Adaptive Hybrid Mesh Refinement for Multiphysics Applications

Presented by

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SC07

Office of Science
U.S. DEPARTMENT OF ENERGY

SciDAC
Scientific Discovery through Advanced Computing

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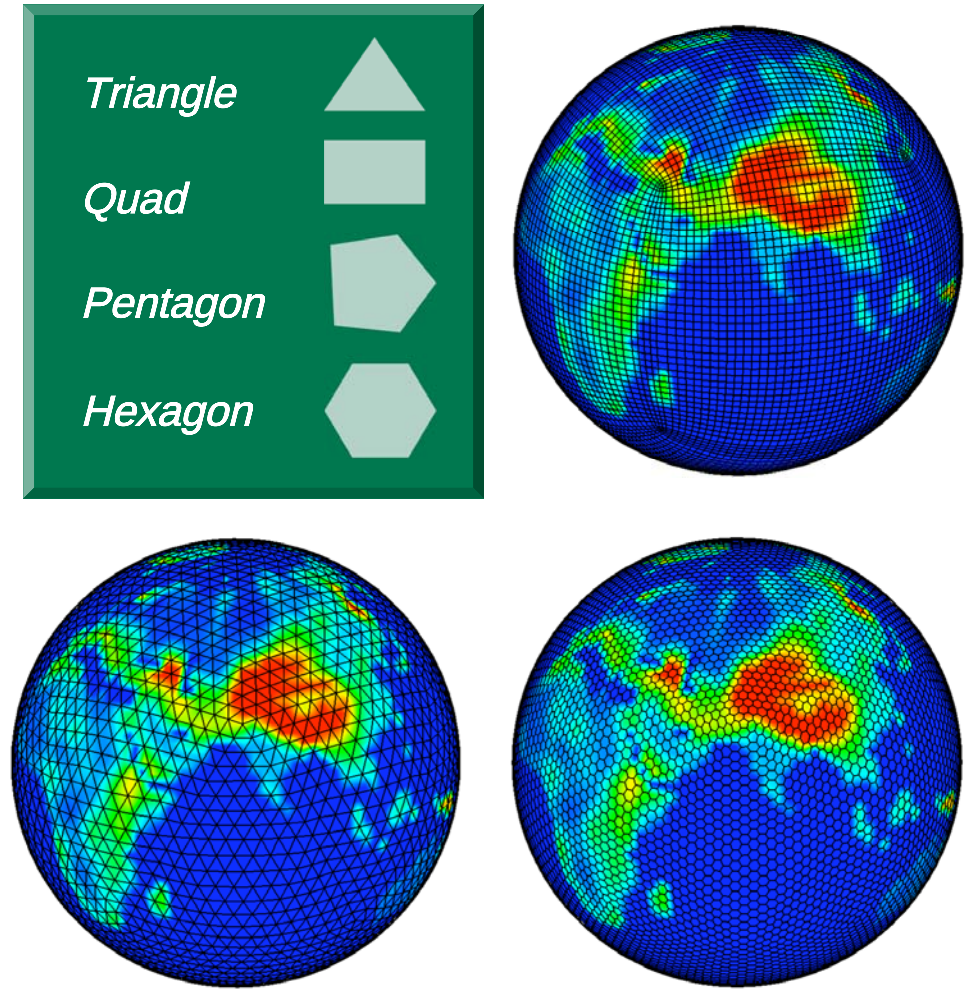
Hybrid mesh generation

