-Analytic Method
  - Contour integral method if surfaces are diffuse and not shadowed;
  - For shadowed surfaces, deterministic or "pseudo Monte Carlo" method is used: elements are subdivided into subelements and rays are traced between subelements;



  - Rays which hit specular or transparent surfaces are further traced through the model (view factors no longer just "geometric")
  - Potentially more efficient than Monte Carlo since rays are traced only when specular surfaces are hit

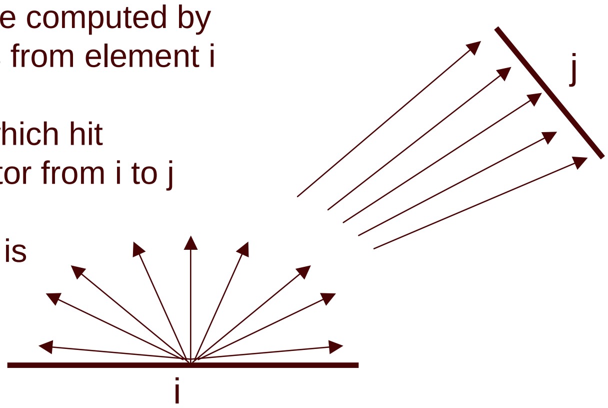
Geometric View Factors (cont'd)

- Hemicube Method
  - Scene of elements is projected onto a hemicube from the view point of each element, similar to the Nusselt Sphere Method
  - Uses graphics card for high-speed rendering
  - Only useful for diffusely reflecting surfaces

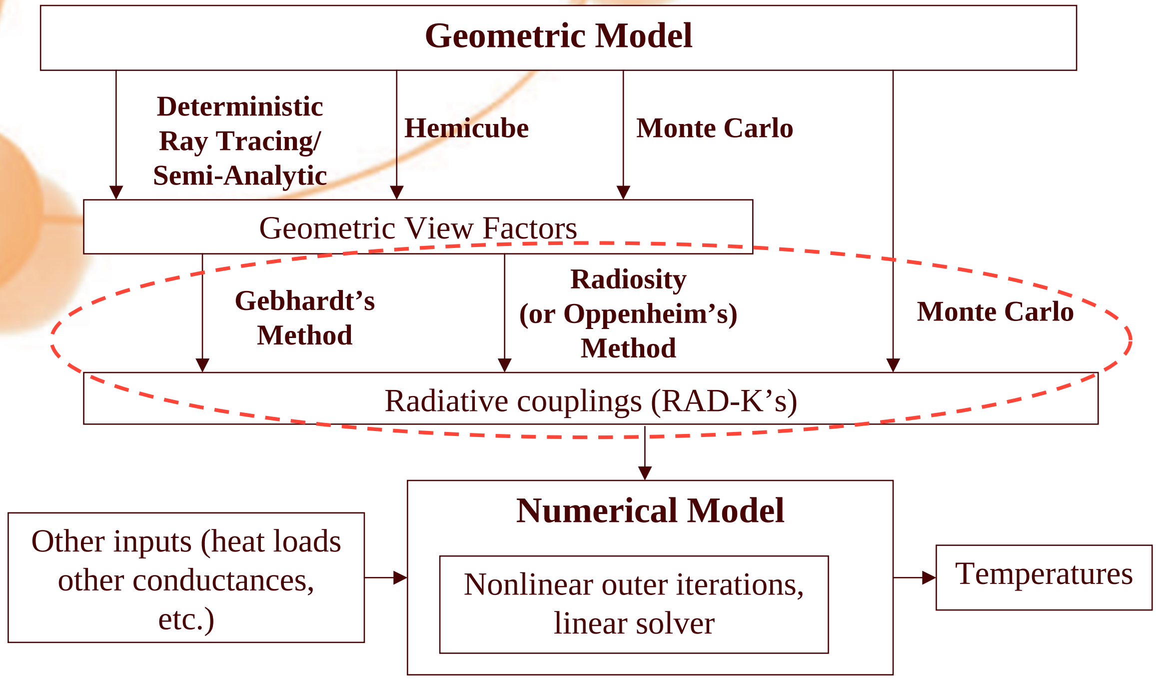


Geometric View Factors (cont'd)

- Monte Carlo Method
  - Determination of geometric view factors is one of the simplest S/C thermal applications of MC
  - The view factor can be computed by randomly launching rays from element i
  - The fraction of rays which hit element j is the view factor from i to j
  - No further ray tracing is necessary for diffuse surfaces



