SAND2015-8437C

Exceptional service in the national interest

Mesh Optimization for Grid-Based Hex Meshes

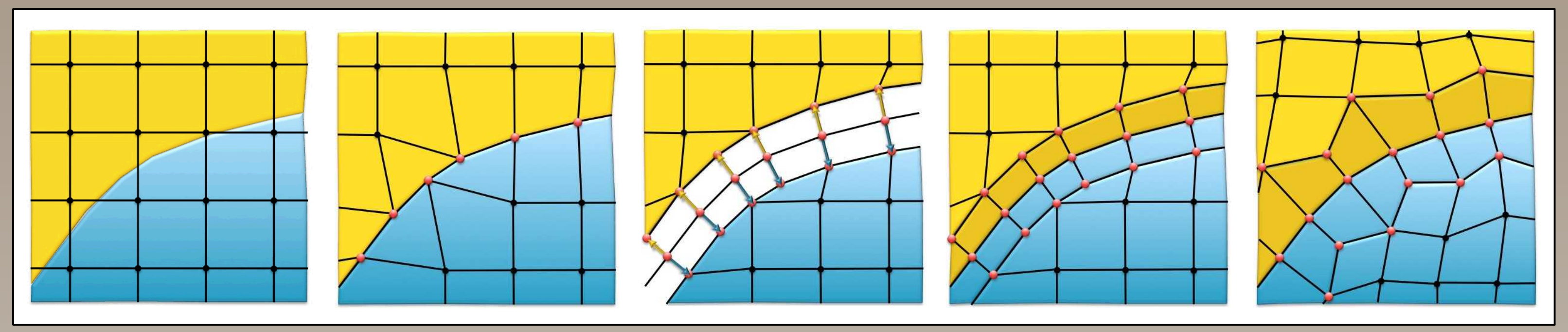
Steven Owen

Sandia National Laboratories

Mesh Optimization in Sculpt

Mesh Optimization is critical to grid based hex meshing tools such as Sandia's Sculpt tool. Work was accomplished this year (FY15) to improve overall success of Sculpt by dramatically increasing minimum mesh quality through a new procedure for parallel smoothing. It incorporates Laplacian and Optimization smoothing but adds damping and parallel coloring to achieve improved results.

Sculpt Meshing Procedure



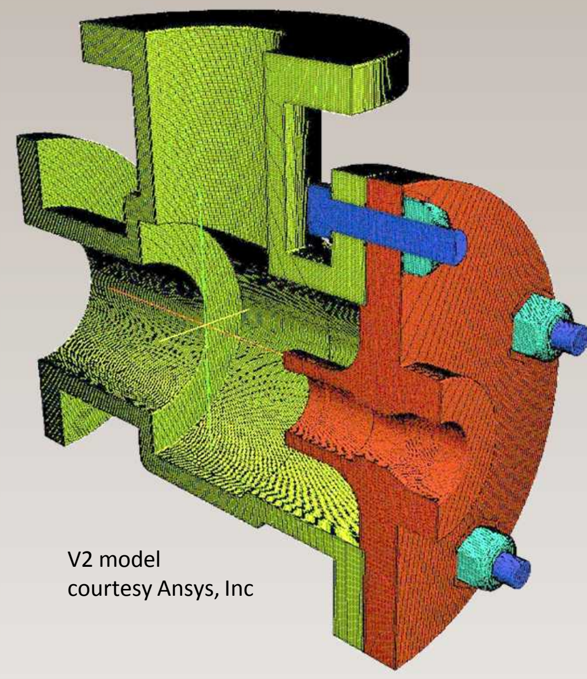
Overlay Cartesian Grid on Geometry

Nodes projected to interfaces

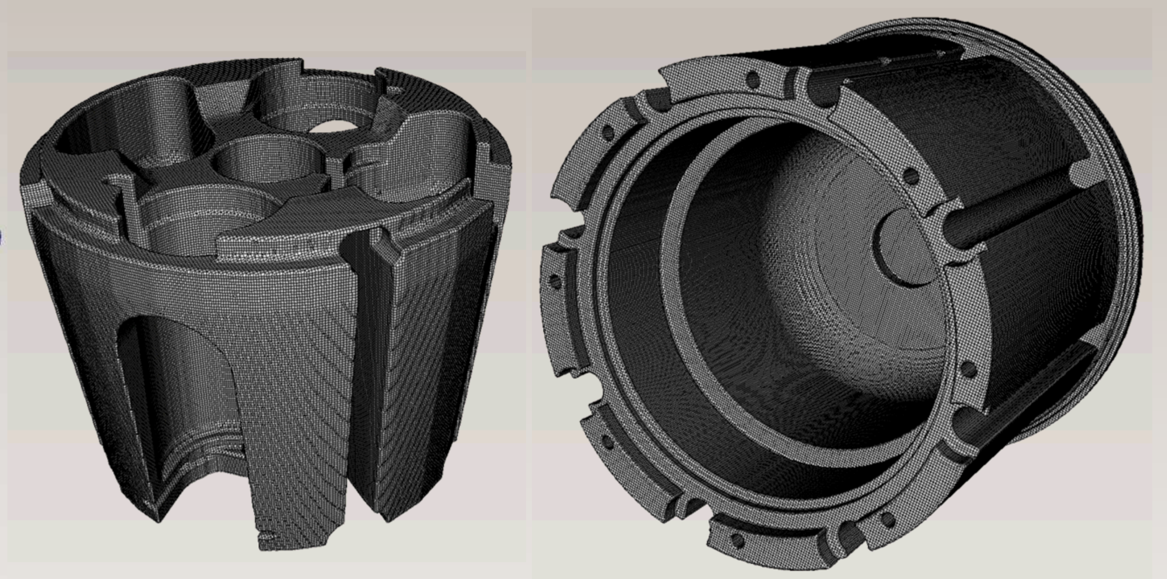
Nodes duplicated at interfaces and moved orthogonally

Layers of hexes created at interfaces

Smoothing performed

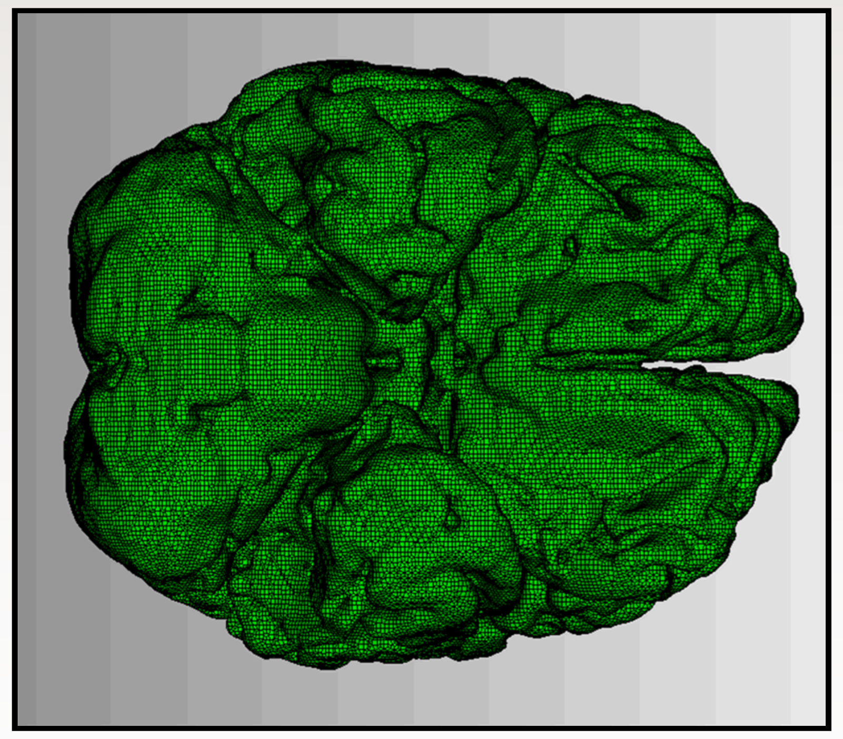


V2 model courtesy Ansys, Inc



Weapon Component Models Courtesy Stephen Recchia, US Army, Picitinni. Used with Permission