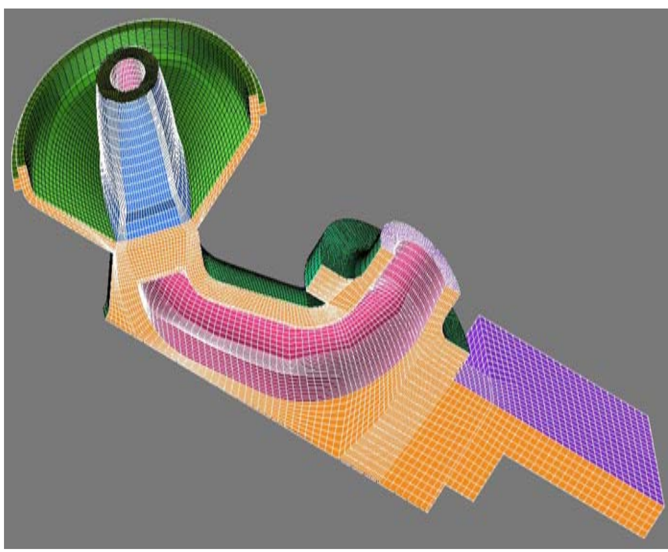
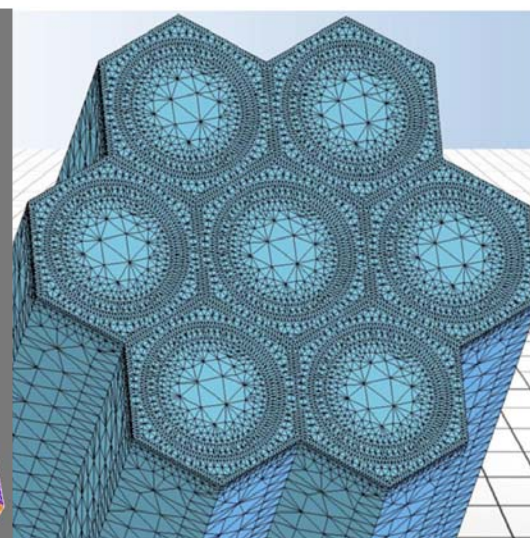
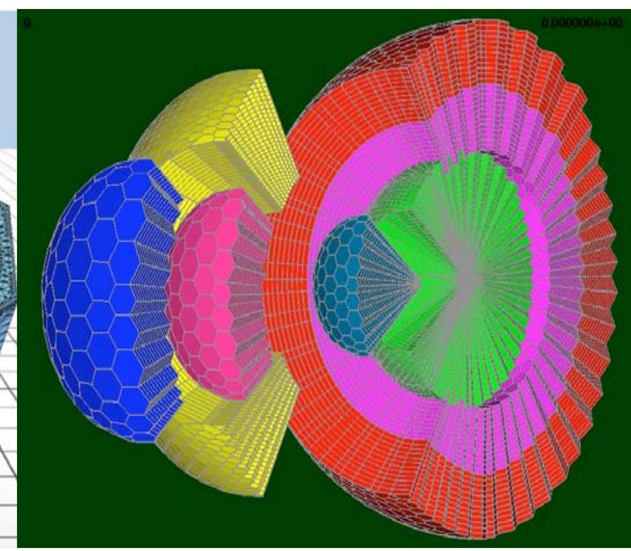
- Generation of isotropic or anisotropic structured, unstructured, or hybrid meshes.
- Mesh cell faces are composed of triangles, quads, pentagons, and hexagons.
- Mesh optimization algorithms to improve geometric quality measures such as angles, lengths, and areas.
- Elliptic and algebraic models are used to optimize and redistribute mesh nodes to capture geometric or simulation features.



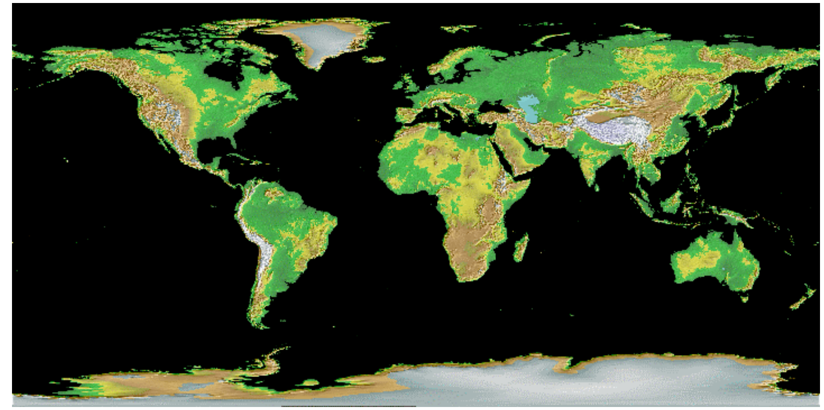
Multiphysics meshing requirements

- Different physics models impose distinct mesh requirements:
  - thermal-hydraulics in fluid regions
  - thermo-mechanics in solid regions
  - reaction/diffusion in fuel
  - neutronics everywhere

- Which physics model should define the mesh characteristics?
  - A fine, anisotropic mesh is used to capture boundary layer flow and heat flux.
  - A coarse mesh is needed for neutronics in the coolant channel.

