On the Generation of a Spiral Tool Path for High Speed Pocket Machining and Related Applications

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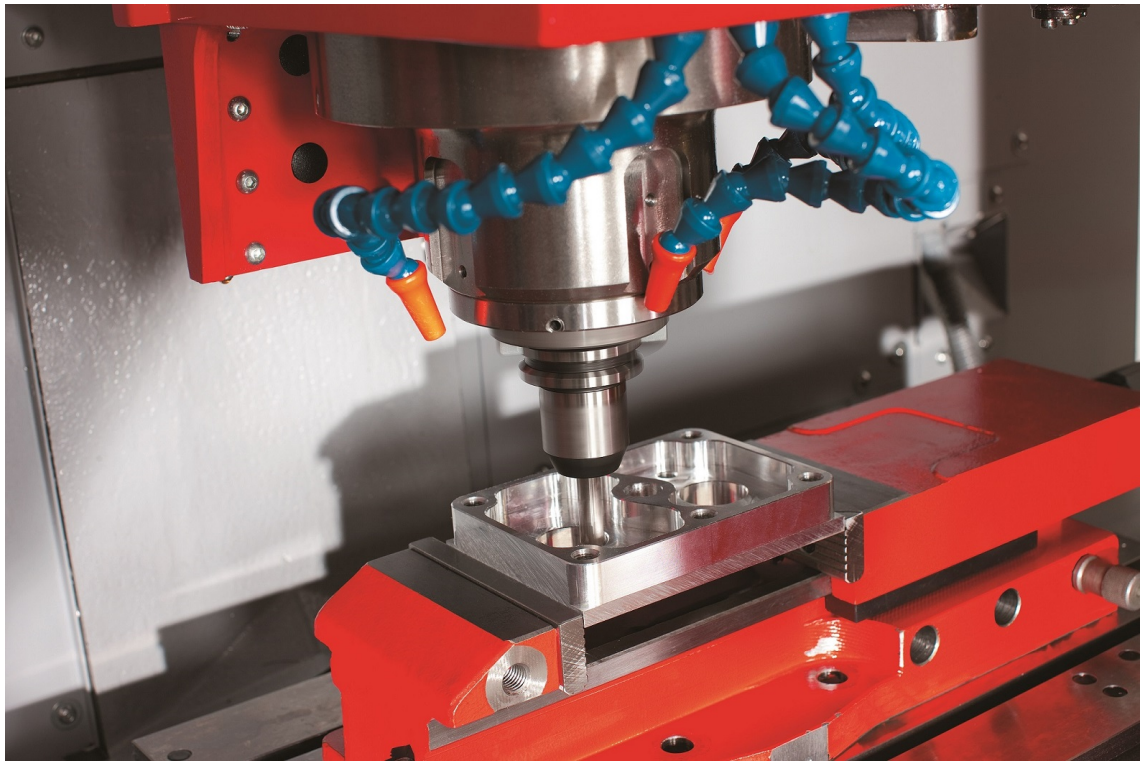
Introduction

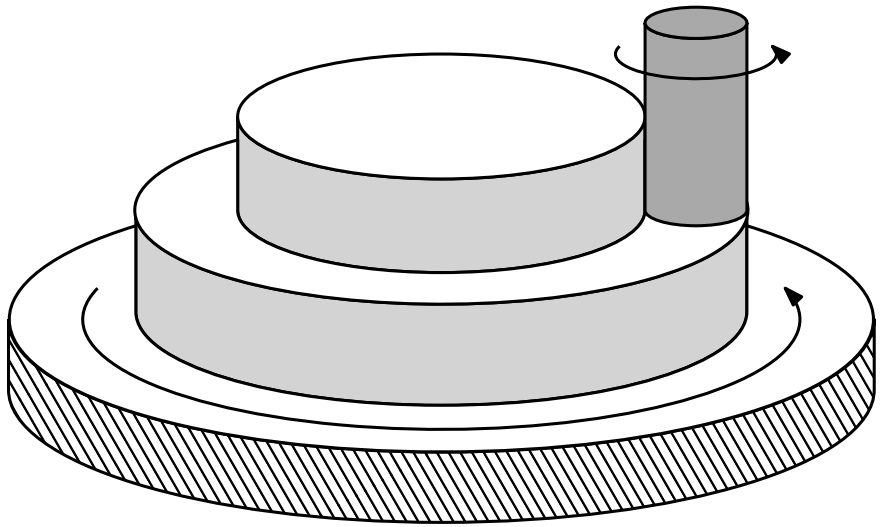
- Material is removed from a **workpiece**.
- Milling cutter can be regarded as a **cylindrical object**.
- Tool is positioned using multiple **axes**.
- Different types of **path control** can be distinguished.



Types of Path Control

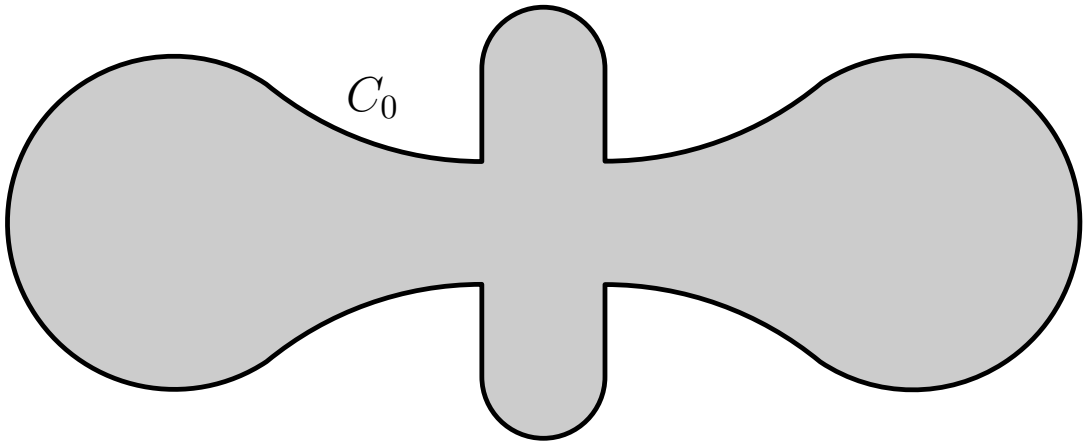
- Most milling tasks can be carried out using $2^1/_2$D milling.
- Hybrid between 2D and 3D milling.
- Parallel **machining planes** are considered.

$2\frac{1}{2}\mathrm{D}$



Input Specification

- A **contour** is a simple, closed curvilinear chain.



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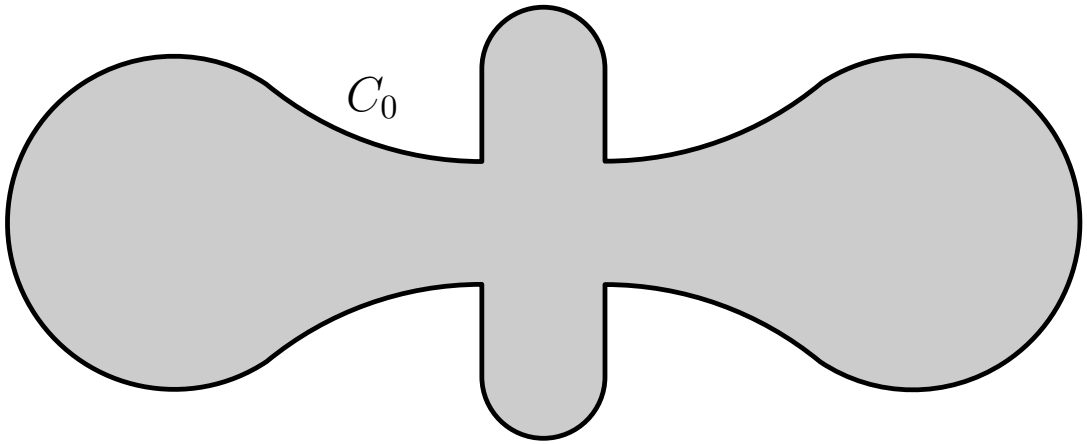
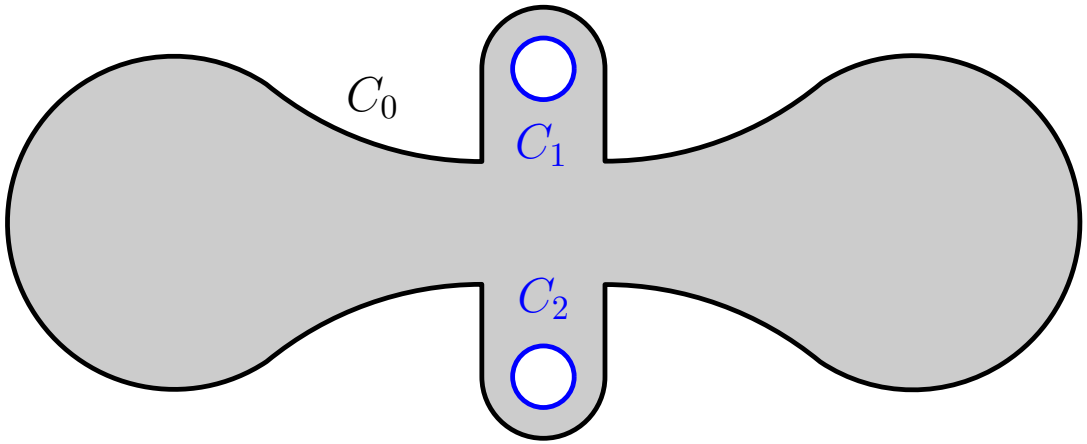


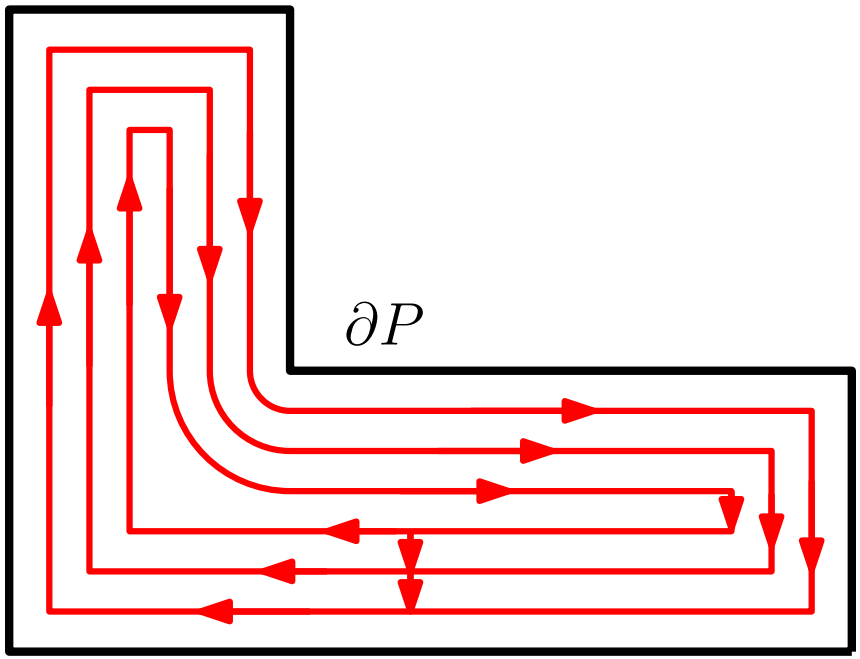
Input Specification

- A **contour** is a simple, closed curvilinear chain.
- The boundary ∂P of a **pocket** P consists of exactly one **outer contour** and (possibly) **inner contours** (the so-called islands).
- Islands are disjoint and do not include islands themselves.



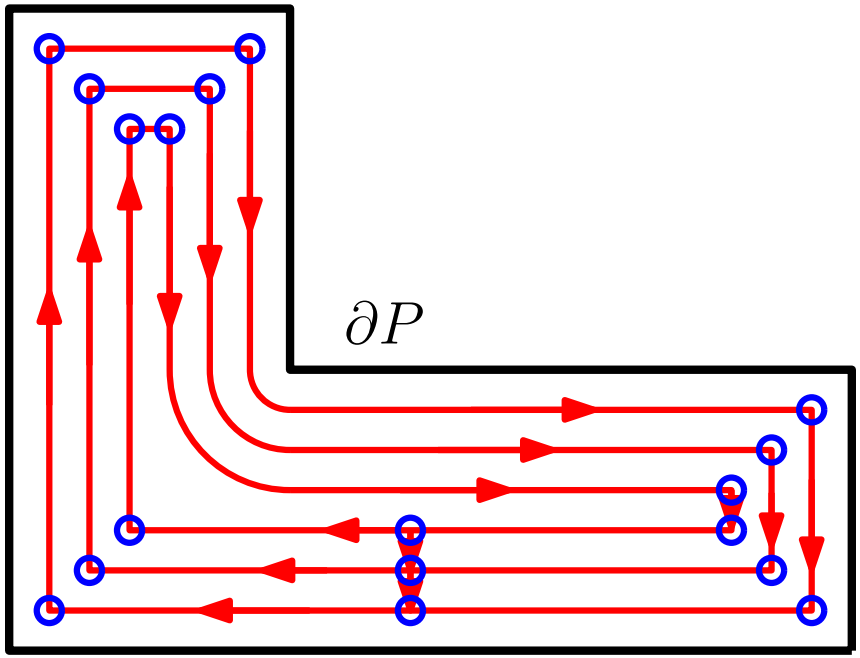
High Speed Machining

- High **spindle speeds** and **feeds**.



High Speed Machining

- High **spindle speeds** and **feeds**.
- Conventional strategies introduce **sharp corners**.
- Rapid acceleration and deceleration should be avoided.
- Cornering greatly contributes to **tool wear**.
- **Engagement angle** varies highly.
- **Continuous** tool path is crucial.