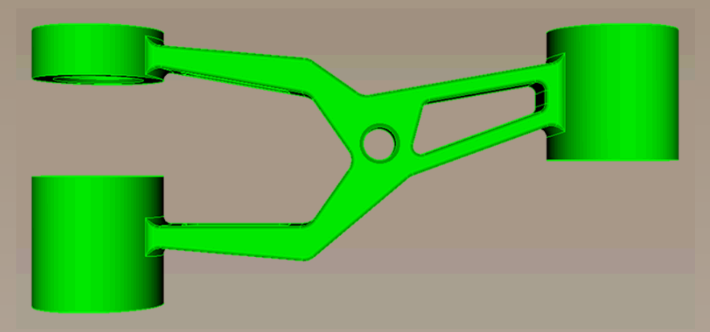
Weapon Component model, Sandia Labs



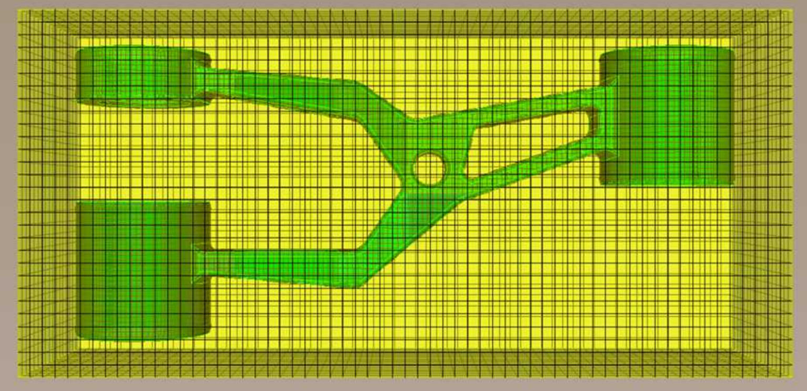
STL MRI Brain Model, Courtesy Bryce Owen, Brigham Young University, Provo, UT

Parallel Meshing in Sculpt

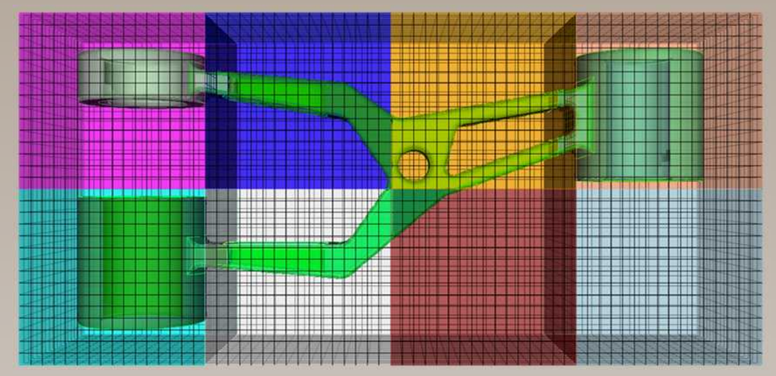
An overlay Cartesian grid is distributed among processors and a hex mesh is independently generated on each processor for a subset of the Cartesian domain. MPI is used for communication between neighboring processors to ensure continuity across processor boundaries. The same mesh will be generated regardless of the number of processors



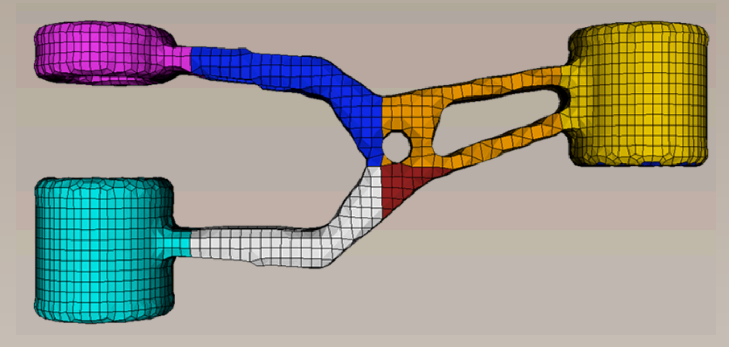
CAD geometry



Global overlay Cartesian grid



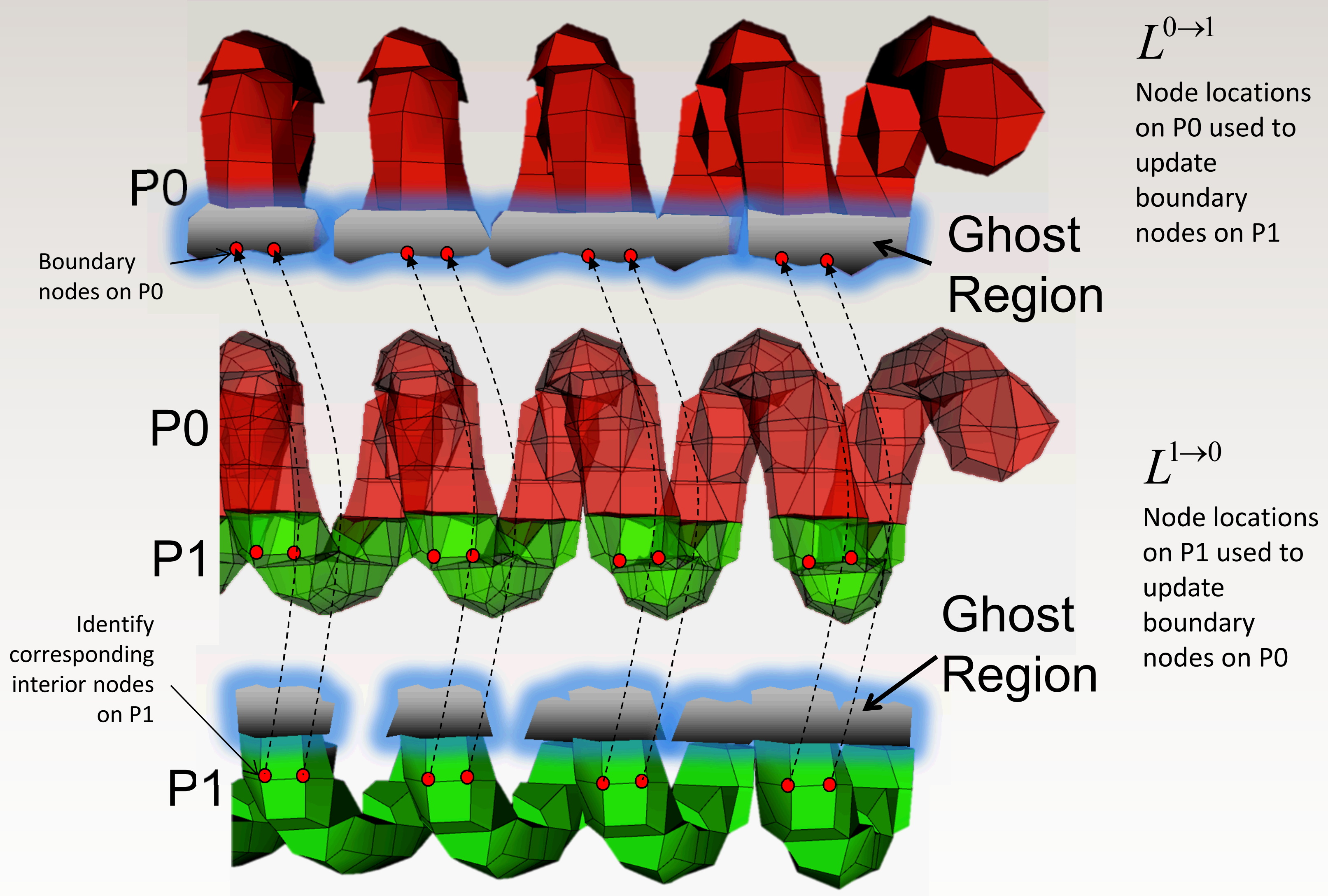
Cartesian grid decomposed and distributed amongst many processors



