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Mesh generation for fusion applications

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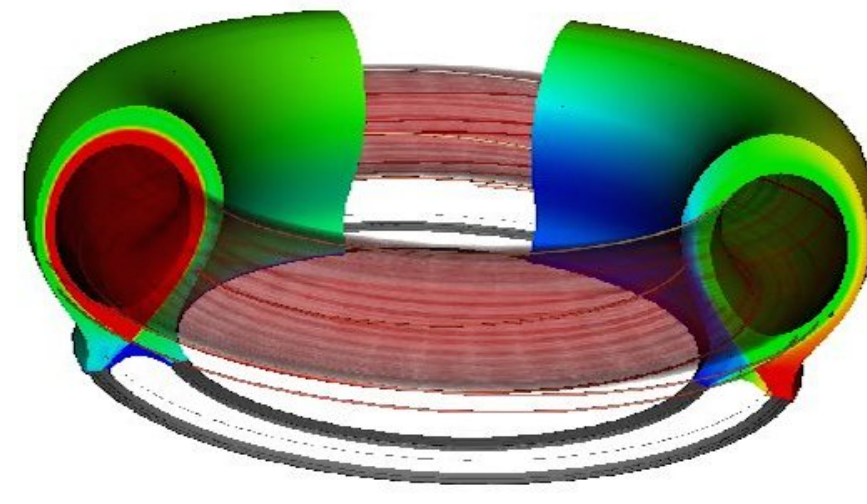
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Context and motivations

- High anisotropy in magnetized fusion plasmas:
⇒ requires the use of **flux aligned meshes**.
- Complex and realistic geometries:
⇒ need other strategies (equidistribution, orthogonality).
- High order derivatives (in MHD for example):
⇒ require **regular representation**.