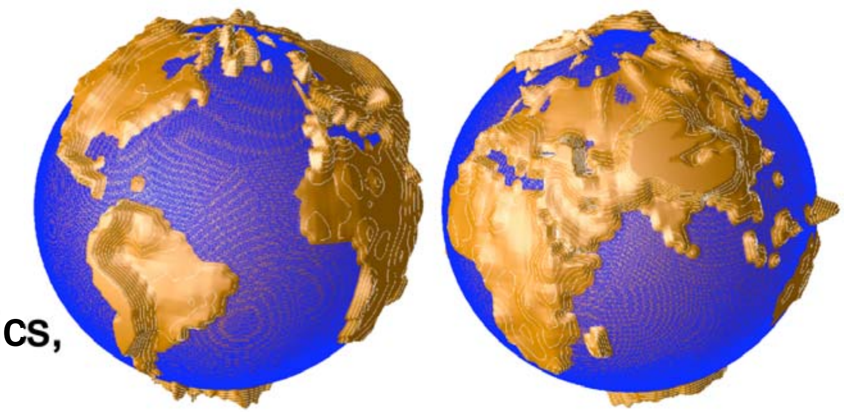




Adaptive shallow atmosphere simulation



Why orography and how it is used in climate codes

- Orography is the average height of land, measured in geopotential meters.
- Orography plays an important role in determining the strength and location of the atmospheric jet streams.
- The orographic impact is most pronounced in the numerical simulation codes for the detailed regional climate studies.
- Crucial parameter for prediction of many key climatic dynamics, elements, and moist physics, such as rainfall, snowfall, and cloud cover.



- The phenomena of climate variability are sensitive to orographic effects and can be resolved by the generation of finer meshes in regions of high altitude.
- Resolving orography produces a more accurate prediction of wetter or dryer seasons in particular regions.
- Orography defines the lower boundary in general circulation models.

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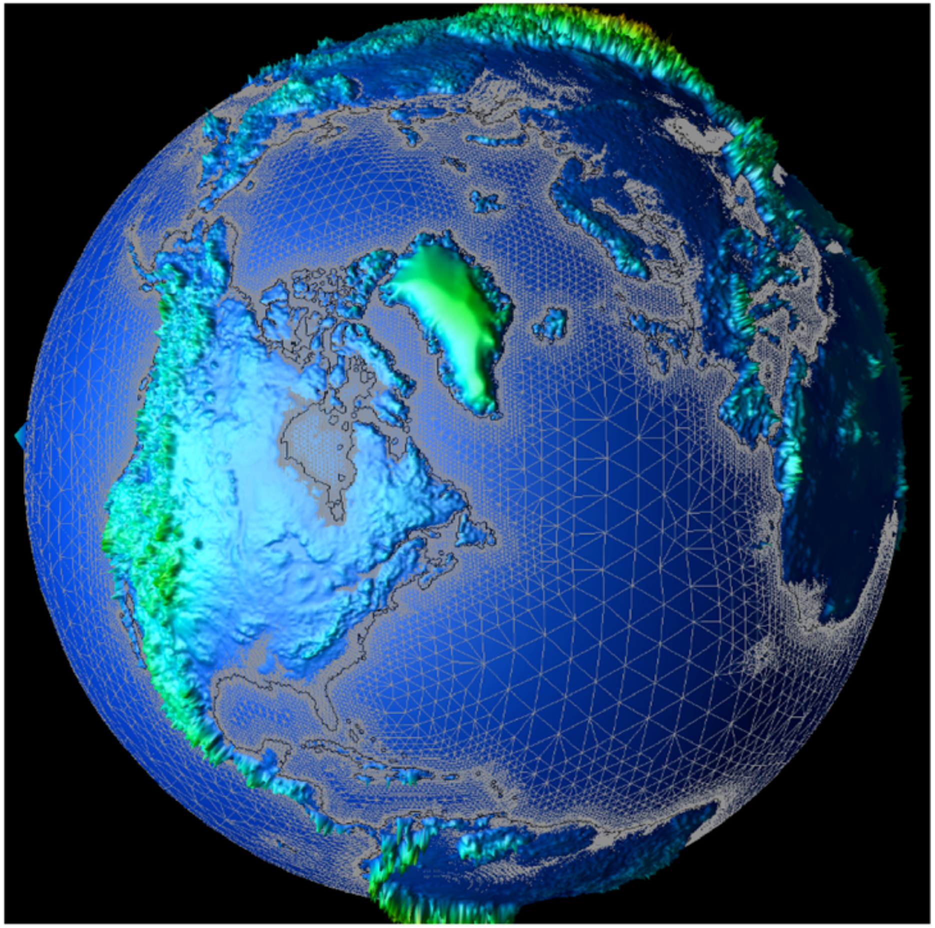
Solution adaptation