Each processor independently meshes its portion of Cartesian grid

Parallel Smoothing

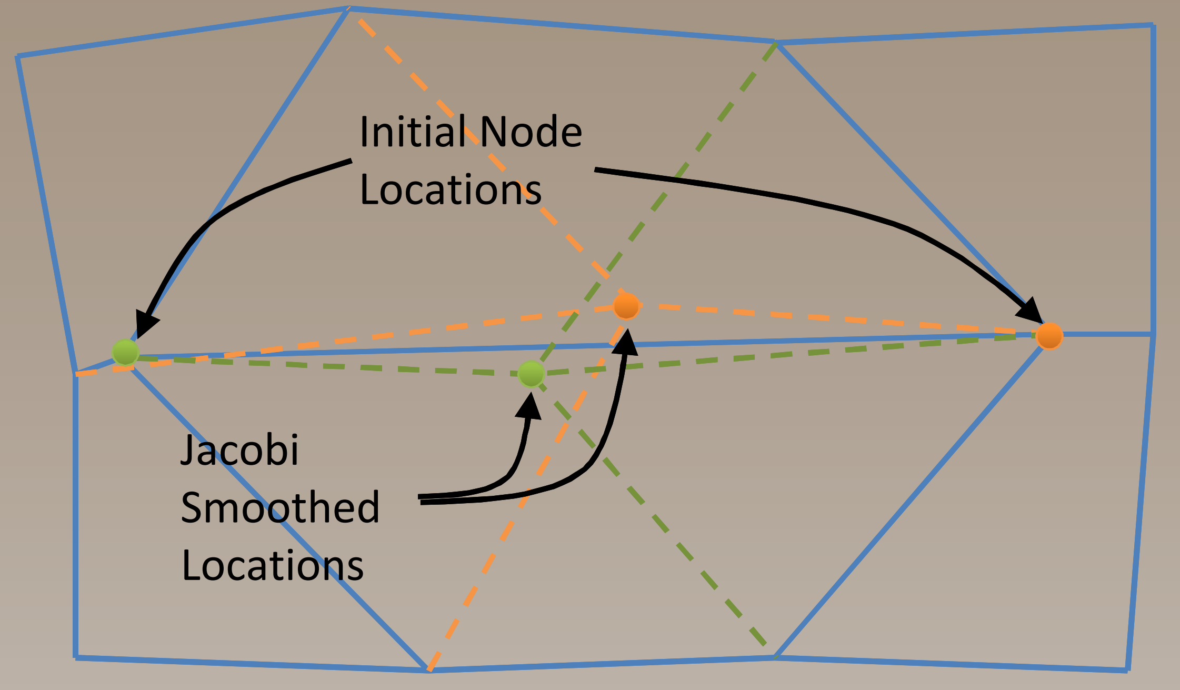
Ghosted elements and nodes are established and used to facilitate efficient MPI communication following each Jacobi iteration.



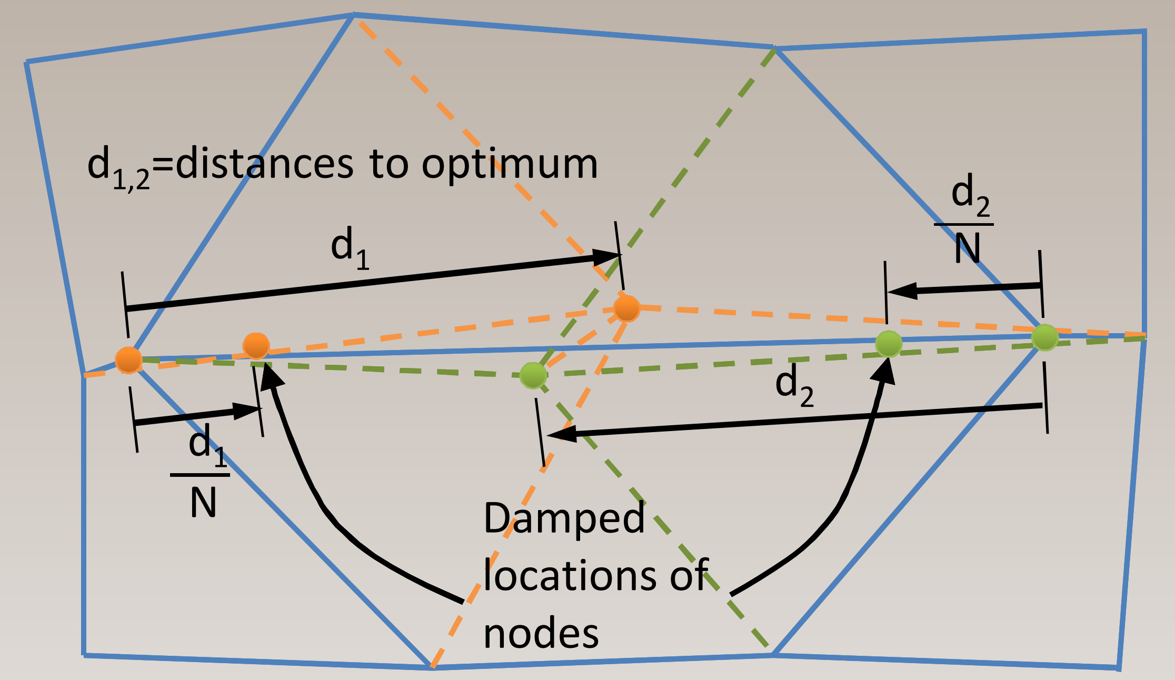
$L^{0\to1}$
Node locations on P0 used to update boundary nodes on P1
P0
Boundary nodes on P0
Ghost Region
P0
P1
$L^{1\to0}$
Node locations on P1 used to update boundary nodes on P0
Identify corresponding interior nodes on P1
Ghost Region
P1

Damping

With Jacobi optimization smoothing it is common to get inverted elements following one or two iterations that are normally resolved with additional iterations. However there are cases that can oscillate and not allow for improvement. Smooth damping is employed to slow convergence avoiding inversions.



