Some recent developments of ElmerSolver

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Elmer/Ice splinter meeting

Outline

- Gmsh format based restart and interpolation between different meshes
- …
- …
- …
- Improvements for semilagrangian transport

Some developments in other fields that may be of integest, or probably not

File based hierarchical coupling

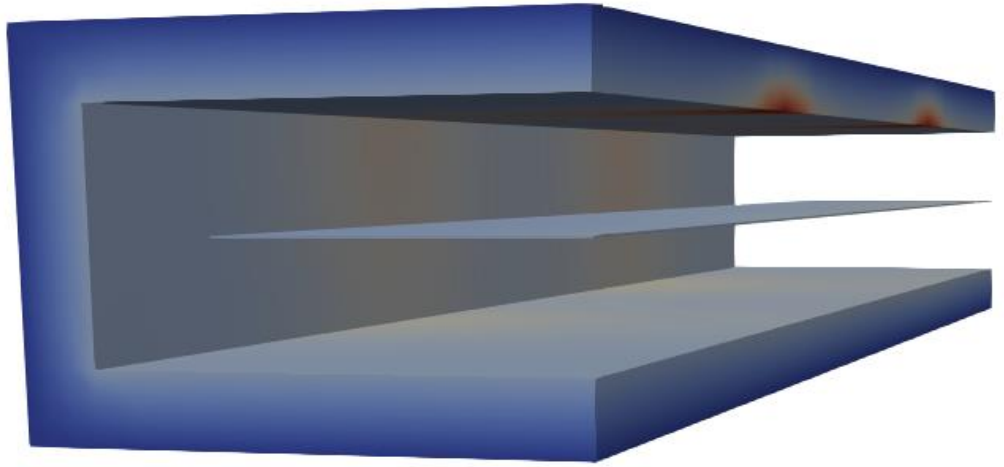
- Shortcomings of restart file of Elmer
  - Includes only results, needs to be consistent with the mesh
  - In parallel requires exactly same partitioning
  - Always saves the full model
  - Impractical for boundary-only coupling
- Wishlist for coupling
  - Selection on what to save and read (which bodies or boundaries)
  - Intermediate results should visualized, if needed
  - Robust operation regarding parallel operation

