Hybrid curve fitting for accurate object construction

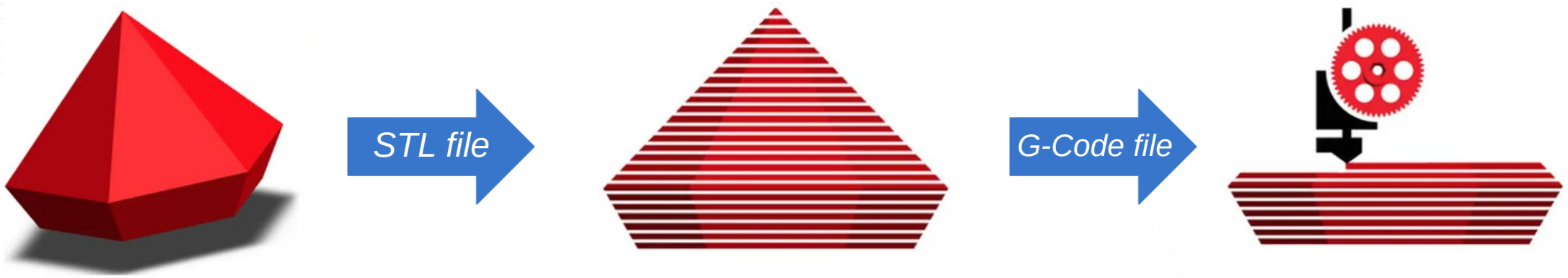
Charles Wade
Digital Manufacturing & Analyses Frameworks
Oak Ridge National Laboratory



ORNL is managed by UT-Battelle
for the US Department of Energy

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Additive Manufacturing Workflow

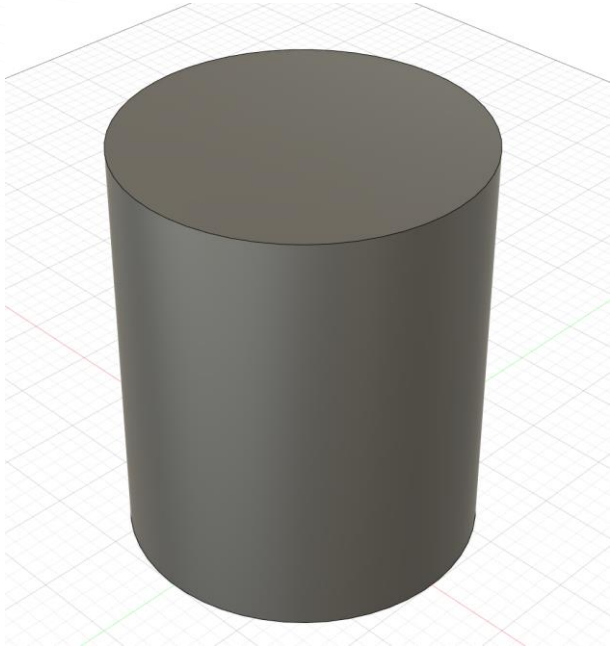


Design **Slice** **Print**

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Exporting STL Files

CAD File

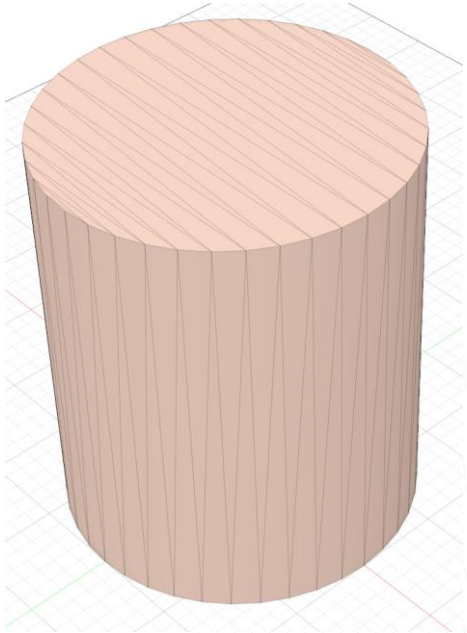


Geometry stored as exact equations

Results in loss of accuracy

Convert

.STL File

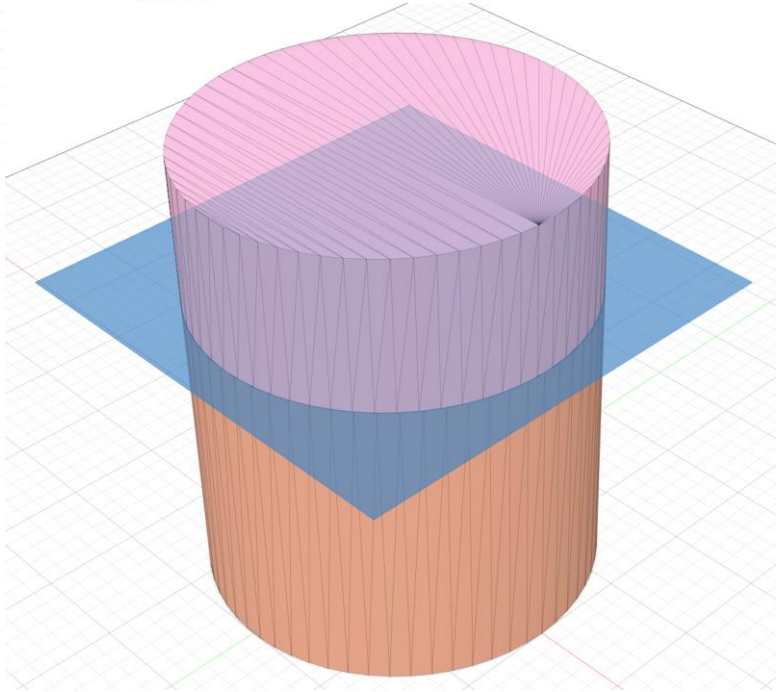


Geometry stored as points and faces in mesh

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Why use STLs?