Jacobi Smoothing can result in inverted elements

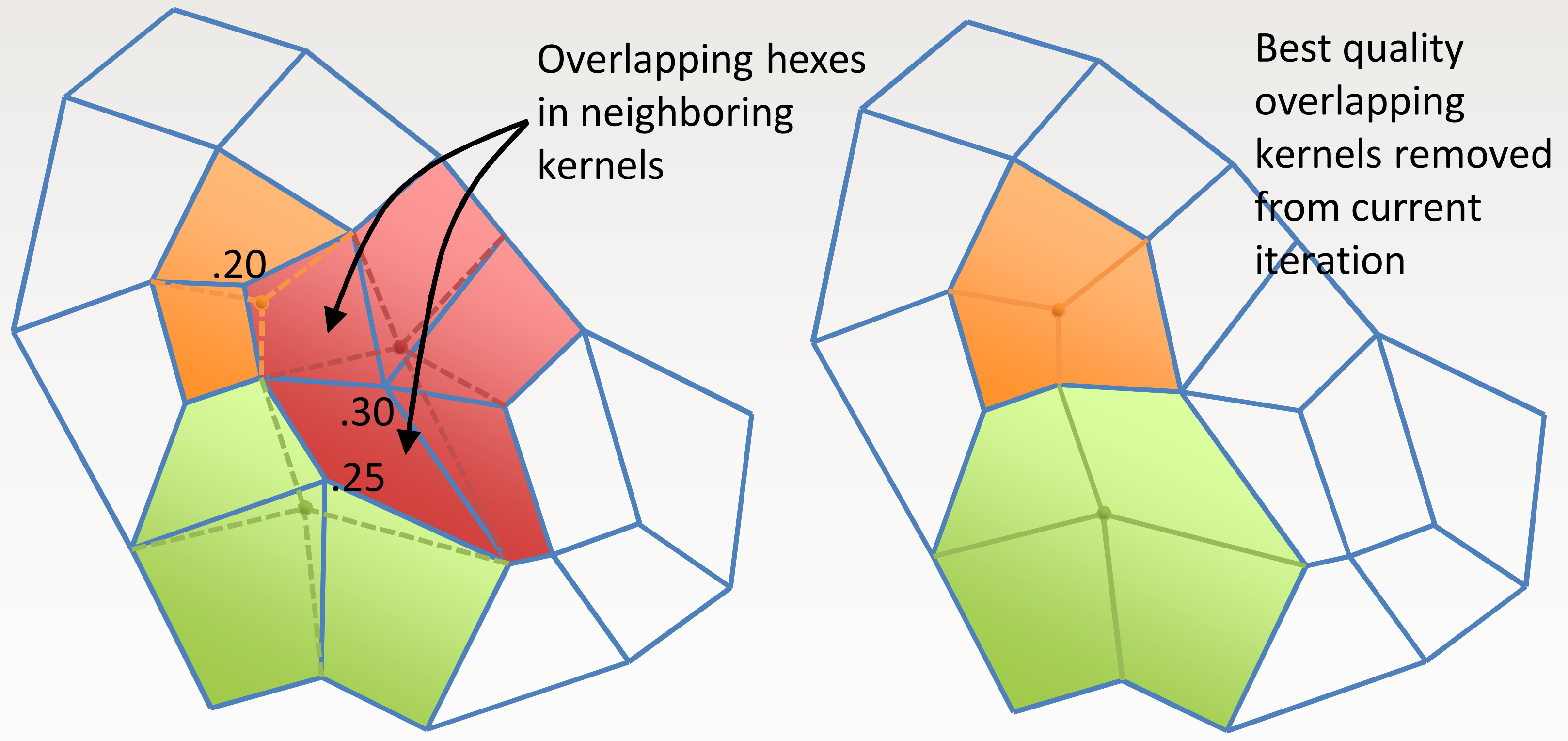


Damping limits the distance a node can move for a given iteration

N = number of remaining smoothing iterations

Parallel Coloring

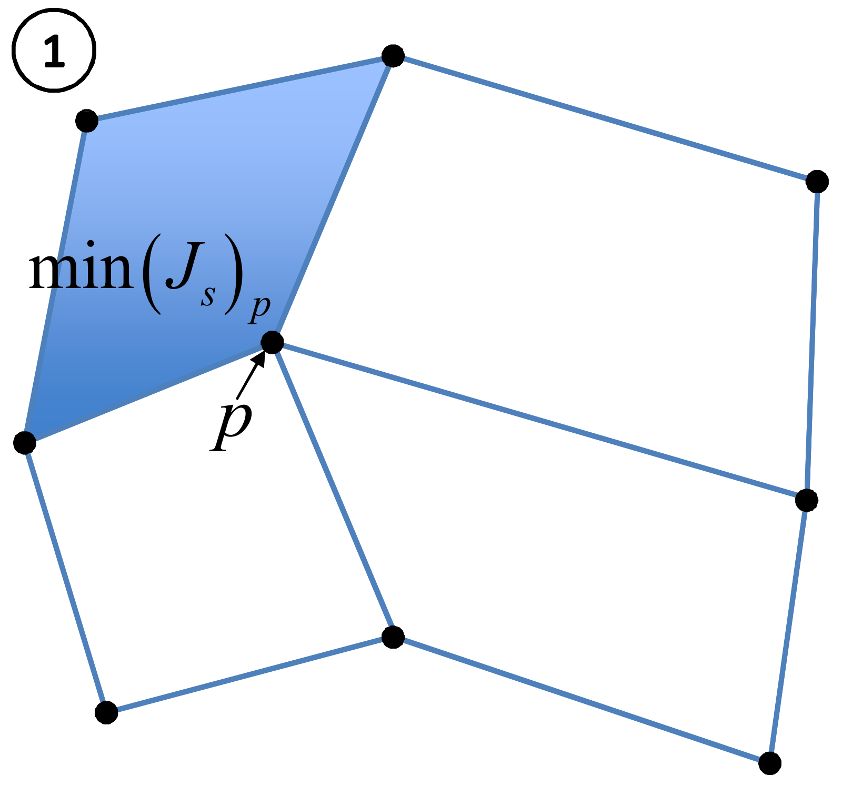
The coloring algorithm will attempt to isolate kernels of hexes surrounding a node so that kernels do not overlap. Selection of kernels is ordered based upon minimum scaled Jacobian at the node. For each Jacobi iteration only non-overlapping kernels of hexes are used.



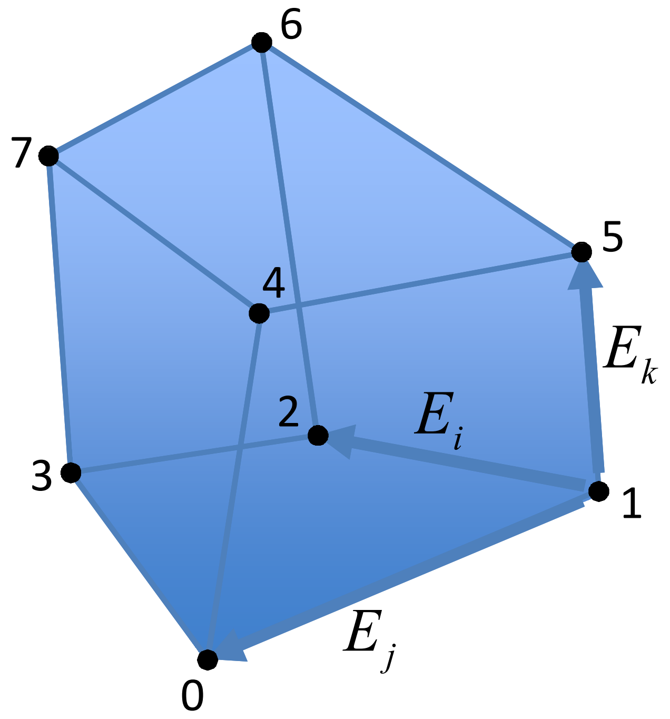
Overlapping hexes in neighboring kernels
.20
.30
.25
Best quality overlapping kernels removed from current iteration

Node Optimization

A combined Laplacian and Optimization smoothing procedure is used. Following a fixed number of Laplacian iterations, Optimization is run until a minimum Scaled Jacobian is achieved.