IR interchange between surfaces



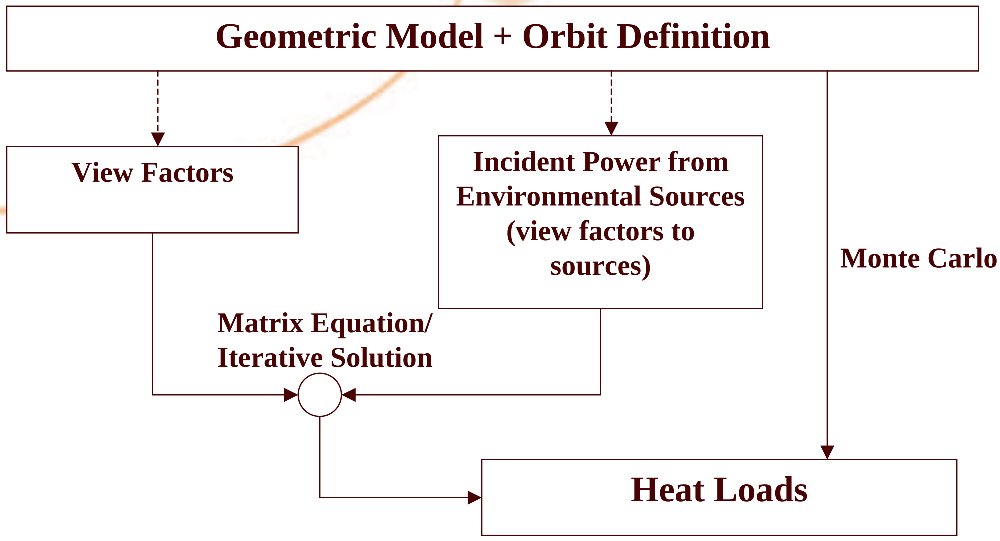
Radiative Couplings

- Radiative couplings (RAD-K's) also account for all reflections
- Gebhardt's method:
  - Radiative couplings are computed by solving a matrix equation involving the view factors
- Radiosity (Oppenheim's) method:
  - Additional radiosity nodes are introduced into the model, view factors can be used directly to calculate radiative couplings
- Monte Carlo
  - Radiative couplings are computed directly by tracing rays through the model: ray behaviour statistically follows exactly the (non-wave) behaviour of the light travelling through the system

Radiative Couplings

	Gebhardt's	Radiosity / (Oppenheim's)	Monte Carlo
Speed	Mediocre, requires matrix solve	Good, no matrix solve necessary	Slow, ray tracing with multiple intersection tests
ε(T)?	NO, must re-solve matrix	YES, goes right into numerical model	NO, must repeat ray tracing
BRDF, ε(θ,φ)?	NO	NO	YES, easy to do
Accuracy (within limitations)	Uniform illumination approximation	Uniform illumination approximation	Depends on number of rays
Intuitive results?	YES	Difficult to interpret	YES

Environmental Heat Loads



Determination of Heat Loads

- View factor iteration method :
  - incident powers on surfaces are calculated from environmental sources (shadowing counts)
  - A number of methods can be used to compute the effects of diffuse reflections:
    - Gebhardt's method
    - Radiosity (Oppenheim's method)
    - Iteratively use the view factors to redistribute the reflected energy

- Monte Carlo method:
  - Many rays are traced from the environmental sources and through the model until they are absorbed (or until their energy value is negligible)

Determination of Heat Loads

	View factor method (matrix or iterative)	Monte Carlo
Speed	"Fast" (Depends on how you generate RAD-K's and/or VF's)	Depends on number of rays – ray tracing with multiple bounces
Accuracy (within limitations)	Uniform illumination approximation Influenced by accuracy of view factors (shadowing, specular ray tracing)	Depends on number of rays
BRDF?	NO	YES, easy to do

Primary Advantages of Monte Carlo

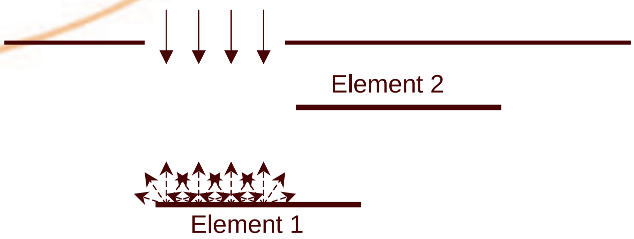
- Direct computation of radiative couplings and heat loads (easily understandable)

