



Model design and Gale

Introduction to Lithospheric Geodynamic Modelling



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- Gale input file, running Gale



Gale

- <https://geodynamics.org/cig/software/gale>
- Finite element code for long-term tectonic models
- Solves the equations for conservation of heat, mass and momentum
 - Thermo-mechanical code
 - Body forces (gravity) related to density
 - Density related to temperature
 - Flow driven by body forces and/or boundary conditions



Gale

- Gale uses FEM – From user's point of view, the concepts of grid and boundary/initial conditions apply like in finite differences
 - “Grid” → “Mesh”
 - Elements between grid points
- In Gale, different material and field variables are defined using two different meshes
 - Velocity mesh (incl. strain rate)
 - Pressure mesh
- Again, not so relevant from user's point of view
- The mesh is deformable



Gale – particle-in-cell method

- Flow implies advection ...
 - ... of heat
 - ... of material
- Heat advection solved within the heat equation
- Material advection
 - Not relevant if the whole model consists of one material that has homogeneous inherent density, viscosity and other material parameters
 - ... which often is not the case

*inherent &
effective
material
properties*



Gale – material advection

- Material properties in Gale
 - Diffusivity (heat eq.)
 - Density (stokes eq.)
 - Rheological parameters – viscosity, cohesion, internal angle of friction, ... (stokes eq.)
 - Constants that describe how these are affected by pressure and/or temperature
- (simplified) lithology of the model



Gale – material advection

- Particle-in-cell method, marker-in-cell method, tracer method (“swarm” in Gale)
- Large number of particles “injected” into the whole model domain
 - Each carries information about its material and thus about its material parameters
- Velocity field solution from stokes equation
 - Flow velocity known at grid points
 - Interpolated to calculate velocity of each particle
 - Once moved, material information from particle is interpolated to mesh for use in heat/stokes equation



Solver methods

- Conservation laws are discretized into a set of linear equations
 - Can be solved *directly* or *iteratively*
 - At least once per time step
- Further iterations needed for non-linear rheologies
 - $\eta_{\text{eff}} = \frac{\tau_s}{\dot{\epsilon}_s} = A_{\text{eff}}^{\frac{1}{n}} \dot{\epsilon}_s^{\frac{1}{n}-1}$
 - Solving stokes equation gives new velocity field → new strain rate values → new effective viscosity values → solution of the stokes equation changes
- *Convergence and tolerance*



Model design

- Choose
 - Model geometry
 - Size and shape, locations of boundaries
 - Internal structure: initial material boundaries, immobile regions, etc.
 - Physical material parameters
 - Initial condition (temperature, velocity)
 - Boundary conditions (temperature, velocity)
 - Resolution, run time



Model design – model geometry

- Model geometry
 - Size and shape, locations of boundaries
 - Scale of the problem (intrusion, crust, lithosphere, upper mantle)
 - Internal structure: initial material boundaries, immobile regions, etc.
 - Resolution of the model: Smallest interesting feature vs element size (distance between grid points)
 - Complexity (models are replicas of nature)



Model design

- Choose
 - Physical material parameters
 - Literature; *de facto* standards
 - Often need simplification (cf geometry)
 - Does the model software support them? (e.g. plasticity, temperature dependent rheology or diffusivity)



Model design

- Choose
 - Boundary conditions (temperature, velocity)
 - “Active” vs “passive”
 - A driving force of the model (e.g. basal heating, horizontal tectonic movement, ...) – u described, $T > T_{ini}$ described or $dT/dx > 0$ described
 - Boundaries necessary only to keep model size finite, effect on processes inside model domain as small as possible. Described du/dx or $dT/dx = 0$
 - Ensure compatibility with each other



Model design

- Choose
 - Initial condition (temperature, velocity)
 - Make sure they are compatible with boundary conditions (e.g. $T > T_{ini}$ implies active heating)
 - Stability / steady-state



Model design

- Choose
 - Resolution, run time
 - How good resolution is needed to observe the wanted features?
 - How long does the model have to run (model time), 1000 yrs, 1 Myrs, 100 Myrs?
 - How good computer you have got
 - How long (wall clock time) you are prepared to wait for the results