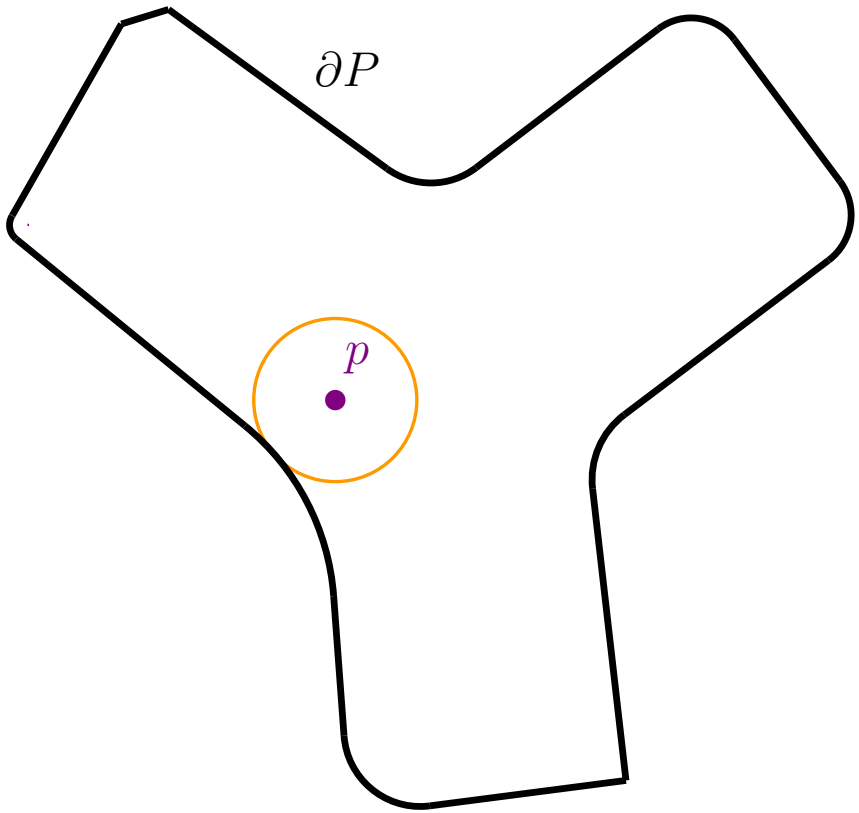


Obtaining a Raw Tool Path

- A **basic version** of the tool path.
- Starts in the interior of the pocket.
- Ends on the pocket boundary.
- Does not intersect itself.
- Respects the user-specified maximum **step-over** δ.

Medial Axis Tree

- The **medial axis** $\mathcal{MA}(P)$ inside a pocket P is a subset of the respective Voronoi diagram.
- $\mathcal{MA}(P)$ is union of all points whose **clearance disks** touch the border of P in at least two distinct points.



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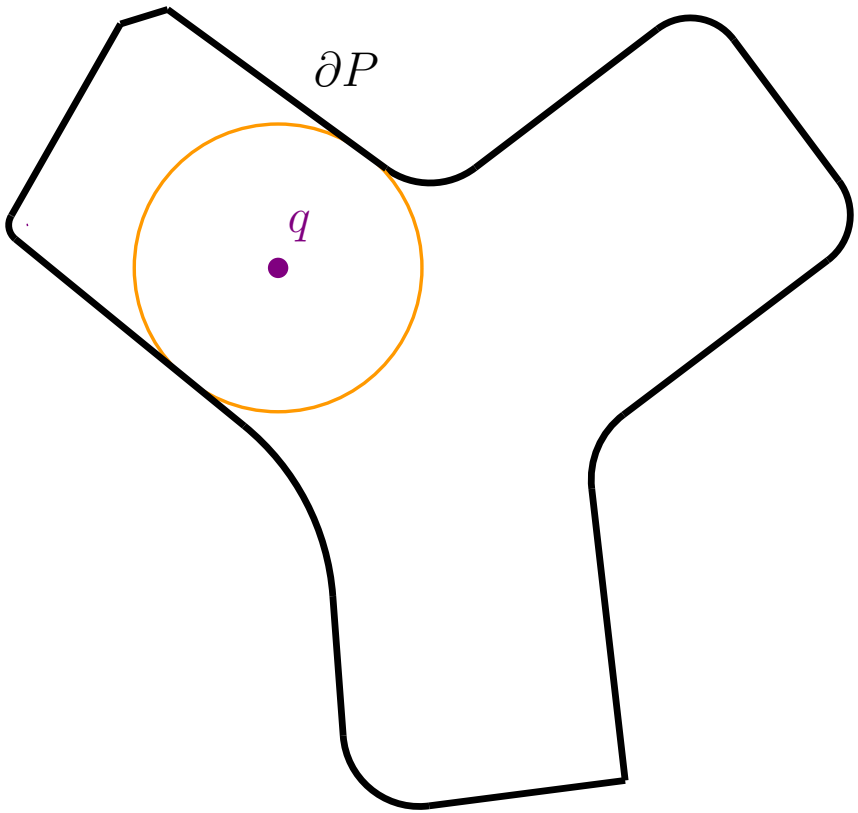

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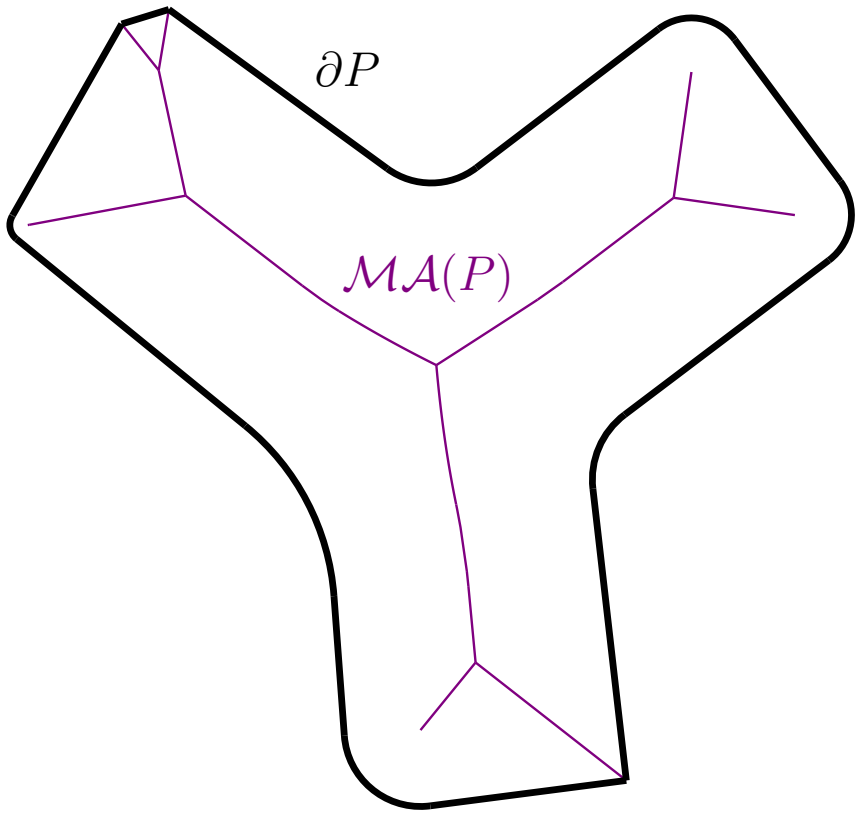

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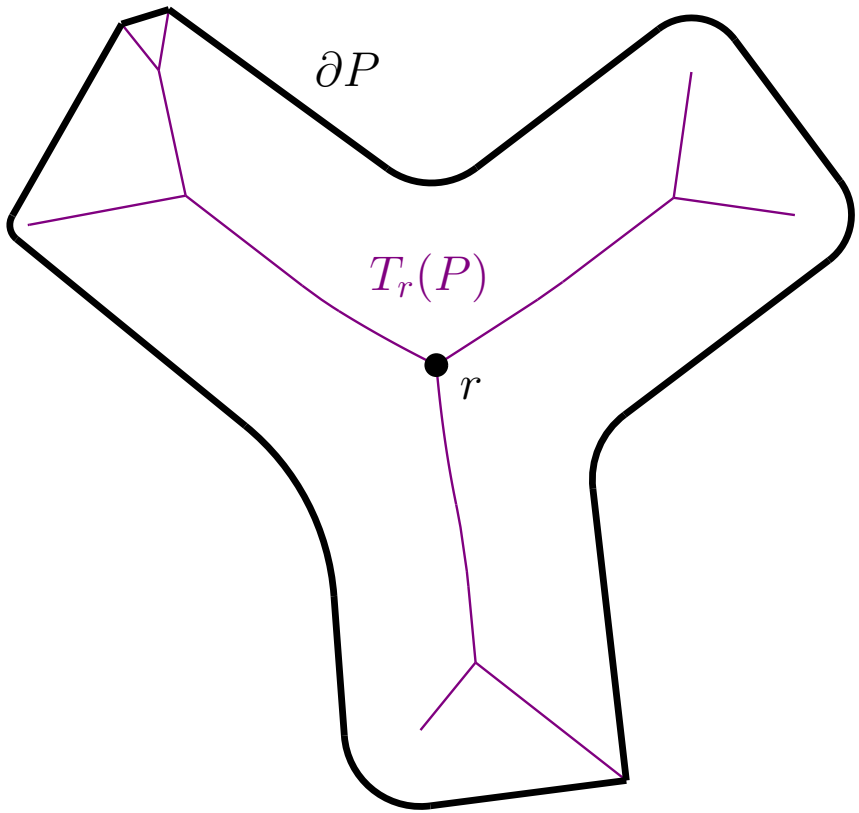
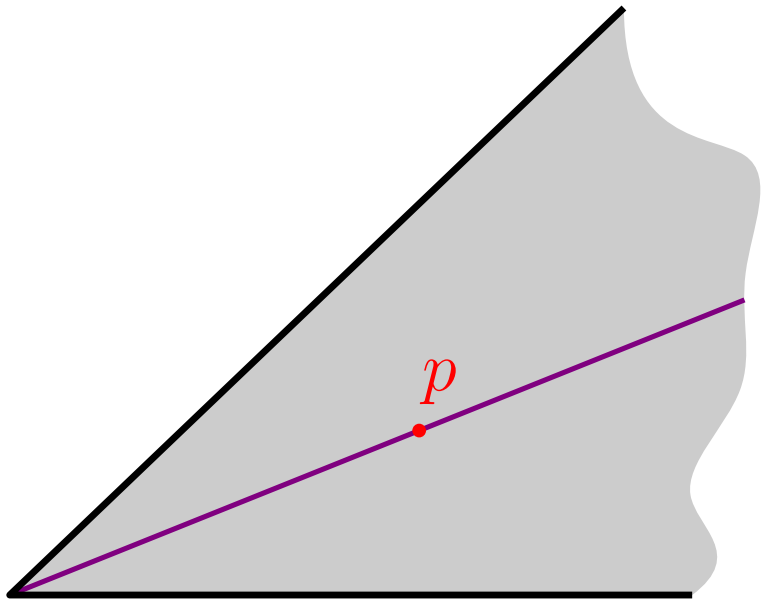
- $\mathcal{MA}(P)$ is union of all points whose **clearance disks** touch the border of P in at least two distinct points.
- $\mathcal{MA}(P)$ forms a tree $T_r(P)$ inside a pocket without islands.
- It is assumed that r is **height-balanced**.



Basic Concept of Clearance lines

- **Clearance lines** are the fundamental building blocks of the tool path.
- Straight-line segments starting on the medial axis.
- They end at one of the corresponding **defining sites**.



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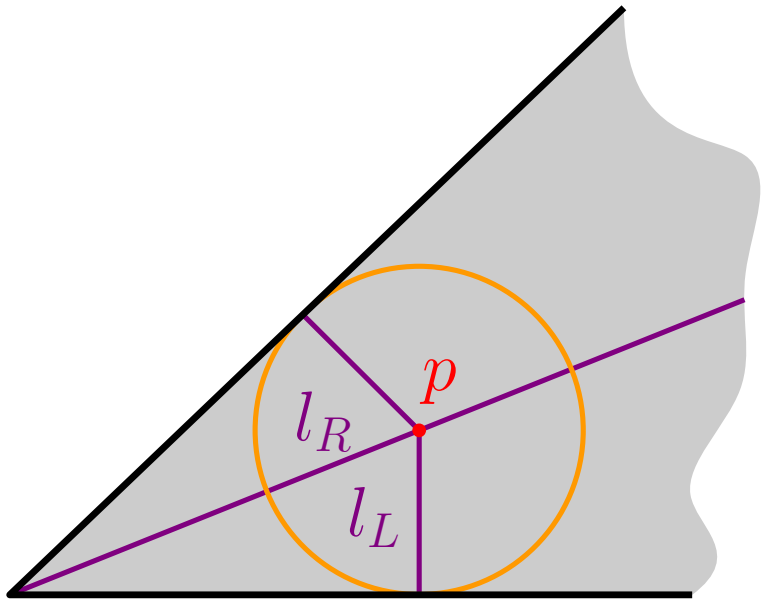
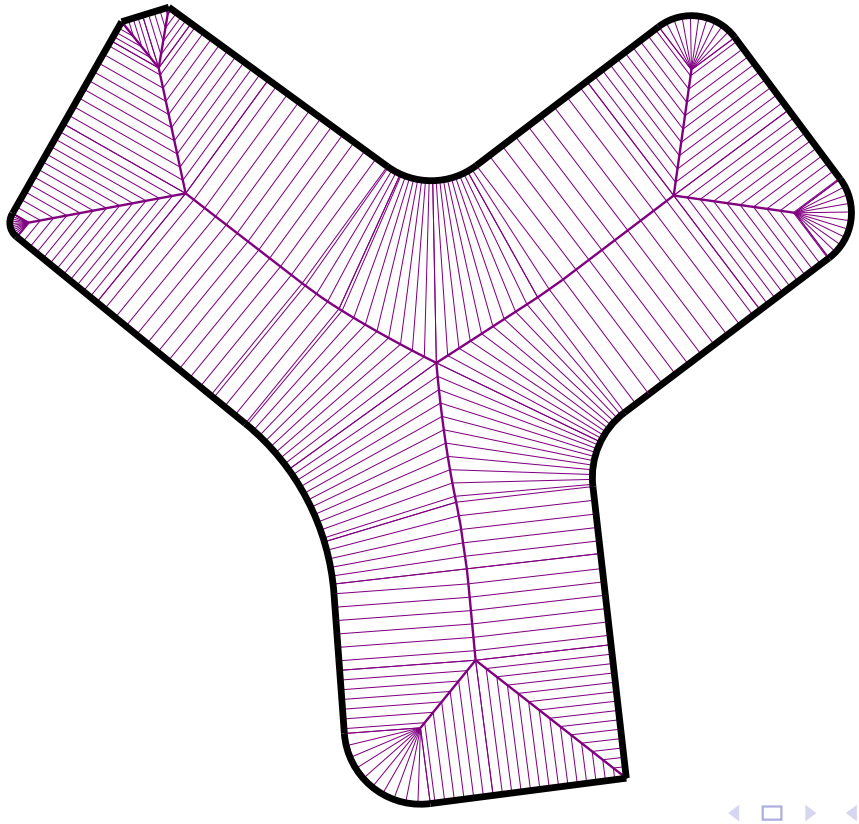


Clearance Line Distribution

- Only a finite number of clearance lines can be handled.
- Thus, **sample points** are distributed uniformly on each edge e of $T_r(P)$.
- Additionally, a sample point is placed at the start and end point of e.