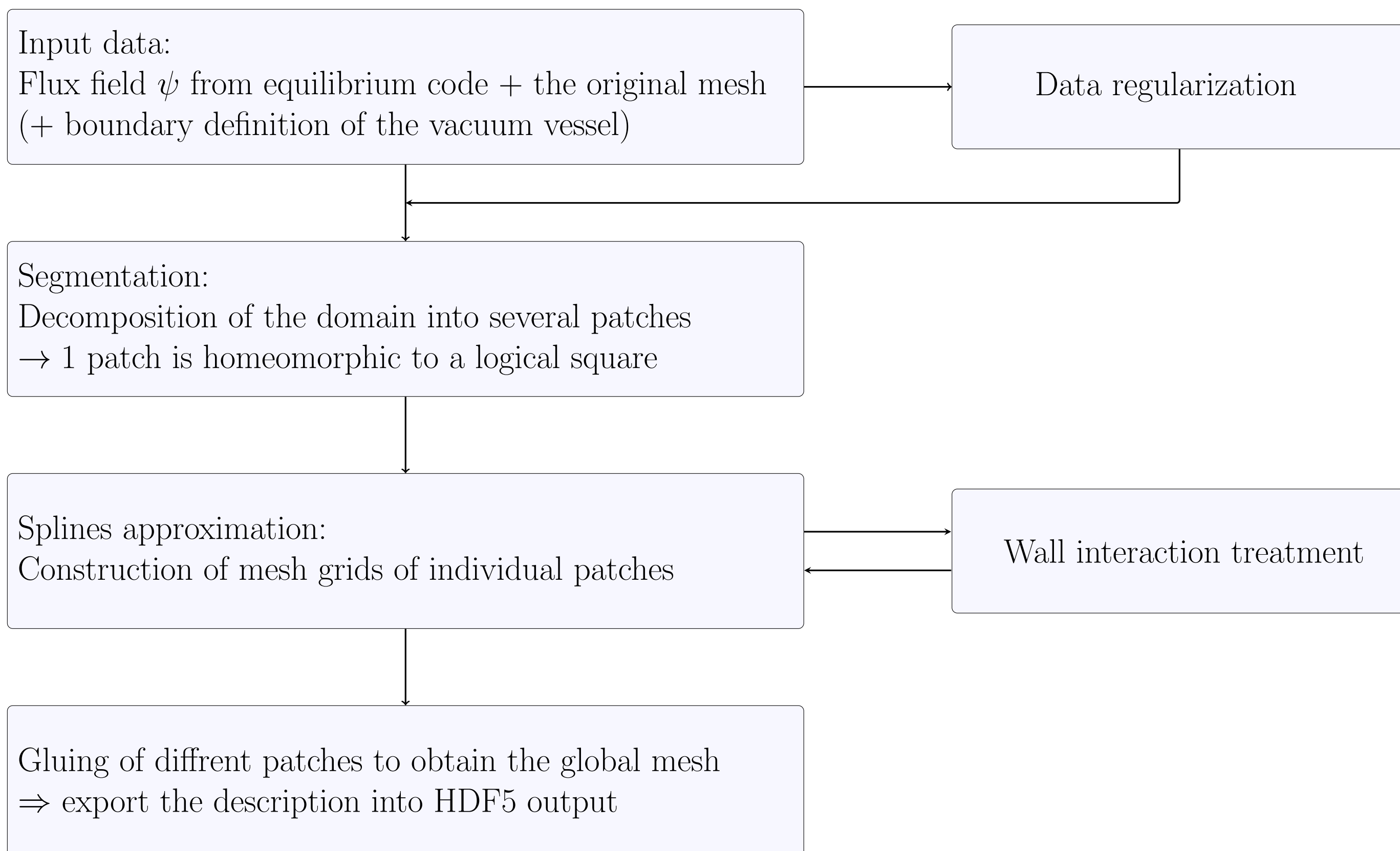


Sketch of a Tokamak reactor

Unified code for the generation of flux aligned mesh in the poloidal plane.

- Different codes and type of meshes.
- Different numerical methods:
 - Semi-Lagrangian approaches.
 - Finite difference, Finite volume
 - Finite Element (Spline or Hermite-Bezier on quadrangles; Powell-Sabin, Clough-Tocher on triangles, etc..)