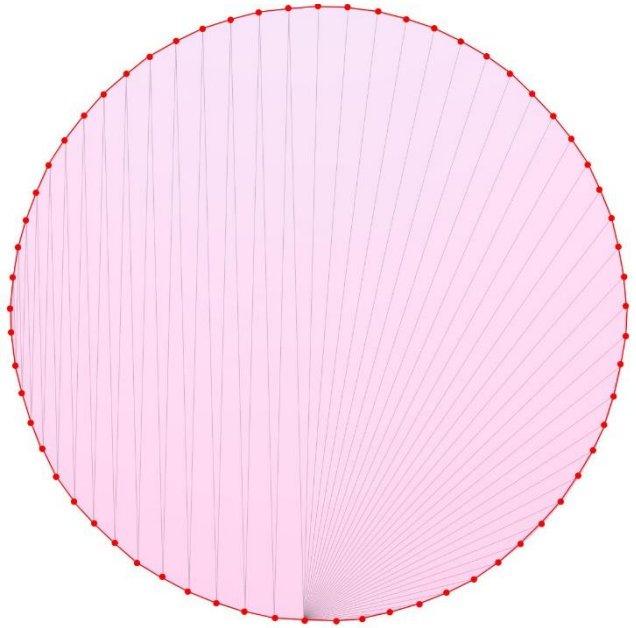
.STL File



Triangulated mesh representation

Cut with plane

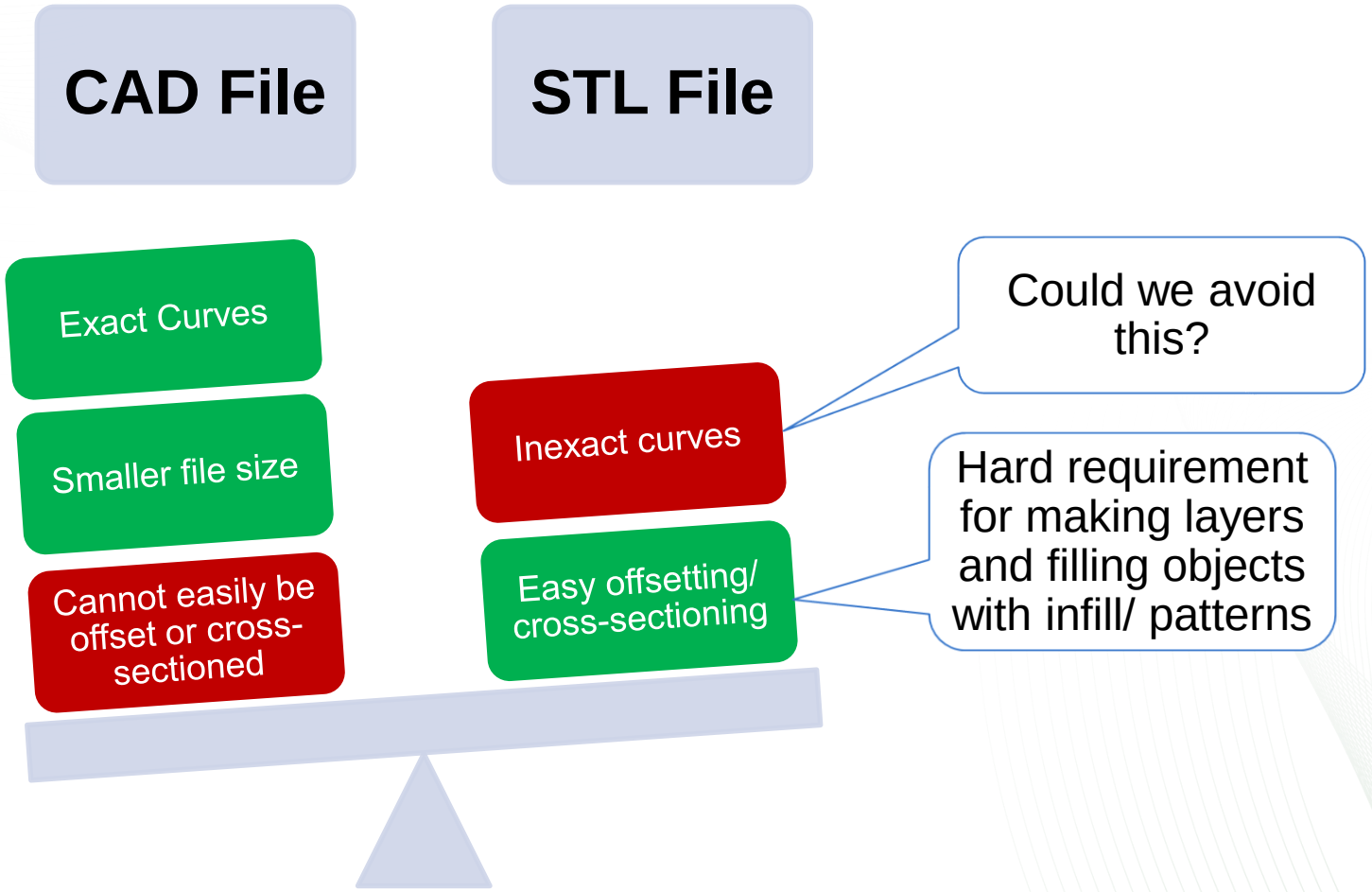
Polygon



Cross-section will always form closed polygon when using triangles/ STL file

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STL File Cost and Benefit

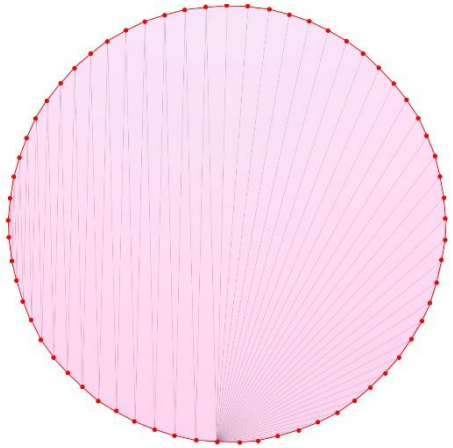


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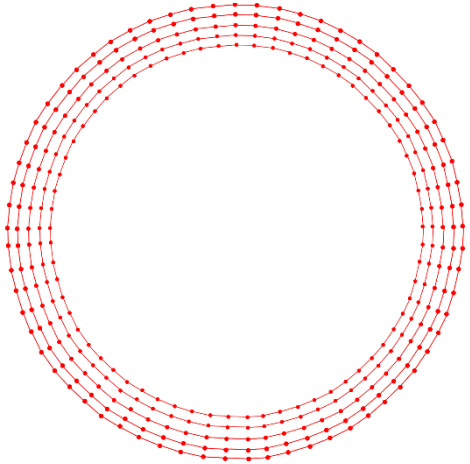
Slicer Software

Could we convert the lines back into curves?

Cross-section



Offset/ fill



Creates solid object

Export

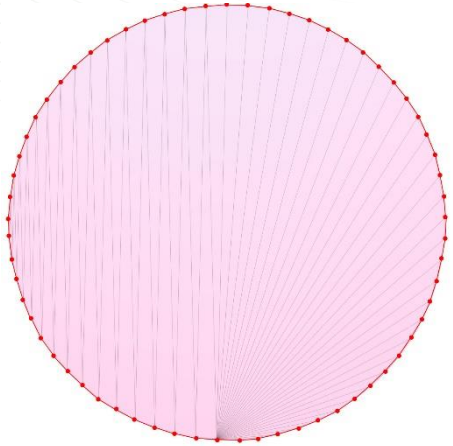
```
(LAYER COUNT: 583)
(BEGINNING LAYER: 1)
G0 W-0.1500 (MOVE W - LAYER CHANGE)
M1 (OPTIONAL STOP - LAYER CHANGE)
M12 (PERIMETER SPINDLE ADJUSTMENT)
M66 L0.2655 (SET ACCELERATION)
M64 L0.7 (TURN TAMPER ON)
M11 (TURN OFF EXTRU...DER SERVOING)
M3 S300 (TURN EXTRUDER ON)
G4 P0.0500 (DWELL)
G1 F120.1431 S95.0451 X143.5800 Y30.1701
G1 X143.5800 Y54.8086 (PERIMETER)
G1 X96.4200 Y54.8299 (PERIMETER)
G1 X96.4200 Y30.1913 (PERIMETER)
...
```

Machine instructions (G-Code)

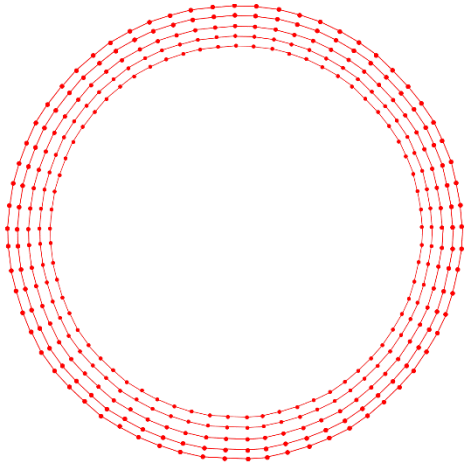
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Slicer Software

Cross-section

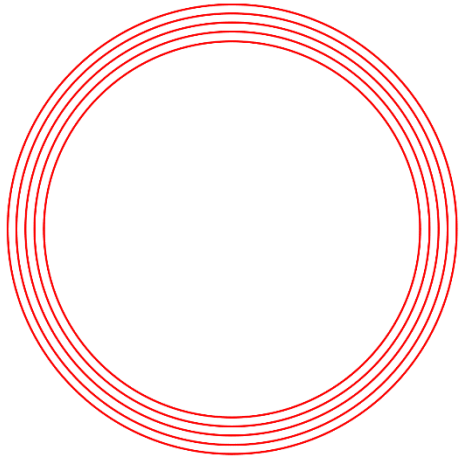


Offset/ fill



Creates solid object

Fit Curves



Fit with arcs/ splines

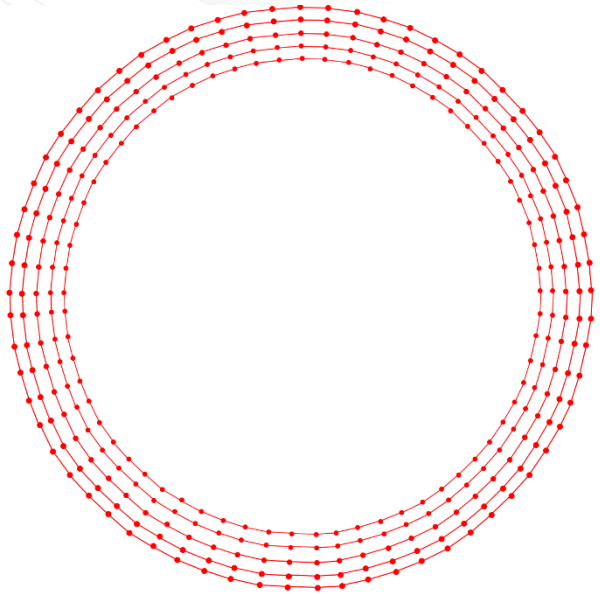
Export

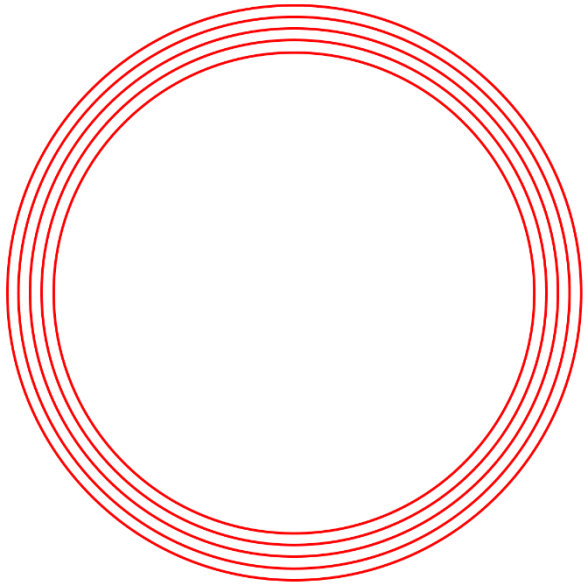
```
(LAYER COUNT: 583)
(BEGINNING LAYER: 1)
G0 W-0.1500 (MOVE W - LAYER CHANGE)
M1 (OPTIONAL STOP - LAYER CHANGE)
M12 (PERIMETER SPINDLE ADJUSTMENT)
M66 L0.2655 (SET ACCELERATION)
M64 L0.7 (TURN TAMPER ON)
M11 (TURN OFF EXTRU...DER SERVOING)
M3 S300 (TURN EXTRUDER ON)
G4 P0.0500 (DWELL)
G3 F120.1431 S95.0451 X143.5800 Y30.1701
G3 X143.5800 Y54.8086 (PERIMETER)
G3 X96.4200 Y54.8299 (PERIMETER)
G3 X96.4200 Y30.1913 (PERIMETER)
...
```

Machine instructions (G-Code)

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Post-Process Curve Fitting

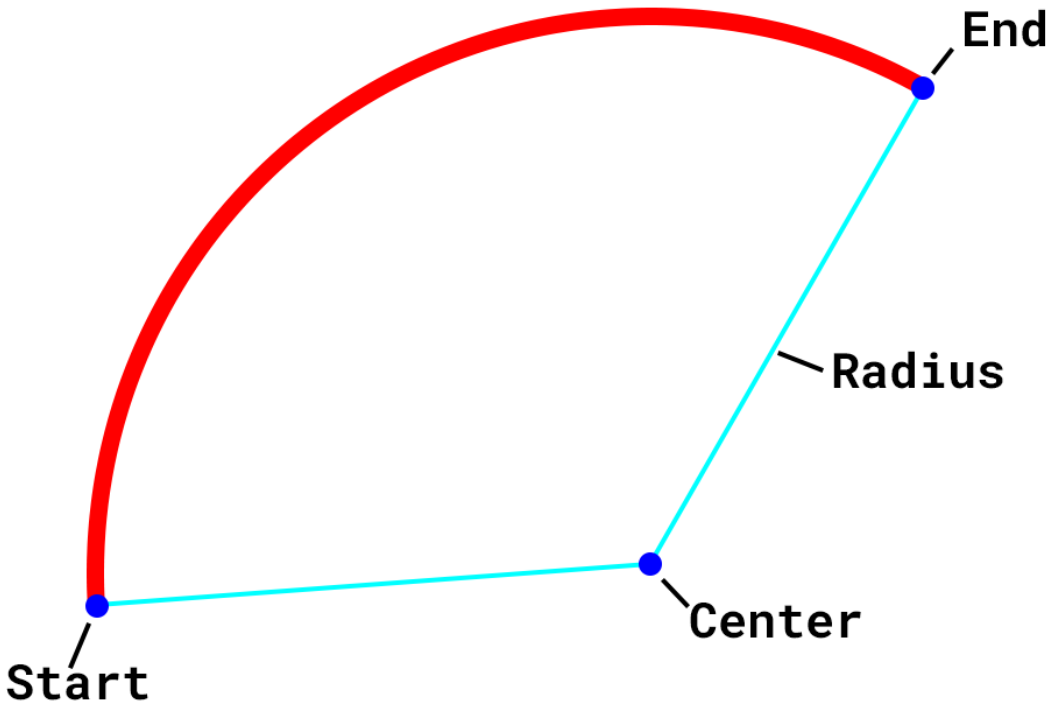




Goal:

Optimally fit constant-radius arcs and b-splines to sets of lines segments.