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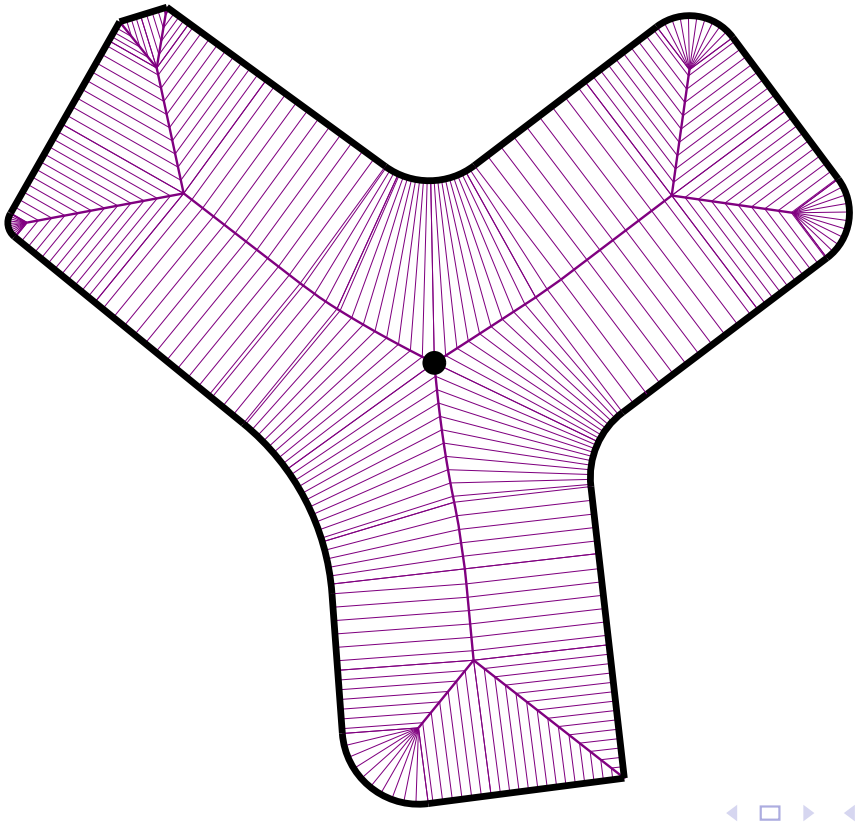
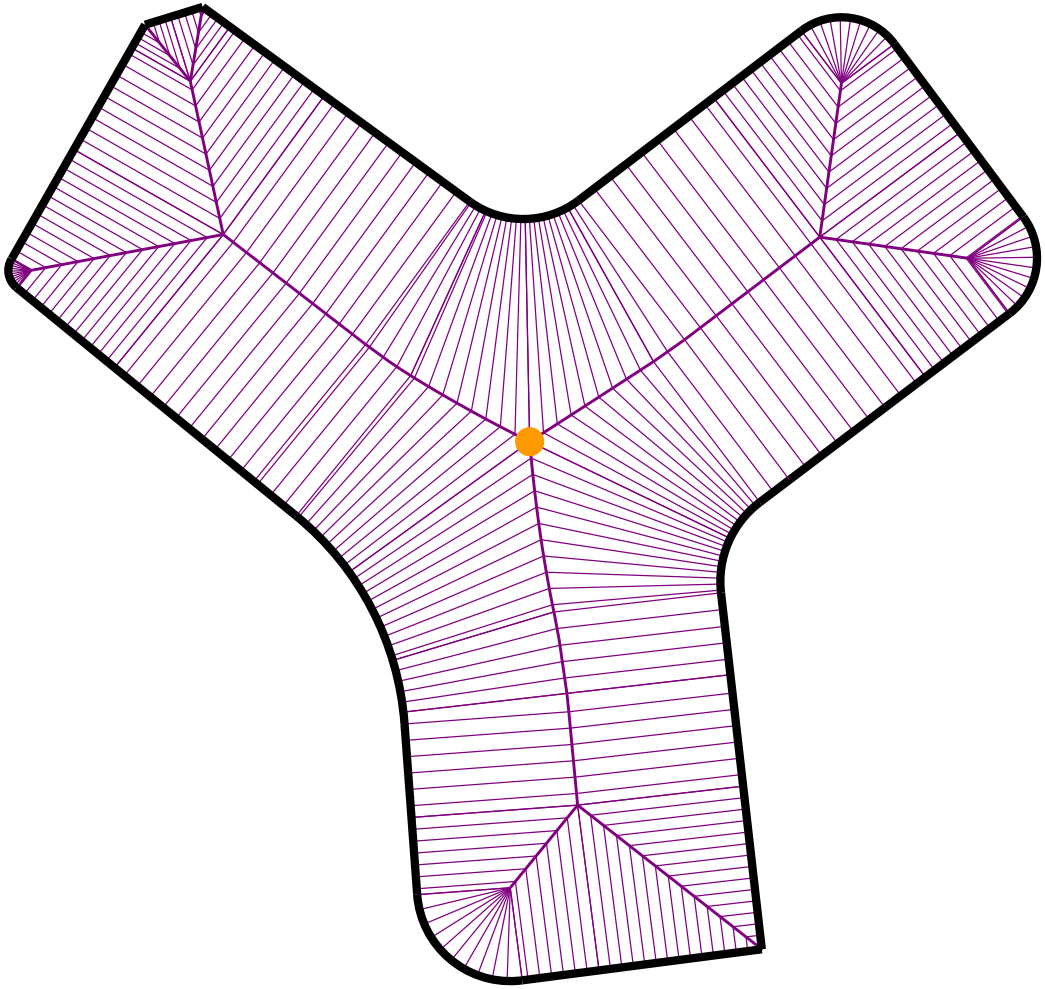
- Thus, **sample points** are distributed uniformly on each edge e of $T_r(P)$.
- Additionally, a sample point is placed at the start and end point of e.
- Clearance lines together with the medial axis tree.
- New structure forms also a tree (the **discrete medial axis tree (DMAT)**).



Basic Idea of Impulse Propagation

- General idea based on [Held and Spielberger, 2009].
- An **impulse** flows through the DMAT.
- It starts at the root, splits at each vertex, and simultaneously arrives at all leaves of the DMAT.
- The impulse is active during the time interval $[0, 1]$.

Animation: Impulse Propagation



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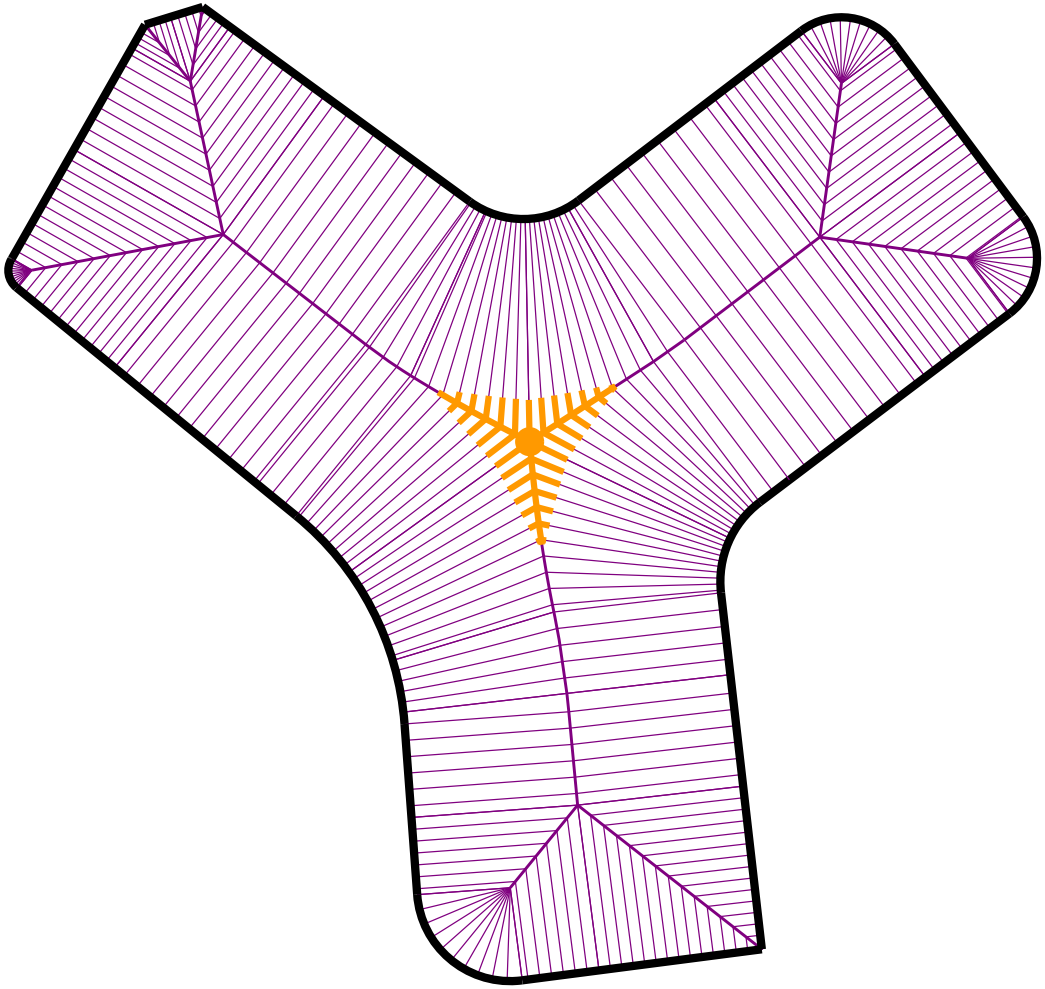

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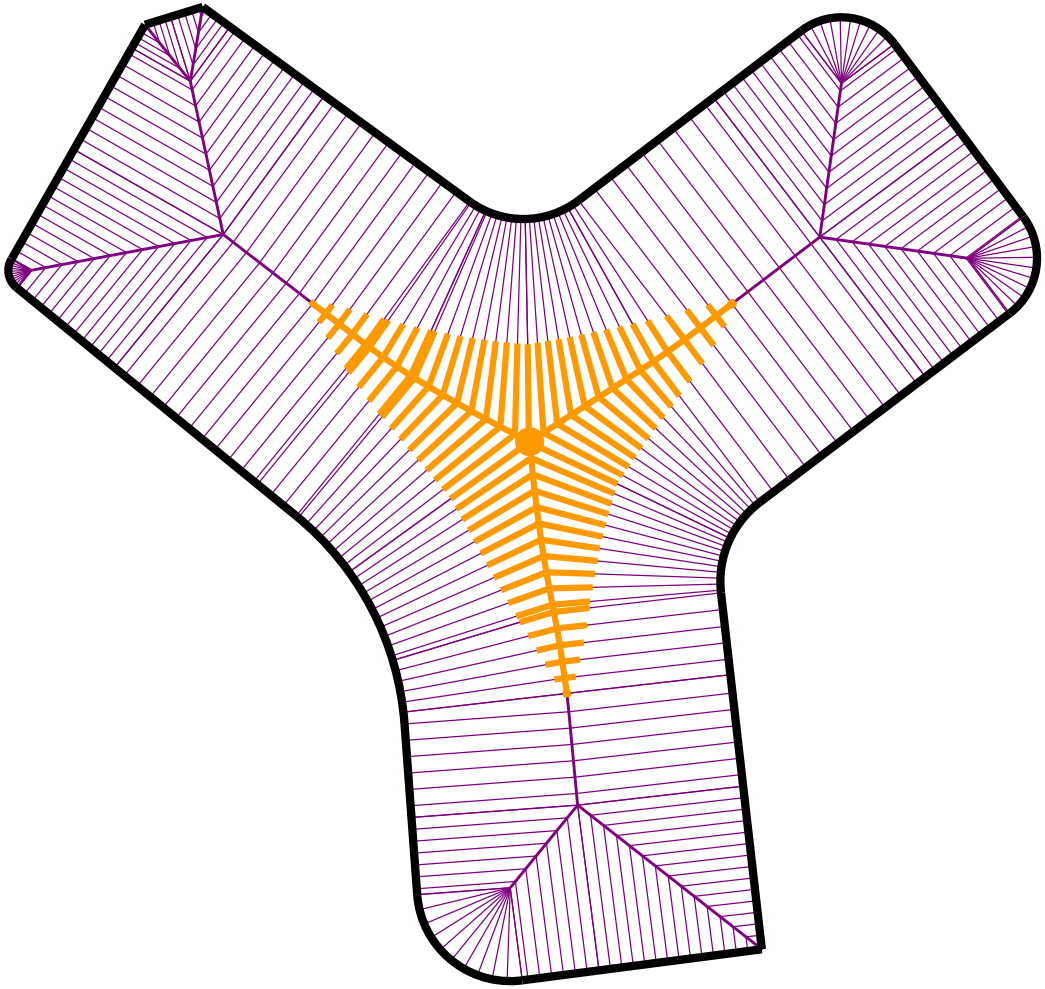

