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BOUT++ workshop 2022

hypnotoad grid generator

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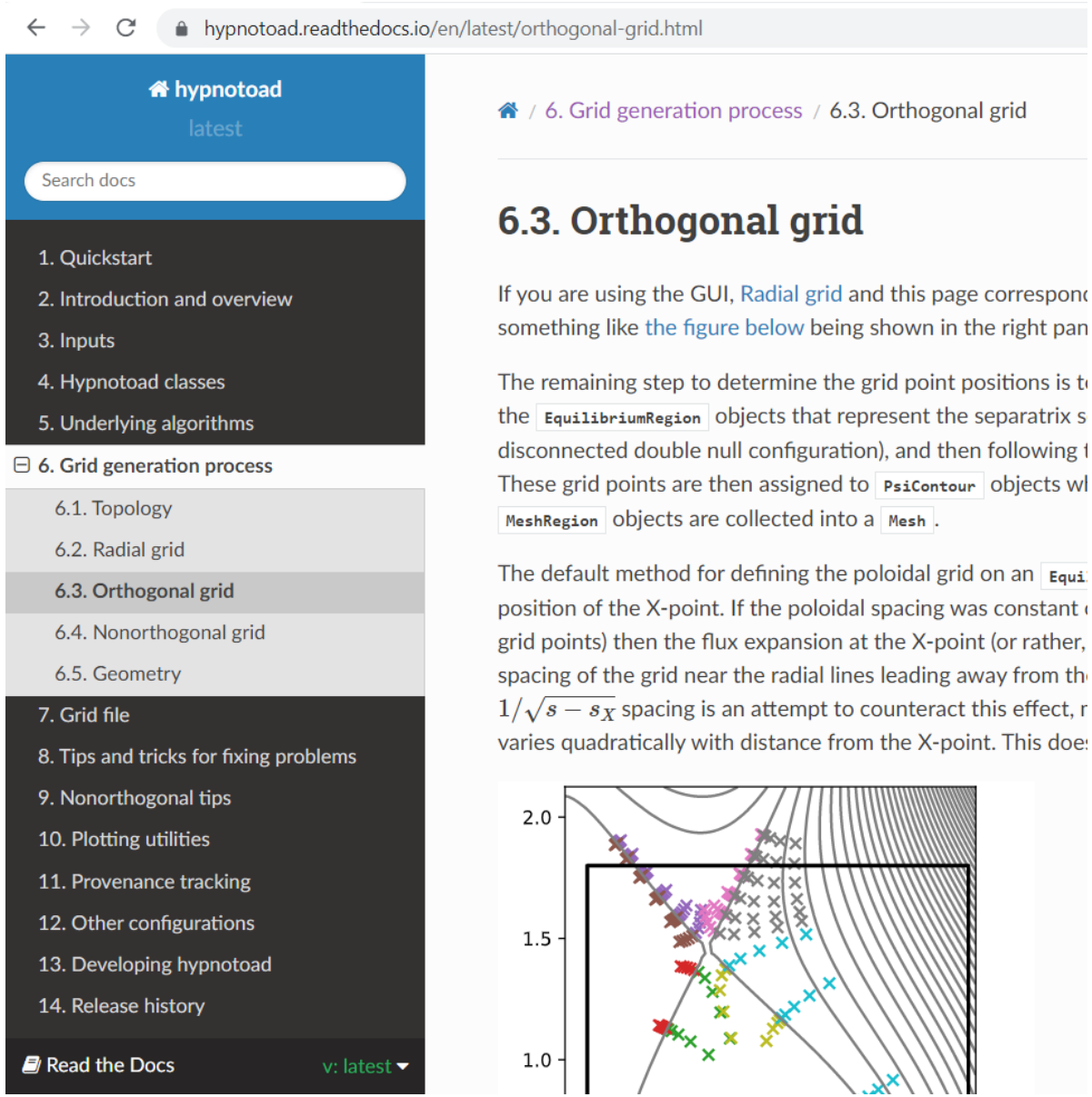
CULHAM CENTRE FOR FUSION ENERGY

- Thanks to:
  - Ben Dudson for the tokamak setup
  - Peter Hill for the GUI
  - All the users who have reported problems!



