Tutorial II
Using the adaptive mesh refinement & spherical shell geometry

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Overview

• At the end of this tutorial, you should be able to:
  – Set up a model with Earth-like geometry and temperature in Aspect
  – Set up a model with adaptive mesh in Aspect
  – Decide which mesh refinement strategy to use
  – Know a bit more about how the mesh influences the flow field 😊
Setup: Convection in a Shell

• Geometry: Quarter of a spherical shell
• Constant initial temperature with a perturbation to start the upwelling

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Tasks

• We will split the class into multiple groups identified by the mesh refinement (number of global refinements)
• You will need to:
  1. Modify the spherical_shell.prm file to use your assigned refinement number/strategy
  2. Run the simulation
  3. Visualize the results and make sure they are realistic
  4. Check which features of the flow field are resolved
  5. Note: to halt a simulation, press “Control-C”
Using ASPECT

• We will begin by editing the input file

1. Change to the appropriate directory
   cd ~/ASPECT_TUTORIAL/models

2. Open the parameter file for editing
   gedit spherical_shell.prm
Material model

set Adiabatic surface temperature = 1600

subsection Material model
  set Model name = simple
subsection Simple model
  set Thermal expansion coefficient = 2e-5
  set Viscosity = 3e21
  set Thermal viscosity exponent = 3
  set Reference temperature = 1600
end
end

These should be the same

Temperature-dependent viscosity
subsection Geometry model
  set Model name = spherical shell

subsection Spherical shell
  set Inner radius = 3481000
  set Outer radius = 6336000
  set Opening angle = 90
end
end

subsection Gravity model
  set Model name = radial earth-like
end

The gravity model has to be changed together with the geometry
set Adiabatic surface temperature = 1600

subsection Initial conditions
  set Model name = adiabatic

   subsection Adiabatic
       set Amplitude = 10
       set Radius = 500000
   end
end

This is the temperature used as initial condition
Adiabatic initial conditions

- Calculated using depth-dependent $\rho$, $\alpha$, $c_p$
Boundary conditions

subsection Model settings
set Zero velocity boundary indicators = 0
set Tangential velocity boundary indicators = 1, 2, 3
set Prescribed velocity boundary indicators =
set Fixed temperature boundary indicators = 0, 1

set Include shear heating = false
set Include adiabatic heating = false
end
subsection Model settings
subsection Model settings
  set Zero velocity boundary indicators = inner
  set Tangential velocity boundary indicators = outer, left, right
  set Prescribed velocity boundary indicators =
  set Fixed temperature boundary indicators = inner, outer
  set Include shear heating = false
  set Include adiabatic heating = false
end
subsection Mesh refinement
set Initial global refinement      = 5
set Initial adaptive refinement   = 0
set Strategy                      = temperature
set Time steps between mesh refinement = 0
set Coarsening fraction          = 0.05
set Refinement fraction          = 0.3
end
subsection Mesh refinement

- set Initial global refinement = 5
- set Initial adaptive refinement = 0
- set Strategy = temperature
- set Time steps between mesh refinement = 0
- set Coarsening fraction = 0.05
- set Refinement fraction = 0.3

end

Running the model
aspect spherical_shell.prm

Or in parallel
mpirun –np 2 aspect spherical_shell.prm

This is what we want to change:
- Group 1: 3
- Group 2: 4
- Group 3: 5
- Group 4: 6
Numerical Challenges

Different scales

- High viscosity contrasts
- Advection of steep thermal/compositional gradients
- Complex material properties
- Problems with large number of DOFs

GeoMod2014
Mesh adaptation

• Example: Composition as refinement strategy

Compositional field

Mesh cells, colors indicate the estimated error

GeoMod2014
Mesh adaptation

• Stokes solver for problems with complex interfaces and high viscosity ratios

Circular inclusion test, viscosity contrast $10^3$
Mesh adaptation

Analytical Solution for Pressure:

Aspect’s solution for Pressure:

(Schmid, Podladchikov, 2003)
Mesh adaptation

Choose **Strategies**: temperature, density, velocity, composition, thermal energy density

Calculate error estimate $c_K$ (based on 2nd derivatives & cell diameter)

$$E = \sum_{K \in T} c_K$$

Total error estimate $E$

Normalize refinement criteria?

Scale errors for each criterium?

Add errors/take maximum?

Choose **refinement + coarsening fraction $\alpha$**

Look for the smallest subset $M$

$$aE = \sum_{K \in M} c_K$$

(sum up $c_K$ in the cells with the largest/smallest error until you reach fraction $\alpha$ of the error)

Mark those cells for refinement/coarsening

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*GeoMod2014*
Mesh refinement options

- Strategies: (nonadiabatic) temperature / pressure, composition, density, velocity, viscosity, thermal energy density...
- Refinement criteria scaling factors
- min/max refinement level function
  - Phase transitions / jump in material properties
- Additional refinement times
  - Onset of new processes (convection? melting? plate velocities?)
Inspecting the results

1. With Paraview
   paraview
2. How does the flow field change with varying the resolution?
3. How does the runtime change with the adaptive refinement compared to global refinement?
4. What refinement / coarsening fraction is sufficient?
Results

Time snapshots of models with different resolution

Group 1: 3

Group 2: 4

Group 3: 5

Group 4: 6
subsection Mesh refinement

set Initial global refinement = 5
set Initial adaptive refinement = 0
set Strategy = temperature
set Time steps between mesh refinement = 0
set Coarsening fraction = 0.05
set Refinement fraction = 0.3
end

This is what we want to change:

- Group 1: 4 + 0
- Group 2: 5 + 0
- Group 3: 6 + 0

Set to a value > 0 to enable adaptive refinement
Results

10/28/14

global

3 | 4

4 | 5

5 | 6

6 | 7

adaptive

GeoMod2014
Results

Global 6

Adaptive 6
Results

Run time in seconds for different refinement levels:
- Refinement 3
- Refinement 4
- Refinement 5
- Refinement 6

Comparison of Global and Adaptive runtimes:
- Global
- Adaptive

Date: 10/28/14

GeoMod 2014
subsection Mesh refinement
  set Initial global refinement = 4
  set Initial adaptive refinement = 2
  set Strategy = temperature
  set Time steps between mesh refinement = 5
  set Refinement fraction = 0.3
  set Coarsening fraction = 0.05
end

This is what we want to change:
• Group 1: 0.6 + 0.01
• Group 2: 0.1 + 0.1
Results