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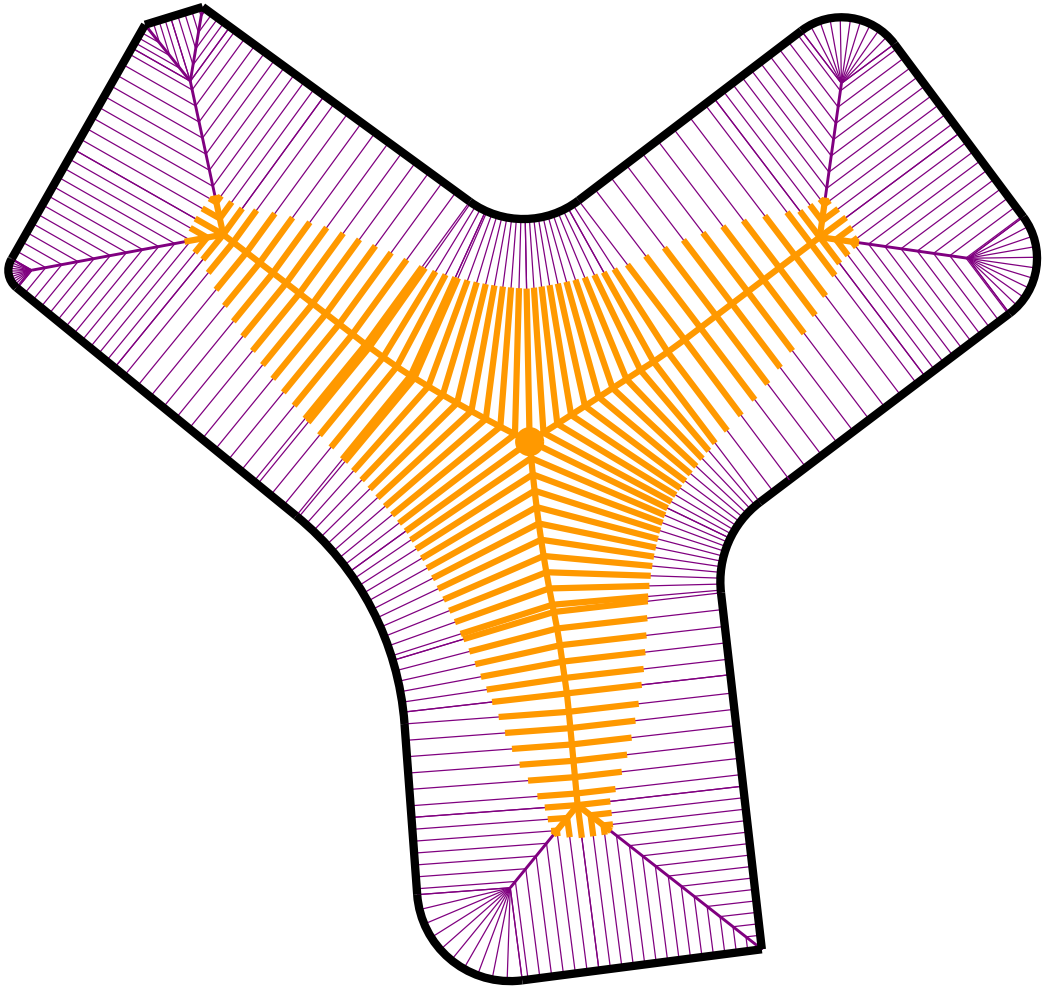

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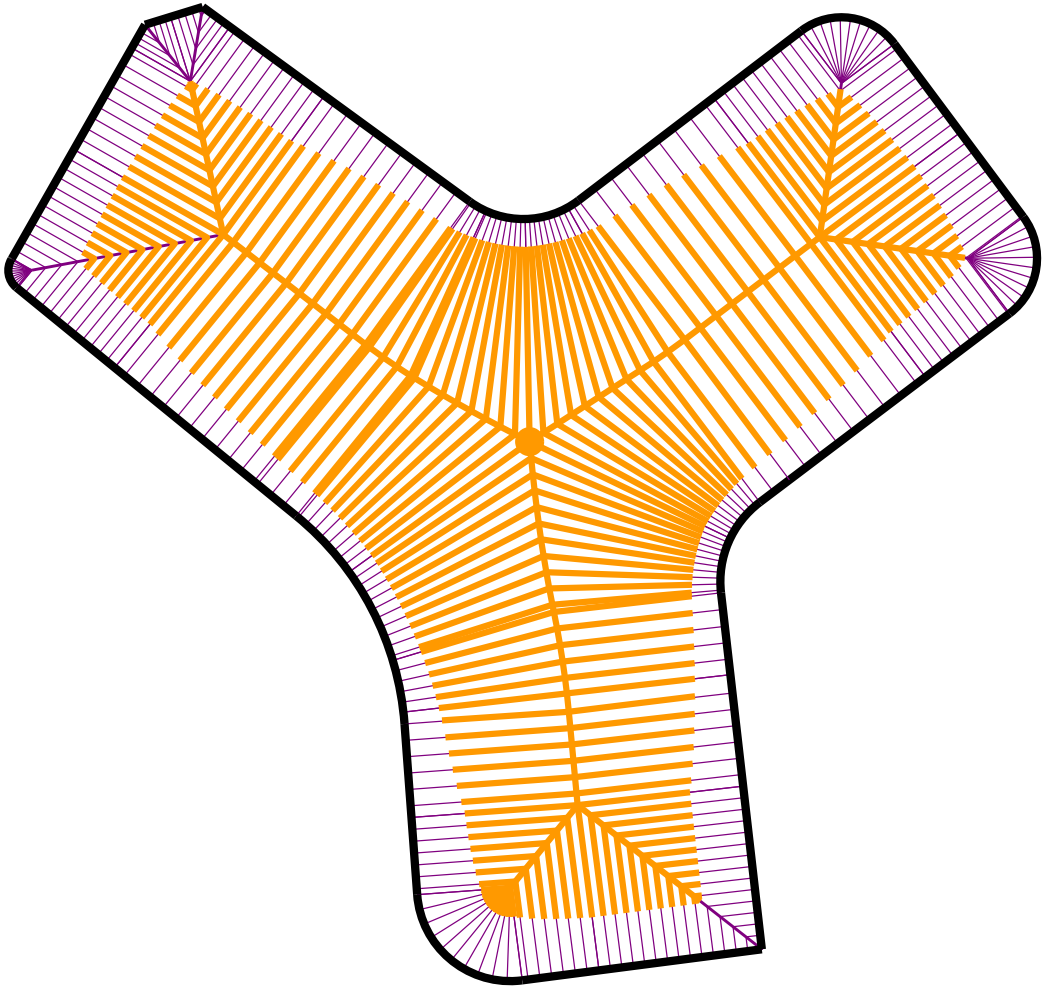

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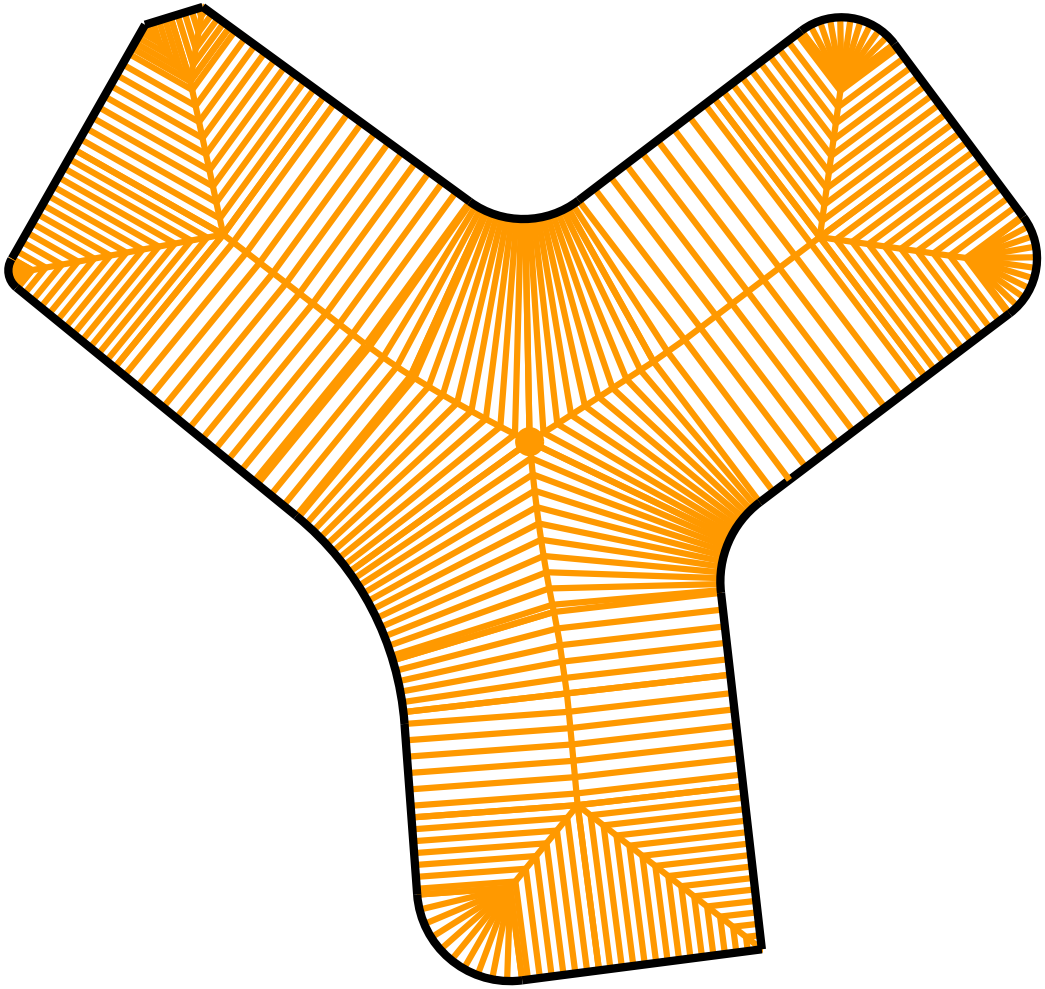
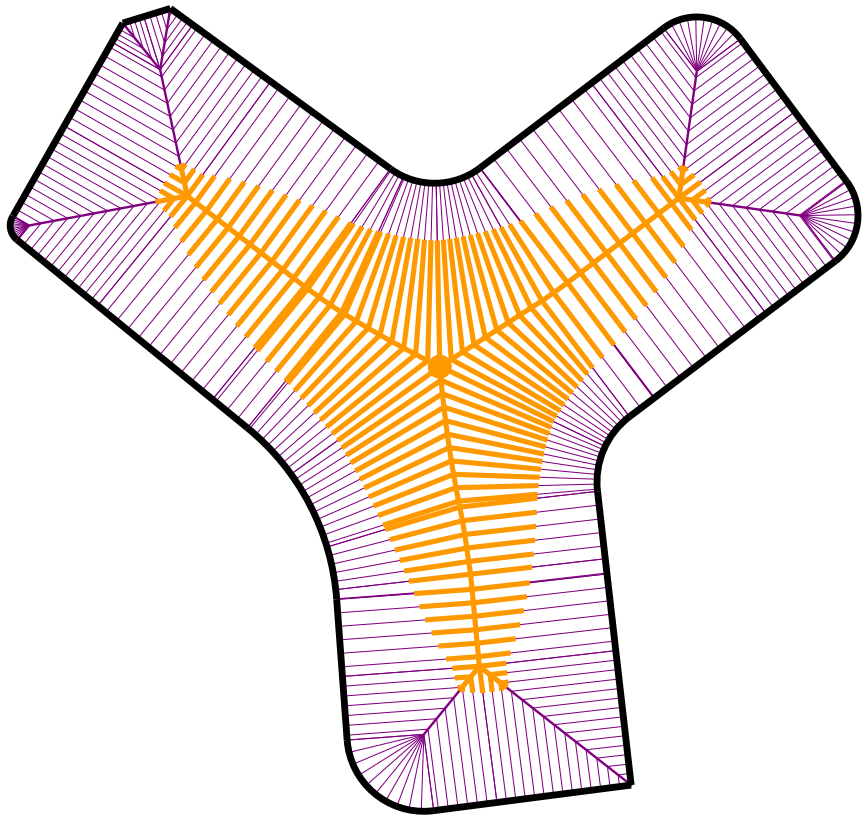


A Series of Wavefronts

- A **wavefront** is a closed polygonal chain.
- Consider impulse at a fixed point in time.



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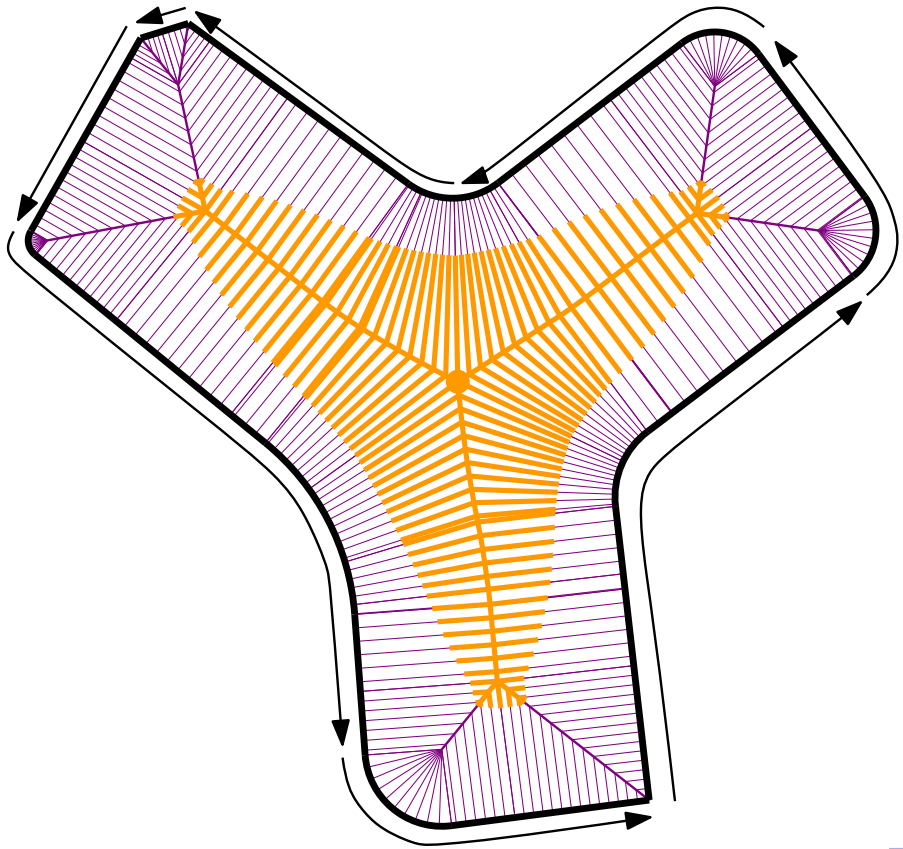

