Current LS-DYNA® Developments in Thermal Radiation

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Motivation

Heat transfer

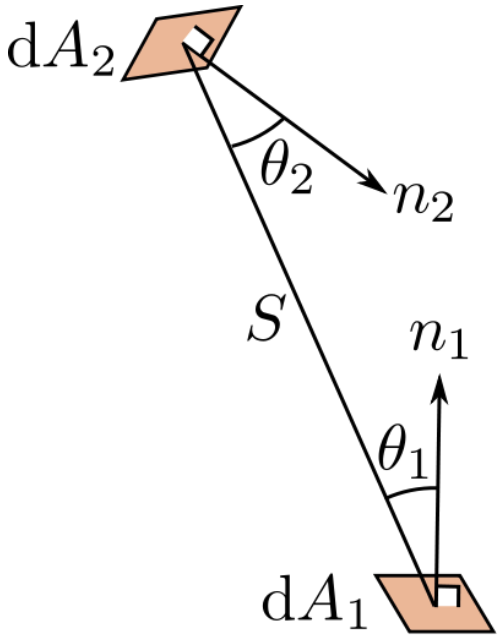
- Thermal Conduction – heat transfer inside a body
- Thermal Convection – heat transfer by the movement of a fluid
- Thermal Radiation – heat transfer from a surface to another surface via electromagnetic radiation

Examples thermal radiation in an enclosure

- Temperature distribution in an engine compartment
- Temperature distribution muffler system
- Paint and adhesive curing in oven

View Factor

- View factors are essential to solve the thermal radiation problem
- A view factor is the relation of the diffuse energy leaving surface dA_1 and reaches surface dA_2 and the total energy leaving surface A_1 .
- $F_{1\to 2} = \frac{1}{A_1}\int_{A_1}\int_{A_2}\frac{\cos\theta_1\cos\theta_2}{\pi s^2}dA_2 dA_1$



Source: Wikipedia

Current Feature Set

LS-DYNA provides a feature to calculate the effects of thermal radiation via the keyword *BOUNDARY_RADIATION_..._VF_...

Usage:

- Define all surfaces which emit heat
- Define emissivity of the surface (can be defined temperature dependent)
- Calculate the view factors or read them from an ASCII file
- View factor calculation can be done in LS-DYNA SMP version (shared memory version) and LS-DYNA MPP version (massively parallel processing)
- Solving for radiosity can only be done in LS-DYNA SMP version

Characteristics *BOUNDARY_RADIATION_..._VF_...

- Overall memory and cpu time consuming
- Main contributor to memory and cpu time is the calculation of the view factor matrix
- View factors are calculated for each segment interacting with all other segments; the memory quadratically with number of segments
- Practical for moderate size problems
- Difficulties in combining with other LS-DYNA features which require LS-DYNA MPP or HYBRID versions (HYBRID is a combination of MPP and SMP)

Objective

- Implementation of a new solver to solve for radiosity
- Available in LS-DYNA MPP or HYBRD versions to couple with other LS-DYNA features, namely the fluid solver for large problems
- Needs to scale in memory and cpu time
- Visualization of the view factors in LS-PrePost

Algorithm

- Solve $\left[\delta_{ij} - \frac{(1-\varepsilon_i)}{A_i \varepsilon_i} F_{ij}\right] \cdot B = \sigma T^4$ for Radiosity B

  δ_{ij}… Kronecker delta

  A_i… area of segment i

  ε_i… emissivity of segment i

  F_{ij}… View factor matrix

  σ … Stefan–Boltzmann constant

  T … temperature

- Conjugate gradient method is used to solve the above equation (also used to smooth the view factor matrix if requested).