Constant-radius Arcs

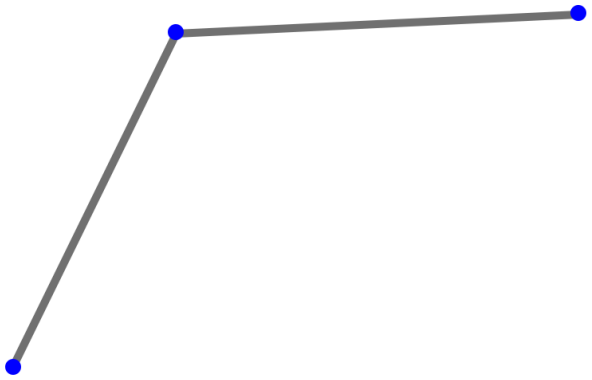




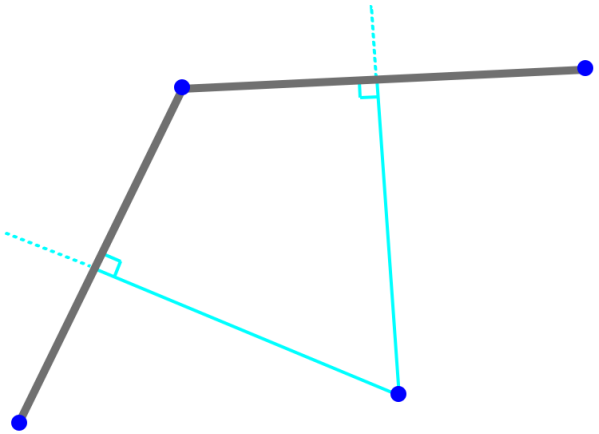
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Fitting points

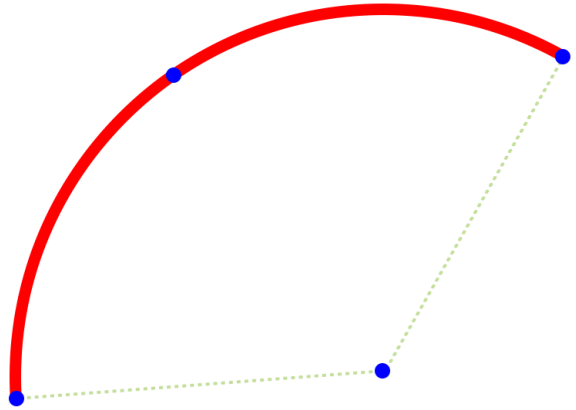
Start with 3 points



Use perpendicular bisectors to find center point



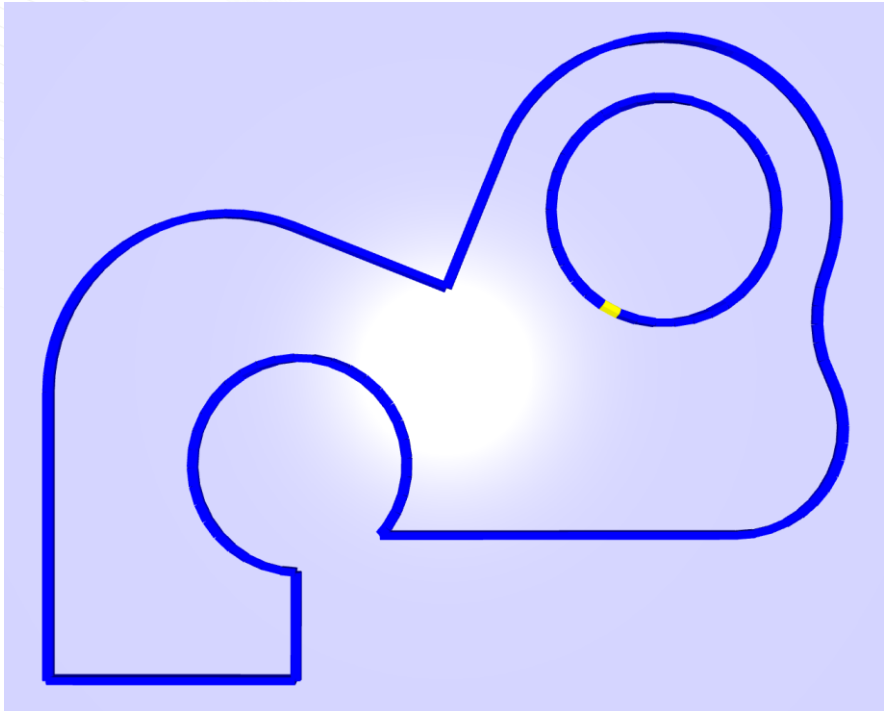
Draw arc to pass through



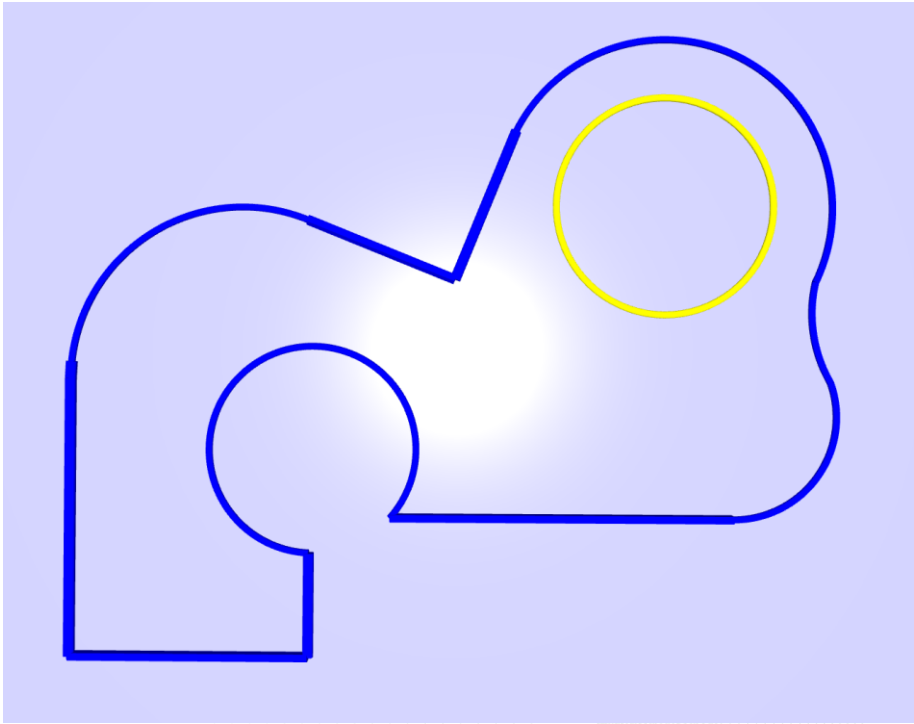
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Arc Fitting Results