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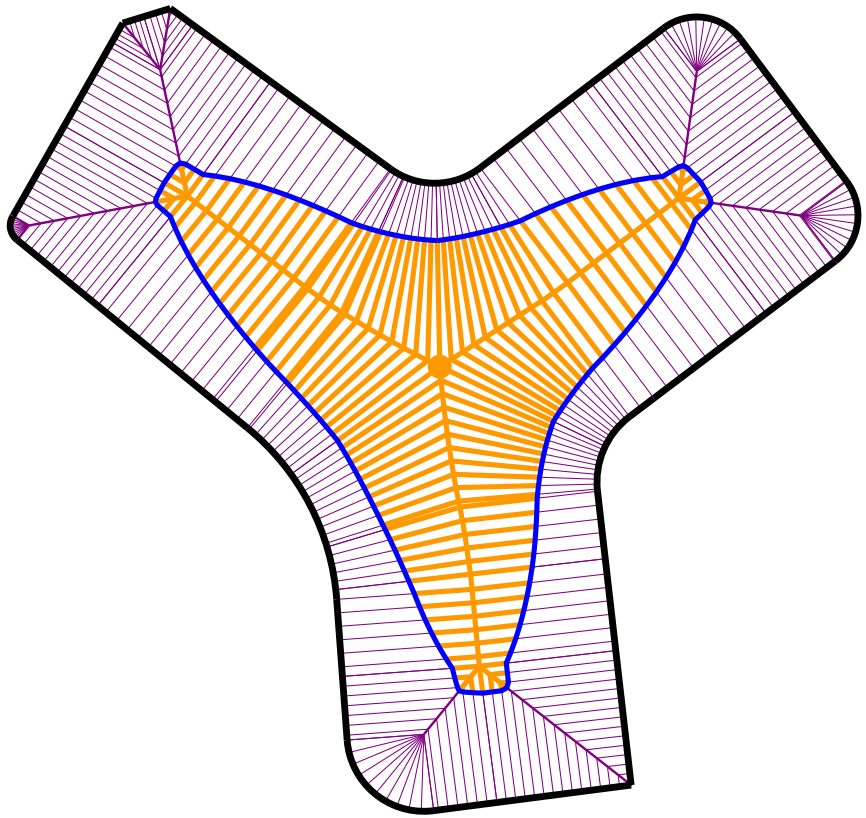

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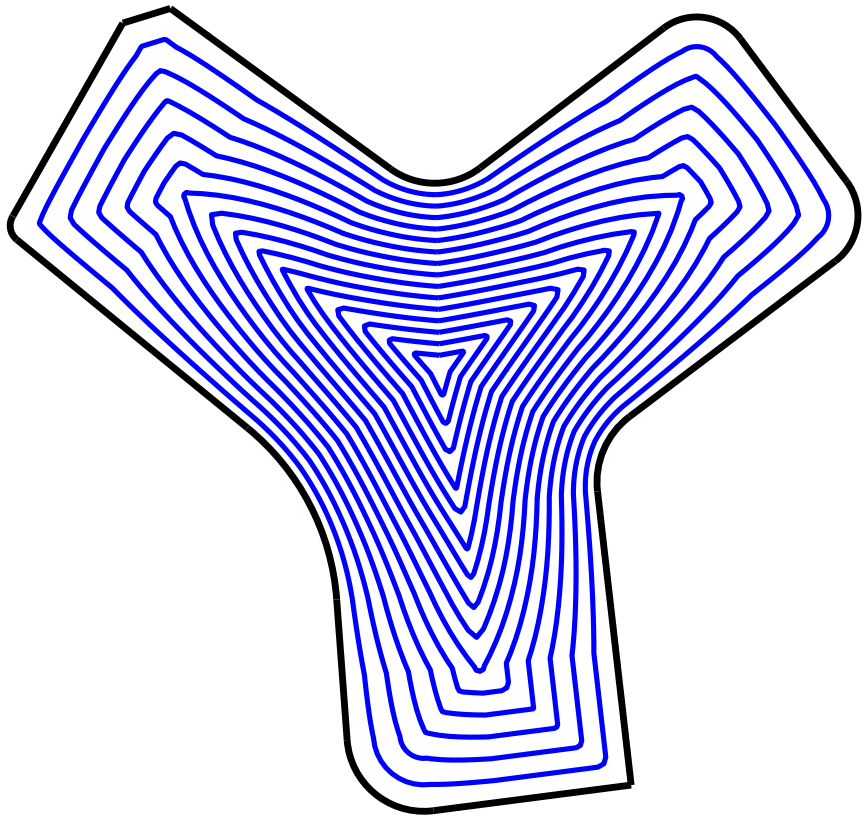
- Wavefronts must be distributed **uniformly** such that δ is respected.
- This process yields a uniform decomposition of time, i.e., the interval $[0, 1]$.



Generating a Closed Tool Path

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- The number of laps necessary to machine a specific pocket equals the number of sub-intervals of the respective uniform decomposition of time.
- Interpolate between first and last lap.

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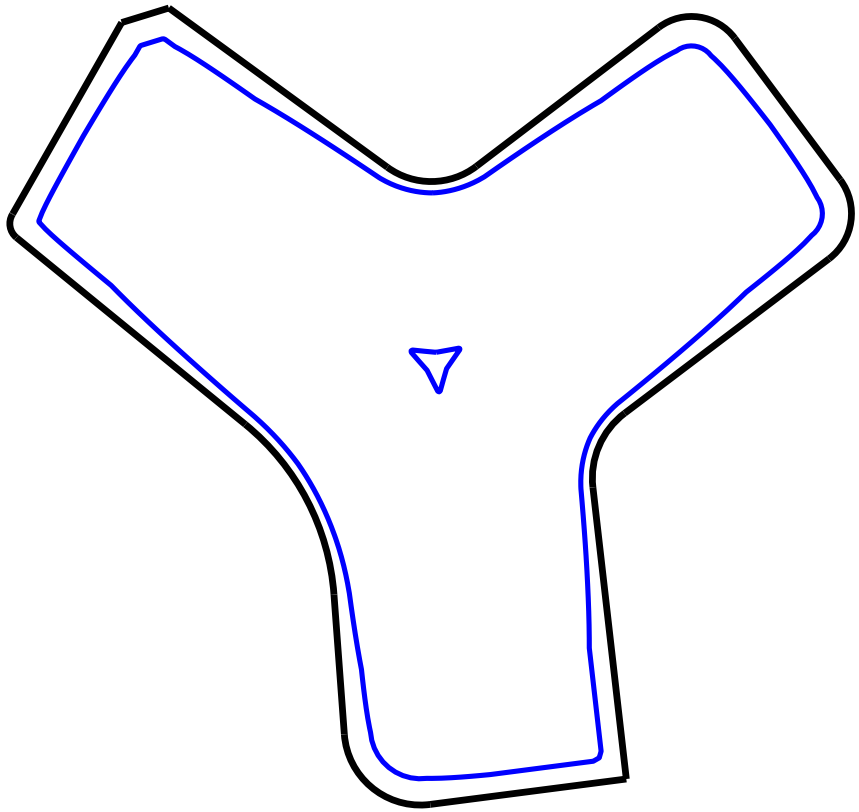

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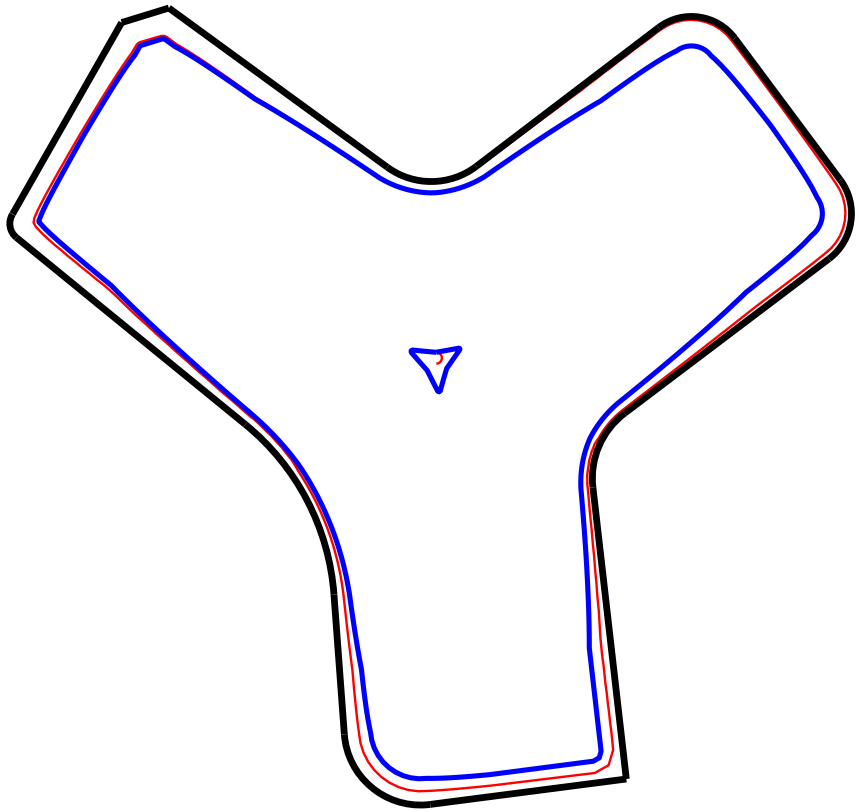

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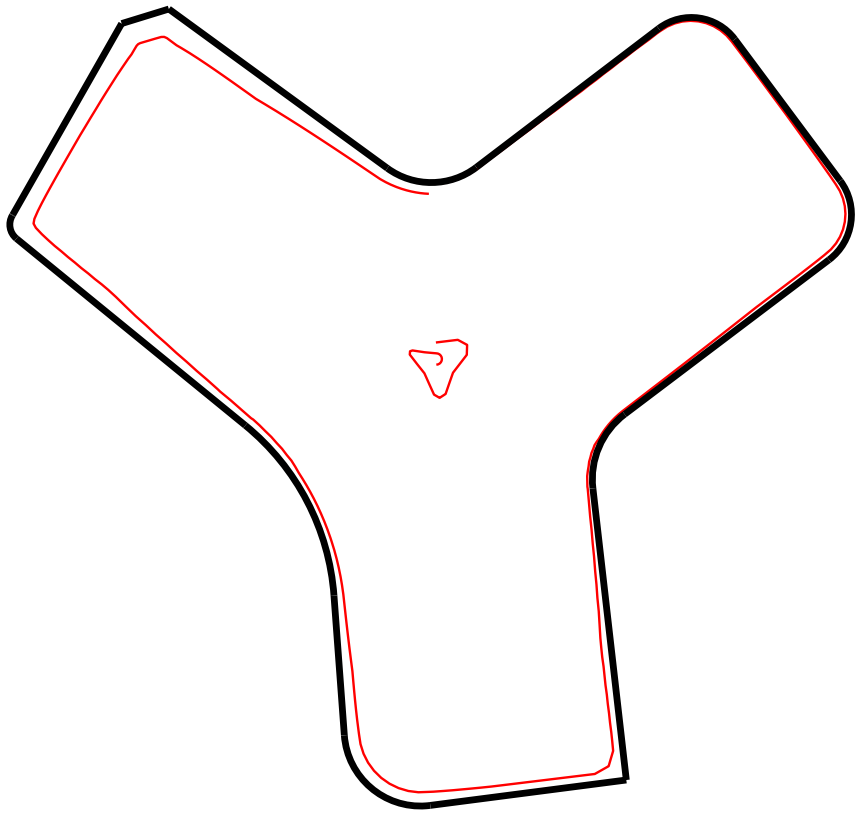

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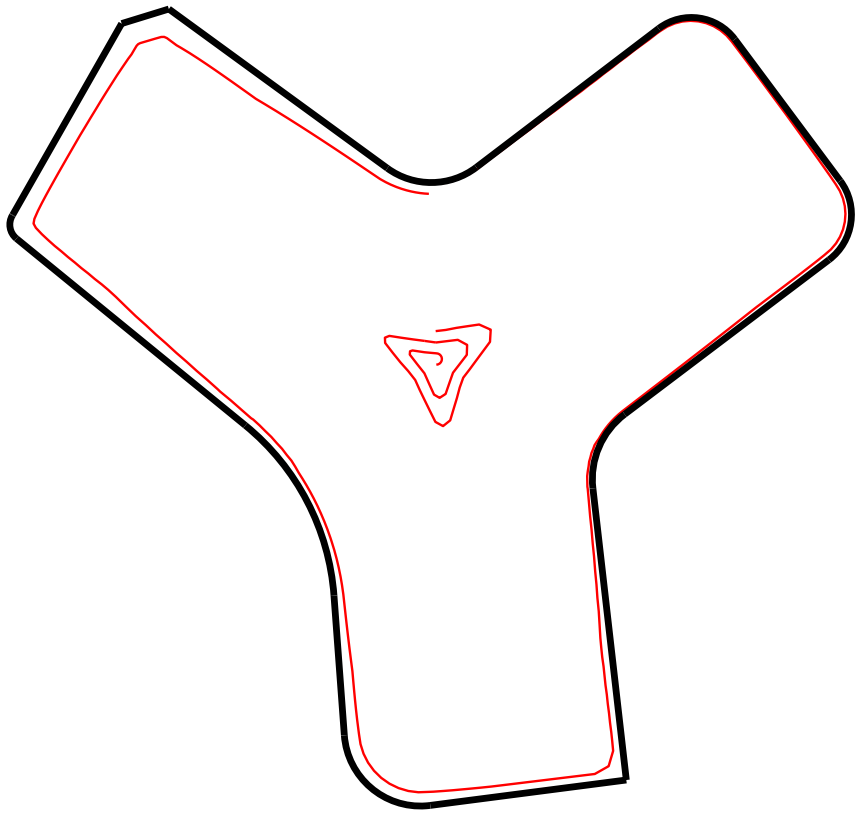