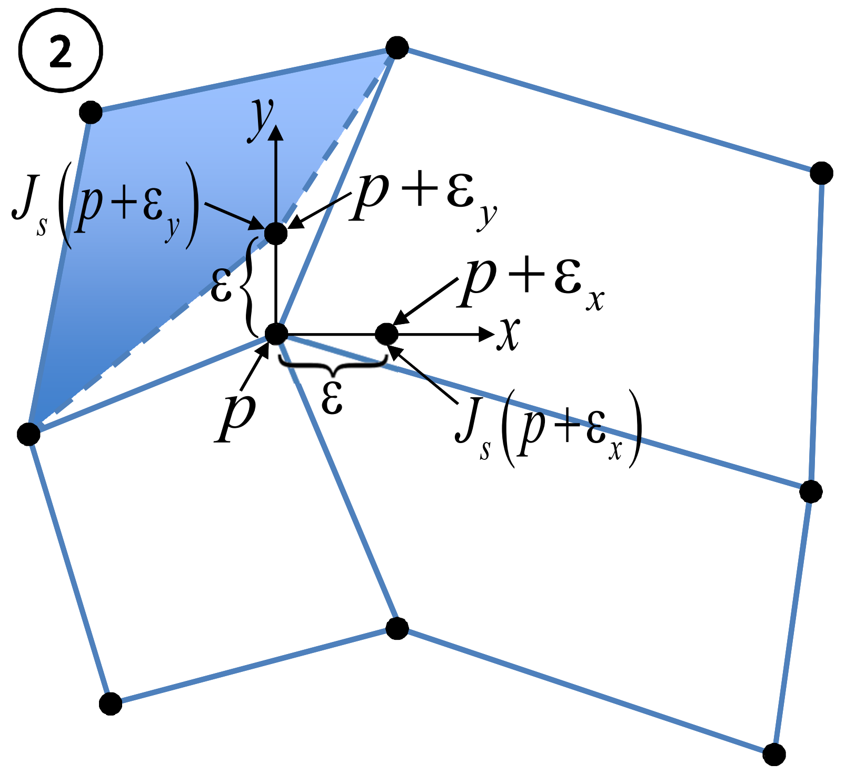
Compute minimum scaled Jacobian, $(J_s)_p$ of node p in all attached hexes



$$(J_s)_I = det\left\{\hat{E}_i\hat{E}_j\hat{E}_k\right\}^\top$$

$$J_s = min\left((J_s)_I, I = 0, 1, ...7\right)$$

Scaled Jacobian Definition

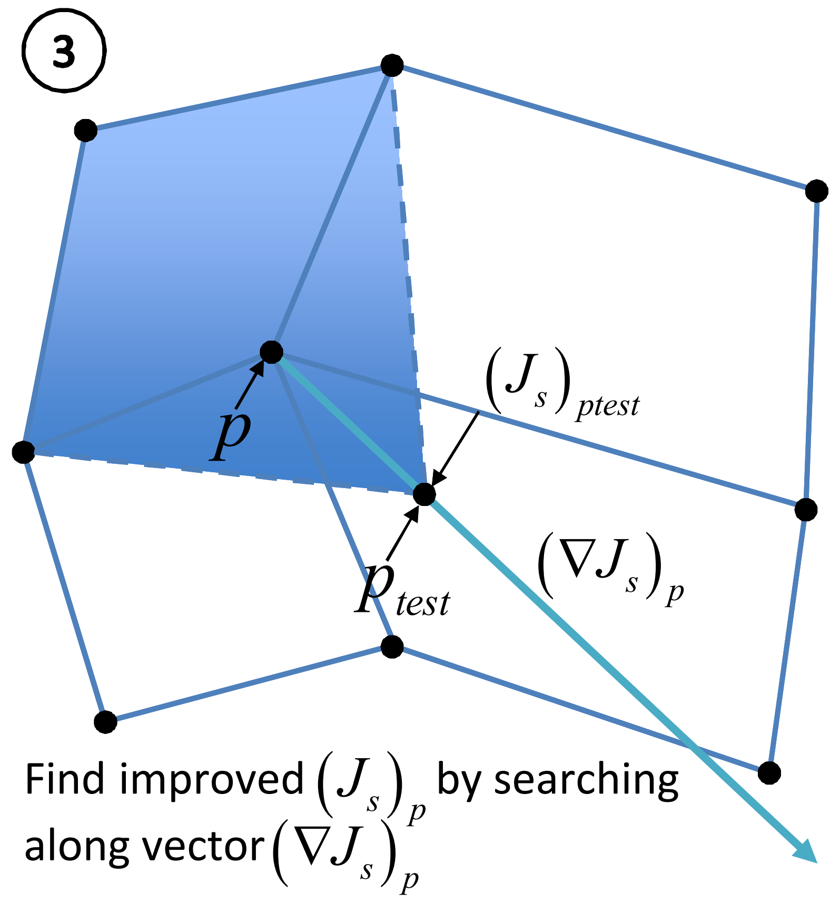


Compute numerical gradient $(\nabla J_s)_p$

$$(\nabla J_s)_{py} = \left\{\frac{J_s(p+\varepsilon_y) - J_s(p)}{\varepsilon}\right\}$$

$$(\nabla J_s)_{px} = \left\{\frac{J_s(p+\varepsilon_x) - J_s(p)}{\varepsilon}\right\}$$

Numerical Gradient



Find improved $(J_s)_p$ by searching along vector $(\nabla J_s)_p$

4

Procedure repeated until minimum J_s exceeds 0.2 or maximum iterations reached.

The standard scaled Jacobian definition is modified to account for a target element size

S_t =Target element size

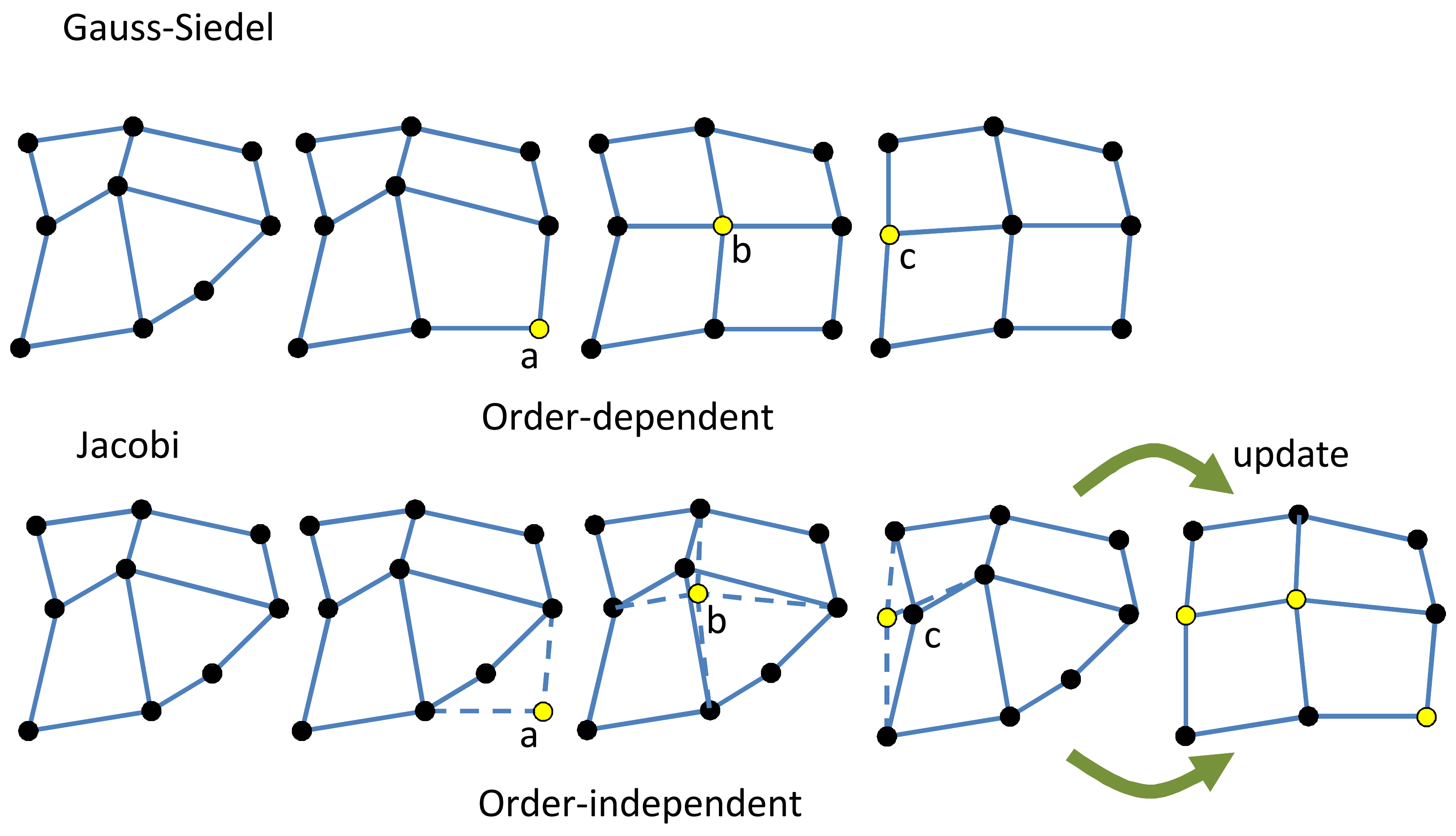
$$(J_s)_I = S_f det\left\{\hat{E}_i\hat{E}_j\hat{E}_k\right\}^\top$$