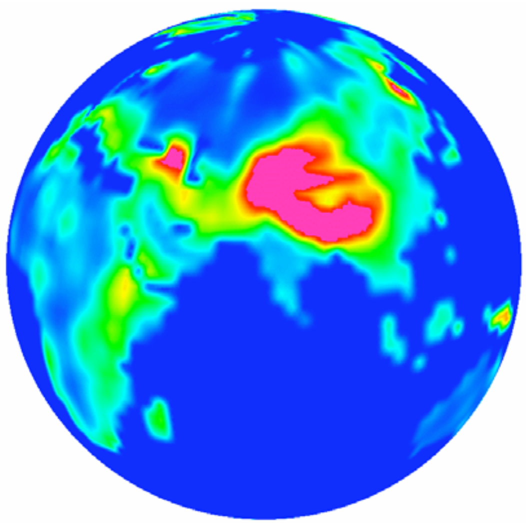
- Solution adaptation enables accurate and predictive solutions while limiting the total number of mesh elements.
  - Selective refinement.
  - Increase element order.
  - Mesh motion, element repositioning.
  - Mesh edge swapping.
- Robust, automatic adaptive methods needed:
  - Multiphysics applications.
  - Implicit, coupled adaptation schemes are required.
  - Leverage the advantages of combining multiple approaches.

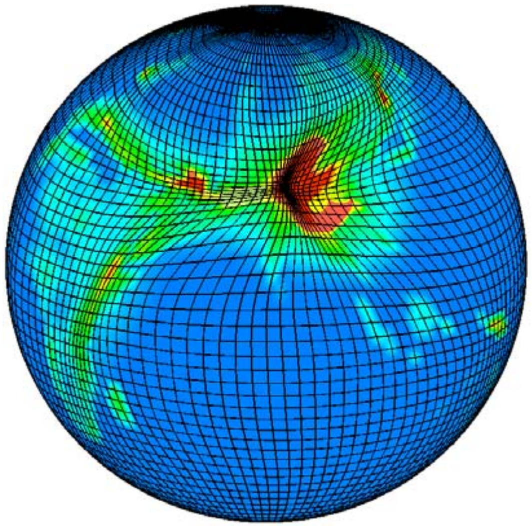


h-p adaptation for climate simulation, ORNL

r-Adaptive hybrid mesh generation for climate modeling

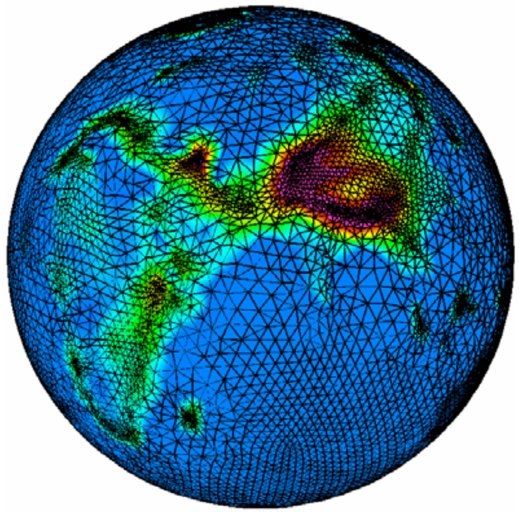
Orography field exhibiting high altitude regions of *Himalayas and Alps*