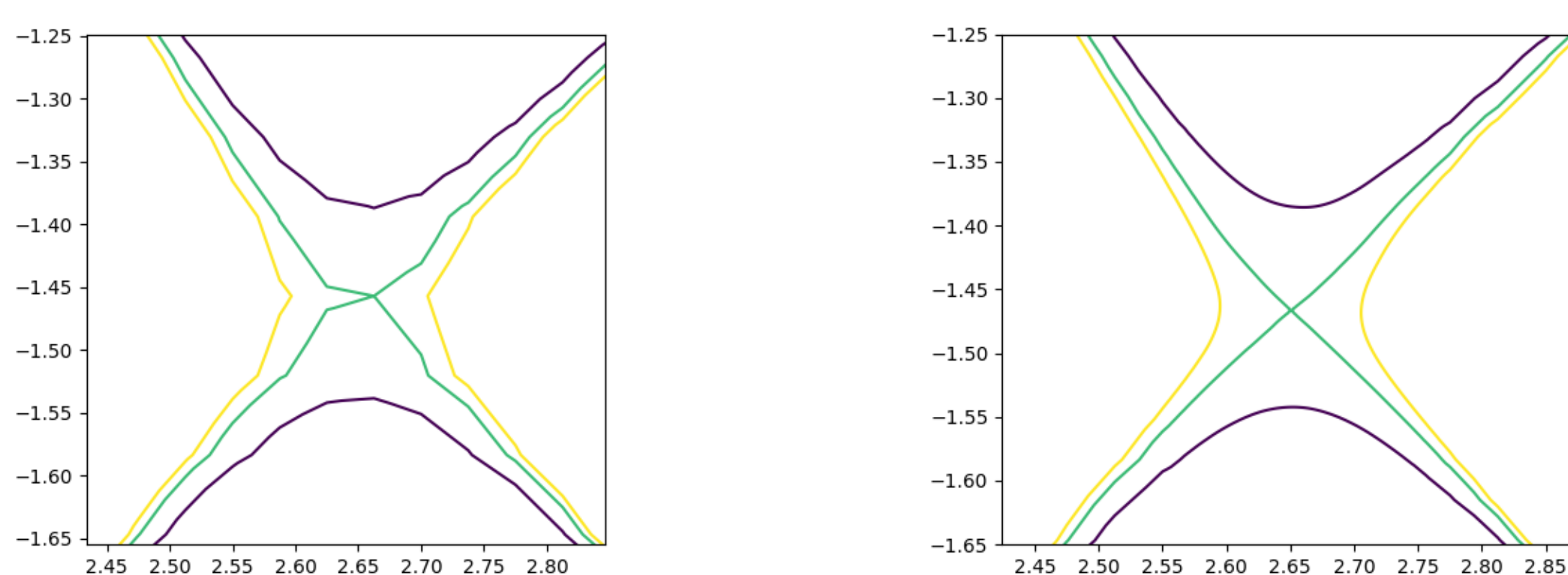
Workflow diagram



Pre-processing of the data

Isolines regularization

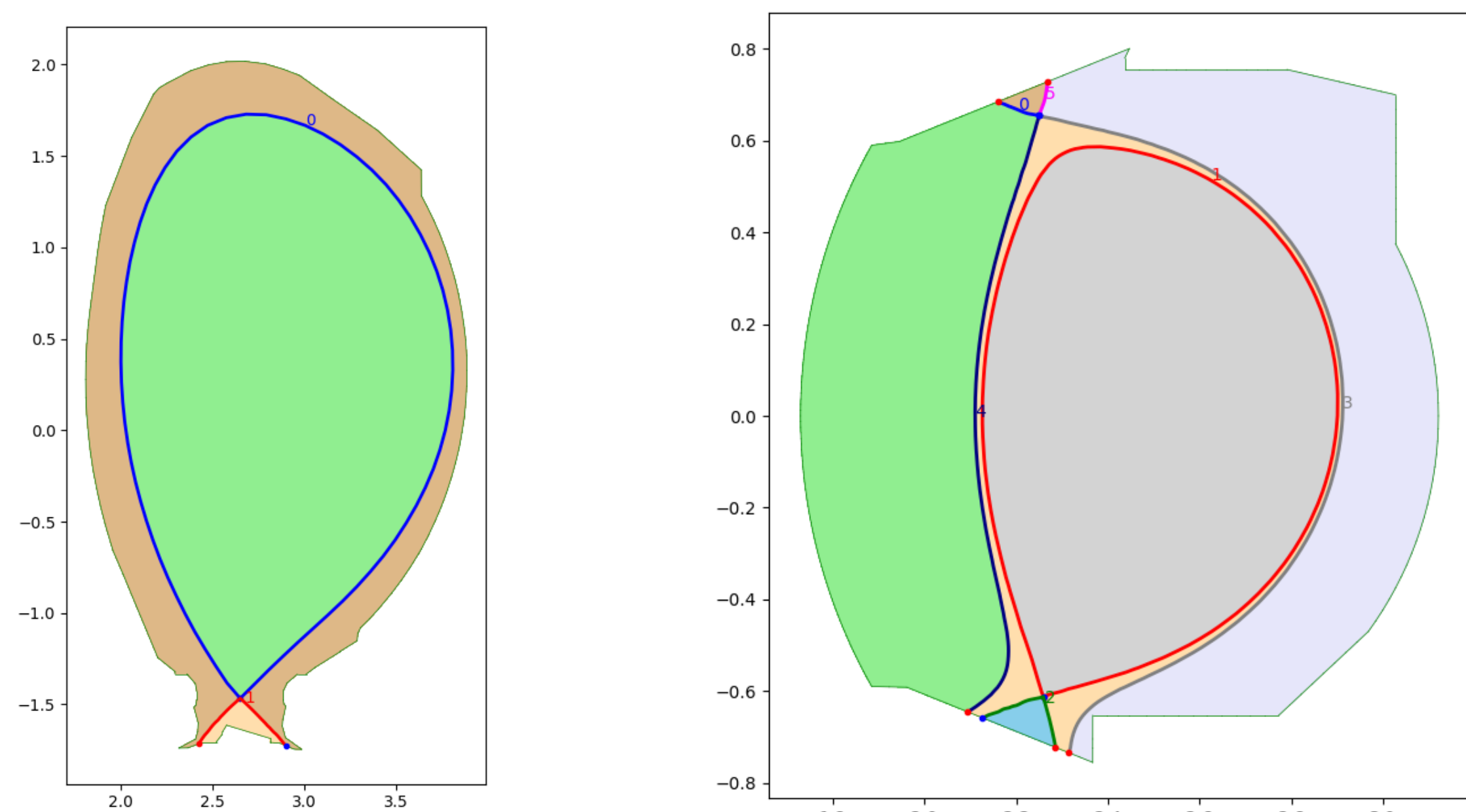
If the equilibrium solver results are not smooth enough : low-order discretization, coarse resolution, ...
⇒ Replace the flux function by its Clough Tocher interpolant on the refined mesh (locally).