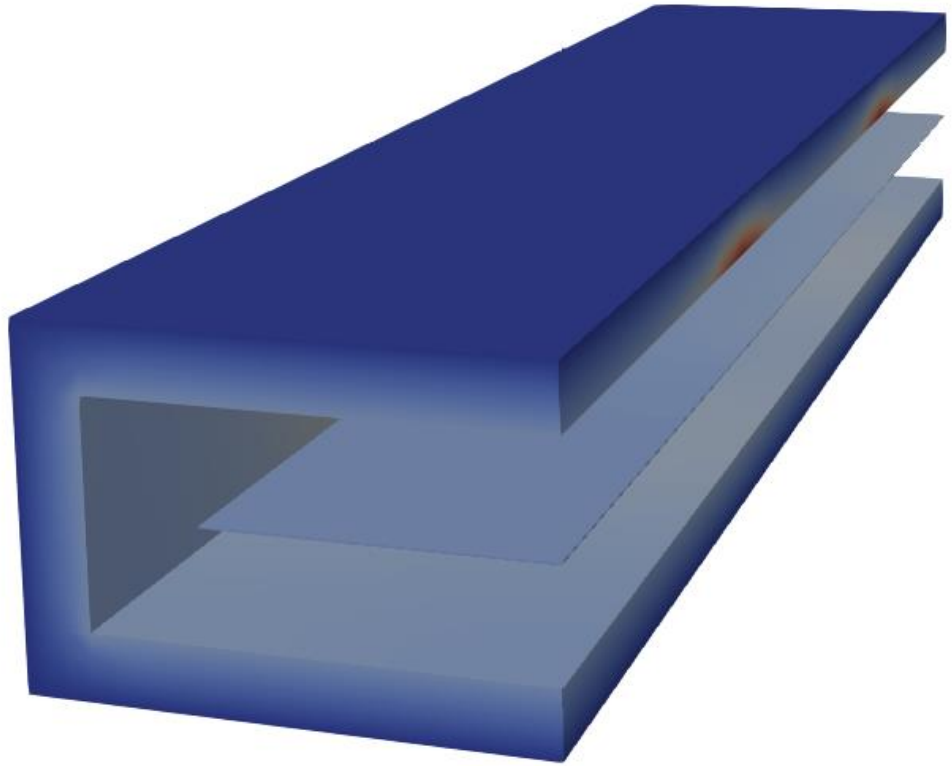
Gmsh file format for restart

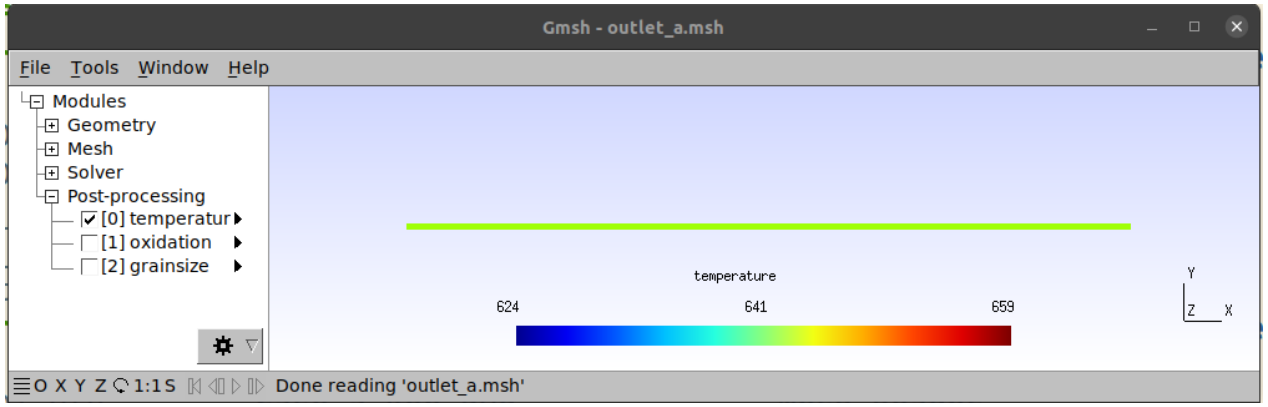
- **`Gmsh`** output existing since long
  - Part of **`ResultOutputSolver`**
  - Ability to choose what to save and what not
  - Now also saves in parallel (with suffix _np#np)
- **`GmshOutputReader`**
  - Reads Mesh + Results from Gmsh file
  - Performs the coupling with **`MeshToMeshInterpolationQ`**
  - Passive coordinates may be used to enable exact hits in lower dimensional entities
- Parallel operation
  - Each partition performs its own interpolation which may results to some I/O bottle-necks.
  - Every process reads every file, process N starts reading part N
    - Room for easy improvement if this becomes I/O bottle-neck
  - Bounding Boxes used to eliminate non-overlapping pieces of mesh

Gmsh-file based restart

- First application heat treatment of metal sheets over several owens
  - The 1st oven gives the temperature used as boundary condition for the 2nd oven
  - Helps to split heavy simulations to independent ones
- Intermediate results visualizad with Gmsh