$$S_f = \begin{Bmatrix} e_s \le S_t, \frac{e_s}{S_t} \\ e_s > S_t, \frac{S_t}{e_s} \end{Bmatrix}$$

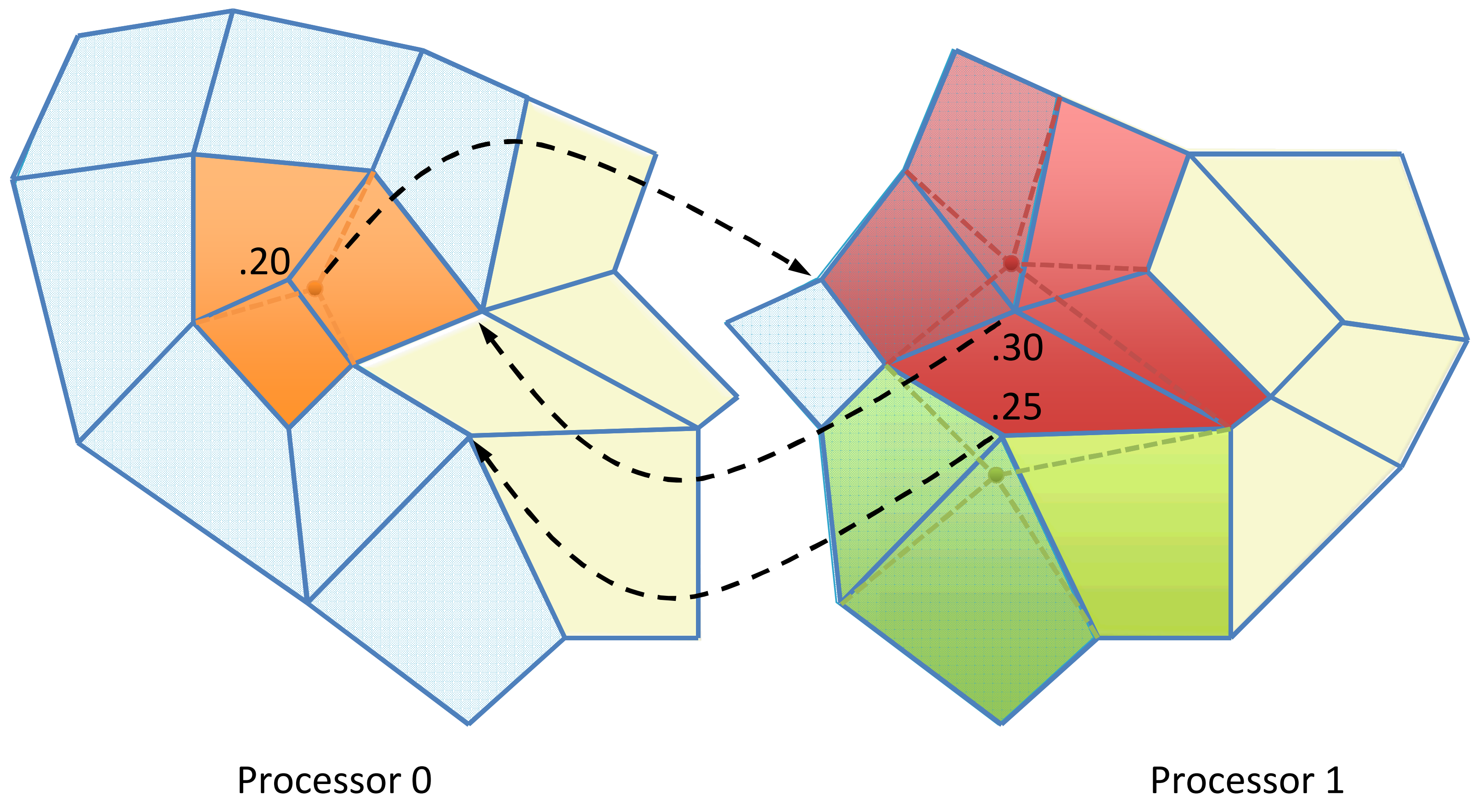
$$e_s = min(\|E_i\|, \|E_j\|, \|E_k\|)$$

Smoothing Strategies

For serial applications, where order of operations is normally not important, a Gauss-Siedel approach is used. In order to maintain parallel consistency we use a Jacobi-based smoothing procedure.