Segmentation

- Based on Morse theory and Reeb graph.
- Automatic decomposition of isolines including arbitrary number of X-Points.
- Topological set of the isolines consists of finite connected components and contains only closed orbits.

Examples of domain segmentation for JET and WEST tokamaks:



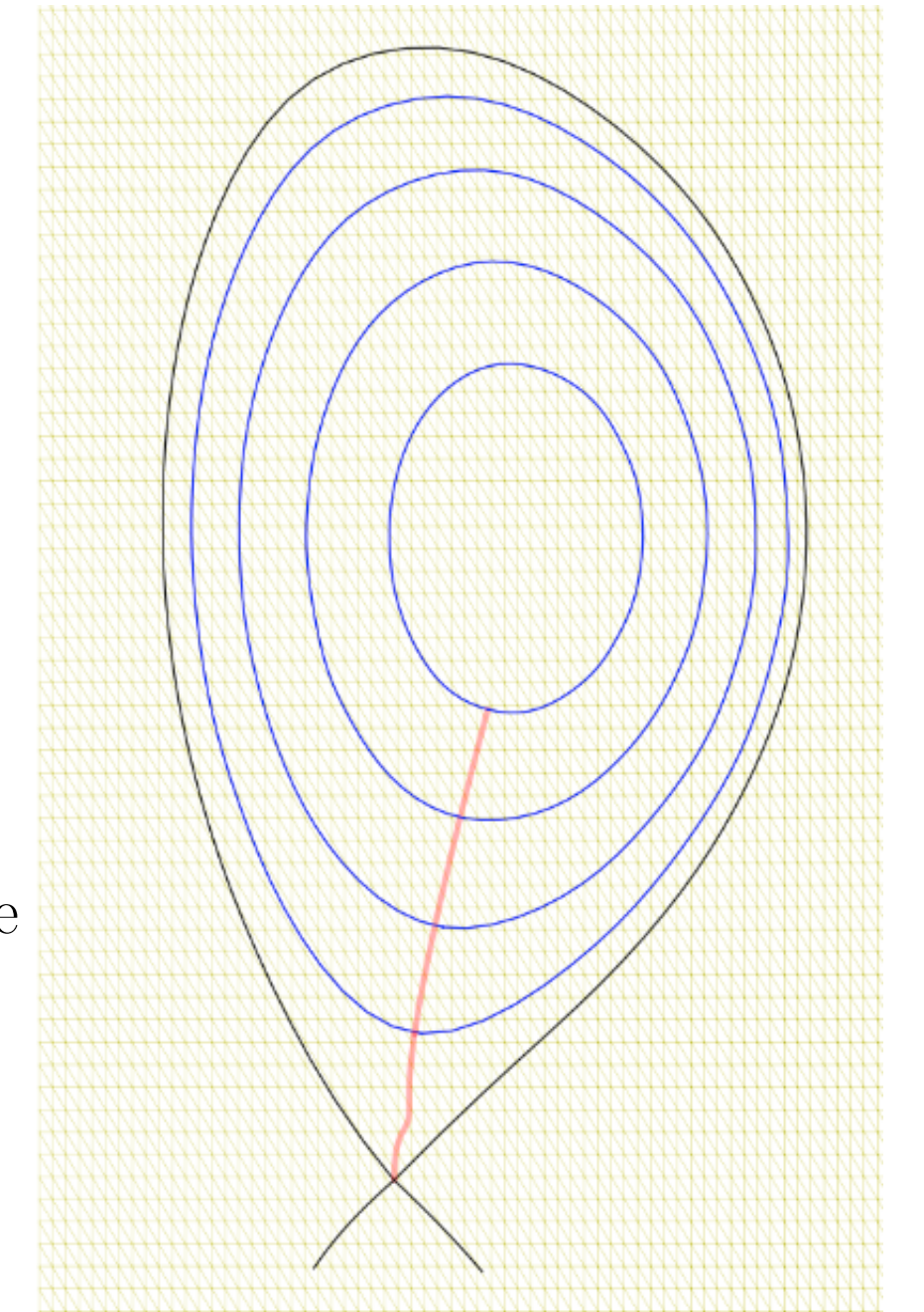
Structured grid construction

I. Isolines generation

1. Identify a mapping: $(s, t) \in [0, 1] \times [0, 1] \rightarrow \mathbf{x}(s, t) \in \Omega$
2. Get the radial curve $\mathcal{S}(s)$, solution of the ODE:

$$\begin{cases} \frac{d\mathbf{x}}{ds} = \frac{\psi_M - \psi_0}{\|\nabla\psi\|^2} \nabla\psi \\ \mathbf{x}(0) = \mathbf{x}_0 \end{cases}$$

3. Compute the spline interpolation of the radial curve and generate a set of internal isolines.



II. Meshing of individual patch Ω_k

1. Choose a finite number of isolines $f^{-1}(c_i)$.
2. Approximate each level set by a spline: $f^{-1}(c_i) \sim \mathcal{C}_i(t) = \sum_j \mathbf{C}_j^i N_j(t)$.
 N_j : B-spline Basis.
 \mathbf{C}_j^i : Control Points.
3. Construct a 2D tensor product mapping $[0, 1] \times [0, 1] \rightarrow \Omega_k$:

$$\mathcal{S}(s, t) = \sum_i \sum_j \mathbf{P}_{i,j} N_i(s) N_j(t), \text{ s.t. } \mathcal{S}(s_i, t) = \mathcal{C}_i(t), \forall i.$$