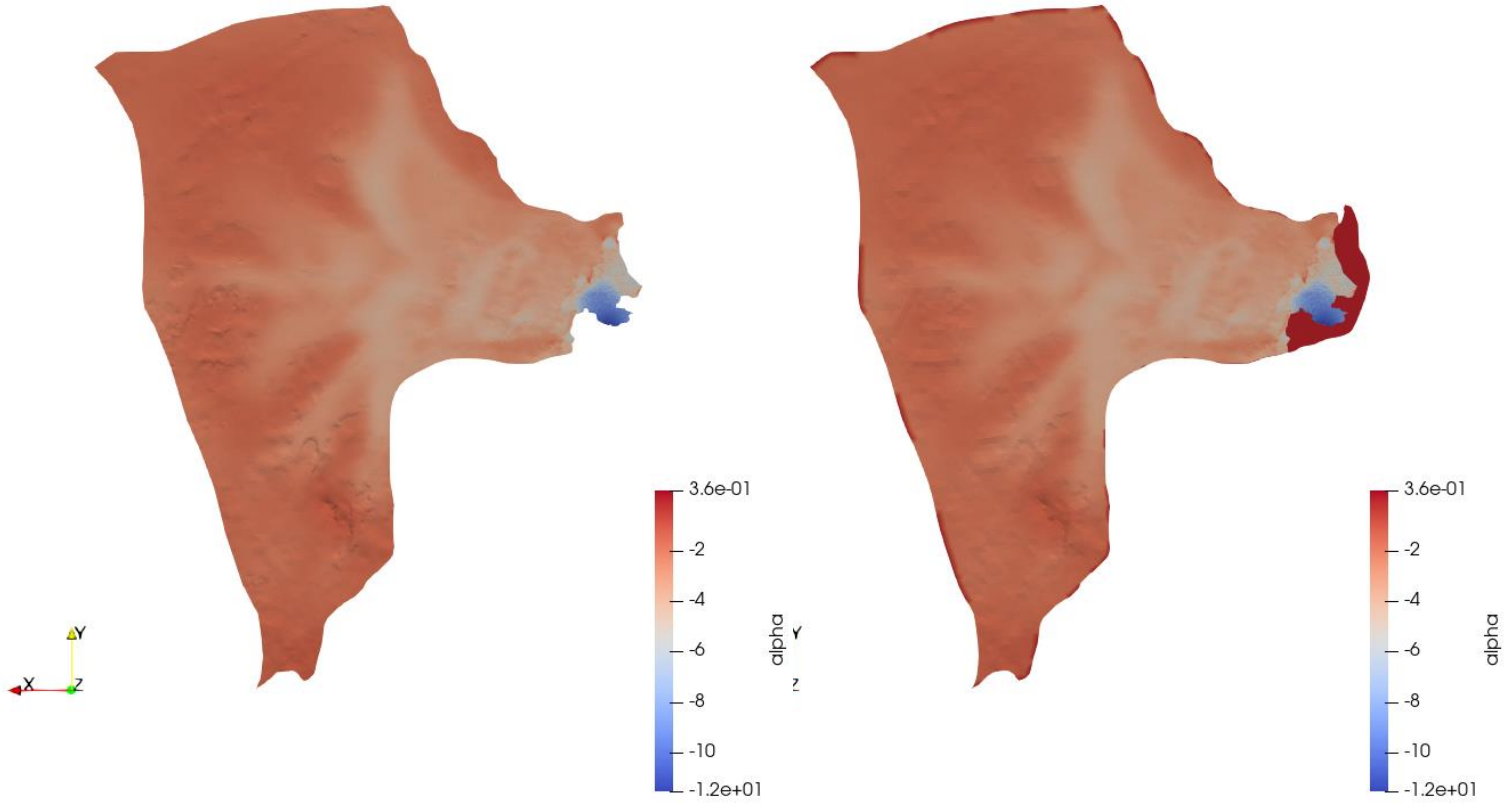






Gmsh restart for Elmer/Ice

- In Elmer/Ice we often need to map data between meshes
- Often mapping on surface is sufficient even in 3D
  - Save data at bedrock only
  - Read data on bedrock only
- Strategy bit heavy for mapping all 3D results

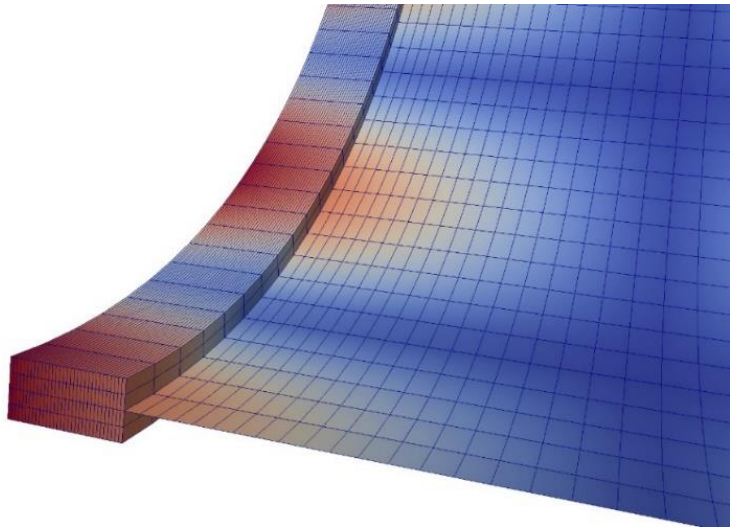


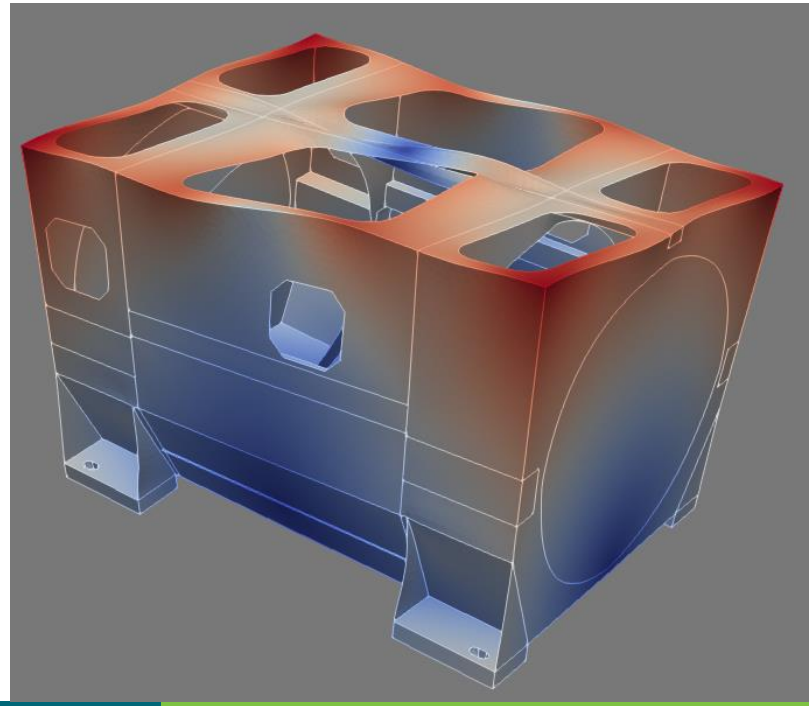
Mapping of fitted slip coefficient between two meshes. Figures by Anna Crawford, 2023.

- Test case to start from: **ParallelBoundaryMapGmsh**

Coupling of shells and solids

- Many mechanical models have shells and solids
  - Shells to economically model thin regions
  - Solids to accurately mode thick regions
- Completely new and generic coupling approach has been developed
  - Requires no modification from solid and shell models
  - Only coupling matrices need to be defined
- Applicable to eigen analysis as well





M. Malinen & P. Råback: *The coupling of solids and shells by conjugate approximations*, Rakenteiden mekaniikka,55(4), 2022.
DOI: https://doi.org/10.23998/rm.120470