No Arc Fitting



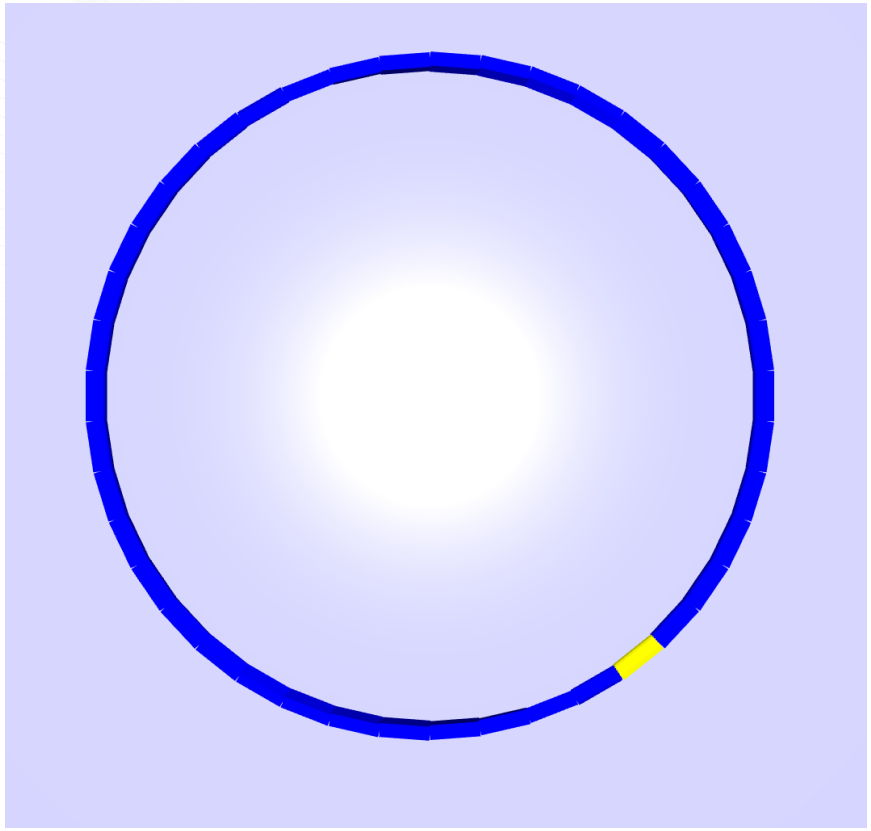
With Arc Fitting



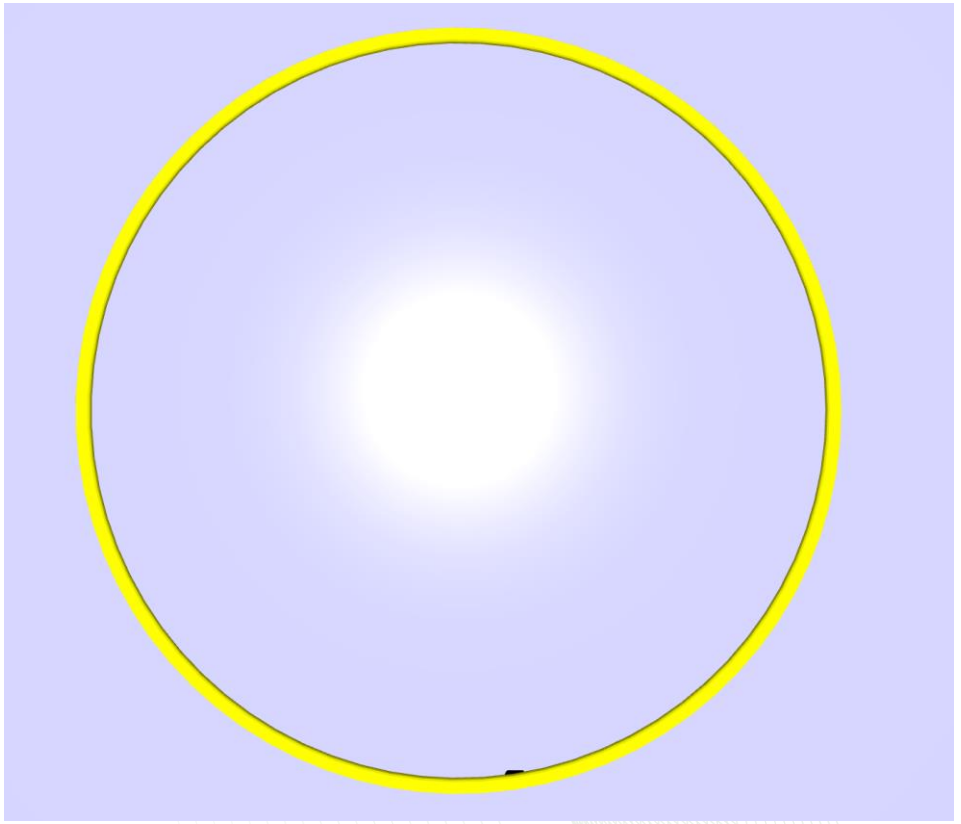
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Arc Fitting Results