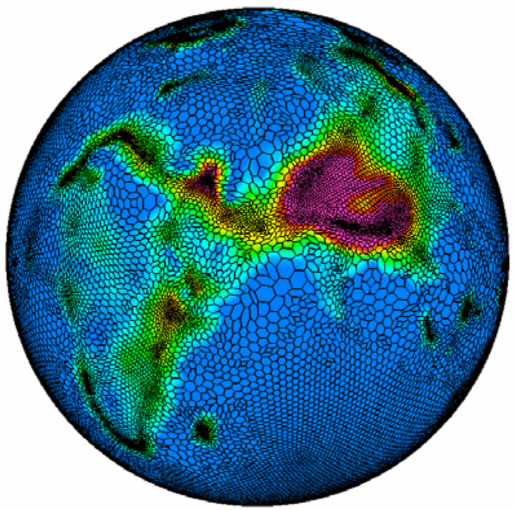




Structured adapted spherical mesh based on orographic field data

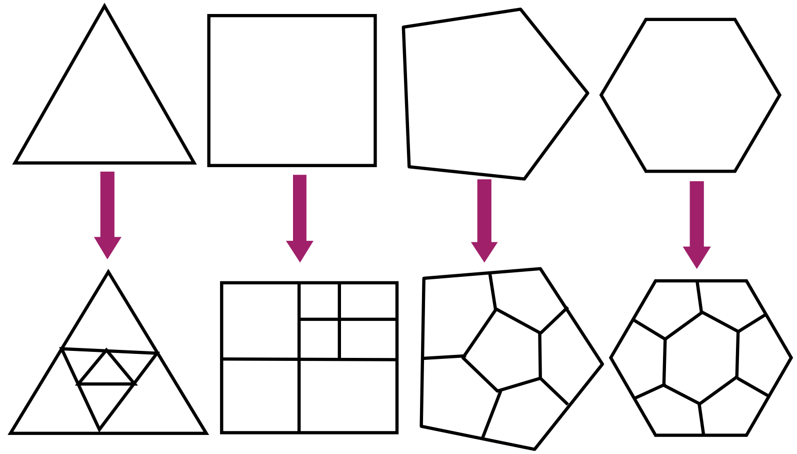
Unstructured adapted geodesic mesh based on orographic field data





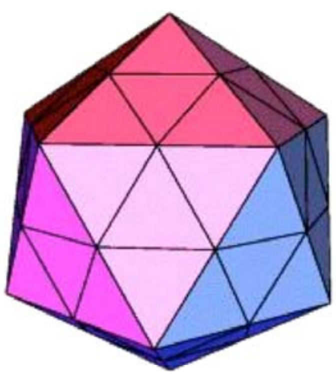
Hybrid adapted geodesic mesh based on orographic field data

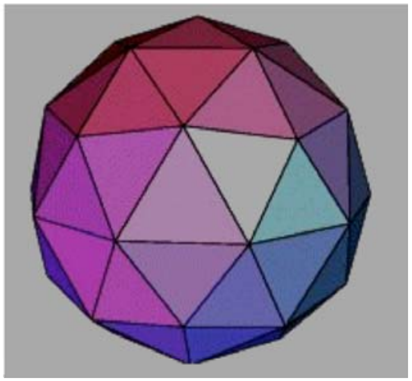
h-Adaptive hybrid mesh generation for climate modeling