`hypnotoad` **has a manual!**

https://hypnotoad.readthedocs.io/

Outline

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

Aims

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- 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
  - https://hypnotoad.readthedocs.io/en/latest/provenance-tracking.html

https://hypnotoad.readthedocs.io/en/latest/introduction-overview.html#aims

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Inputs

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

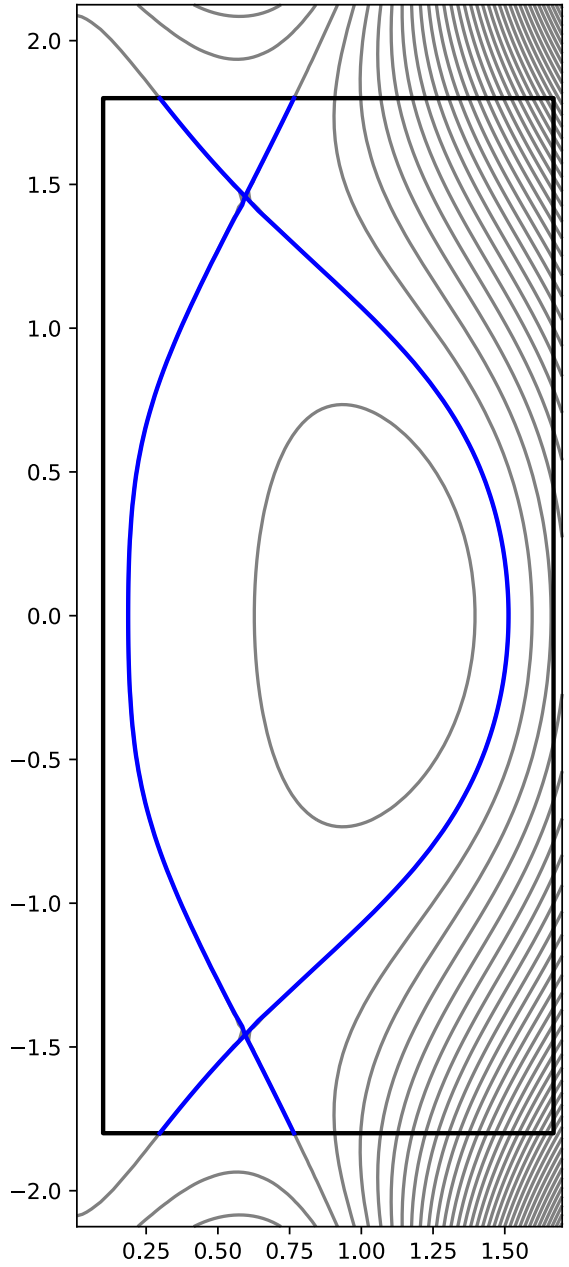
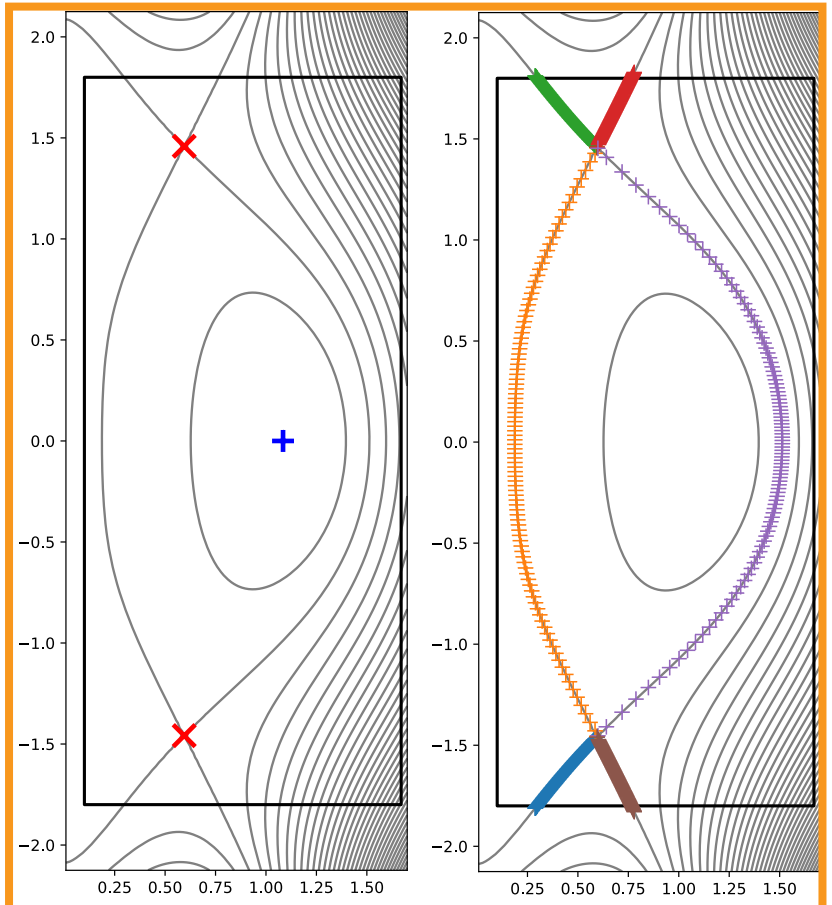