Reduced dimensional Navier-Stokes - FilmFlowSolver

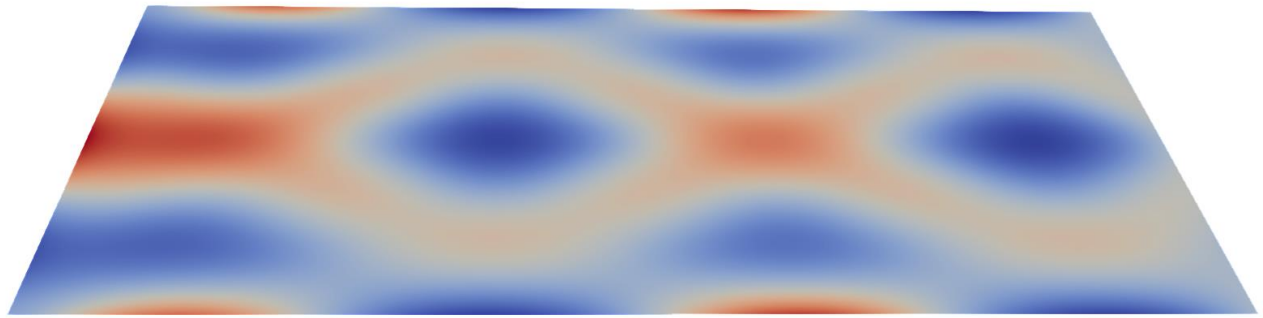
- Motivation
  - Coupling of ice and glacier outburst (joint work with T. Johannesson & T. Zwinger)
  - Initially idea was to use ReynoldsSolver i.e. flow solver reduced to 2D pressure field
  - Problematic to solve the coupled system because the assumption behind Reynolds equation are not well compatible with dynamical coupling
  - New solver was coined, very much work under progress

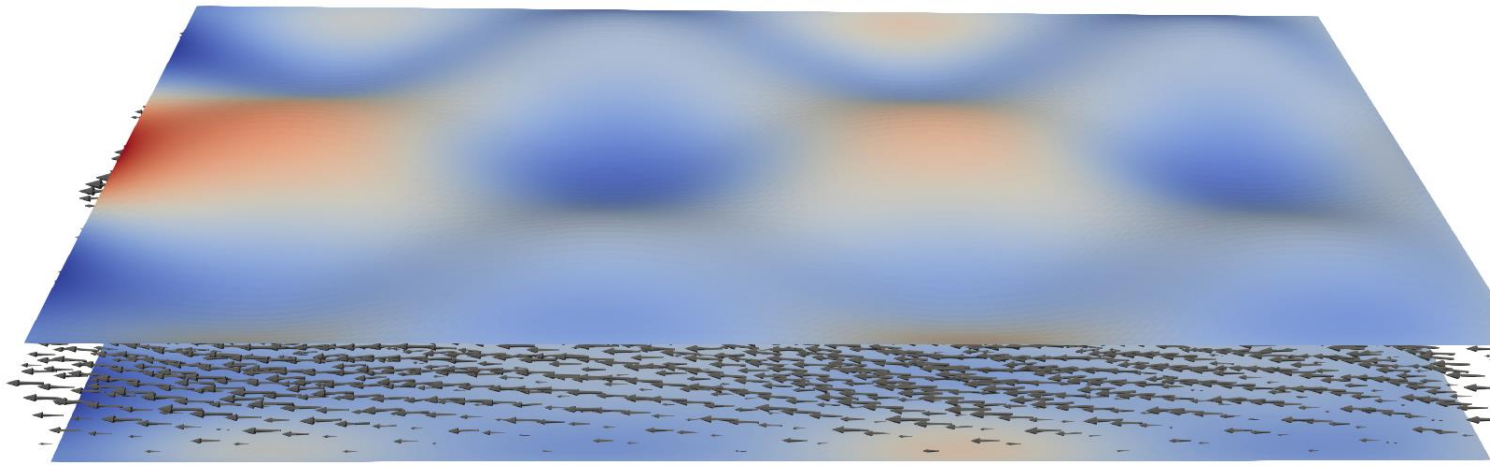
FilmFlowSolver

- Test cases for full dimensional and reduced dimensional problems
  - Good agreement