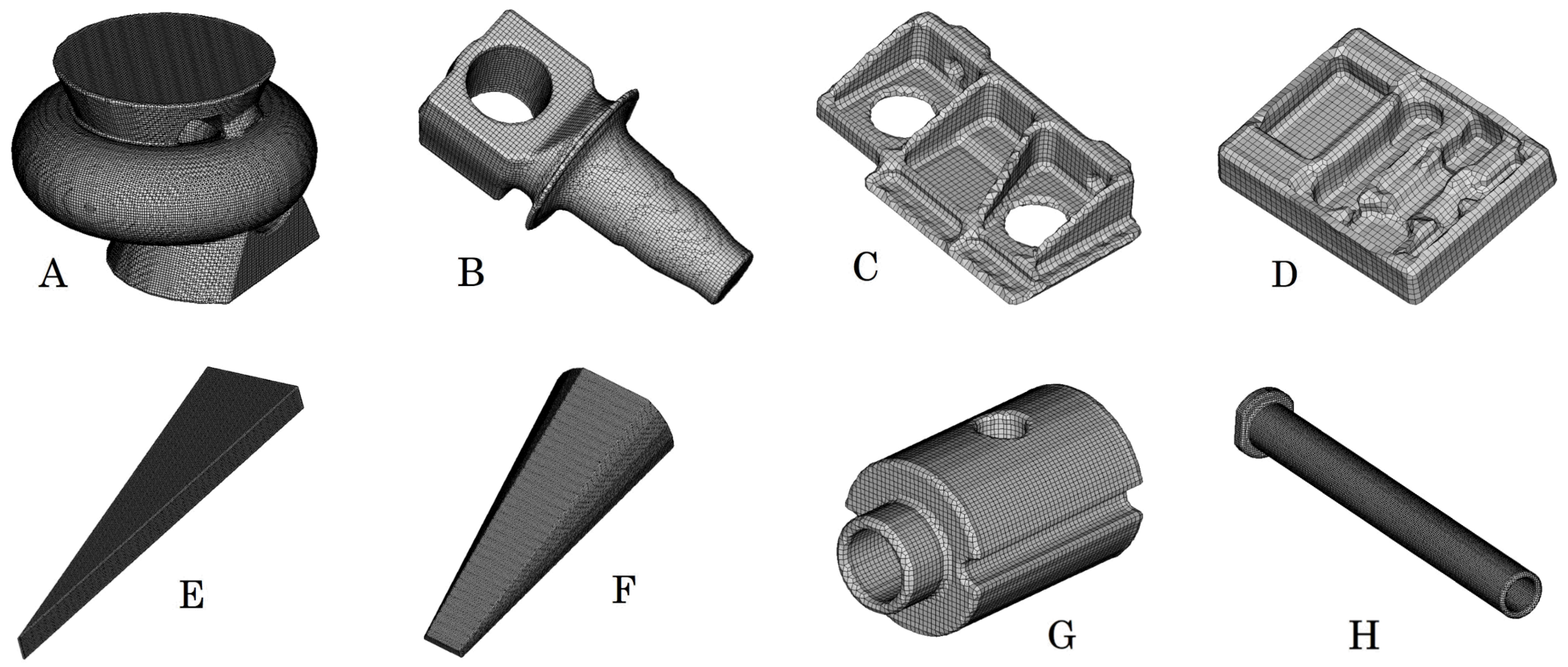
For parallel, master nodes must communicate with their ghosted (slave) nodes the minimum scaled Jacobian of their surrounding hexes. This ensures each processor consistently selects the same hex kernels for smoothing.



MPI communication of min Scaled Jacobian at node between neighbor processors

Sculpt Smoothing Comparison

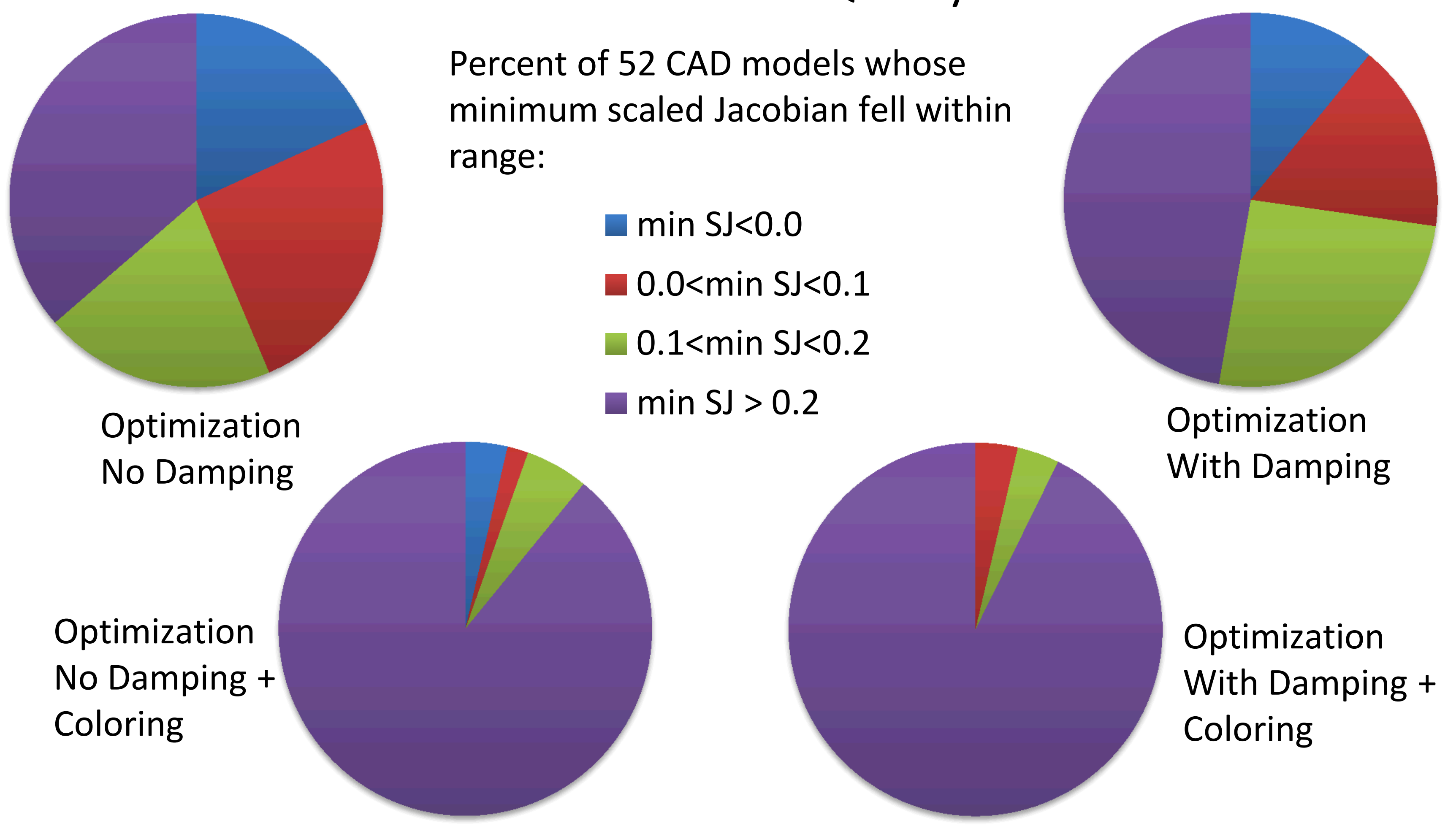
Sculpt's nightly test sweet includes a set of 52 single part CAD models. These were used in a comparison study of before and after new smoothing methods were employed.



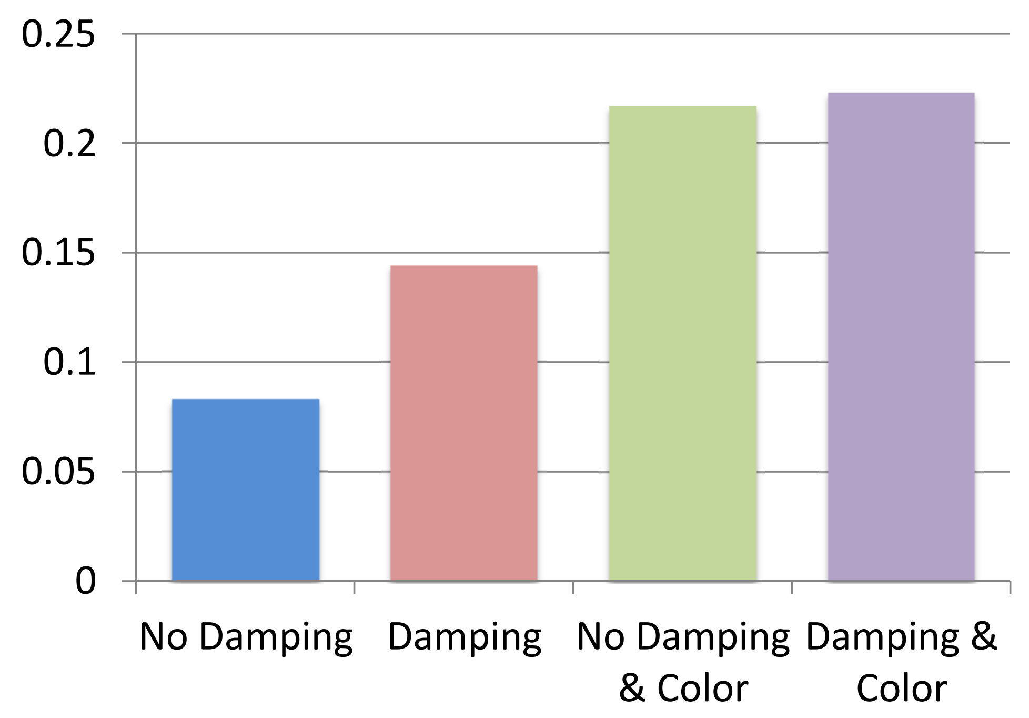
Examples of Test Suite Models: 52 Single Part CAD Models