- Add possibility to choose different solvers

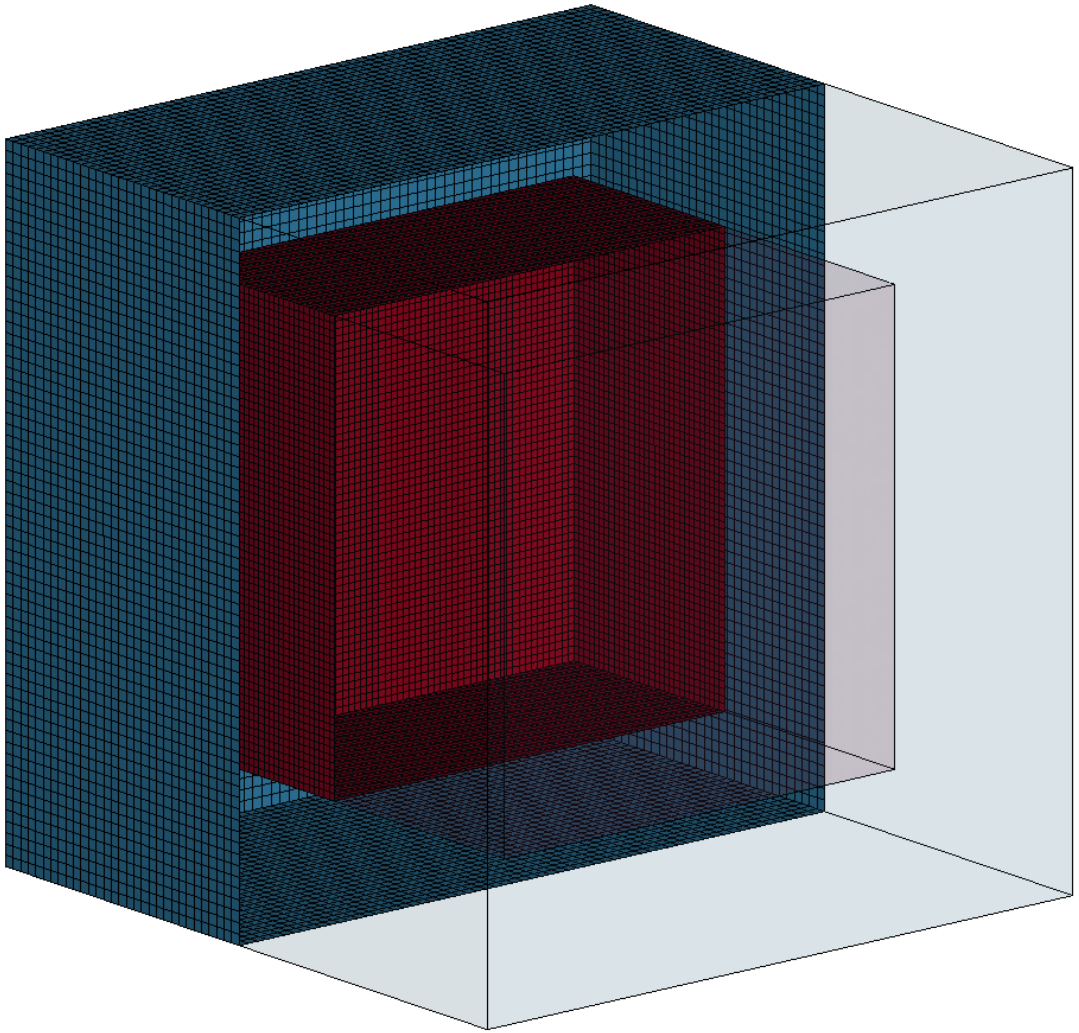
Scalability

Test case model

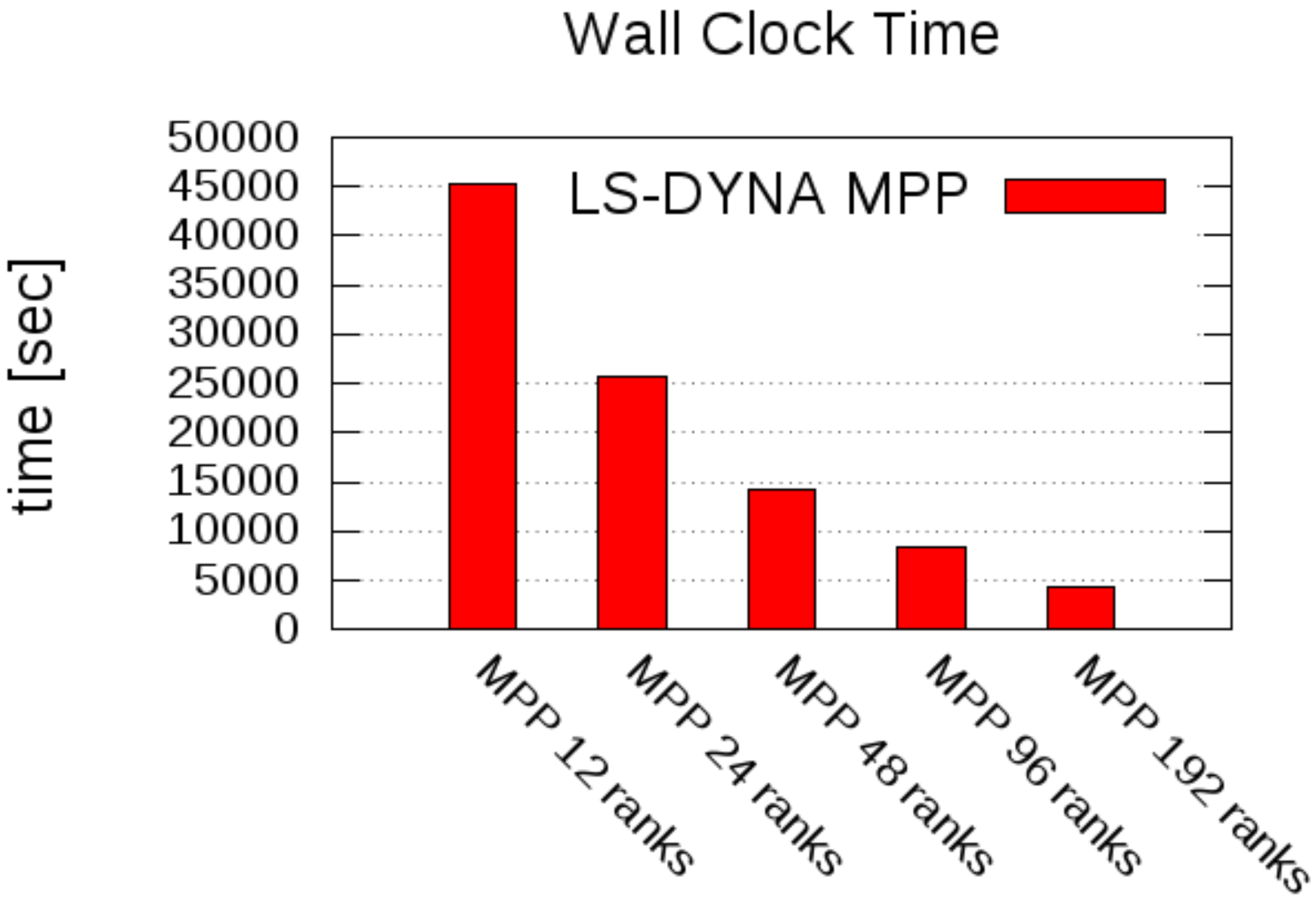