Figure made with `hypnotoad-plot-equilibrium`

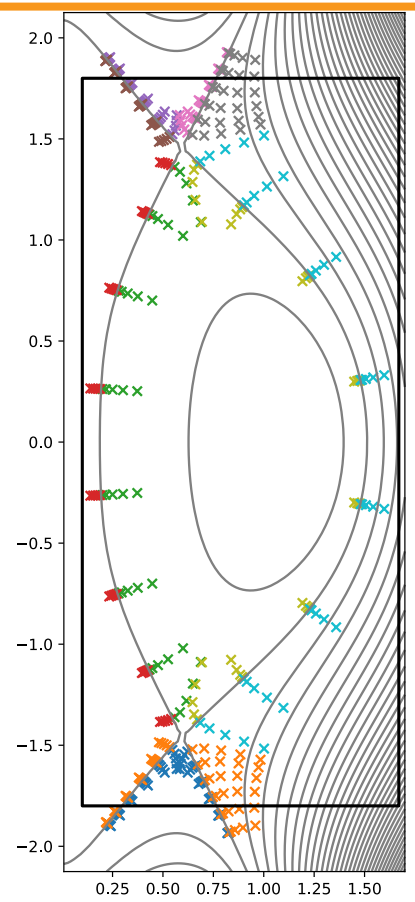
https://hypnotoad.readthedocs.io/en/latest/inputs.html

Grid generation process



Identify O-points, X-points.

Grid separatrices.