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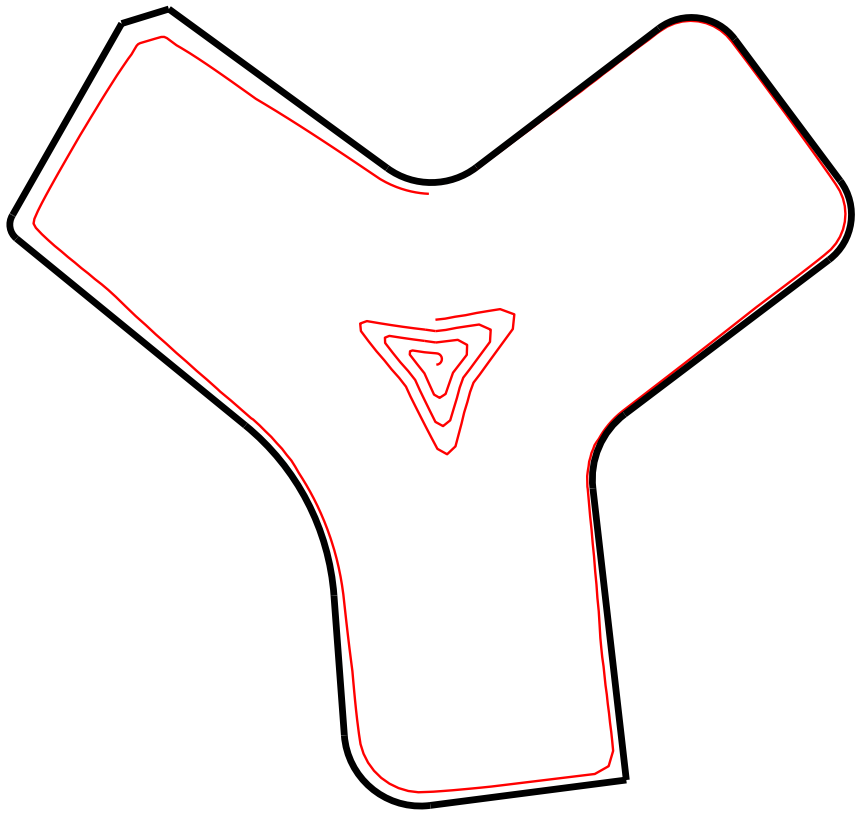

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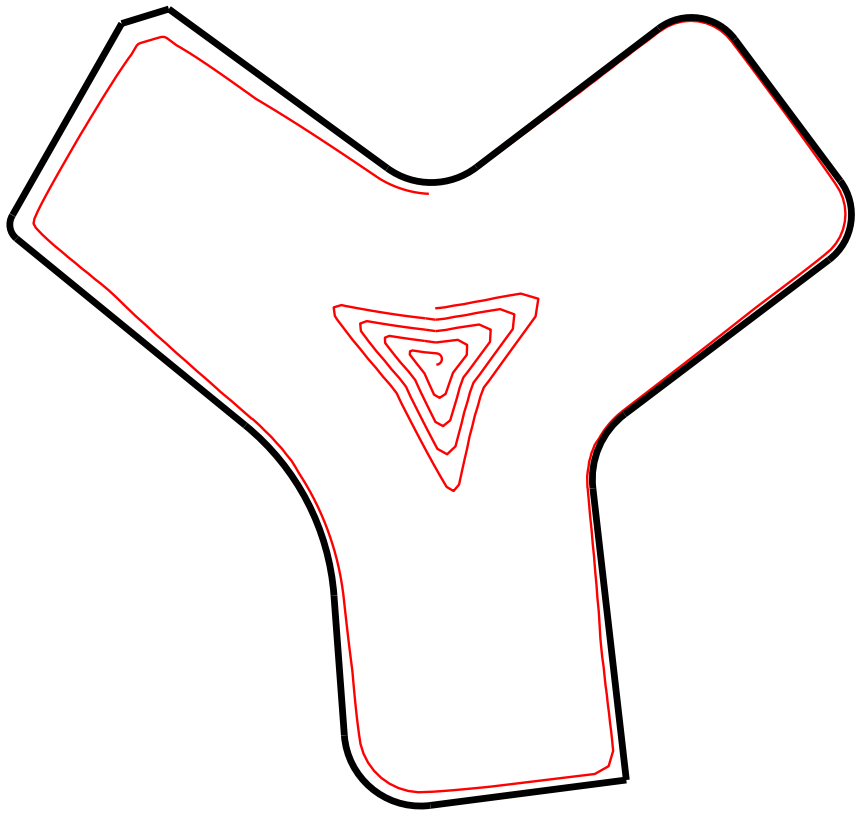

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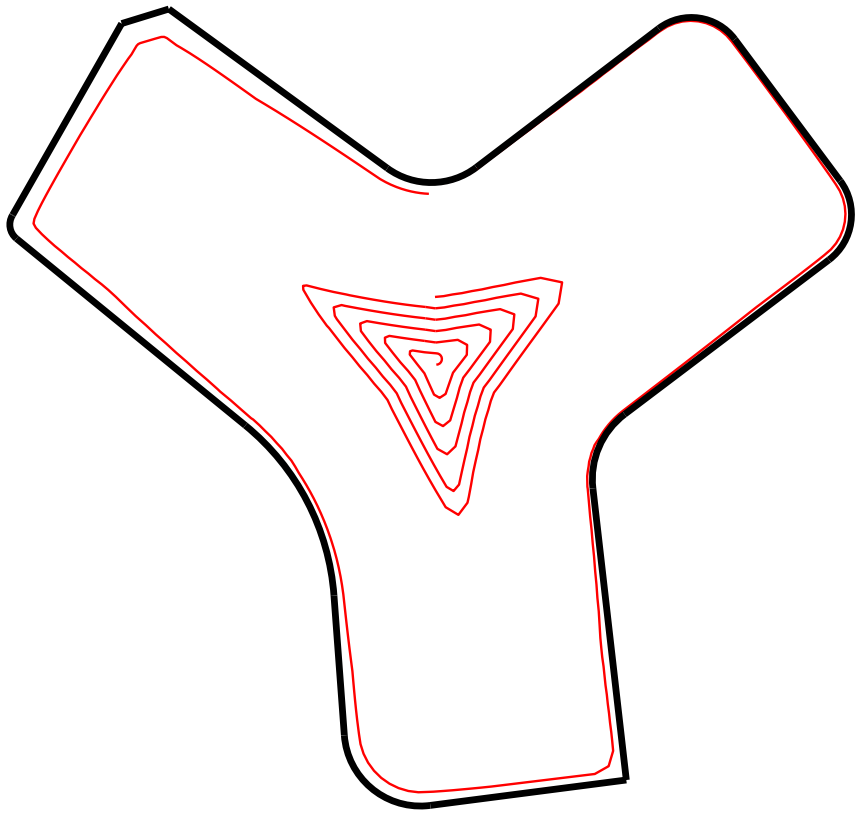

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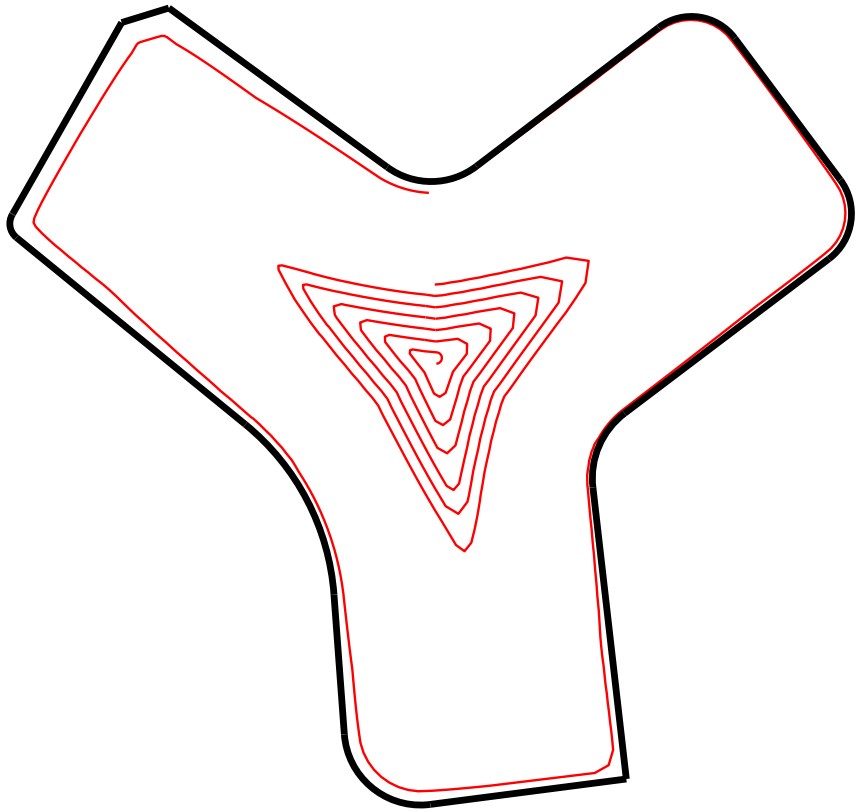

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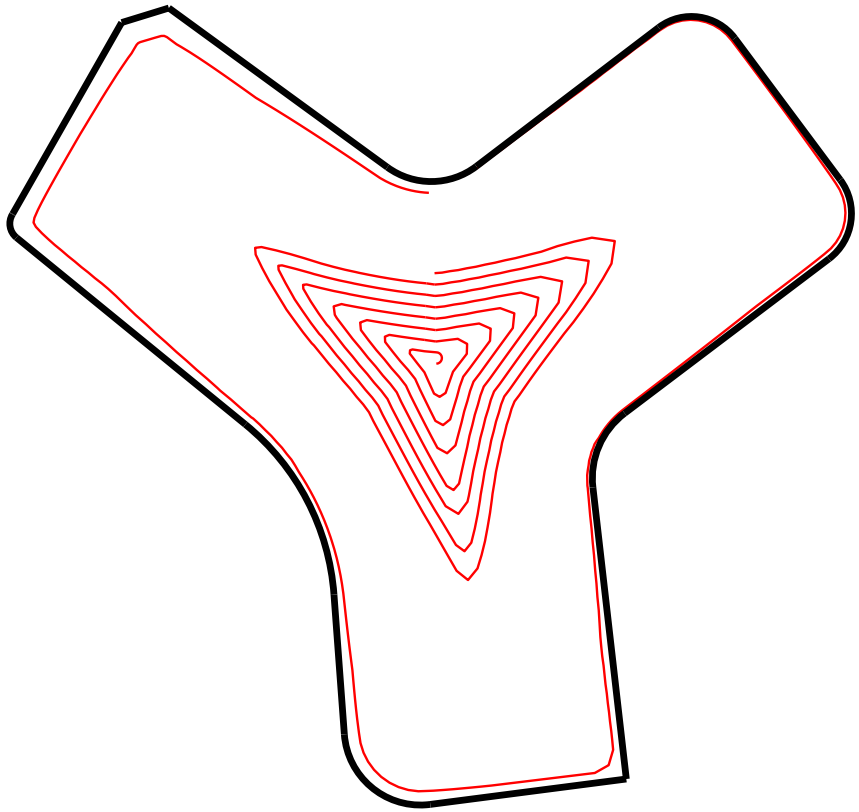

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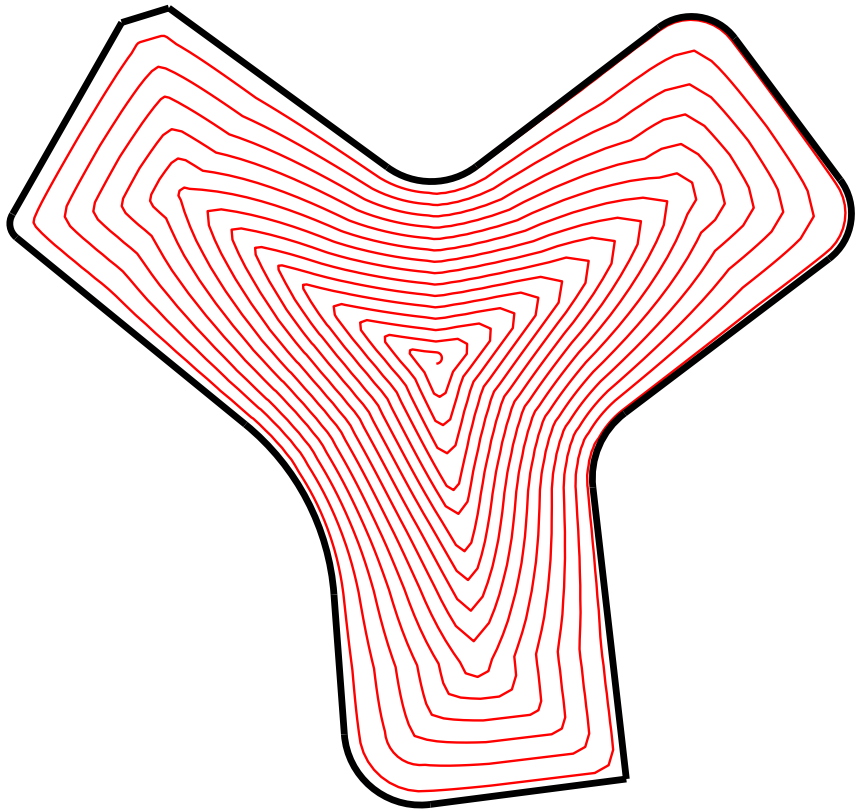