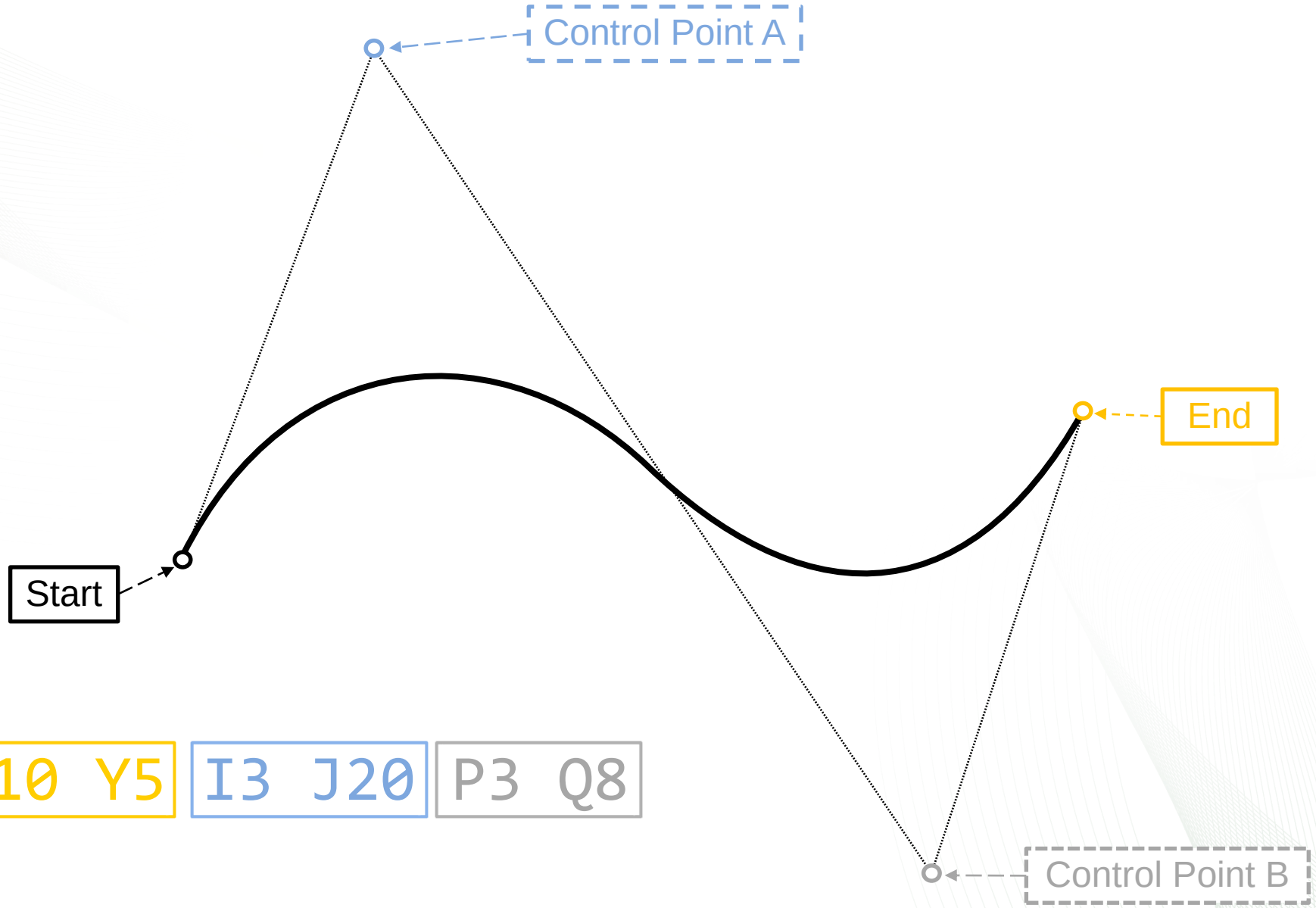
No Arc Fitting



With Arc Fitting



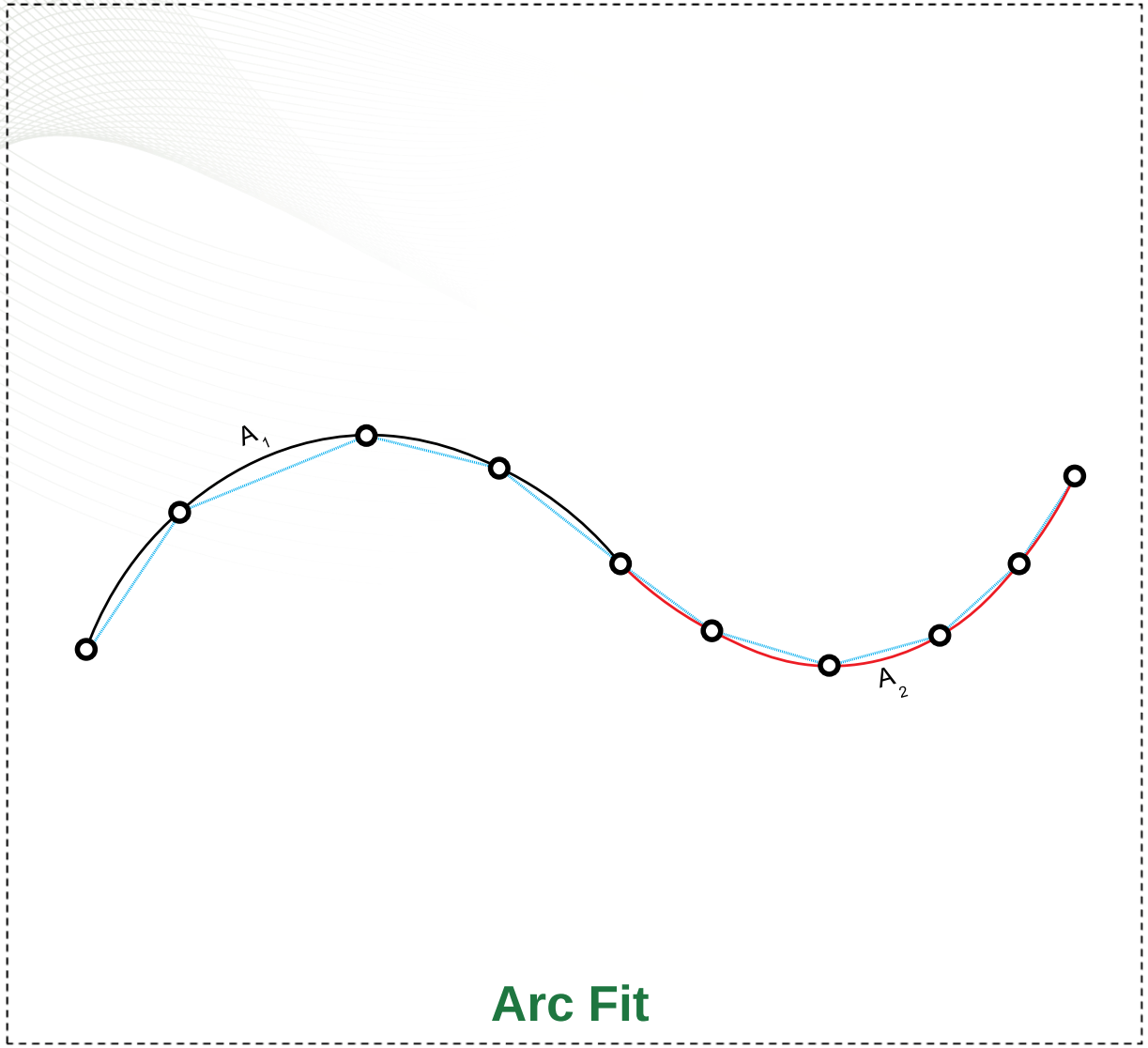
Splines



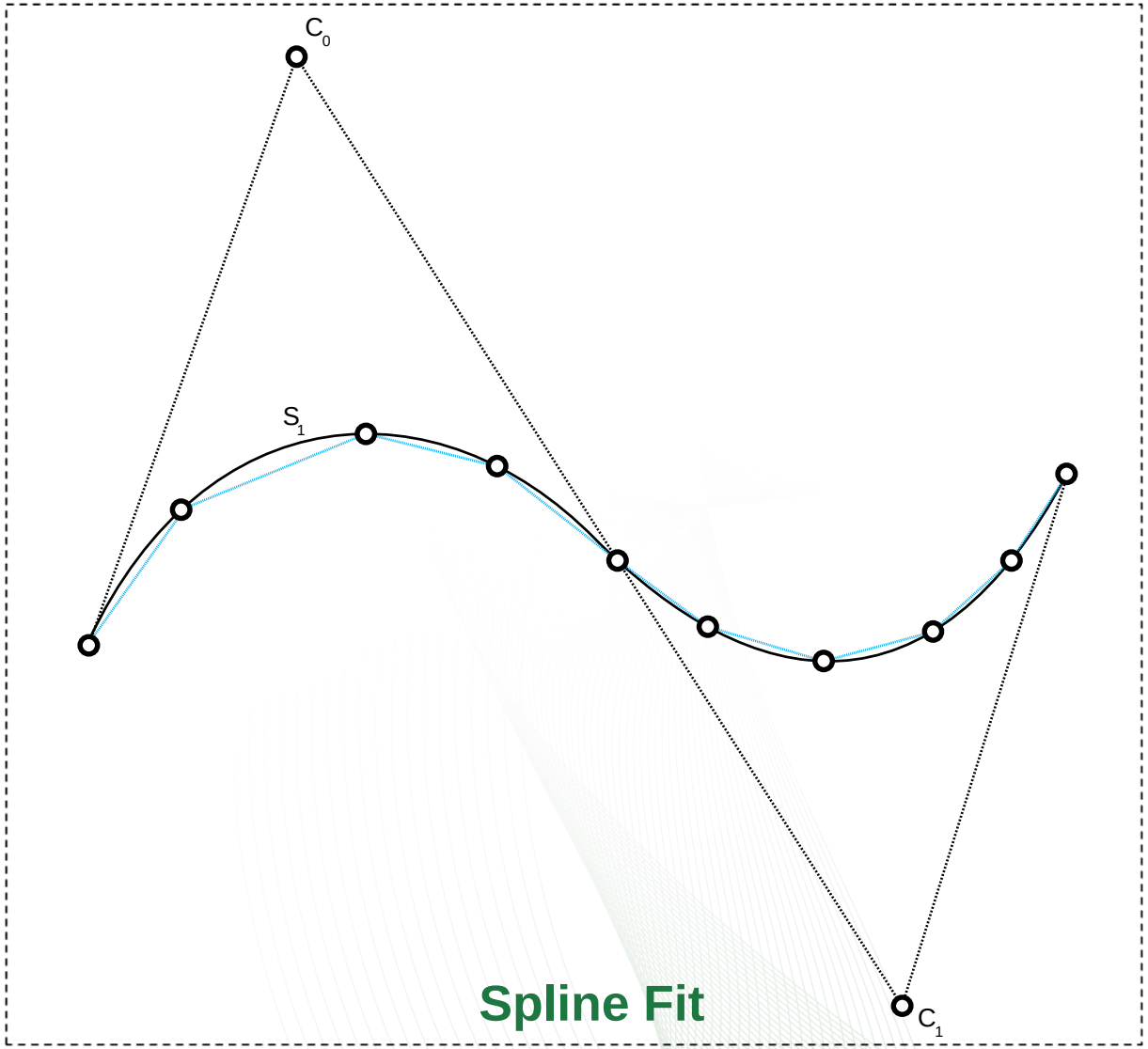
G5 X10 Y5 I3 J20 P3 Q8

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Spline > Arc



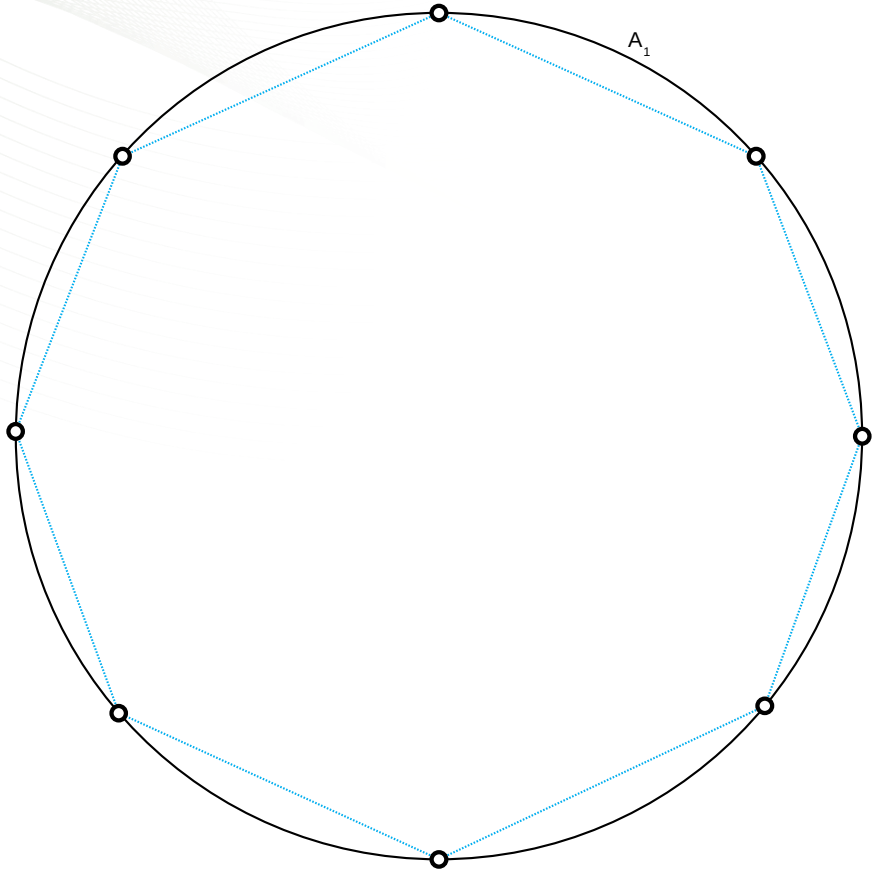
Arc Fit



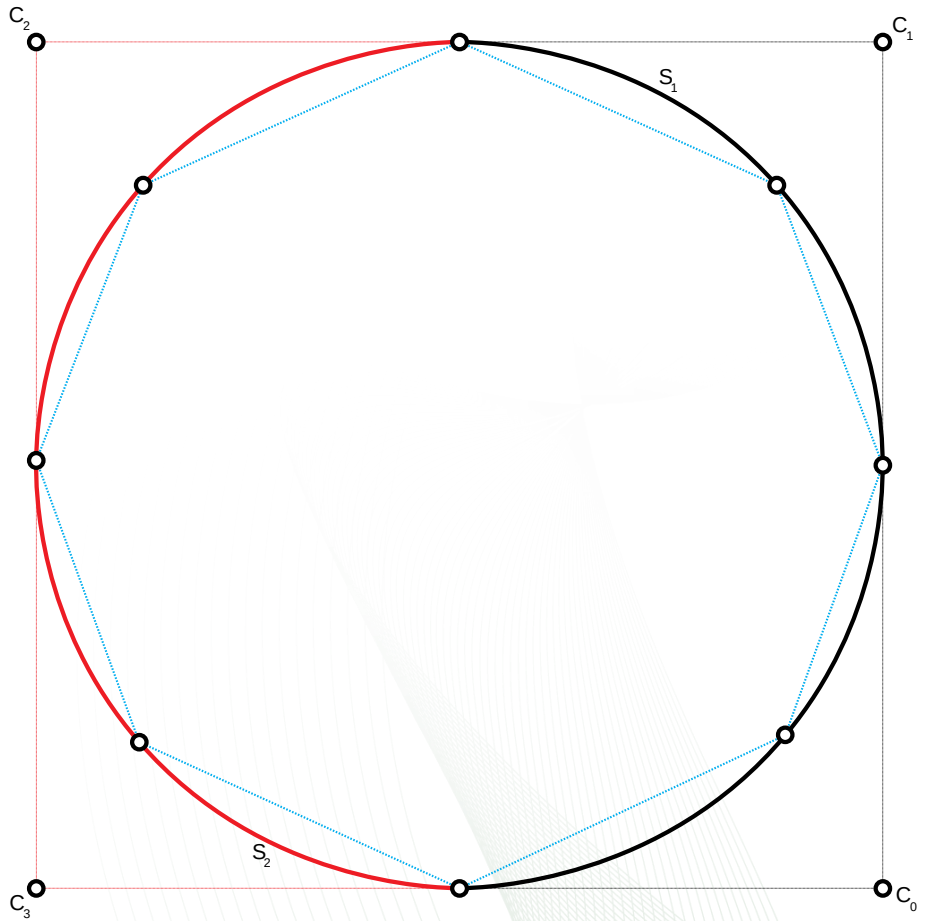
Spline Fit

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Arc > Spline



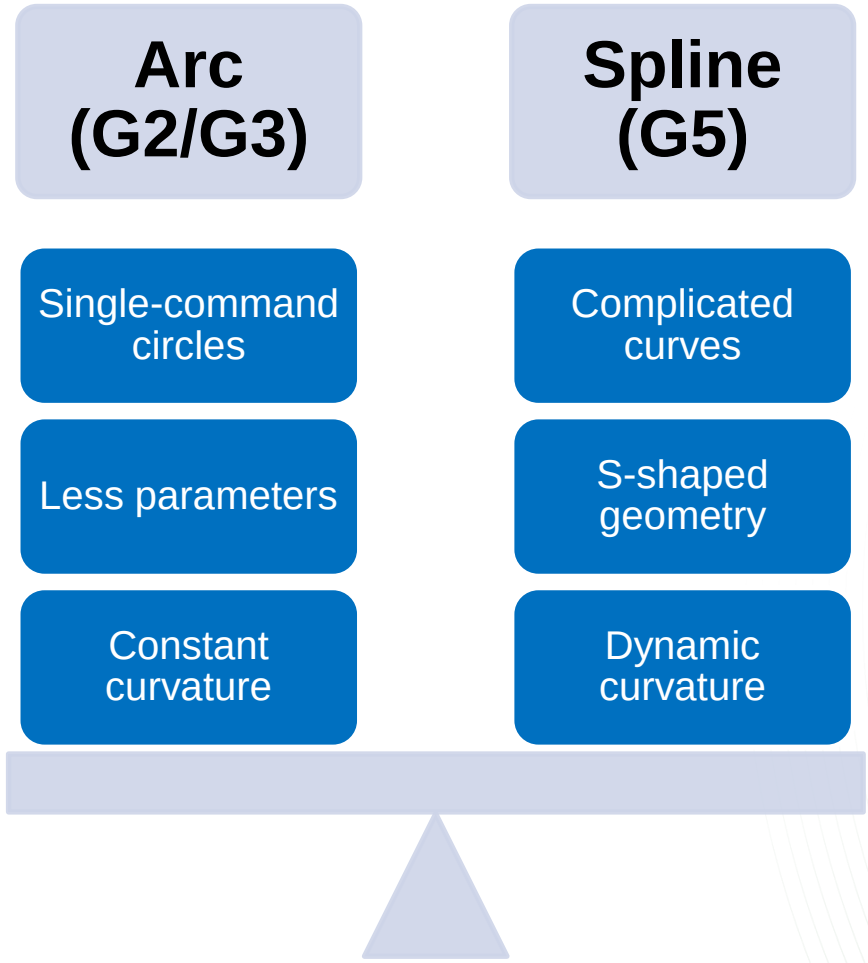
Arc Fit



Spline Fit

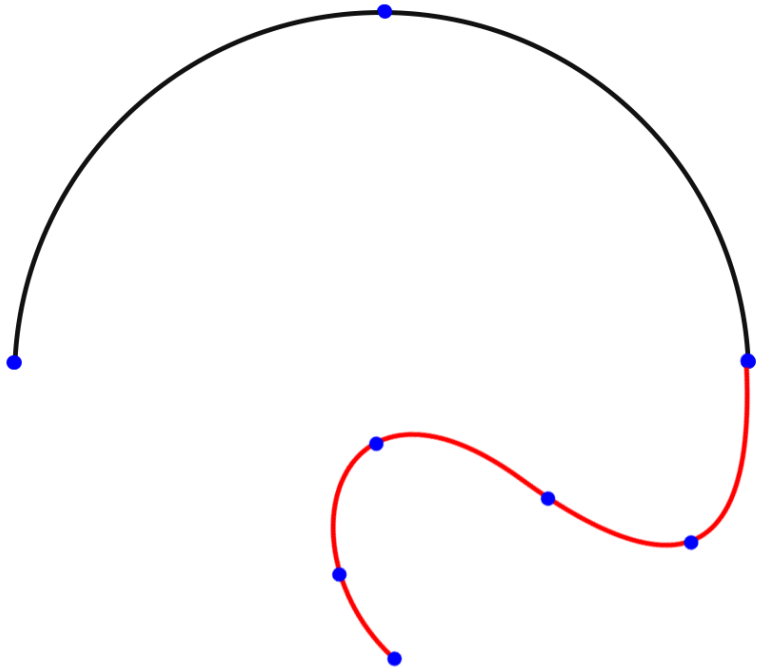