- Monte Carlo gives you the ability to handle advanced surface properties, e.g., BRDF's
  - Bidirectional reflectance distribution function: $\rho(\theta_i, \phi_i, \theta_r, \phi_r)$
  - Probability distribution that a ray coming in at (θ_i,φ_i) will leave at (θ_r,φ_r)
  - Allows relaxation of Lambertian surface assumption, more accurate representation of measured optical properties

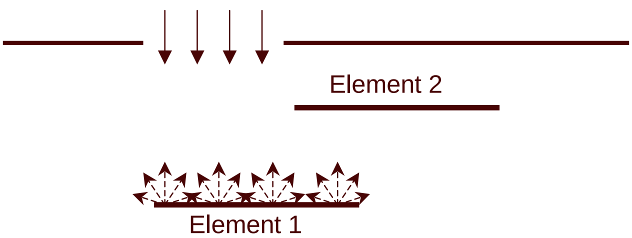
- Do not have to rely on the uniform illumination approximation
  - The view factor-based methods approximate that for the redistribution of diffusely radiation, light hitting an element is uniformly distributed over it

Uniform Illumination Approximation

- Consider the following case of solar heating:
  - A portion of element 1 sees the sun
  - The only solar radiation hitting element 2 is what is diffusely reflected from element 1.

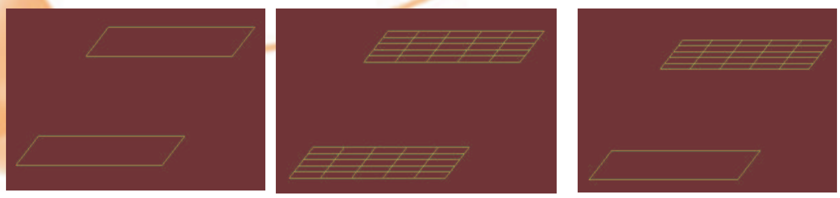


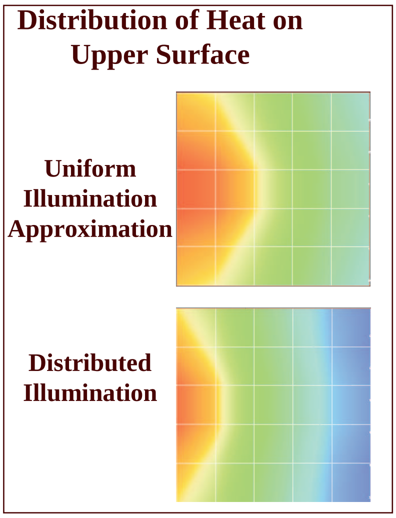
- With the view-factor based methods, the reflected radiation is treated as if distributed uniformly over the element:



Uniform Illumination Example

- Compare view factor method with Monte Carlo
  - Element 1 is 50% reflective, Element 2 is 100% absorptive
  - 50 Watts incident on half of Element 1
  - Also refine mesh where Element 1 and 2 divided into 25 elements each





	View Factor Method	Monte Carlo
Single Element	5.19 W	3.53 W
Refined Mesh	3.61 W	3.54 W

Heat load reflected onto upper surface

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Uniform Illumination Approximation (cont'd)

- Note that similar errors can occur when determining radiative exchange factors (RAD-K's) using the view factor method.
- This does not mean that with the view factor method you always need a fine mesh
  - The above example was designed to fail with the VF method and the coarse mesh.
  - What is important is that the analyst is cognizant of the potential pitfalls.
- It does also not mean Monte Carlo is inherently superior
  - For example, we have not demonstrated the trade off between CPU time and accuracy.
  - If view factors can be computed quickly (e.g., Hemicube methods), then it is often more advantageous to use *more elements* and the radiosity method over fewer elements and Monte Carlo.

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Status of Monte Carlo in TMG

- Release schedule
  - Activated through modifying input deck in I-DEAS 12 (to be released soon)
  - Graphical user interface to be released with I-DEAS 12+1 & NX-5
- Present capabilities include:
  - Calculation of view factors, radiative conductances, and heat loads
  - Absorption and scattering of environmental heat sources in ‘participating’ media
  - Limited BRDF support
- Verification & Validation
  - Approximately 80 QA test cases
- In progress
  - Faster ray-tracing
  - Full BRDF support
  - Variance reduction methods