Dealing with Islands

- A pocket P with islands is described by multiple contours.
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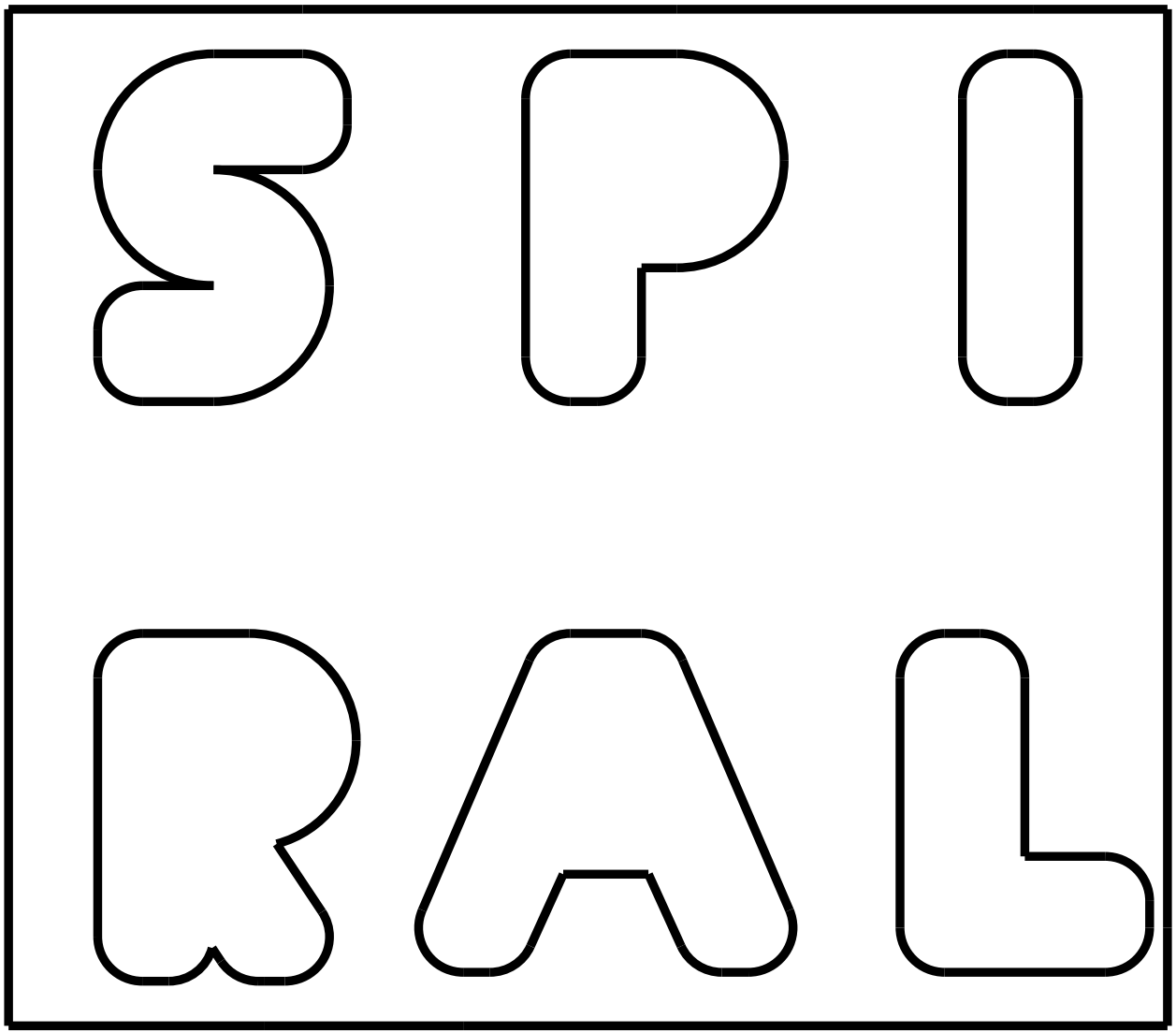
- A pocket P with islands is described by multiple contours.
- The medial axis $\mathcal{MA}(P)$ inside P forms no tree.
- Solution: Connect the input contours through straight-line segments (so-called **bridges**).
- Therefore, a single, connected boundary is produced.
- Closing narrow **bottlenecks** results in a lower step-over variation.

Animation: Dealing with Islands



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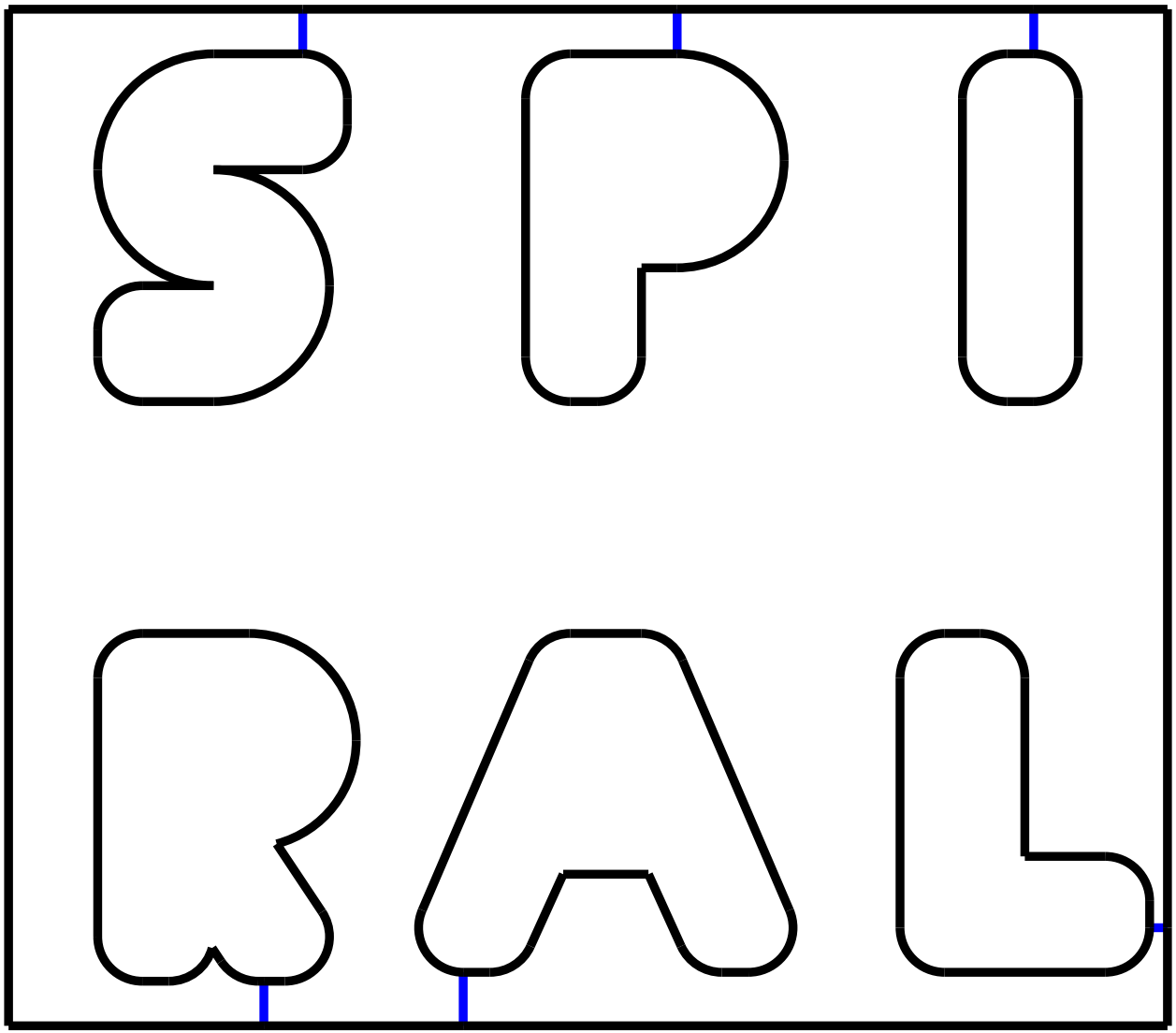

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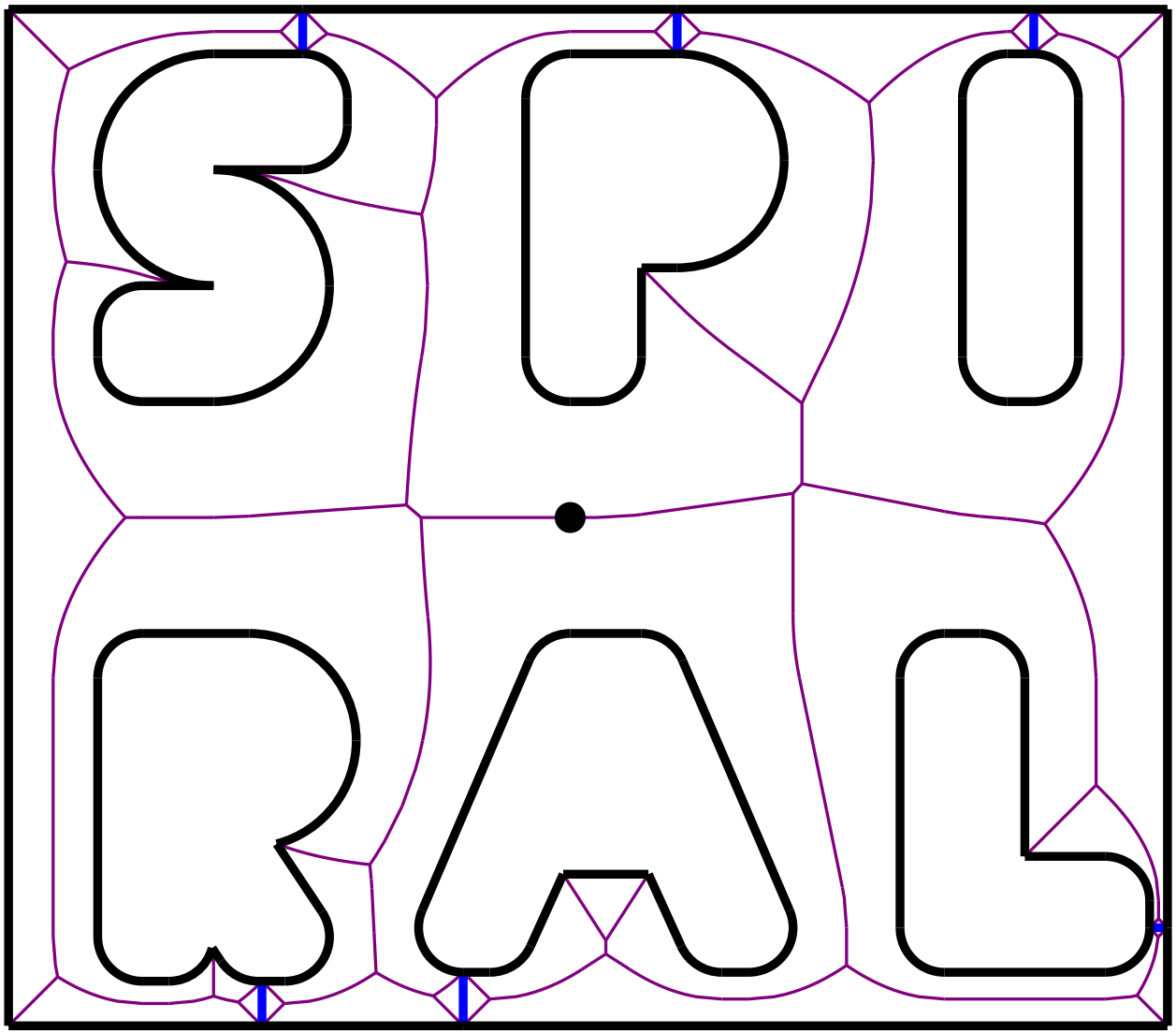

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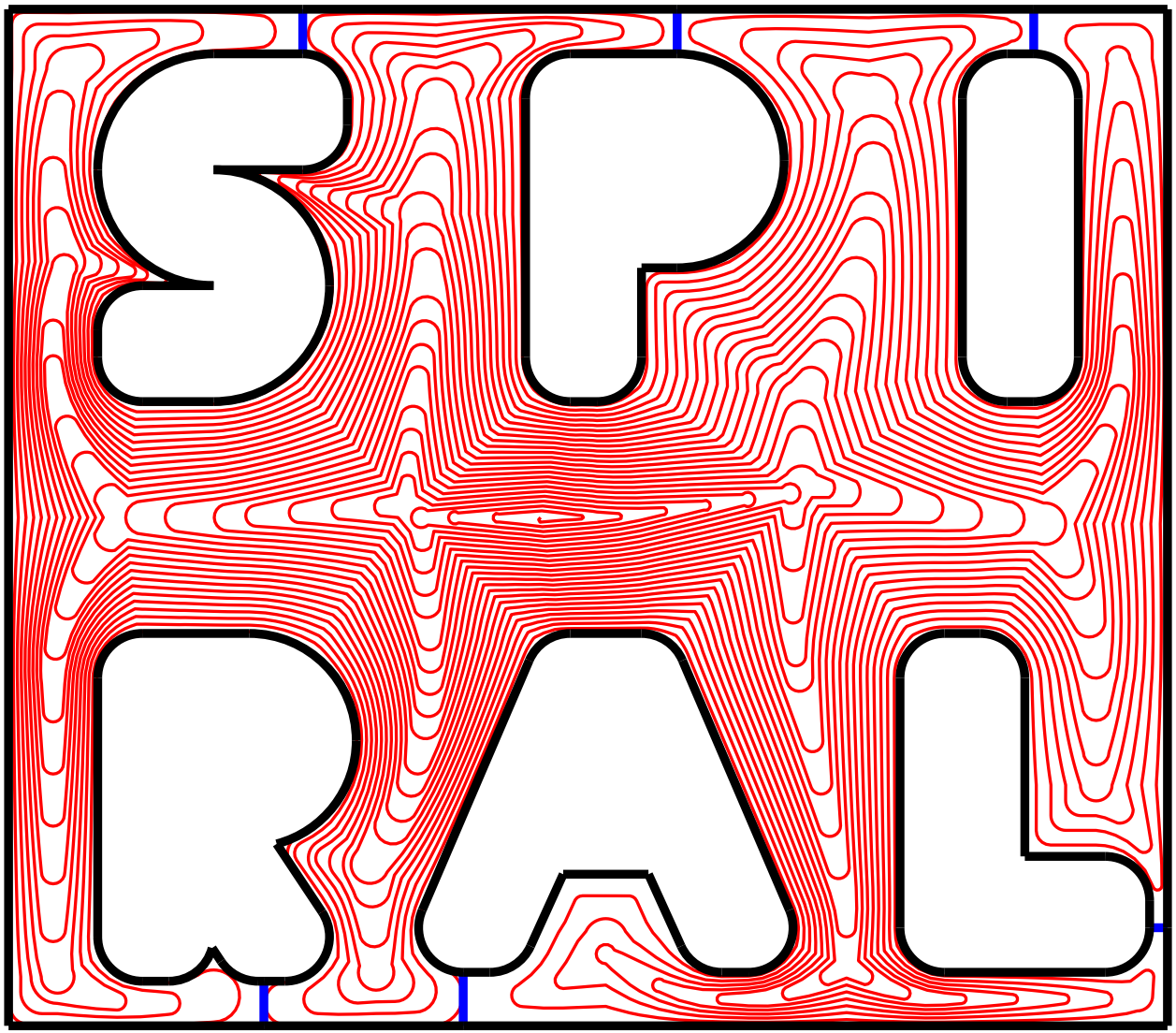
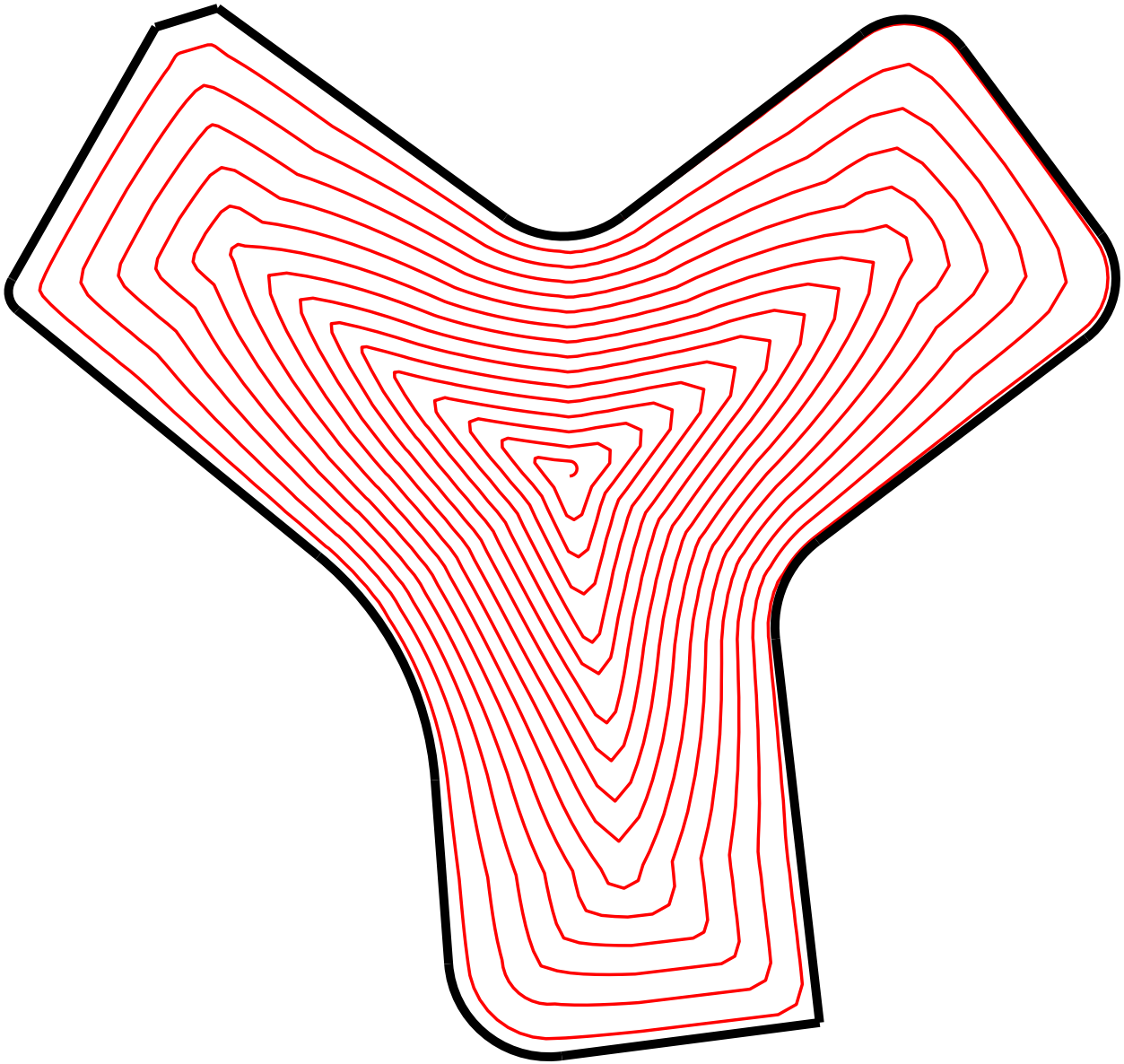