- Cube in cube
- ~ 49k segments

Run environment

- Intel® Xeon® CPU E5645 @ 2.40GHz
- Infiniband Interconnect



Scalability



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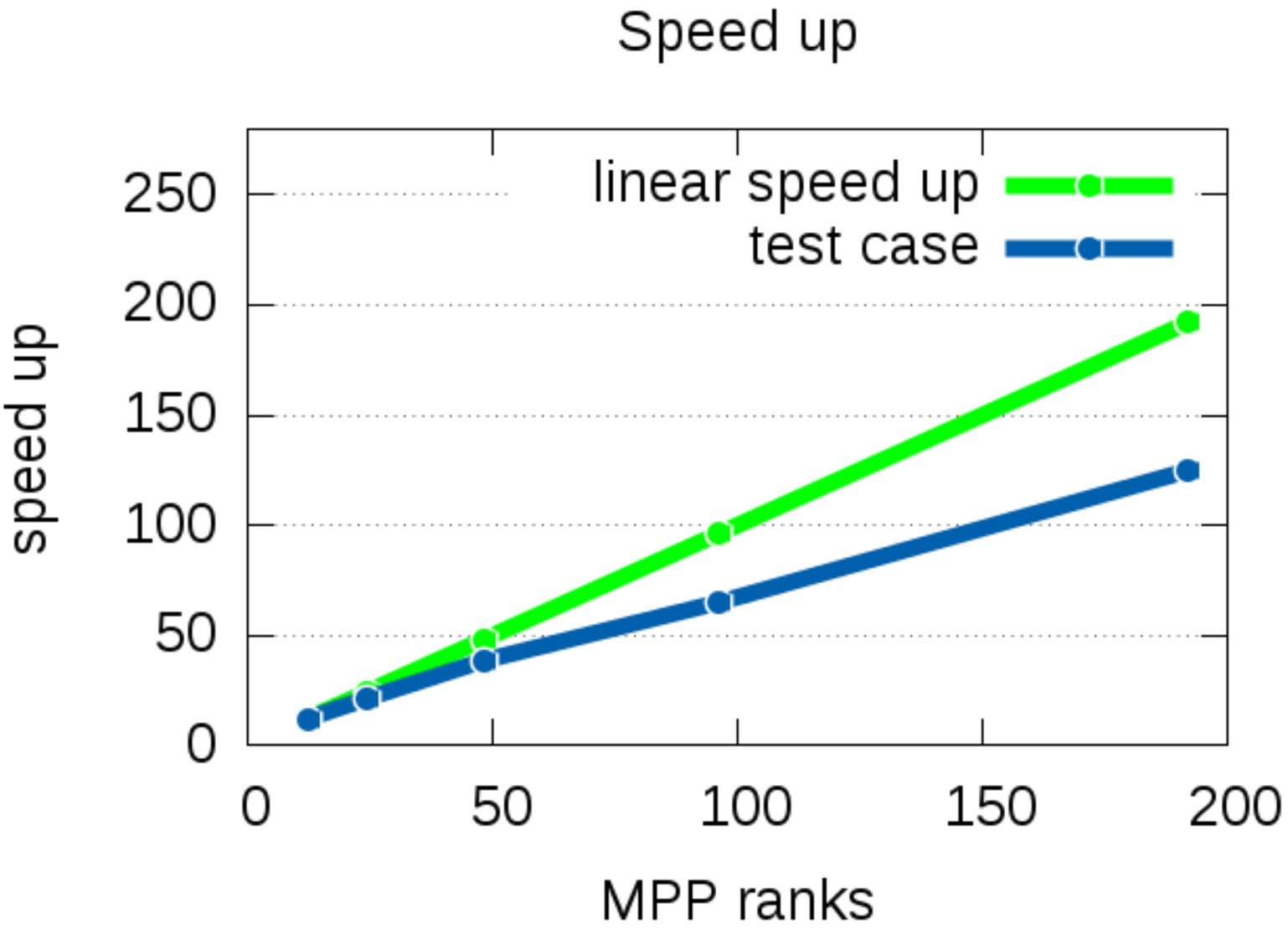
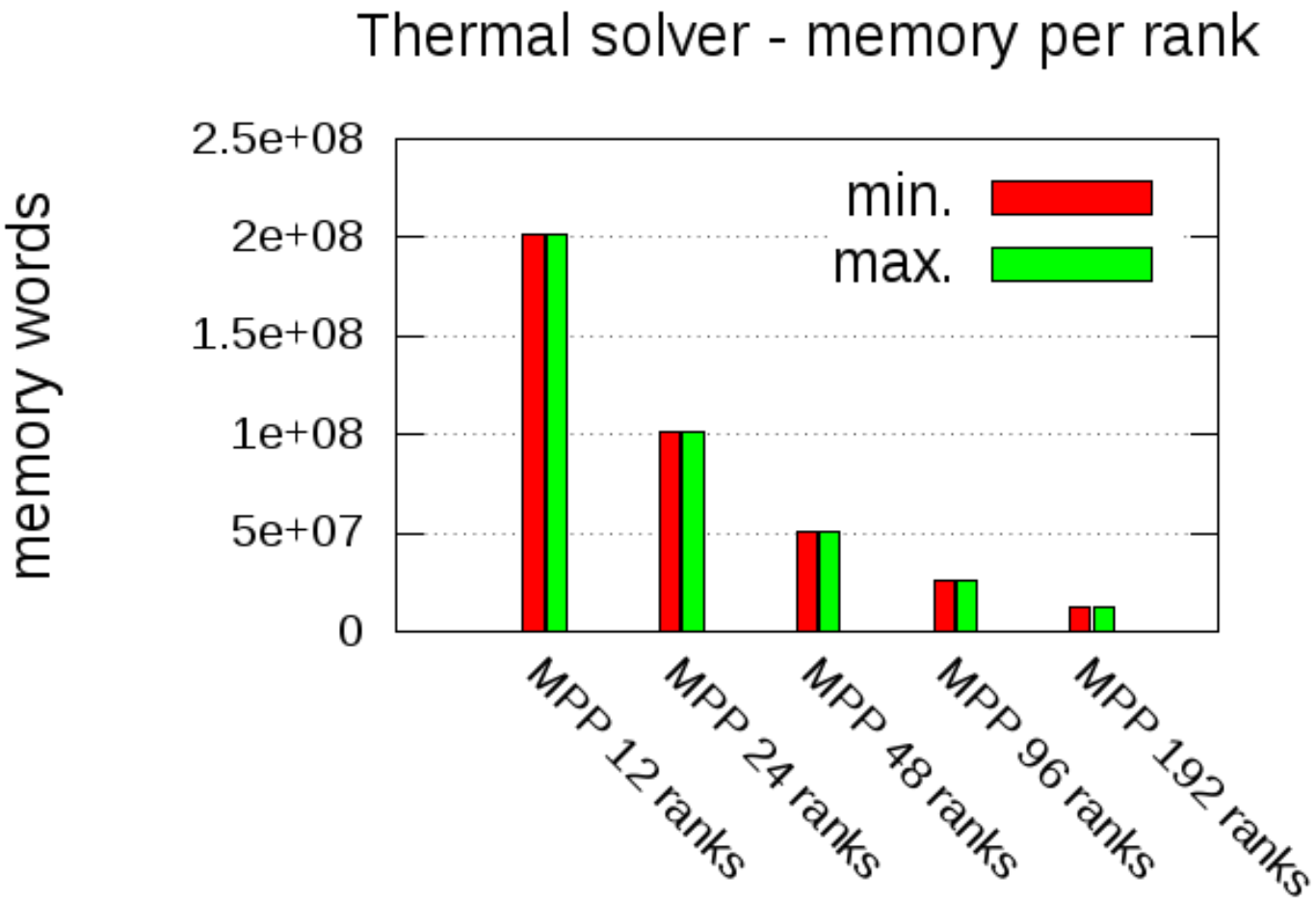