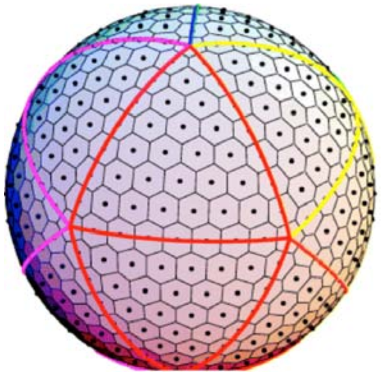


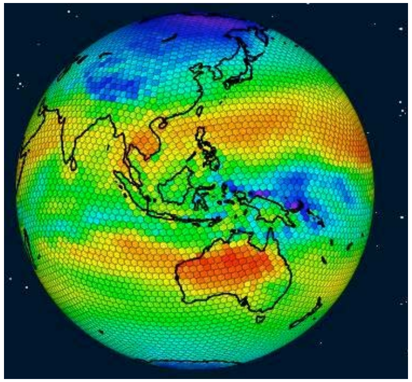
- Given an adaptive solution or geometric field with large error gradient.
- Generate an initial course isotropic or anisotropic geodesic surface mesh.
- Mesh cell topology range from triangles, quads, pentagons, to hexagons.
- Solution based adaptation and redistribution of mesh nodes to minimize solution error.
- Mesh is adaptively refined until mesh density function ρ is less than prescribed tolerance or convergence.

$$\rho = \lambda_a + \lambda_\kappa \left(|\mathcal{K}\sqrt{\phi}| \right) + \lambda_s \left(|\nabla \psi \sqrt{\phi}| \right)$$



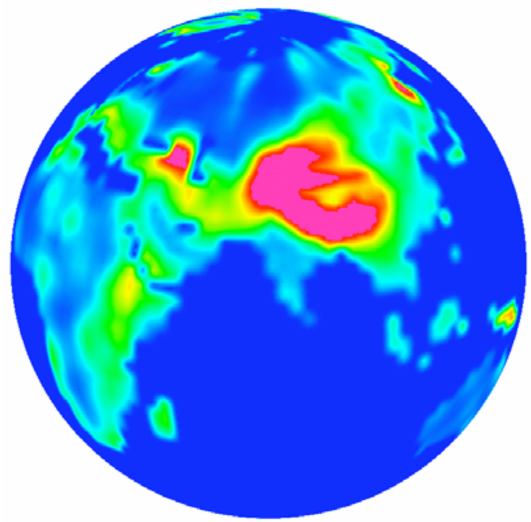


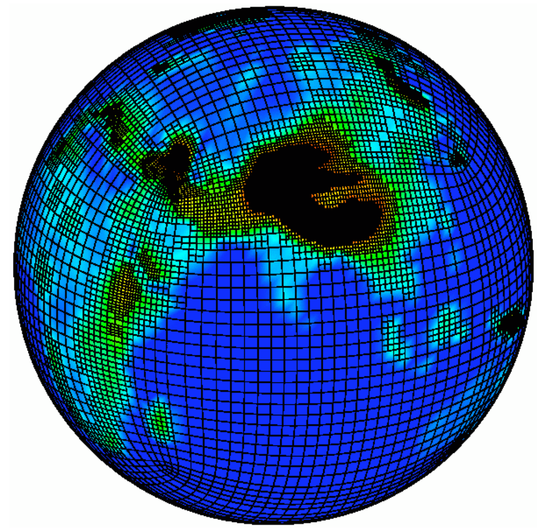




r-Adaptive hybrid mesh generation for climate modeling

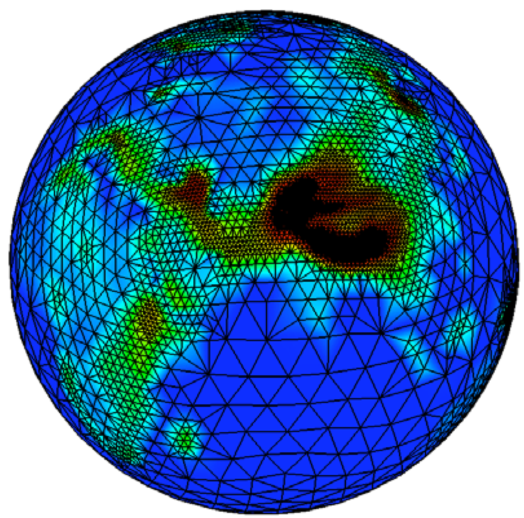
Orography field exhibiting high altitude regions of *Himalayas and Alps*