Smoothing the Tool Path

- Tool path unsuited for high speed machining (HSM) due to discontinuities.
- Needs to be **smoothed**.
- PowerApx-package (developed by Heimlich and Held [2008]) allows smoothing through **Biarcs**.
- Choose **tolerance bands** accordingly.

Animation: Smoothing the Tool Path



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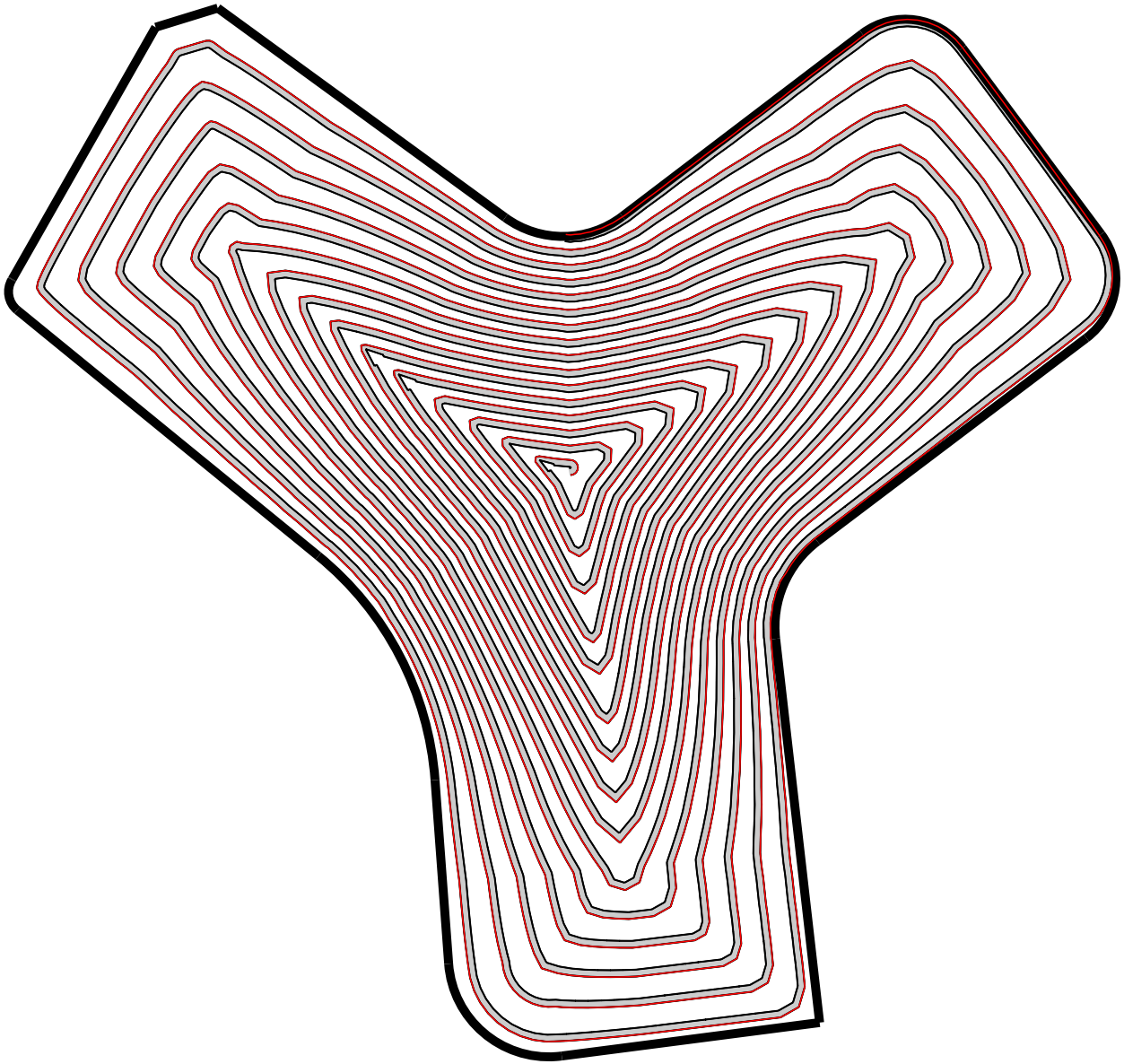

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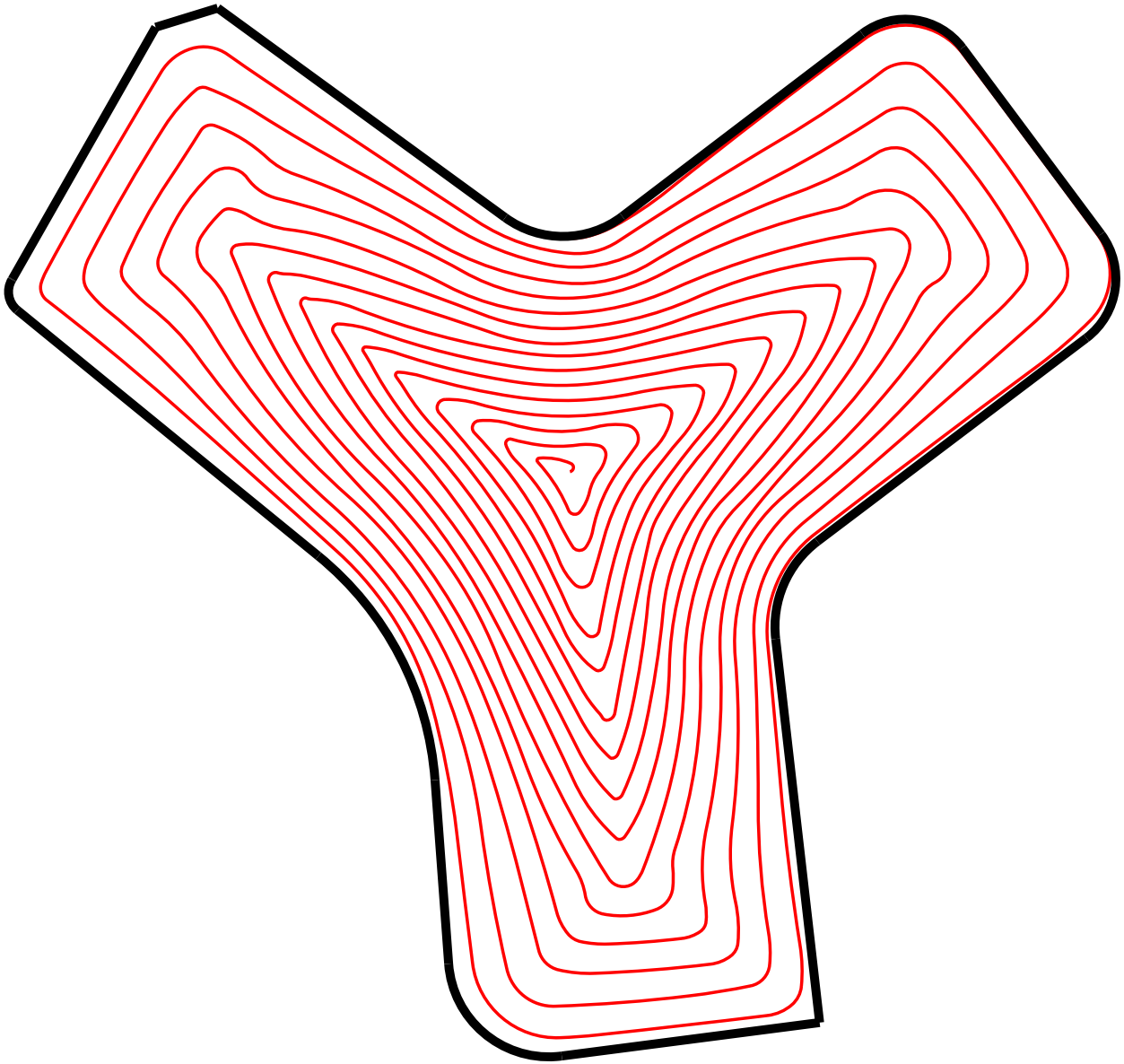
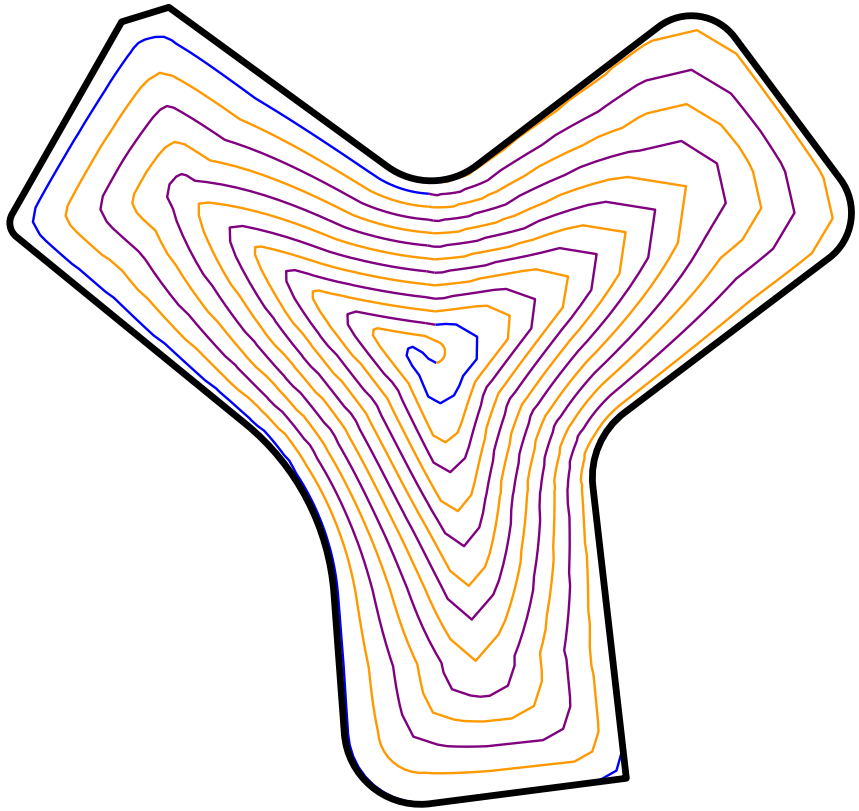


Double Spiral

- **Double spiral** provides an alternative approach.
- **Not** suited for pocket milling.
- May find other applications (such as spray paintings or aerial. surveillance)



The End

Thank you for your attention!

References I

M. Heimlich and M. Held. Biarc approximation, simplification and smoothing of polygonal curves by means of Voronoi-based tolerance bands. *International Journal of Computational Geometry & Applications*, 18(03):221–250, 2008.

M. Held and C. Spielberger. A smooth spiral tool path for high speed machining of 2d pockets. *Computer-Aided Design*, 41(7):539–550, 2009.

CCW	counter-clockwise
CW	clockwise
MAT	medial axis tree
DMAT	discrete medial axis tree
HSM	high speed machining
CCL	center of clearance lines
EMST	Euclidean minimum spanning tree
SOV	step-over variation