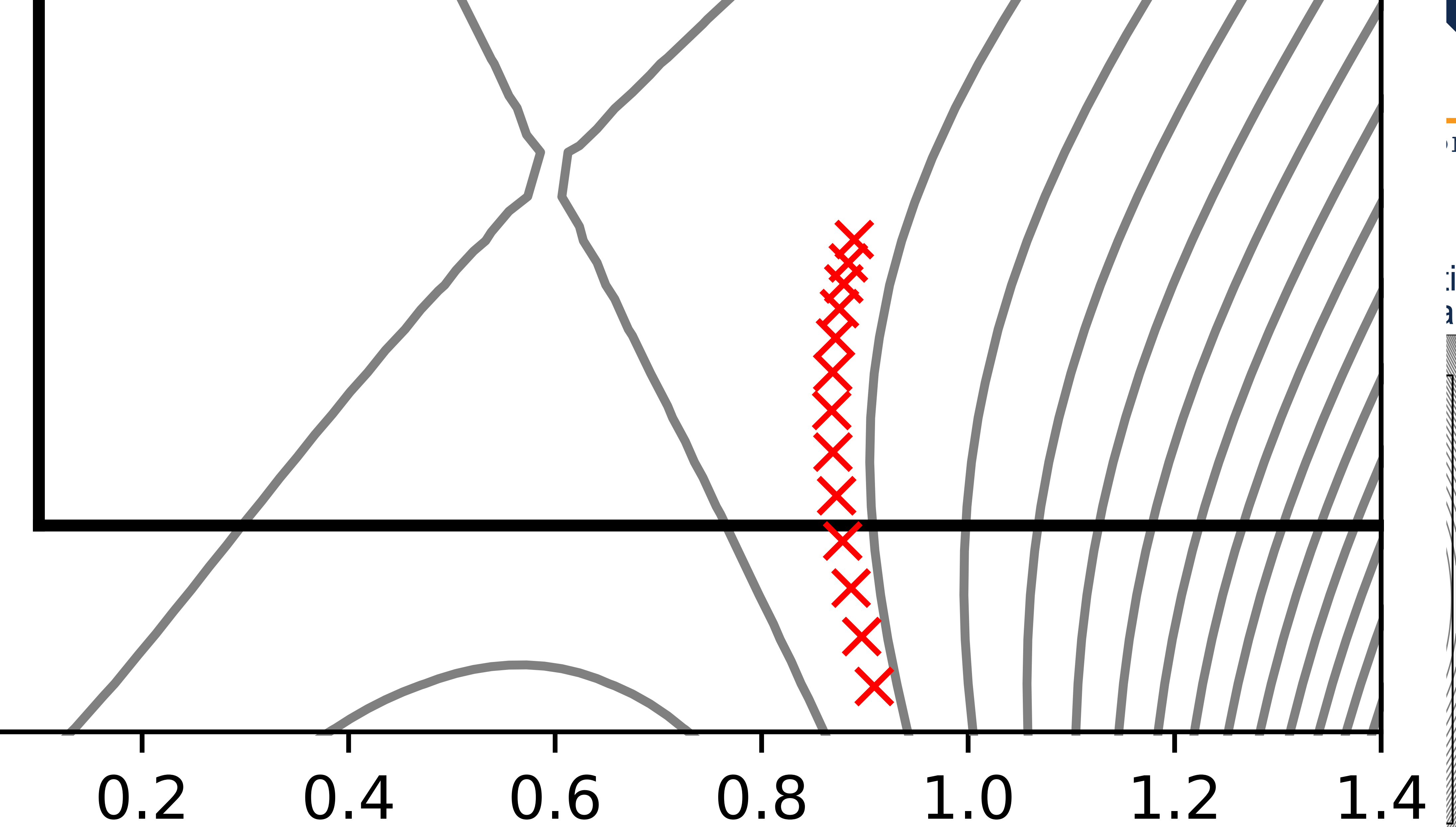


Follow perpendiculars to flux surfaces to find all flux surfaces to be gridded.

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

Write to grid file.

https://hypnotoad.readthedocs.io/en/latest/grid-generation.html



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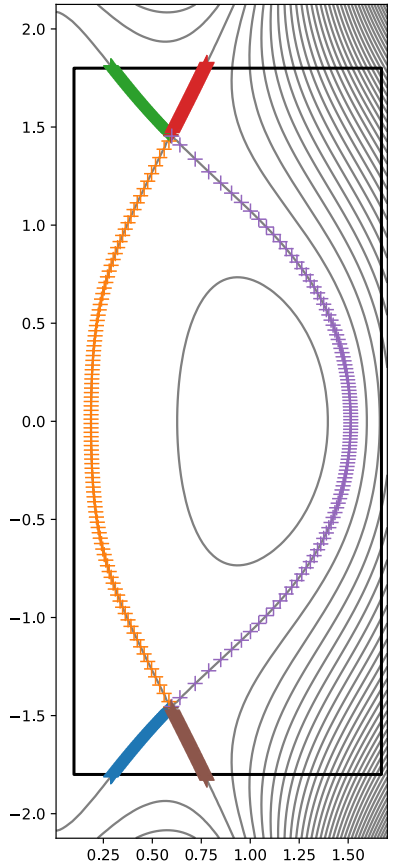
Building blocks 2/2