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Are arcs or splines better?



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Hybrid fitting

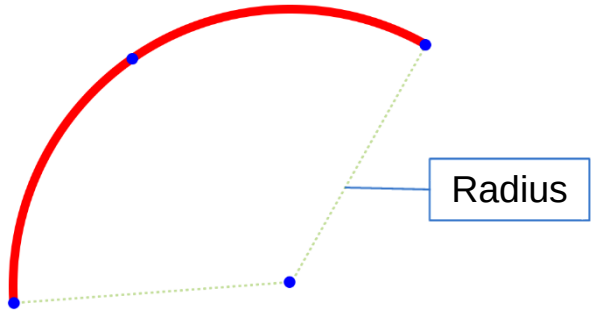


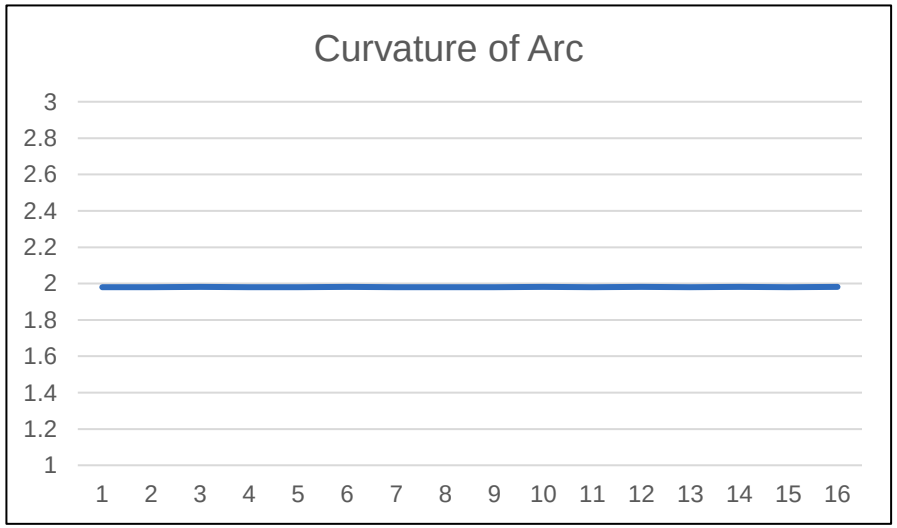
Goal:

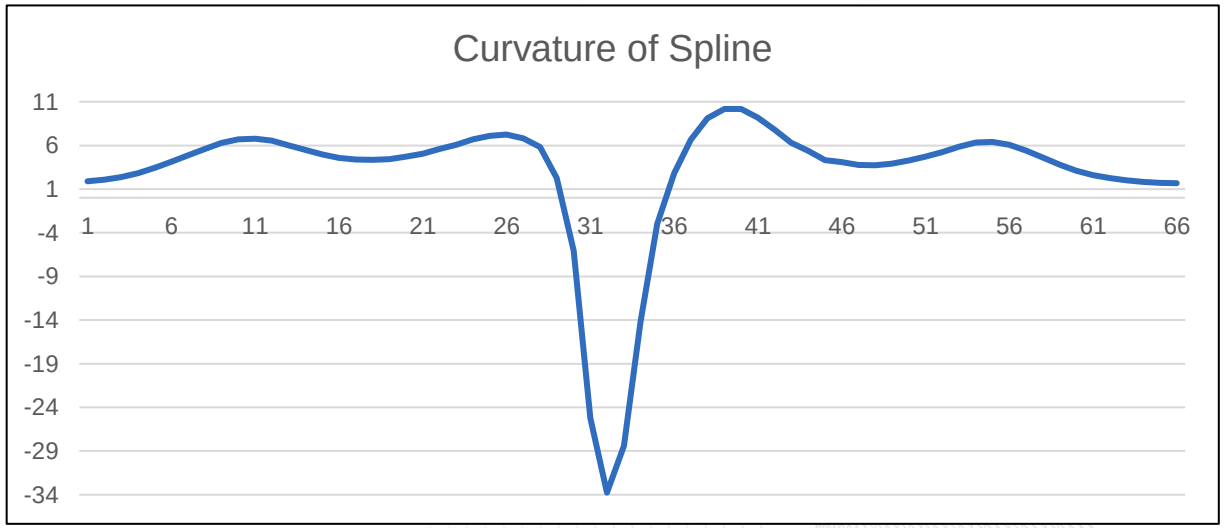
Determine when and where arcs or splines should be used to fit geometry.

Radius of Curvature

$$curvature = \frac{1}{radius}$$



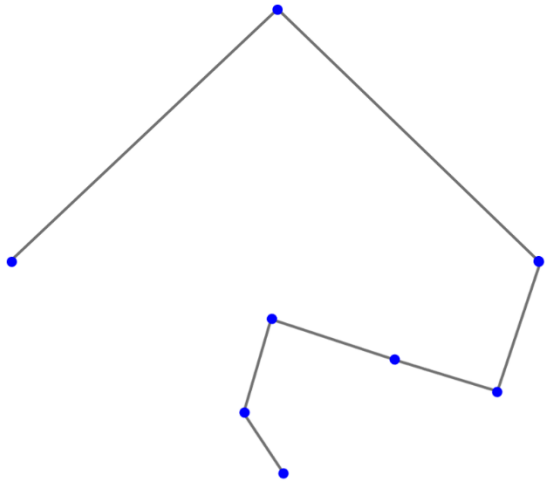




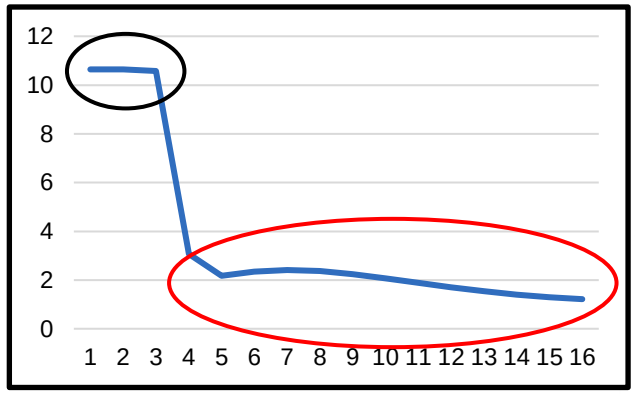
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Identifying Sections