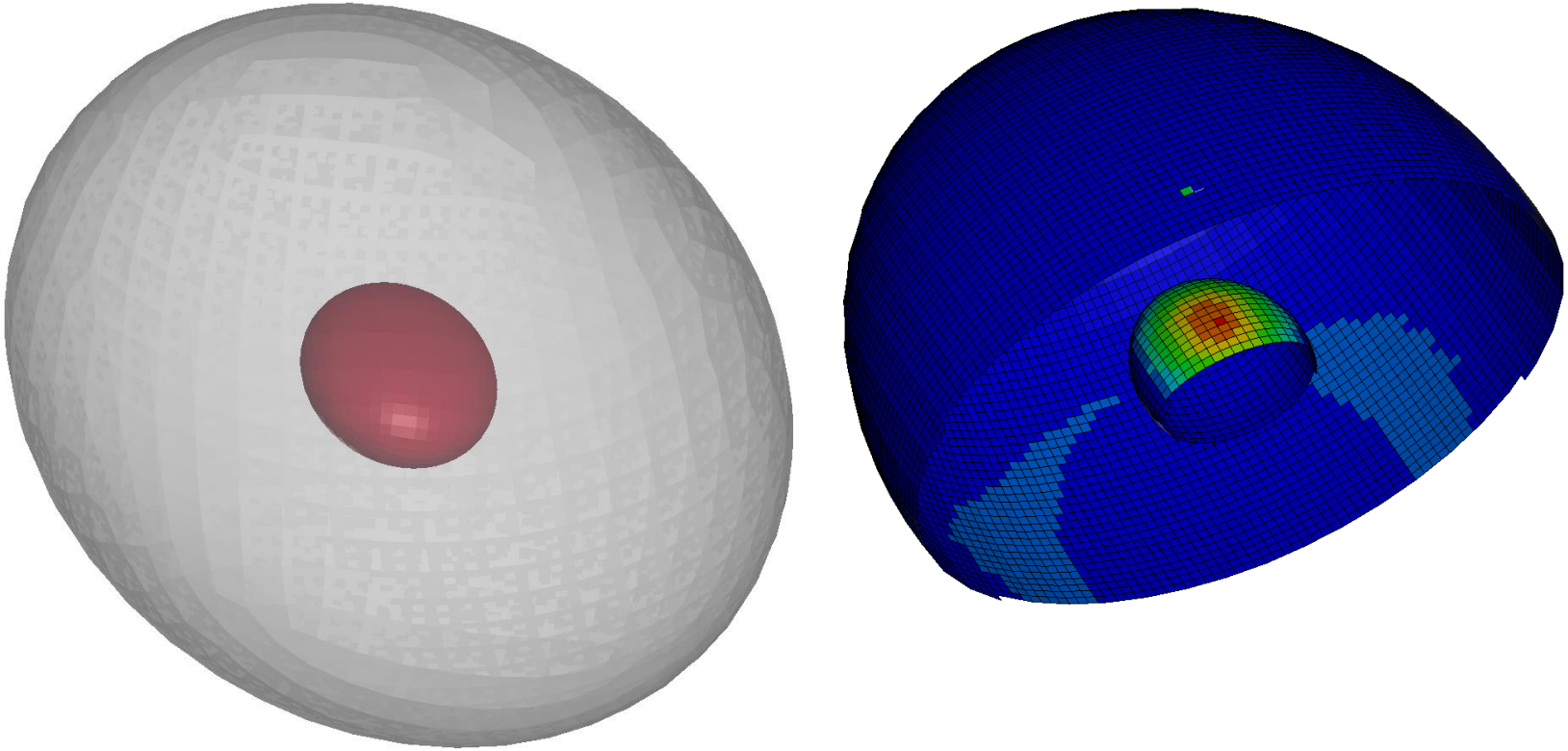
Scalability



Remark: memory does not include BR solver and view factor calculation overhead

Visualization

- Example: test case ellipsoid in ellipsoid contains 16713 segments, view factor matrix has 16713^2 components (~ 280 M)
- lsda format



Ellipsoid in Ellipsoid model

Keyword Format

Enclosure and view factor options

Enclosure ID and Name								
Card 1	1	2	3	4	5	6	7	8
Variable	BRENCID	ENCNAME						

BRENVID Boundary radiation ID for this enclosure

ENCNAME Name of enclosure, used for output purposes

View factor options								
Card 2	1	2	3	4	5	6	7	8
Variable	CALOPT	OUTOPT	CONOPT	INCR				

CALOPT Calculation option: View factors

OOPT Output option: view factor file format

CONOPT Control option: calculate view factors matrix and preform thermal analysis

INCR Time increment, recalculating the view factor matrix.

View factor output file name								
Card 3	1	2	3	4	5	6	7	8
Variable	FILENAME							

FILENAME File name for the view factor output file

Keyword Format

Smoothing and radiosity solver options

View factor matrix smoothing								
Card 4	1	2	3	4	5	6	7	8
Variable	SMFLAG	SMSTYP	SMMAXI	SMABST	SMRELT			

SMFLAG View factor matrix smoothing flag

SMSTYP View factor smoothing solver

SMMAXI Maximum number of iterations for view factor matrix smoothing

SMABST Absolute convergence tolerance for view factor matrix smoothing

SMRELT Relative convergence tolerance for view factor matrix smoothing