  FilmFlowLine
  FilmFlowPipe
  FilmFlowPlane
  FilmFlowPlane2
  FilmFlowPlane3

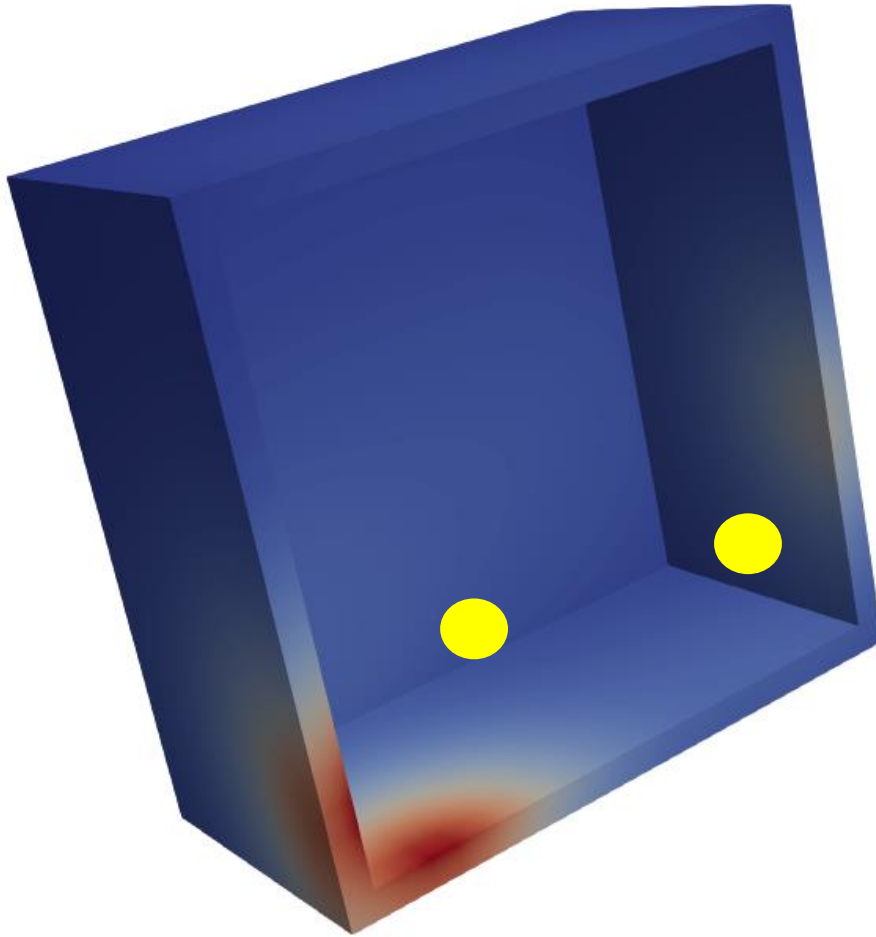
- Started with laminar cases
  - Poisseille velocity profile assumed
- Other choices to be added





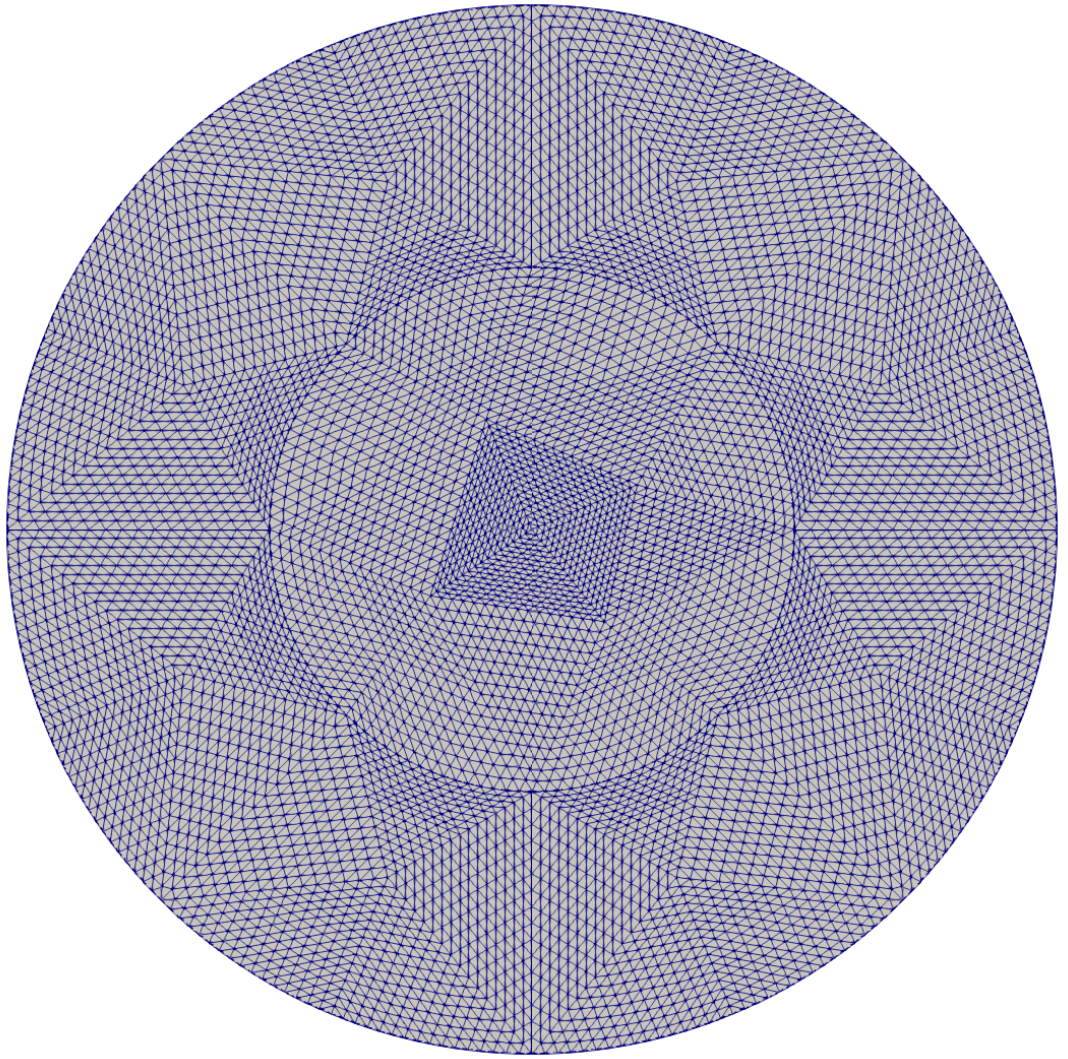
Improvements in radiation heat transfer

- Radiator
  - Point like sources that radiate in all directions
  - Viewing angle is compute similarly as for ViewFactors
  - Econimical way to model e.g. heaters
- Radiosity
  - Explicit treatment of radiation heat transfer
  - More economical way to treat radiation problems compared to Gebhart Factors
  - Emissivity and Absorptivity may be temperature-dependent, possible also wavelength-dependent
- Documented in *Elmer Models Manual* under HeatSolver!
- Probably totally impractical for solar enforcing