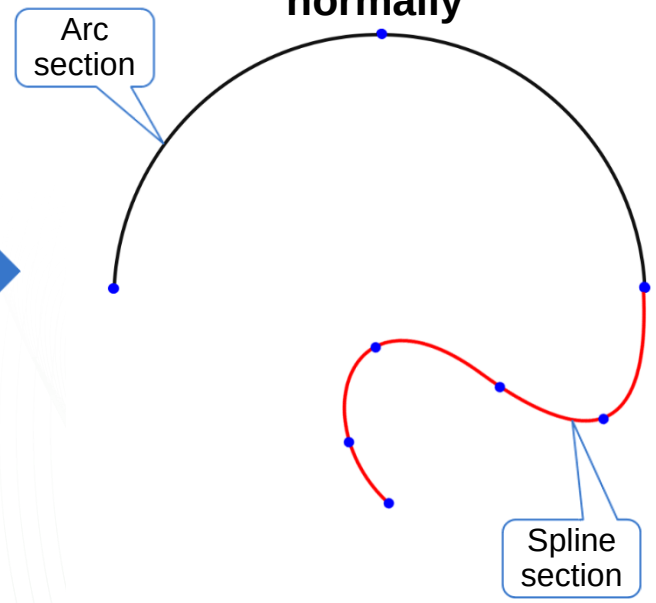
1. Input geometry



2. Analyze curvature & determine sub-sections

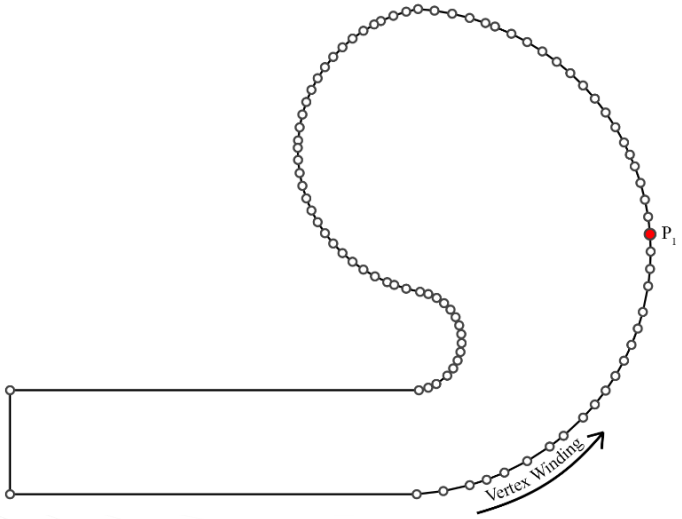


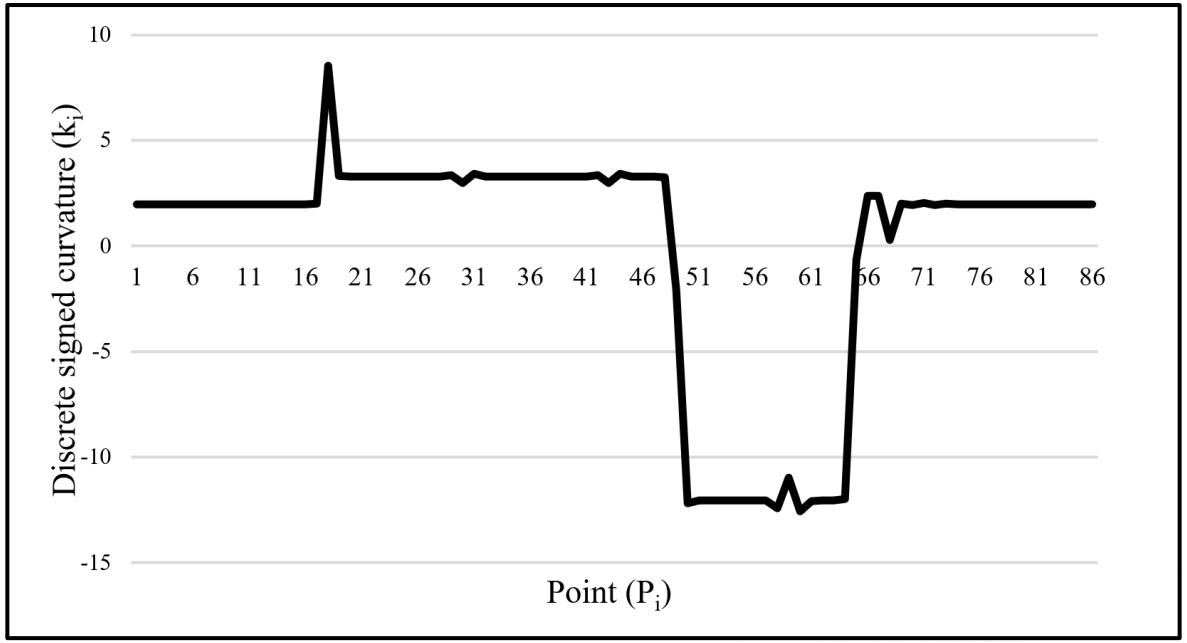
3. Fit sub-sections normally

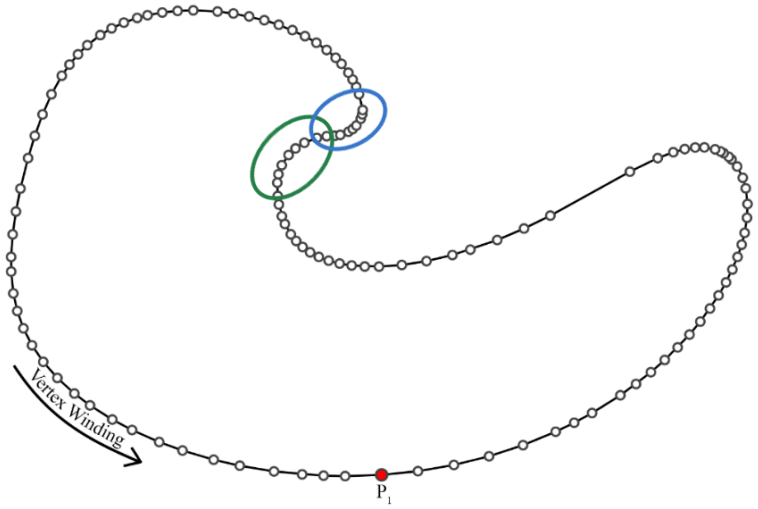


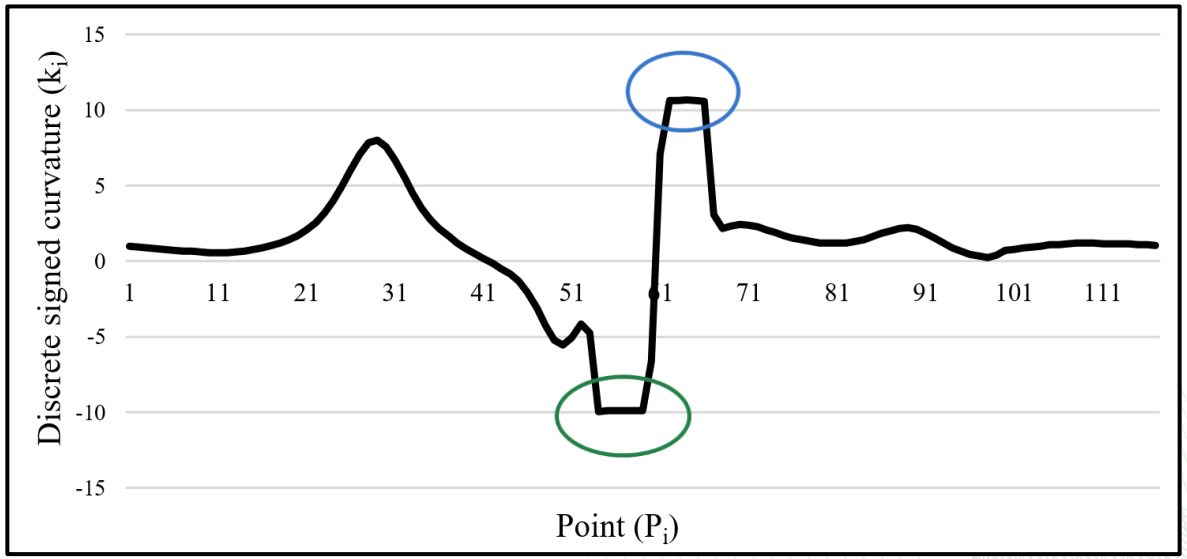
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Section Partitioning



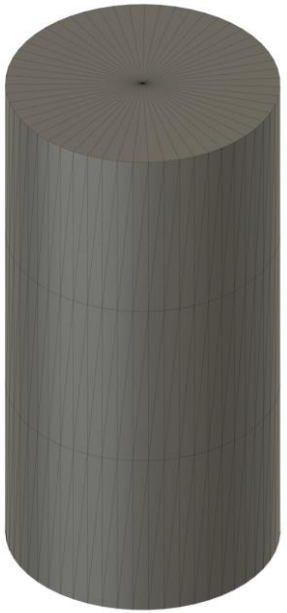


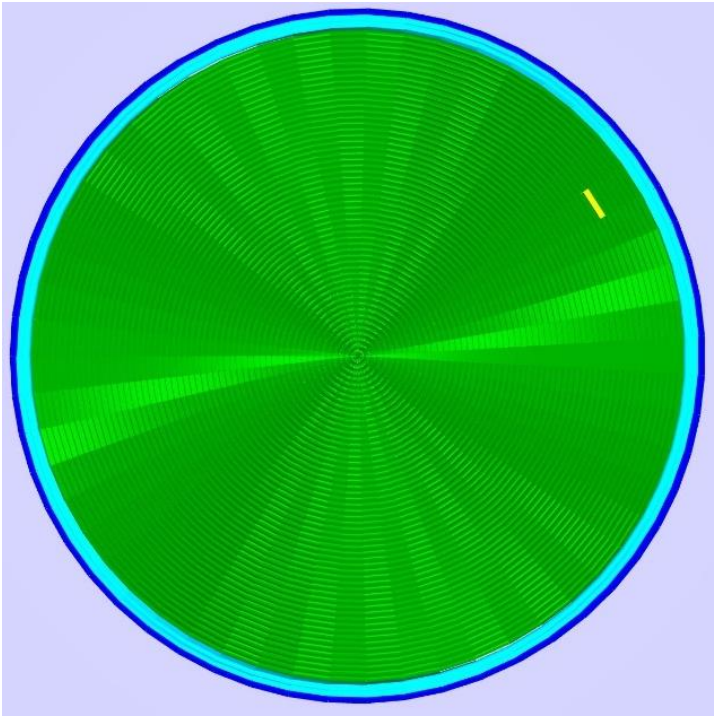




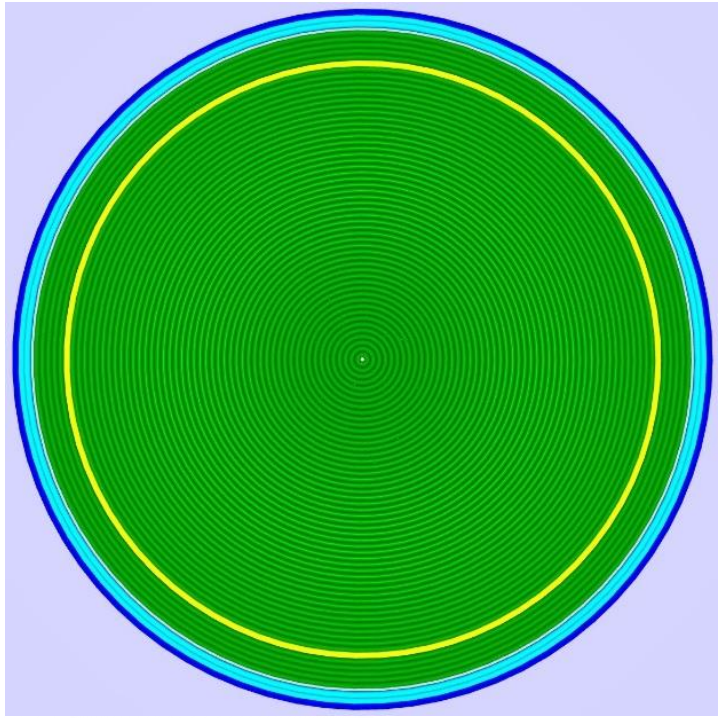
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Case Study 1: Cylinder