Minimum Mesh Quality

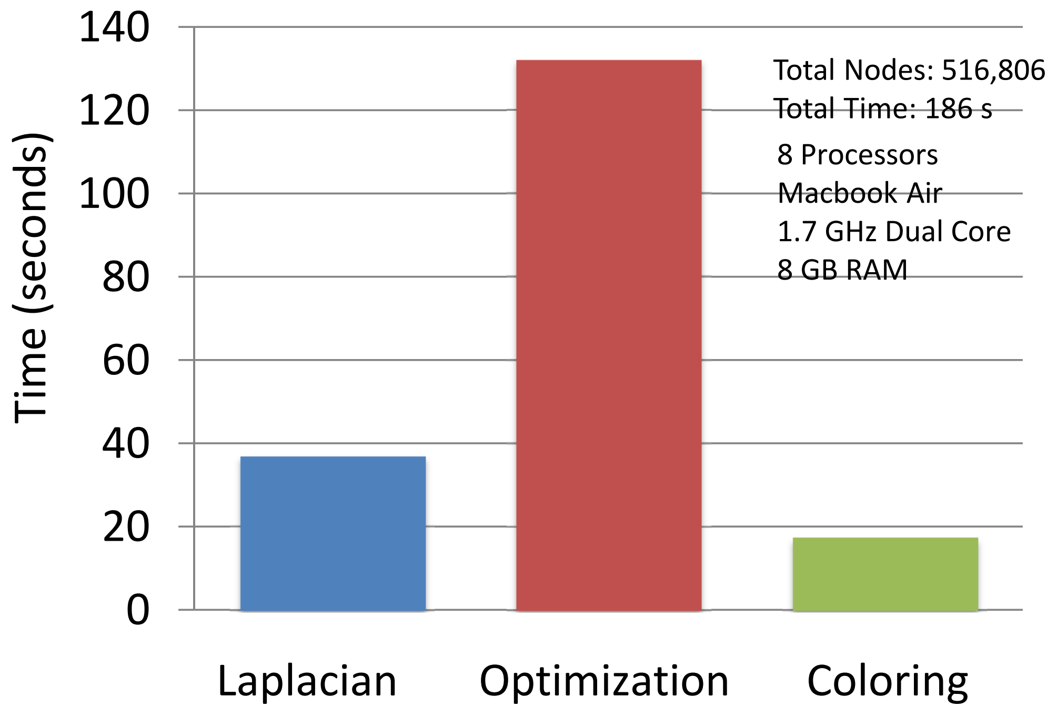
Percent of 52 CAD models whose minimum scaled Jacobian fell within range:



Average Minimum Mesh Quality

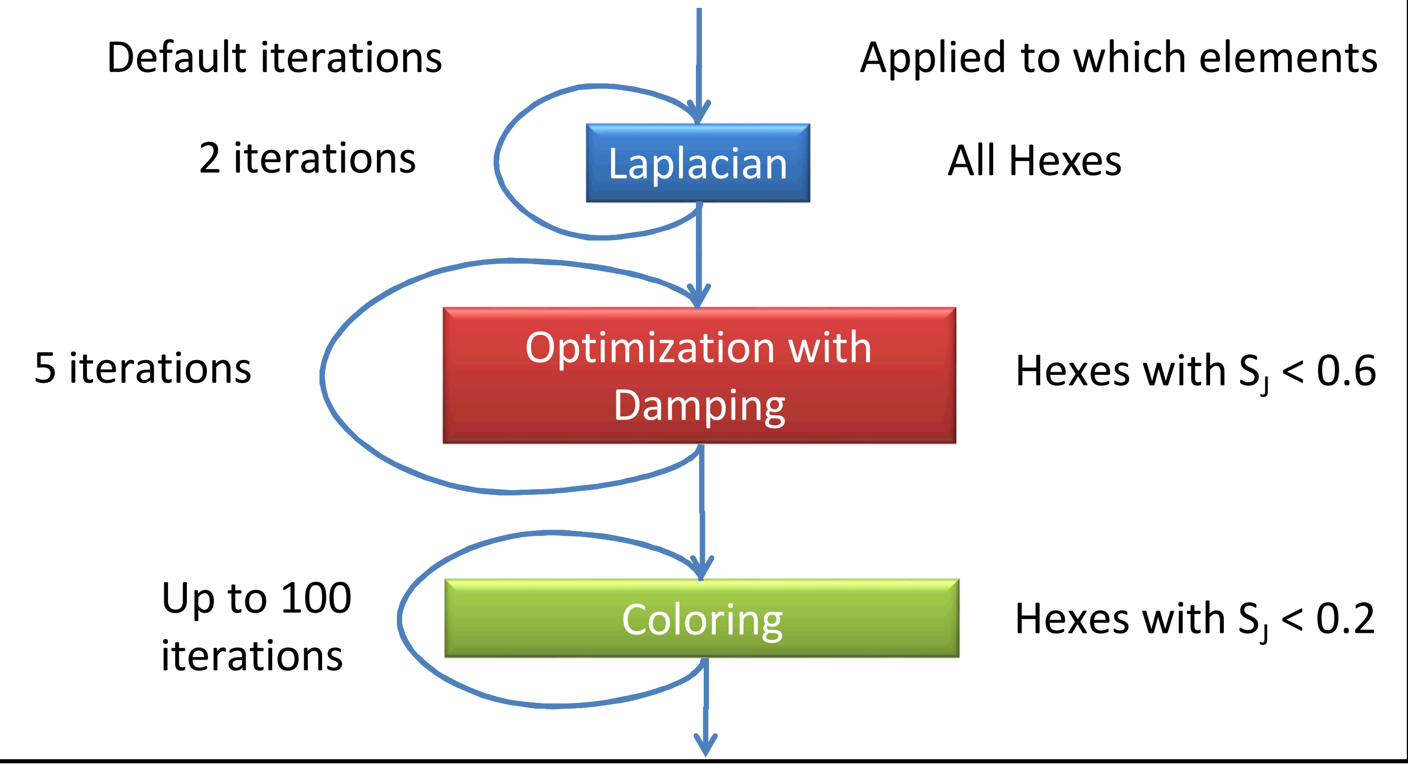


Total Time in Smoothing



Total Nodes: 516,806
Total Time: 186 s
8 Processors
Macbook Air
1.7 GHz Dual Core
8 GB RAM

Sculpt Smoothing Procedure



U.S. DEPARTMENT OF ENERGY
National Nuclear Security Administration

Sandia National Laboratories is a multi-program laboratory managed and operated by Sandia Corporation, a wholly owned subsidiary of Lockheed Martin Corporation, for the U.S. Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.
SAND No. 2011-XXXXP