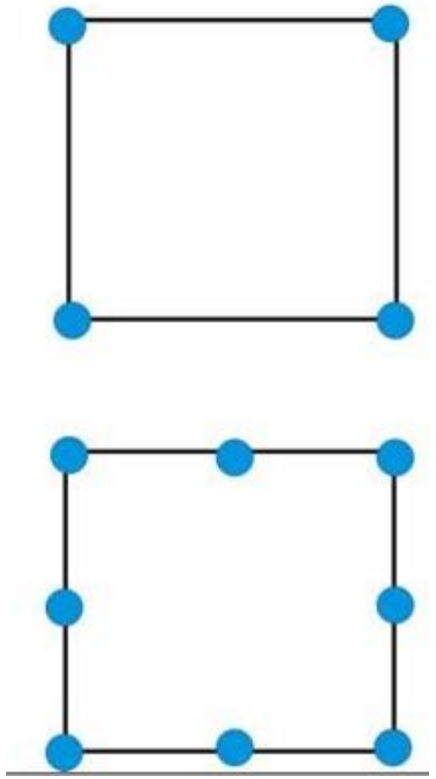
Geometry following shape

- Motivation
  - Need to accurately present curved shapes for better accuracy
  - Problem is particularly important for p-elements
  - Faceted geometry will limit accuracy in mesh multiplication
- Current state
  - cylinder, sphere
  - Levelset $\phi(r) = 0$
- Low hanging fruit
  - Follow data from another (denser) mesh



Increase of element order

- Elmer supports higher order nodal elements
  - But mesh extrusion and mesh multiplication do not
- Simple method to add nodes at element edges implemented
  - "Serendipity elements"
  - May be done after extrusion and multiplications
  - Extruded machinery may not be well supported!



Create Boundary condition on-the-fly

- Mesh generation routine might not support 3D, 2D and 1D entities
- User forgot to add the boundary
- A boundary may be created on-the-fly as intersection of two existing ones

```
Boundary Condition 7
  Name = "South-East"
  Intersection BC(2) = Integer 1 2
  Temperature = 1
  Save Line = True
End
```

- Test cases:
  - IntersectionBCs
  - IntersectionBCs0D

Sif file checks added

- Over the years people have spent hours of futile work in stupid sif mistakes
- Trailing crap + wrong sized vectors will result to errors