III. Gluing patches

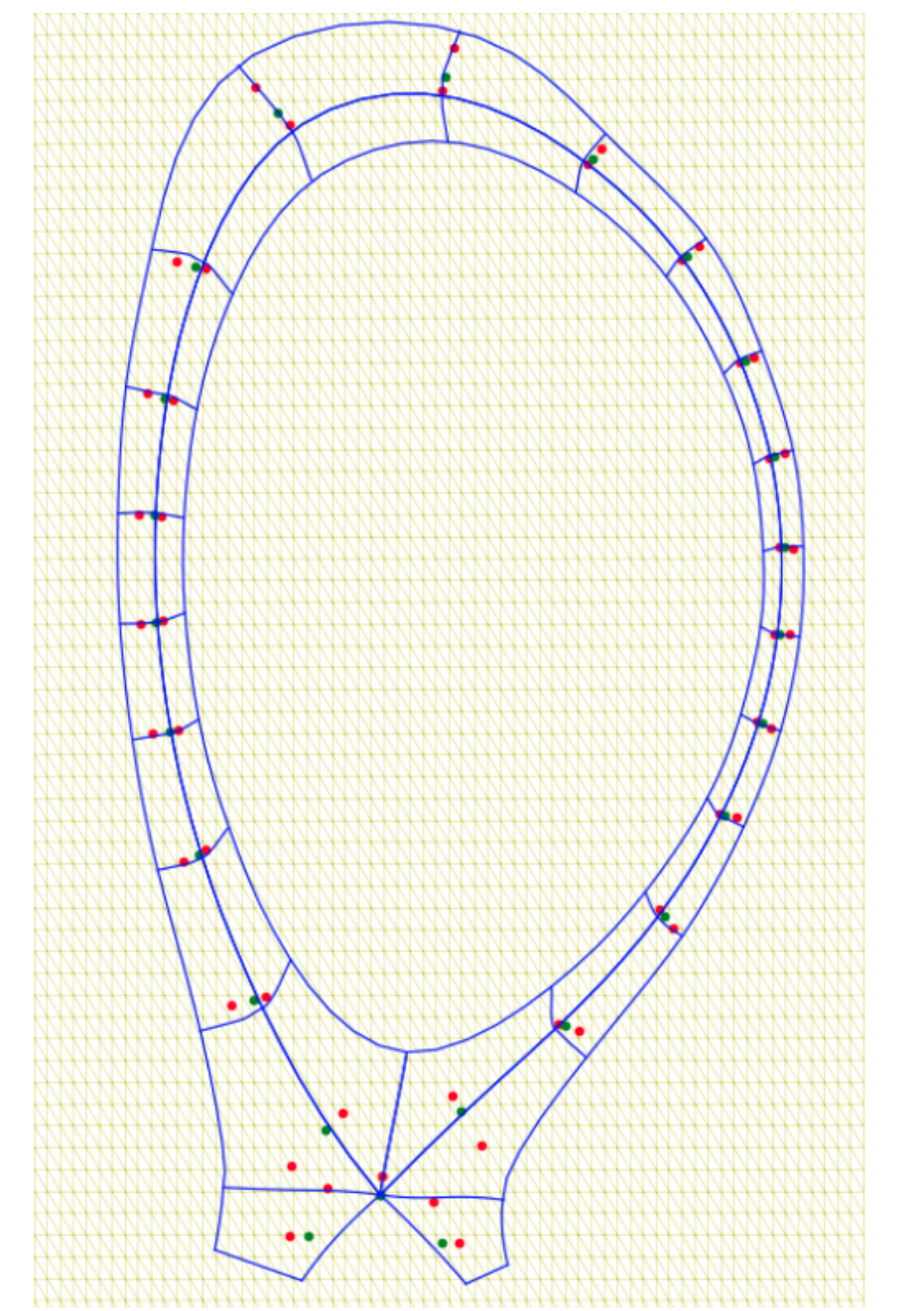
Given 2 subdomains Ω_1 and Ω_2 described by:

$$\mathcal{S}_1(s, t) = \sum_i \sum_j \mathbf{P}_{i,j} N_i(s) N_j(t)$$

$$\mathcal{S}_2(s, t) = \sum_i \sum_j \mathbf{Q}_{i,j} N_i(s) N_j(t)$$

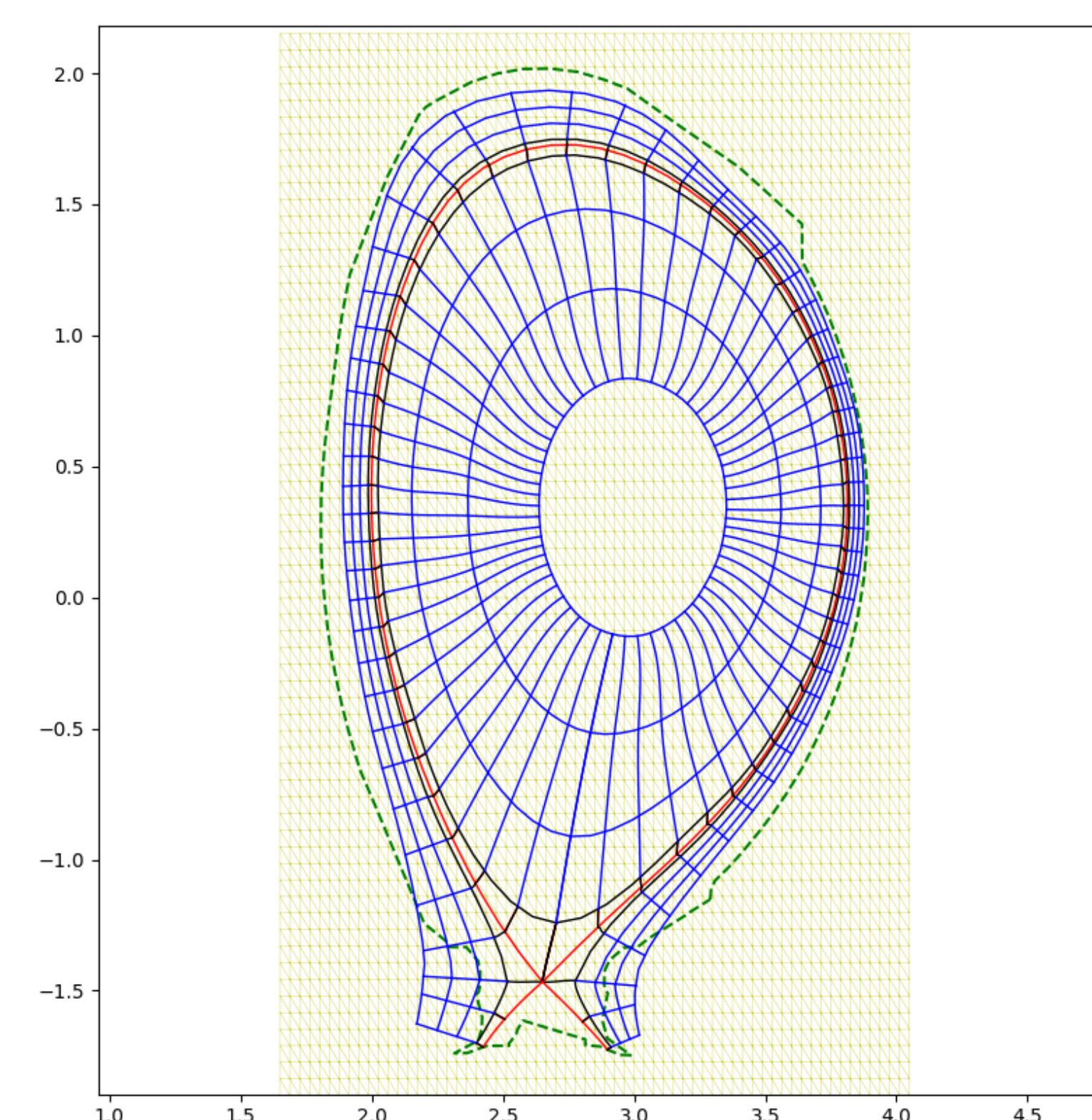
with a common boundary for instance: $\mathcal{S}_1(0, t) = \mathcal{S}_2(0, t)$

1. \mathcal{C}^0 continuity: $\mathbf{P}_{0,j} = \mathbf{Q}_{0,j}, \forall j$.
2. \mathcal{C}^1 continuity: geometric condition on the control points, $\mathbf{P}_{1,j}, \mathbf{P}_{0,j} = \mathbf{Q}_{0,j}, \mathbf{Q}_{1,j}$ have to be aligned.



Multipatch example

Flux aligned mesh for JET (Core/Edge/SOL regions):



Summary

Development of a mesh generation software for tokamak simulations:

- Can be used by different codes and handle different types of meshes.
- Written in Python with Fortran bindings:
→ using open source libraries (except Segmentation module but free for academics).