Radiosity solver options								
Card 5	1	2	3	4	5	6	7	8
Variable	STYPE	SLMAXI	SLABST	SLRELT	SLMLEV	SLMDB		

STYPE Solver type

SLMAXI Maximum number of iterations for radiosity solver

SLABST Absolute convergence tolerance for radiosity solver

SLRELT Relative convergence tolerance for radiosity solver

SLMSGL Radiosity Solver message level

SLMDB Radiosity Solver matrix debug, check positive definiteness

Keyword Format

Segment set definitions (repeating cards)

Segment set								
Card 6	1	2	3	4	5	6	7	8
Variable	SSID							

SSID SSID specifies the ID for a set of segments that comprise a portion of, or possibly, the entire enclosure. See *SET_SEGMENT.

Segment set characteristics								
Card 7	1	2	3	4	5	6	7	8
Variable	NINT	BLOCK	SSLCID	SSLCM				

NINT Number of integration points for view factor calculation:

BLOCK Flag indicating if this surface blocks the view between any other 2 surfaces.

SSLCID Load curve ID for surface emissivity (see *DEFINE_CURVE)

SSLCM Curve multiplier for surface emissivity; see *DEFINE_CURVE.

Summary

- Current state of the development in thermal radiation
- Enhancements scale memory and cpu time wise
- A new binary output format for the view factor was implemented. This binary format can be read in by LS-PrePost® to visualize the view factors
- New keyword format is introduced
- Beta version should be available 11/2018

Acknowledgments: Jason Wang, Brian Wainscott and Lee Bindeman

Thank you for your attention