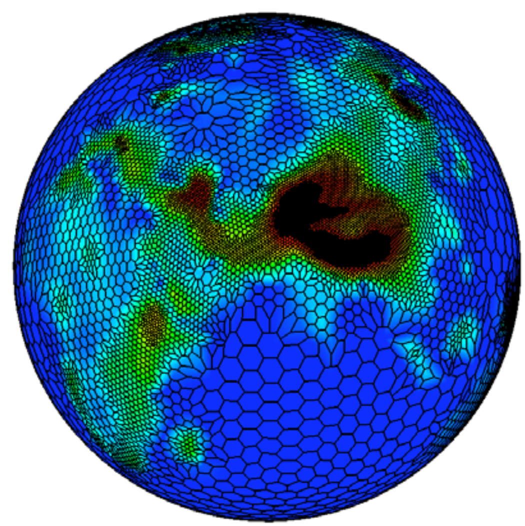




Structured adapted spherical mesh based on orographic field data

h-Adapted unstructured geodesic mesh based on orographic field data





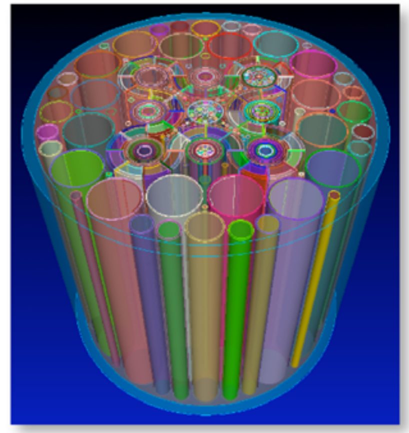
h-Adapted hybrid geodesic mesh based on orographic field data

Modern scientific modeling and simulation

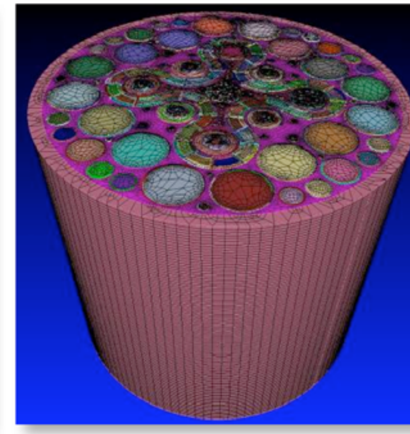
1. Full-core geometry realism
   – A multi-material, multi-region mathematical domain
2. Coupled multi-phenomena modeling
   – Particle transport, heat and fluid flow, solid mechanics
3. Multi-meshing
   – Application-based, interoperable meshes
4. Advanced parallel algorithms
   – Petascale computing

Geometric modeling and mesh generation

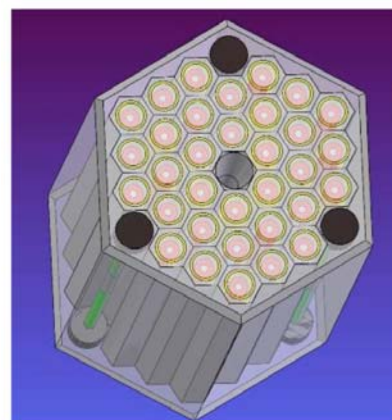
- Meshing and modeling are *enabling technologies* for reactor simulation.
  - A solid model (CAD) is created of the components that describe the problem.
  - The model is “meshed” to meet the requirements of the simulation to follow.
  - Mesh quality is improved, boundary and initial conditions are set, and the mesh is passed to the simulation application.

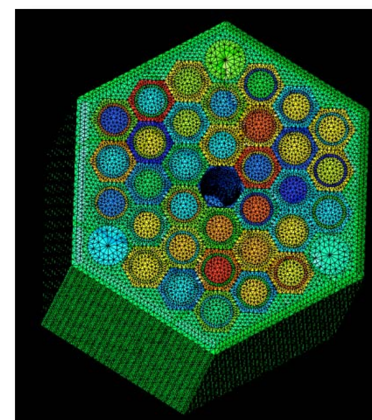


CAD



Mesh





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Technology developments—
Geometry, Meshing, Adaptivity Services (GMAS)

- Integrate geometry, meshing, and adaptivity software (SciDAC, public domain, etc.) and provide services to multiphysics, coupled, PDE solvers.
- Developed or extended functionality of software in the area of geometry modeling, meshing and adaptivity. On-demand-basis development (as of now through short-term projects).
- Aimed at large scale parallel computing.

Contacts

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ITAPS
INTEROPERABLE TOOLS FOR ADVANCED PETASCALE SIMULATIONS

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