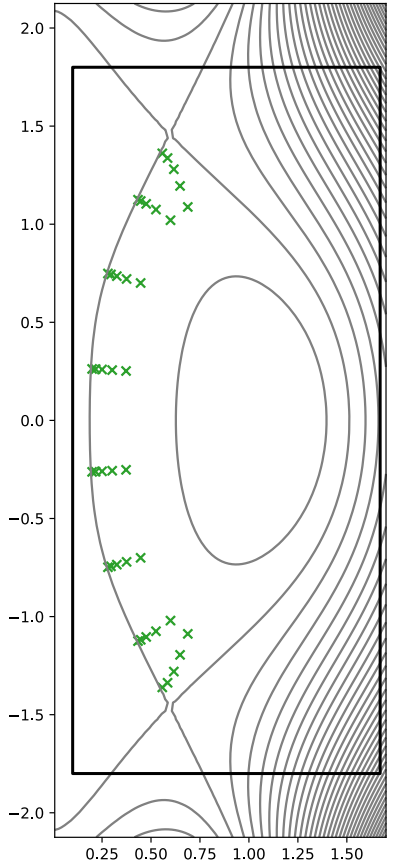
`Equilibrium`

- Equilibrium data
- Collection of `EquilibriumRegions`



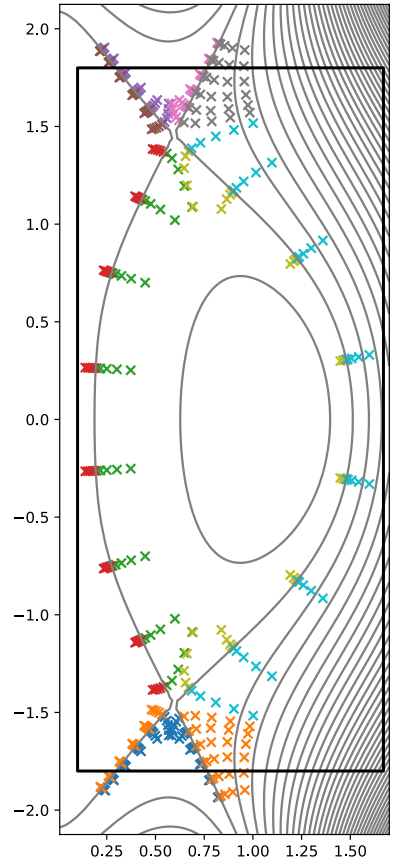
`MeshRegion`

- Collection of `PsiContours`
- One sub-region



`Mesh`

- Collection of `Meshregions`
- Whole grid



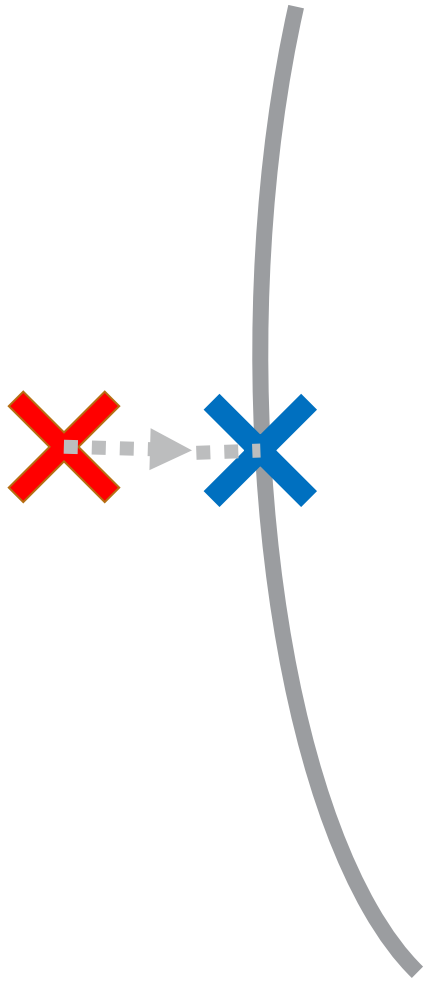
https://hypnotoad.readthedocs.io/en/latest/hypnotoad-classes.html

Algorithm notes

- ψ refinement
- FineContour construction
- ‘Spacing functions’

ψ refinement

- Points on `PsiContour` or `FineContour` generated initially by contour tracing or interpolation: not exactly on the right ψ value
- To make grid as accurate and reproducible as possible, initial guess refined: point moved to correct ψ (with small tolerance)
- Several algorithms, by default tried one after the other for robustness:
  - **integrate+newton**
  - **integrate**
  - line
  - newton



