Proceedings of the 2017 Winter Simulation Conference
W. K. V. Chan, A. D'Ambrogio, G. Zacharewicz, N. Mustafee, G. Wainer, and E. Page, eds.

CALCULATION OF RADIATION EXCHANGE USING MACRO-CLASS VIEWFACTORS

T. Paul Etheredge
M. Blake Haynes
Matthey C. Rigney

Aviation and Missile Research, Development, and
Engineering Directorate, US Army
3707 Aerobee Road
Redstone Arsenal, AL, USA

Brad H. Seal
Jamie E. Burns

Torch Technologies, Inc.

4035 Chris Drive
Huntsville, AL, 35802 USA

ABSTRACT

Radiation exchange for large-scale terrains measuring more than 100km^2 at resolutions of 0.25m and containing billions of facets is a very complex problem for thermal solver simulations. Traditional thermal solvers have used ray-traced approaches to solve the radiation exchange energies but lack fidelity and introduce sampling error due to the limited number of rays that can be cast. A new approach using macro-class view factor maps and statistical temperature distributions for the terrains allow for more accurate calculation of radiation exchange energies in a fraction of the time as the traditional ray-traced solutions.

1 MACRO-CLASS RADIATION EXCHANGE ALGORITHM

In the realm of 3D thermal simulation, the calculation of radiation exchange has historically been a difficult problem to solve in a timely fashion due to the need to calculate appropriate viewfactors with a facet's surroundings. The energy transmitted due to radiation exchange is solved using the equation

$$\dot{Q} = \sum_{i=0}^{n} \left[\sigma * VF_{i \to k} * A * \left(T_i^4 - T_k^4\right)\right], \tag{1}$$

where k is the facet of interest, i is another object in the scene, and VF is the view factor at the point of interest from the other objects in the scene. Most modern thermal solvers operate using a ray-traced approach to calculate the view factors of its surroundings. However, when the Army needed a tool capable of generating thermal signatures for large-scale terrains containing hundreds of billions of facets, this ray-tracing approach was proven to be computationally inefficient for this specific problem set. Solutions investigated included SigSimRT and MuSES, but neither met the necessary fidelity and scalability required. The EOView thermal solver, which uses this ray-traced approach, was adapted to handle the large numbers of facets in the scene. However, the total number of rays cast per facet to its surroundings had to be drastically reduced such that a large degree of sampling error was introduced into the final thermal solution and the solution still required upwards of a month on a high-performance cluster. To address this problem, a new thermal solver called HOTTS was developed that uses a macro-class viewfactor approach which allows for an accurate, yet rapid, thermal solution in just over 24 hours. For ray-traced solutions, a precise value for the T^4 term in (1) is generated at the cost of an inaccurate solution for the VF term. The macro-class algorithm allows for an accurate solution for both the T^4 term and the VF terms in a fraction of the time.

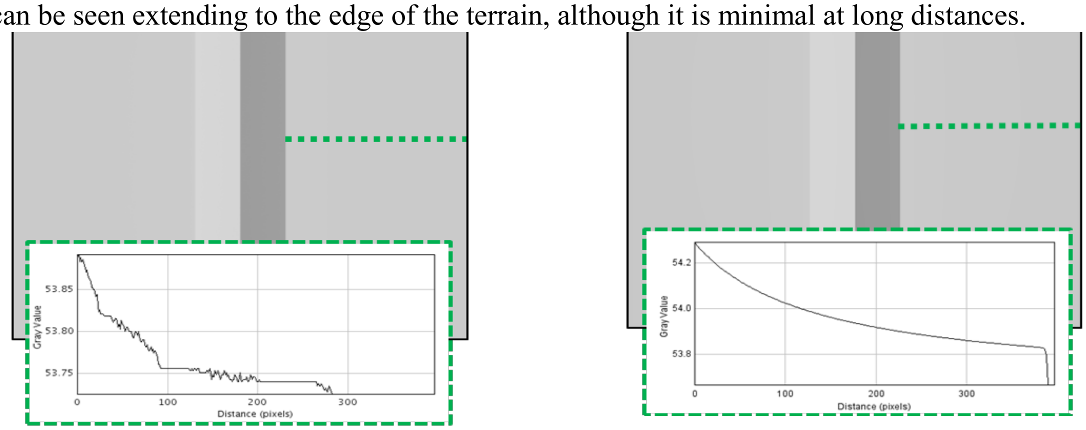
The macro-class radiation exchange algorithm breaks the problem up into components and solves each one separately. The first requirement is an accurate solution for the VF term. To address this, the VF term if first broken up into 4 macro-classes of Air, Sky, Terrain, and Discretes such as trees and bushes. This is done based on the assumption that these macro-classes will have similar temperature profiles among themselves. For example, each tree in the scene will have a fairly similar thermal signature, but could be drastically different from the sky or ground temperatures. A Digital Surface Map (DSM) and Terrain Classification Map are used to generate the viewfactor contributions of each macro-class by running a 360-degree azimuth sweep around each post and running a ray out from the post at each azimuth, using the angles of intersection with the terrain to sum the various viewfactor contributions at each azimuth. This process creates a Viewfactor Map which describes the macro-class contributions at each post of the terrain.

Once the viewfactor contribution is known, the next step is to determine the temperature component of each macro-class. For the air and sky macro-classes, the temperature can be easily derived from the local weather conditions. Terrain temperatures are determined using a look-up table called a Directionally Distributed Temperature (DDT) Map which is constructed using a combination of a Classification Map, Surface Normal Map, Shadow Map, and a thermally solved lookup table for each material in the scene. Leveraging these products, a DDT can be generated which represents a statistically representative temperature for the terrain for each surface normal azimuth and elevation pairing. Objects such as trees and bushes are handled similarly.

The DDT allows for rapid calculation of the representative temperature of the terrain for use in the radiation exchange calculation. The total terrain-on-terrain radiation exchange is calculated based on a post's surface normal and the percentage of the surface normal distribution. For instance, terrain surfaces that are east-facing will weight radiation exchange with the DDT higher on west-facing azimuths and will weight azimuth-elevation pairings with a higher surface normal percentage percentage more than azimuth-elevation pairings with a lower surface normal percentage.

2 RESULTS AND CONCLUSIONS

To conduct the test, two terrains were constructed with a ridge down the center, one with a 30-degree incline and another with a 60-degree incline, which would allow for exact results to be calculated and compared to the results from both thermal solvers. Figure 1 shows results from a thermal solution using the 30-degree incline ridge. The EOView solution produces sharp fall-offs and random noise in the thermal solution. Additionally, at a certain range, the ridge ceases to have any contribution due to the ray distribution algorithm not allowing rays to be projected below certain elevation angles. In contrast. the macro-class algorithm allows for a gradual fall-off and no noise in the radiation influence of the ridge. The influence of the ridge can be seen extending to the edge of the terrain, although it is minimal at long distances.



(a) *(b)*

Figure 1: Temperature plot due to Radiation Exchange using (a) EOView ray-traced solution and (b) macro-class radiation exchange algorithm

Additional studies on large-scale (10km x 10km), high-fidelity terrains that model real-world locations have shown that the use of the Viewfactor Maps and DDT Maps reduces computation time and allow for more accurate radiation exchange calculations when compared to the legacy ray-traced methodologies.