BOUT++ workshop 2022

hynptoad grid generator

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Thanks to:

- Ben Dudson for the tokamak setup
- Peter Hill for the GUI
- All the users who have reported problems!
6.3. Orthogonal grid

If you are using the GUI, Radial grid and this page correponds something like the figure below being shown in the right panel.

The remaining step to determine the grid point positions is the \( \text{EquilibriumRegion} \) objects that represent the separatrix disconnected double null configuration), and then following:

These grid points are then assigned to \( \text{PolyContour} \) objects while \( \text{MeshRegion} \) objects are collected into a \( \text{Mesh} \).

The default method for defining the poloidal grid on an \( \text{Equi} \) position of the X-point. If the poloidal spacing was constant (grid points) then the flux expansion at the X-point (or rather, spacing of the grid near the radial lines leading away from the \( \frac{1}{\sqrt{x}} - a_x \) spacing is an attempt to counteract this effect, varies quadratically with distance from the X-point. This doe
Outline

• Aims
• Inputs
• Grid generation process and algorithms
• Orthogonal and nonorthogonal grids
• Issues and wish list
Aims

- BOUT++ doesn’t support arbitrarily non-uniform grids (yet!)
  - spacing must vary slowly from one grid point to the next
  → constraint, e.g. no jump in $dx$ across separatrix

- Be accurate
  - small change in inputs → small, smooth change in grid
  - outputs independent of BOUT++ grid resolution

- Be reproducible
**Inputs**

- Magnetic equilibrium from geqdsk file
  - array of values of poloidal magnetic flux (divided by \(2\pi\)) \(\psi\)
  - \(I(\psi)\) that gives \(B_{\text{toroidal}} = I(\psi) \nabla \zeta\) with toroidal angle \(\zeta\)
  - also array of points defining wall

- Grid settings from input YAML file

Figure made with [hypnotoad-plot-equilibrium](https://hypnotoad.readthedocs.io/en/latest/inputs.html)
Grid generation process

Using grid point positions and equilibrium data, calculate geometrical quantities – metric coefficients, Jacobian, etc.
Write to grid file.

Identify O-points, X-points.
Grid separatrices.

Follow perpendiculurs to flux surfaces to find all flux surfaces to be gridded.

Building blocks 1/2

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PsiContour
• Represents part of flux surface
• Points are grid points for BOUT++

FineContour
• Belongs to PsiContour, represents same contour
• Higher resolution for accurate poloidal distance

EquilibriumRegion
• Derived class of PsiContour
• Basis for constructing PsiContour s in a region

Building blocks 2/2

**Equilibrium**
- Equilibrium data
- Collection of `EquilibriumRegions`

**MeshRegion**
- Collection of `PsiContours`
- One sub-region

**Mesh**
- Collection of `Meshregions`
- Whole grid

Algorithm notes

• \( \psi \) refinement

• FineContour construction

• ‘Spacing functions’
ψ refinement

• Points on PsiContour or FineContour generated initially by contour tracing or interpolation: not exactly on the right $\psi$ value

• To make grid as accurate and reproducible as possible, initial guess refined: point moved to correct $\psi$ (with small tolerance)

• Several algorithms, by default tried one after the other for robustness:
  • integrate+newton
  • integrate
  • line
  • newton

FineContour construction

• High-resolution representation of psi contour → accurate calculation of poloidal distances

• Independent of BOUT++ grid
  • constant poloidal spacing → consistency of spacing, $z_{\text{shift}}$ between different resolutions

• Construction:
  • Interpolate initial guess from $\Psi_{\text{Contour}}$
  • Iterate:
    1. $\psi$-refine
    2. calculate poloidal distance
    3. check if poloidal spacing is constant, if so stop iteration
    4. make new interpolating functions
    5. redistribute points to have uniform poloidal spacing

‘Spacing functions’

- Poloidal distance as a function of index space \( s(i_N) \)
  - Normalised index space value \( i_N = \frac{i}{n_{d,\text{total}}} \) used so spacing function is independent of grid resolution

- Used to define:
  1. \( \psi(i_x) \)
  2. \( s_{\text{pol}}(i_y) \)

- Input parameters set gradient at either end
- Exact definition, implementation are complex…

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Orthogonal grids

- Some metric coefficients vanish ✓
- Does not conform to wall ❌
- Compression of poloidal spacing moving away from X-point radially ❌

- Poloidal spacing on separatrix (EquilibriumRegion)
  - spacing $\propto \frac{1}{\sqrt{i}}$ near X-point
  - compromise between large spacing at X-point and small spacing at radial boundaries
- Usually fairly robust to generate

Nonorthogonal grids

- Fix cons of orthogonal grids ✓
- May need additions to Physics model ✘
- More complex ✘

- Spacing function on each contour
  - hard to parameterise in a good way
- Poloidal spacing is weighted combination of:
  - orthogonal grid far from X-points and targets
  - perpendicular spacing near X-points
  - poloidal spacing near targets
- Weights vary radially
  - rapid transition to orthogonal near separatrix for smoothness
  - slower transition far from separatrix as orthogonal grid far away from grid aligned with boundary
Nonorthogonal spacing

Actual grid, orthogonal where possible.

Mostly ‘near target’ spacing. Sharp corners from target propagate.

Mostly ‘near X-point’ spacing. Grid lines parallel to region boundary, but discontinuity at separatrix.
Tips and tricks for gridding

- Get something that builds
  - even if only a narrow strip near the separatrix
- Fairly large ‘range’ parameters for nonorthogonal grids
- Nudge parameters slowly towards your desired grid

- See https://hypnotoad.readthedocs.io/en/latest/tips-and-tricks.html for more!
Tools provided by hypnotoad

- **GUI**
  - hypnotoad-gui interface for creating tokamak grids – use to set up input YAML file

- **Command line**
  - hypnotoad-geqdsk interface for creating tokamak equilibria from geqdsk equilibrium files
  - hypnotoad-circular interface for creating grid files for concentric, circular flux surfaces with a limiter
  - hypnotoad-torpex interface for creating grid files for TORPEX X-point configurations

- **Plotting**
  - hypnotoad-plot-equilibrium command line tool for creating plots of the equilibrium (flux surfaces, wall and separatrix) from a geqdsk file
  - hypnotoad-plot-grid-cells creates a plot of the grid cells from a grid file generated by hypnotoad

- **Utility**
  - hypnotoad-recreate-inputs extracts from a grid file copies of the input YAML file and geqdsk file that were used to create the grid file originally
Current issues

- When using parallel execution, hypnotoad hangs at program end #145
- Nonorthogonal coordinate derivation needs to be checked, added to manual #4

Wish list

- Better nonorthogonal poloidal spacing algorithm #146
- Adjustable region boundaries near X-points #152
- Better algorithm for extending PsiContour #140
- Support for IMAS structures #126
- Handle negative $B_p$ #56
Thank you!

https://github.com/boutproject/hypnotoad/

https://hypnotoad.readthedocs.io/