https://hypnotoad.readthedocs.io/en/latest/point-refinement.html

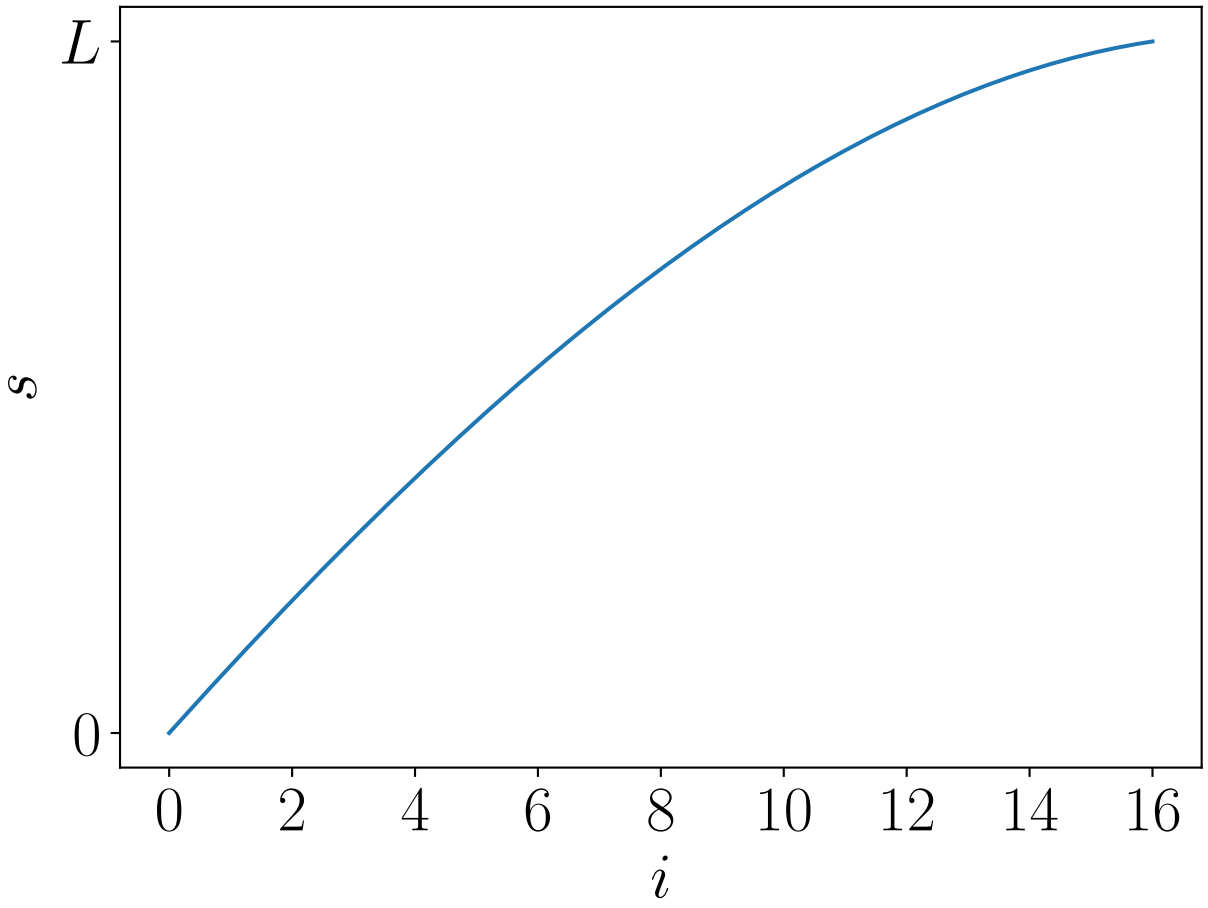
FineContour construction

- High-resolution representation of psi contour
  → accurate calculation of poloidal distances
- Independent of BOUT++ grid
  - constant poloidal spacing
  → consistency of spacing, `zShift` between different resolutions
- Construction:
  - Interpolate initial guess from `PsiContour`
  - Iterate:
    1. ψ-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

https://hypnotoad.readthedocs.io/en/latest/finecontour.html

‘Spacing functions’

- Poloidal distance as a function of index space $s(i_N)$
  - Normalised index space value $i_N = i/n_{d,\mathrm{total}}$ used so spacing function is independent of grid resolution
- Used to define:
  1. $\psi(i_x)$
  2. $s_{\mathrm{pol}}(i_y)$
- Input parameters set gradient at either end
- Exact definition, implementation are complex…