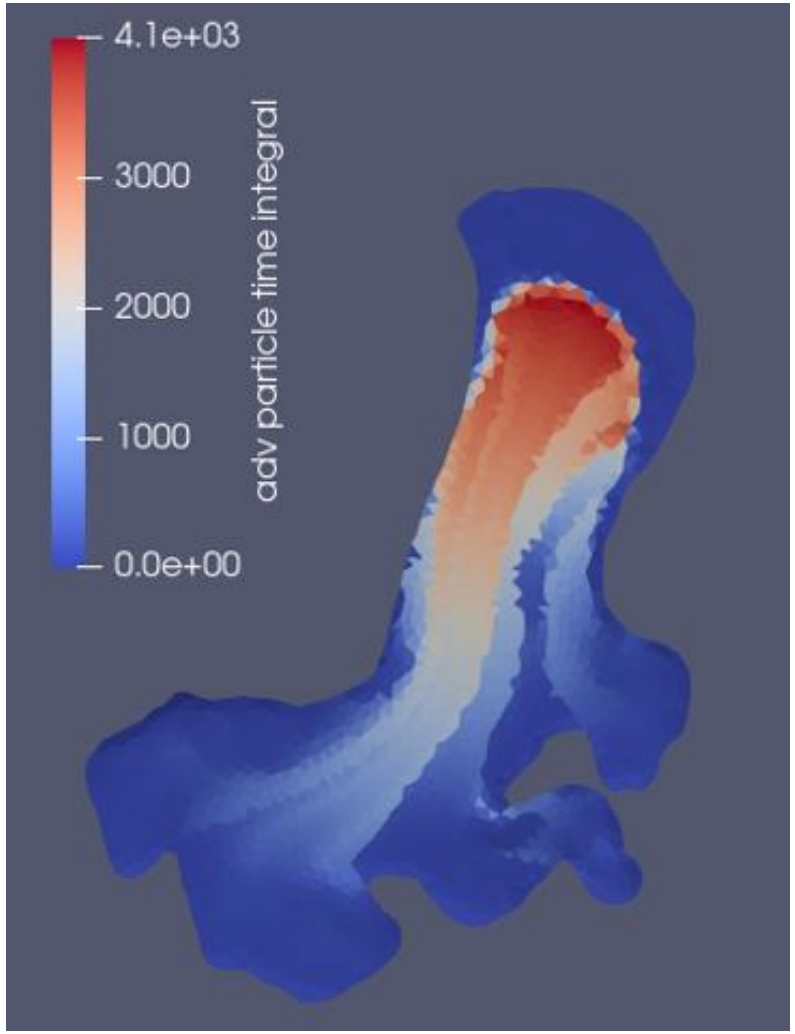
Target Boundaries(2) = 1 4 7

- Note, this is legit too since many years

Target Boundaries(*) = 1 4

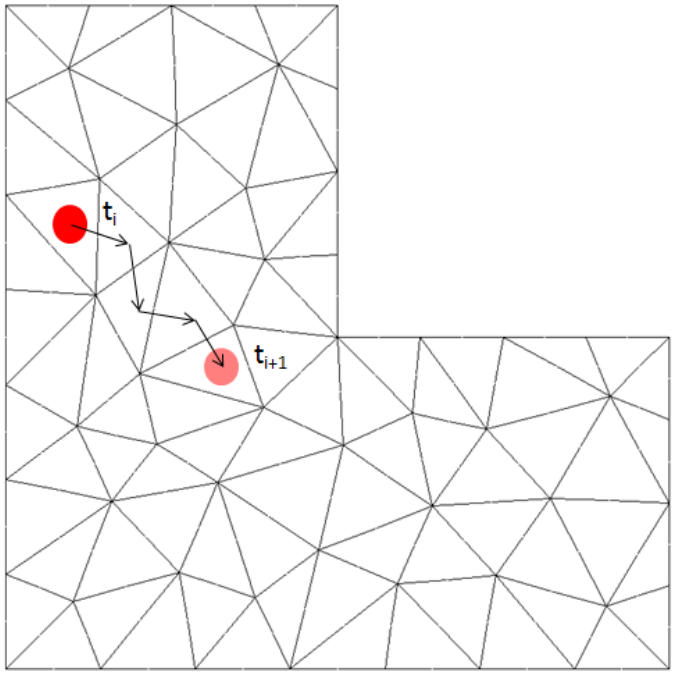
Semi-Lagrangian advection using particles

- Convenient method for fully convective problems
  - No diffusion introduced
  - Module: **`ParticleAdvector.F90`**
- Follow particles backward in time along velocity and register the field value
  - Passive fields are easiest
  - Issues revieled with real usage by Cyrille
- Integrals over path are ideally reversible
  - $F = \int_{-dt}^{0} f(r)ds = \int_{0}^{-dt} f(r)ds$
- Some integrals are not reversible
  - $F = \int_{-dt}^{0} f(f, F)ds$



