

First steps of numerical simulation using Artificial Intelligence

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First Steps of Numerical Simulation using Artificial Intelligence

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Geometric modeling of 3D scenes from measurement data

Analysis, reconstruction, approximation
 Computational geometry, geometry processing, machine learning



CONTEXT AND MOTIVATIONS





- Additive manufacturing yields increasingly complex objects
 - Reduced weight via topology optimization
 - Many more facets elements are required to describe these free-form shapes, which are later added to the full satellite model.

CONTEXT AND MOTIVATIONS



Context of real-time simulation & sensibility

- Radiative thermal simulation is time-consuming: O(*n*²) complexity for the view factors, with *n* the number of faces of the mesh.
- Full simulation intractable on the complete satellite model, in a reasonable time.
 - A thermal-aware geometric approximation process is required, allowing real-time simulation and beyond (multiphysics simulation and predictions).



Image from www.ata-e.com

PROBLEM STATEMENT



 Input: Complex surface mesh (many facets and occlusions, created by a CAD software)

Output: Approximated model respecting the view factors of the thermal nodes

Guarantees: Error bounds under wide range of configurations and conditions

Goal: Optimize trade-off between accuracy and time







DIRECTIONS

Topic of Ph.D. thesis: Design a geometric approximation method preserving a *simulation-aware* error metric rather than a *geometric* error metric.

Application to space thermal analysis: view factor computation and model reduction

Goals:

- Compute reference view factors
- Compare with approximated view factors
- Evaluate simulation with approximation
- Utilize supervised machine learning to automate the reduction process, leveraging a large training dataset.



Image from www.warontherocks.com



VIEW FACTOR

ESTEW -



 θ_2 n_2

 n_1

S

 $\mathrm{d}A$

 $\mathrm{d}A_2$

$$F_{1
ightarrow 2} = rac{1}{A_1} \int_{A_1} \int_{A_2} rac{\cos heta_1 \cos heta_2}{\pi s^2} \, \mathrm{d}A_2 \, \mathrm{d}A_1$$

$$dF_{1
ightarrow 2} = rac{\cos heta_1\cos heta_2}{\pi s^2} \mathrm{d}A_2$$

View factors depend on 3 components:

- area of the faces
- distance between them
- orientation



RELATED WORK



Accelerating computation of view factors

 Jacques, Masset, Kerschen: Ray tracing enhancement for space thermal analysis: isocell method, 27th Space Thermal Analysis Workshop, ESTEC.



RELATED WORK



- Schröder, Hanrahan: On the Form Factor between Two Polygons.
 Proceedings of ACM SIGGRAPH 1993.
 - → <u>Closed form solution</u> for the view factor between two convex polygons

Walton: Calculation of Obstructed View Factors by Adaptive Integration. NIST Report, 2002.



Closed form (without obstruction)



Adaptive Division of Polygons



ACHIEVEMENTS



Hierarchical geometric data structure: AABB-tree (fast intersection queries)





- Quadrature in the presence of occlusions:
 - Point-based (via bounded centroidal Voronoi diagrams)
 - Triangle-based (recursive longest bisection)



Reference view factors

Bounded Centroidal Voronoi Diagrams (CVD) DIREA



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VIEW FACTORS (VF)





COMPARISONS





COMPARISONS





COMPARISONS





RANDOM SAMPLING VS CVD





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RANDOM SAMPLING VS CVD



Results with two random triangles configuration and an obstacle between them View factor value Lloyd 100 obstacle 4 Lloyd 100 obstacle 5 1.6 0,07 1,4 0,06 1,2 0,05 0,04 0,8 0,03 0,6 0,02 0,4 0,01 0.2 0 781 781 881 881 901 921 961 961 981 #quadrature points Random uniform sampling **Bounded Centroidal Voronoi** View factor exact value

VARYING #LLOYD ITERATIONS



Results with two random triangles configuration and an obstacle between them



ON-GOING WORK



Approximation method guided by preservation of the view factors. We keep the constraint of the thermal nodes in order to compare the matrices of the radiative surfaces per nodes.



ON-GOING WORK





Illustration of the thermal nodes with e-Therm

- **Simplification** via face clustering in order to best approximate the thermal nodes.
- Comparison with the reference calculation thanks to thermal nodes:
 - Main idea: compare the radiative surfaces by node matrices from the reference calculation case and the approximation one

WHAT'S NEXT: SUPERVISED MACHINE LEARNING DIREA

Goal: learn geometric error metric able to govern an automatic approximation algorithm so that the resulting thermal simulation is as accurate as possible to a reference calculation.

Constraints = thermal nodes, so we can compare the radiative surfaces of each node before and after approximation.



[Jacobson] Thingie10K (training dataset)

THANK YOU



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