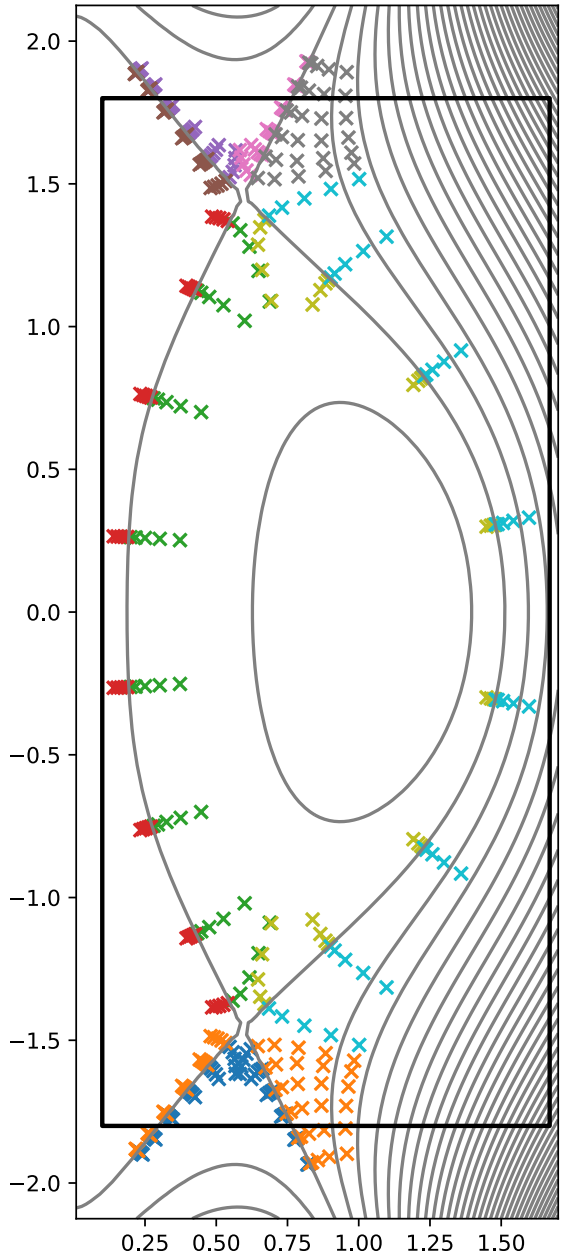


https://hypnotoad.readthedocs.io/en/latest/spacing-functions.html

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

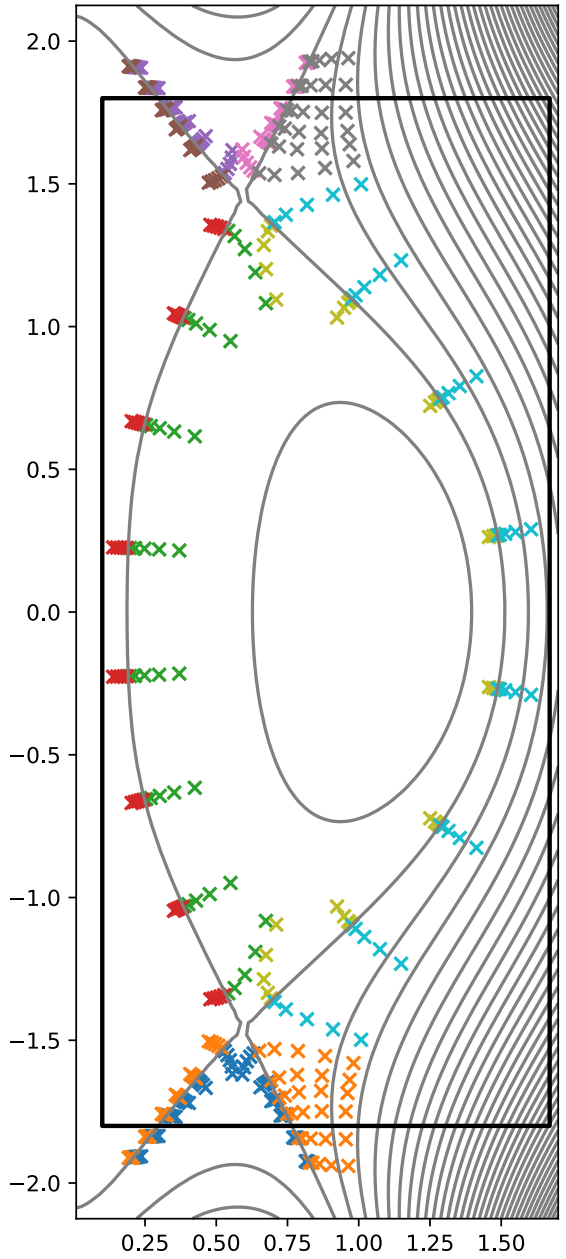


https://hypnotoad.readthedocs.io/en/latest/orthogonal-grid.html

Nonorthogonal grids

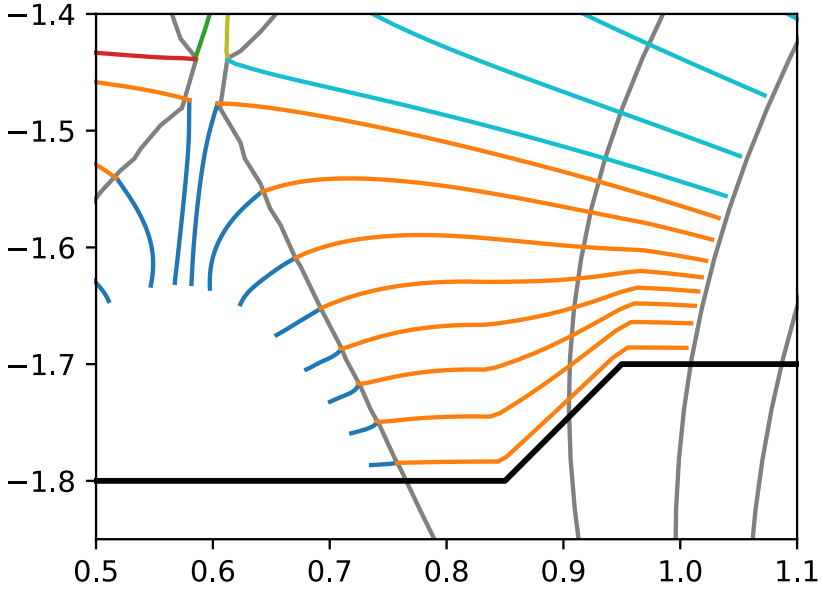
- Fix cons of orthogonal grids ✓
- May need additions to Physics model ✗
- More complex ✗

