Adaptive Hybrid Mesh Refinement for Multiphysics Applications

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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
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

\[ h-p \text{ adaptation for climate simulation} \]
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 coarse 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 $\rho$ is less than prescribed tolerance or convergence

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