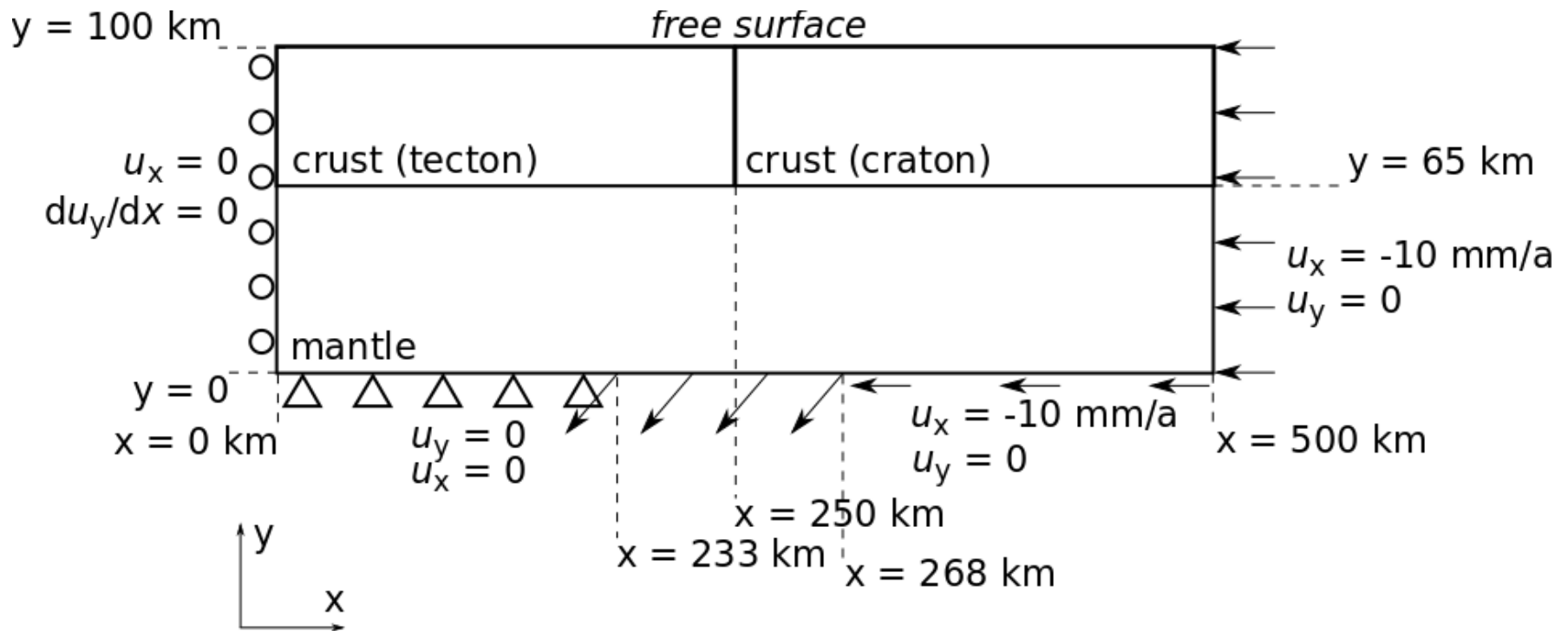


Example model: Colliding plates

- Two colliding plates
 - Old cratonic lithosphere (“craton”) colliding with younger plate (“tecton”) at rate 1 cm/a
 - Craton older, cooler and thus stronger than the tecton
 - What kind of large-scale structures form in the crust?
- Simplifications:
 - Plate boundary vertical and linear
 - Lithology: Crusts of tecton and craton (visco-plastic) and the lithospheric mantle (viscous)
 - Heat diffusion not regarded



Example model: Colliding plates





Example model: Colliding plates

- Material properties
 - Density: 2800 kg/m³ for crust, 3200 kg/m³ for mantle
 - Rheology
 - Linearly viscous mantle, $\eta = 10^{23}$
 - Brittle-viscous crust:
 - Tecton $\eta = 10^{26}$, $C = 20$ MPa, $\phi = 15^\circ \rightarrow 1.5^\circ$
 - Craton $\eta = 10^{26}$, $C = 30$ MPa, $\phi = 30^\circ \rightarrow 20^\circ$



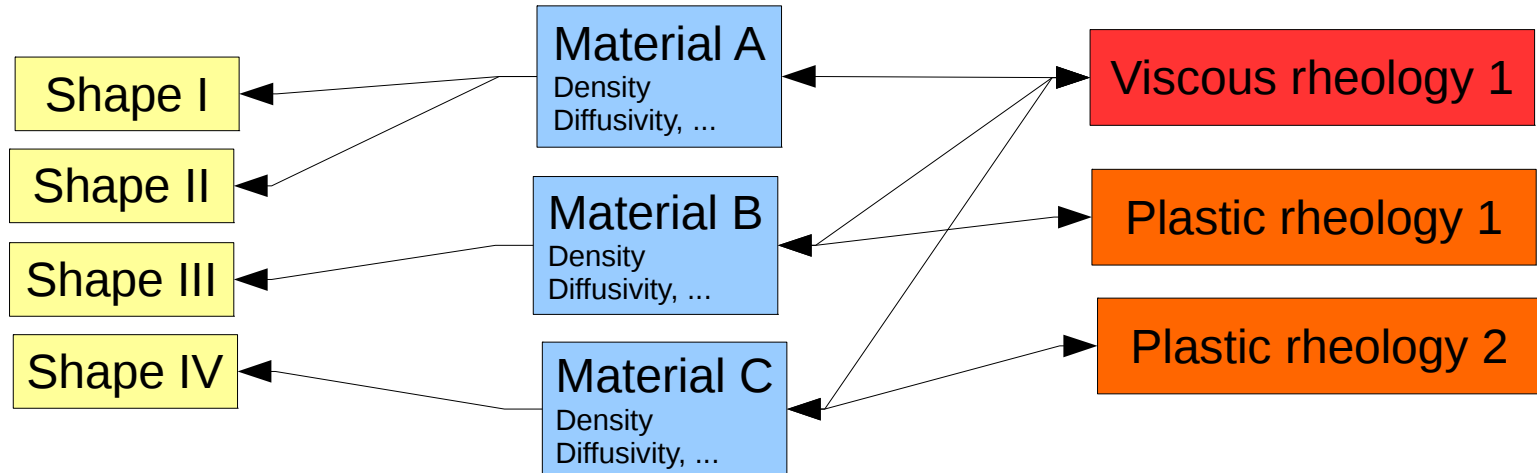
Gale input file

- [something].json
- Formed of blocks
 - EulerDeform: Define mesh deformation
 - velocityBCs: Boundary condition definitions
 - components:
 - “Moving parts” inside the model domain
 - Especially material definitions
- Single variables outside any block:
 - e.g. Model dimensions, number of timesteps, etc.



Gale material definitions

- *Shapes* define areas (volumes) to which *materials* can be assigned
- Each material is assigned with a *rheology*





Running Gale

- Command line arguments
 - Input file name `[something].json`
 - For direct solver, use
 - `-ksp_type preonly -pc_type lu`