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To cite this version:
Vincent Vadez, François Brunetti, Pierre Alliez. Physics Driven Geometrical Model Reduction (GMM). 2020. hal-02964494

HAL Id: hal-02964494
https://inria.hal.science/hal-02964494
Submitted on 12 Oct 2020

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Physics Driven Geometrical Model Reduction (GMM)

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Outline

‣ Previous results on new view factor computation methods

‣ Physics driven geometrical model reduction
  ▪ Problem statement
  ▪ Reduction process coupled to an oracle for the physical component (here thermal)
  ▪ Limits

‣ Conclusion & future works
Progressive geometric view factors

- Polygon-based quadrature
- Adaptive splitting
- Predictions

More details here:
V. Vadez, F. Brunetti, P. Alliez.
Physics driven geometrical model reduction

- **Problem statement:**
  - Radiative thermal computations are time consuming
  - Goal: Geometric reduction consulting *physics unaware* but *physics driven* thanks to an oracle
    - User inputs: Geometric file & decimation step
    - Output: Distortion

- **Global generic architecture:**
  - Preparation: reference calculation case request and clustering
  - Reduction: decimation iterations for each cluster
  - Reassembling: reduced geometry reconstitution and calculations request
  - Distortion: stop criteria according to user input and calculations results (max distortion)
Model geometry
Inputs: reduction ratio & max distortion

Preparation
input: geometry format
output: distortion quantity

Reduction

Reassemble geometric clusters

Distortion

If max distortion not reached

Clustering
(If required)

Computations

Output

If max distortion reached

Oracle (physics calculus)

API

Reduction tool
physics unaware
but
physics driven
Model geometry
Inputs: reduction ratio & max distortion

Preparation
input: geometry format
output: distortion quantity

Clustering
(If required)

Reduction
Reassemble geometric clusters

Distortion

If max distortion not reached

Output

Clustering

Computations

Nodal breakdown

Thermal solver

Temperatures

Oracle (physics calculus)

Reduction tool
physics unaware but
physics driven
Physics driven geometrical model reduction

- **Current prototype thermal limitations**
  - View surfaces face to face only (no solar or albedo fluxes computed)
  - Node-to-node radiative couplings
  - Thermal equation solved: steady state
  - No conductive part in considered model (so only radiative couplings influence final temperatures aka radiative component totally drives temperatures)
  - Same thermo-optical properties everywhere

**Note:** if solar and albedo computations are performed, if conductive couplings are added, if thermo-optical properties are different for each node -> final reduced output would be different **BUT reduction algorithm does not change**
Physics driven geometrical model reduction

- State of the art on geometric model reduction
  - Edge-collapse or halfedge-collapse
  - Cost function & placement function
    - Lindstrom-Turk [1]: optimizes shape, volume & boundaries
    - Garland-Heckbert [2]: encodes approximate distance to the original mesh by using quadric matrices that it assigns to each vertex
  - Volume preserving memory-aware
  - Normal preserving


Physics driven geometrical model reduction

**Considered model:**
- 10 thermal nodes
- 1006 triangle faces
- 4 antennas oriented towards Earth and 2 reflectors
- 0.1W injected at the nozzle
- 1 boundary node

**Algorithm inputs:**
- reduction step ratio: **10%** of faces
- desired max distortion: **0.5 °C**
- Lindstrom-Turk edge collapse (appropriate since boundaries are preserved and view factors depend on area, squared distance and orientations of the faces)
Physics driven geometrical model reduction

**Iteration 1:**
- 895 faces over 1006 original faces (89%)
- Max distortion: $0.083^\circ$ C

![Graph showing max distortion and number of faces over iteration number](image)
Iteration 2:
797 faces over 1006 original faces (79%)
Max distortion: 0.058° C
Physics driven geometrical model reduction

Iteration 3:
703 faces over 1006 original faces (70%)
Max distortion: 0.149 °C
Physics driven geometrical model reduction

**Iteration 4:**
630 faces over 1006 original faces (63%)
Max distortion: 0.133° C

![Graph showing the relationship between iteration number and max distortion/number of faces](image)
Physics driven geometrical model reduction

**Iteration 5:**

552 faces over 1006 original faces (55%)

Max distortion: $0.204^\circ$ C
Physics driven geometrical model reduction

**Iteration 6:**

486 faces over 1006 original faces (48%)

Max distortion: $0.462^\circ$
Physics driven geometrical model reduction

**Iteration 7:**

429 faces over 1006 original faces (48%)
Max distortion: 0.466° C

Max distortion and number of faces over iteration number
Physics driven geometrical model reduction

- Conclusion
  - Volume and boundaries preserved thanks to Lindstrom-Turk edge collapse
  - Results are acceptable until geometry is too much approximated
  - Fast computation times (around 2 minutes for reduction and thermal calculus for this model). And faster at each iteration.

**Note:** The prototype shows that the algorithm can be improved. Even if the geometry is drastically corrupted, the temperatures are still acceptable thanks to the chosen reduction metric preserving the areas.

**Iteration 8:**
- 370 faces
- Distortion: 1.838° C

But antennas can still be reduced without altering too much the global geometry!
Physics driven geometrical model reduction

- **Future works on geometric model reduction**
  - Progressive reduction (with adaptive ratio for each reduction step)
  - Reduce large clusters first to avoid small clusters to be too much approximated

- **Future works for thermal simulation**
  - Test on a complete radiative model by adding maskings & shadows for incident fluxes (albedo, solar & Earth)
  - Test on a real model, with ESA permission Sentinel-3 and BepiColombo are good candidates
  - Examine standard exchange formats between our reduction outputs and STEP-TAS & STEP AP203
  - Sensitivity analysis on thermo-optical properties, use of machine learning to acquire thermal expertise about what drives the reduction process
Future works for 3D conductive couplings

- Implement a new oracle for 3D conductive couplings (finite elements computations)
- Max distortion based on conservation of defined interface nodes conductive couplings
- The oracle could be improved to preserve mechanical structures characteristics

**Note:** Edge connectivity conforming is not required for the radiative calculation. Due to finite elements (volumic connectivity), the edge connectivity between clusters is mandatory.
Thank you for your attention!

Questions are welcomed!