- 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

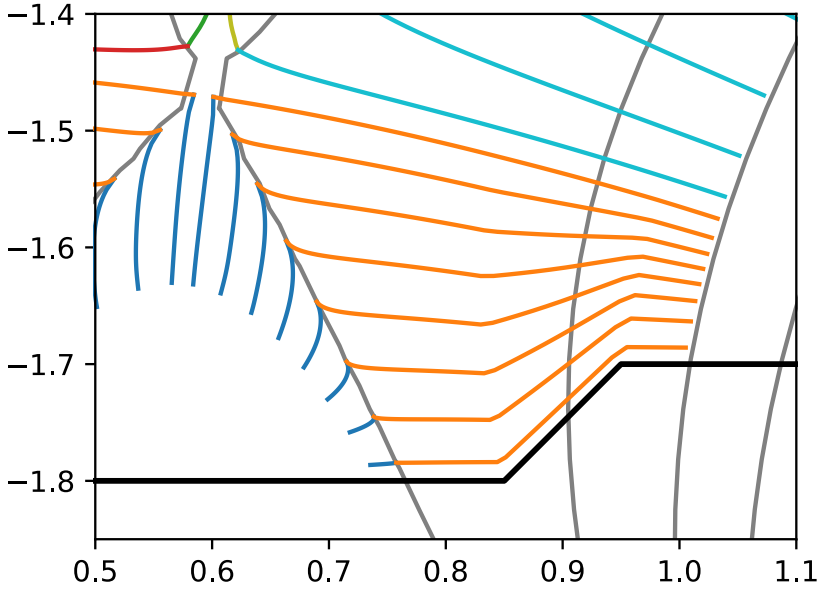


https://hypnotoad.readthedocs.io/en/latest/nonorthogonal-grid.html

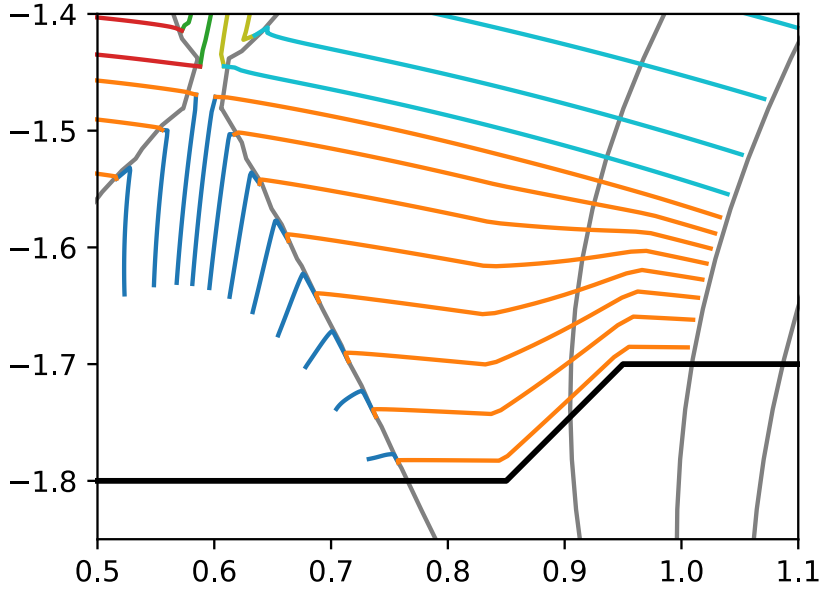
Nonorthogonal spacing



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

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- 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!

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Tools provided by `hypnotoad`

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- 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

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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

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Thank you!

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

https://hypnotoad.readthedocs.io/

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