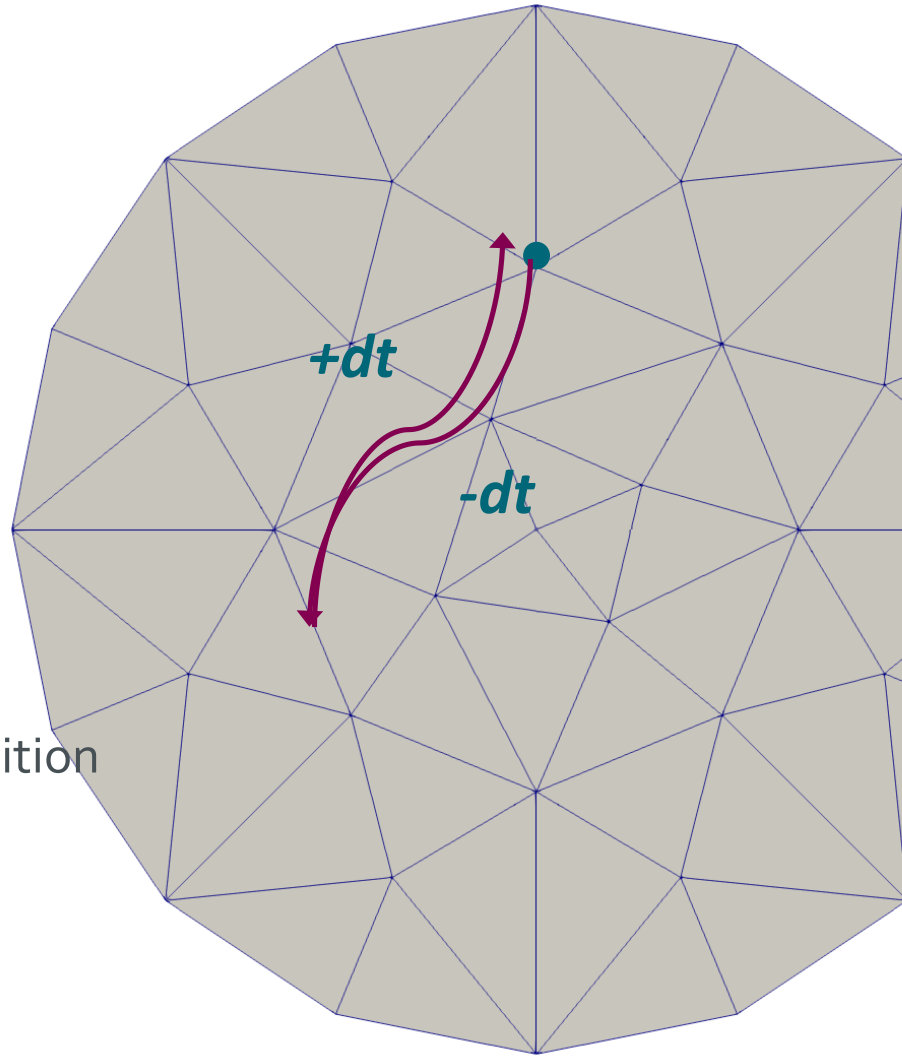
ParticleAdvector - tracking algorithm

- Problem: Locate a particle in the finite element mesh
- Octree based search
  - Scales as N log(N)
  - Same cost for each step
  - Used in Elmer in mesh-to-mesh mapping
  - More difficult to parallelize effectively
- **Marching search**
  - March from element-to-element
  - Initial price scales as N^(1/dim)
  - When the previous parent element is known the additional work is independent of mesh size
  - It is reasonable that the timestep is so small that the particle remains in the same element, or is in the neighbour element



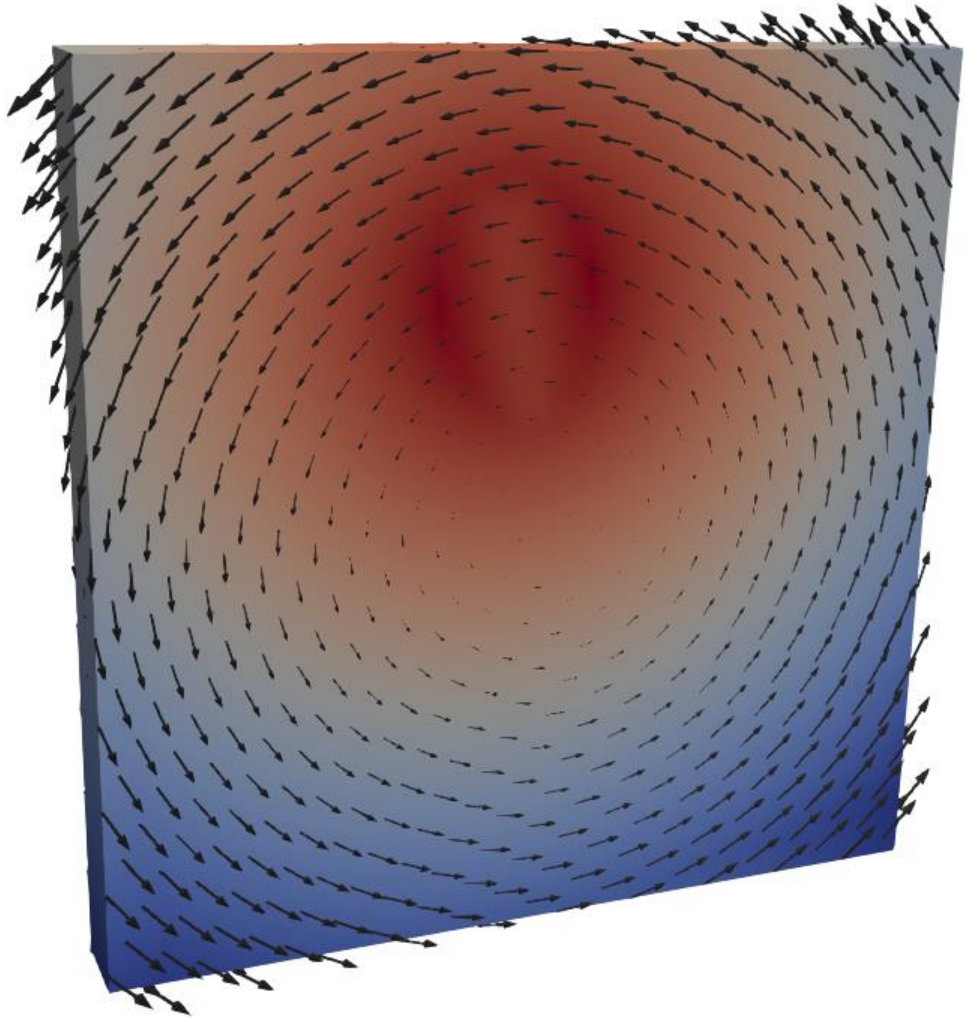
ParticleAdvector - irreversibility

- Idea:
  - Integrate –dt (backwards) in time passively
  - Initiate the value from the field
  - Integrate +dt (forward) in time perfoming the path integral
- Pros
  - The integral may be irreversible
- Cons
  - Twice the labour
  - The back-and-forth integration may end at slightly different position
  - We can register the displacement in the end to follow the error



ParticleAdvector - Outward pointing velocities

- For ParticleAdvector we should ideally not loose any particles
- Particles that follow velocity vectors may go out of the domain if the velocity has a non-vanishing normal component
- Remedy: project the suggested step dr into the plane spanned by the face edges
  - **`Boundary Condition i ::`**
    `Particle Tangent = Logical True`
- There is also a diagnostics solver that can be used to analyze or eliminate normal components of velocity field
  - **`FixTangentVelo.F90`**



Summary

- Some developments that may be usefull for the Elmer/Ice community
  - Many are currently still ongoing
- Working solution for an easy geometry does not imply success in large scale complex geometries
  - Devil lies in the detail
- If you have questions, ideas or wishes contact us
  - Thomas.Zwinger@csc.fi & Peter.Raback@csc.fi