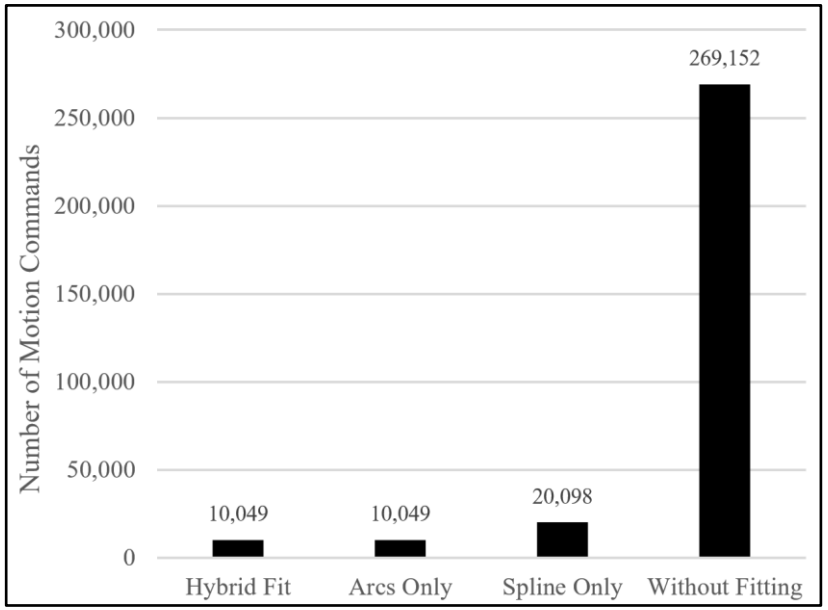




No Fit



Curve Fit



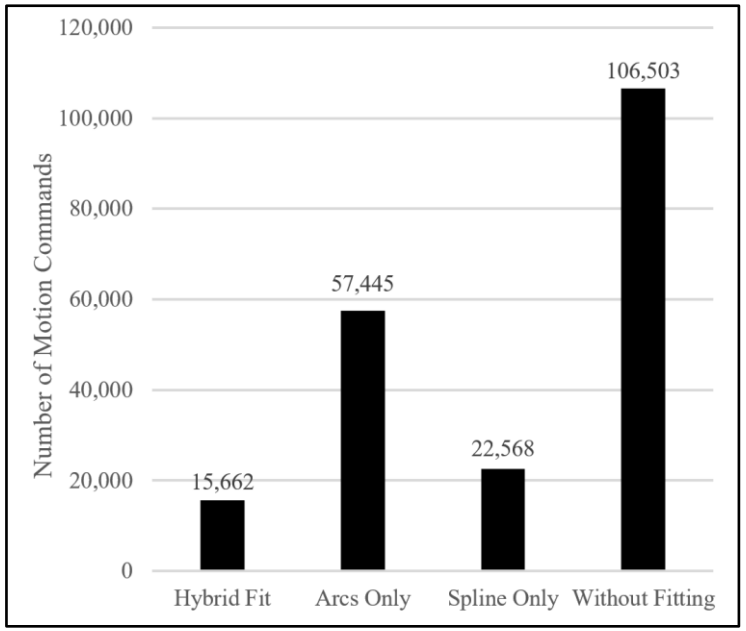
26 times reduction in motion commands

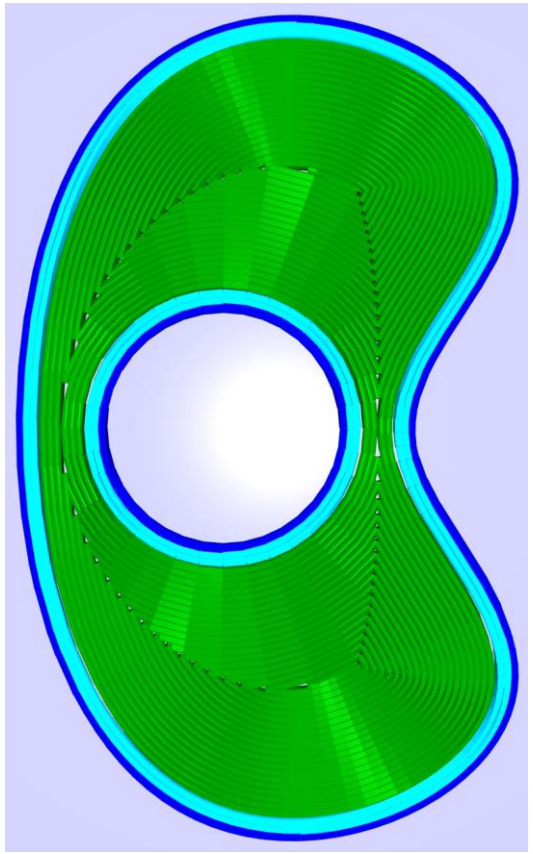
Spline only fitting was **less effective**

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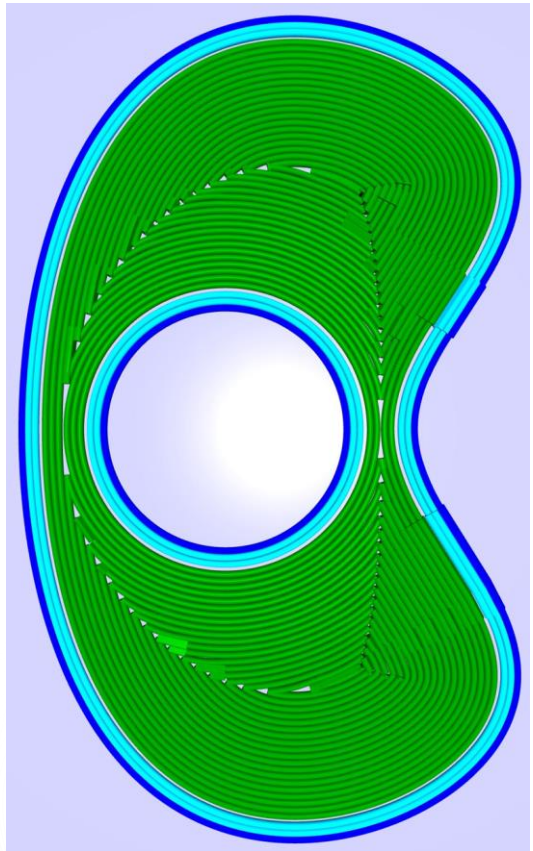
Case Study 2: NURBS with Hole







No Fit



Curve Fit

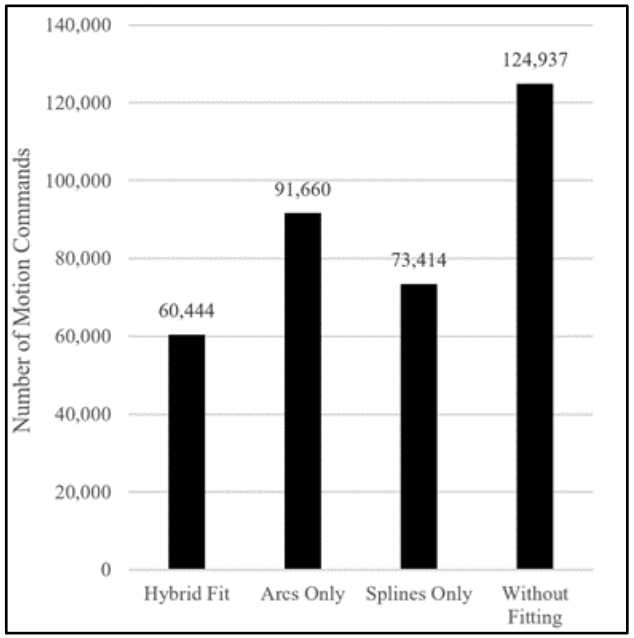
Hybrid fit performed best

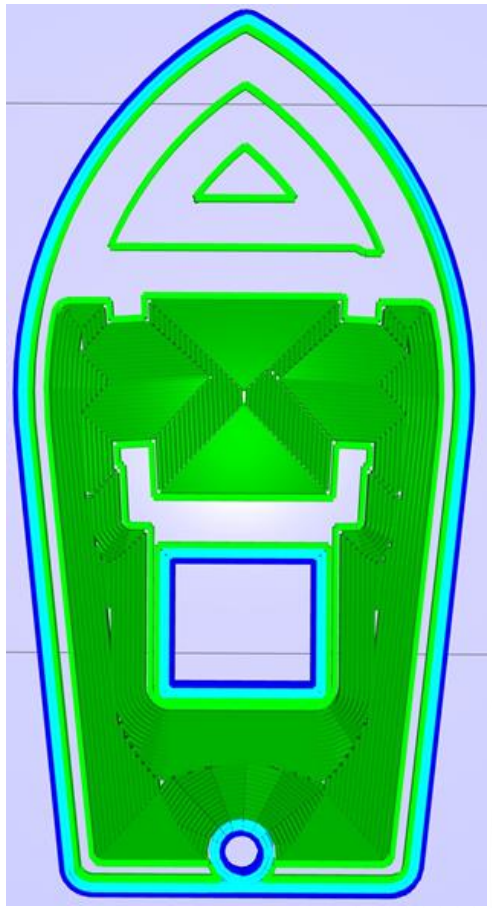
6.8 times reduction in motion commands

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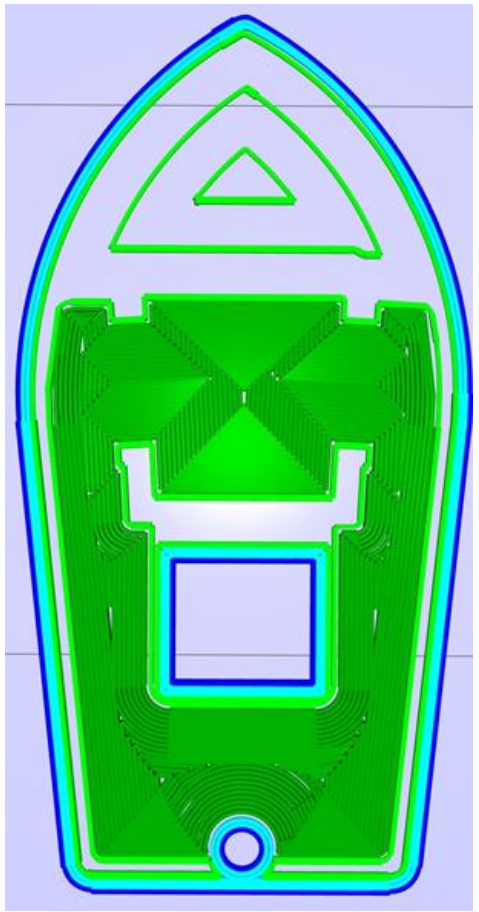
Case Study 3: 3D Benchy







No Fit



Curve Fit

50% reduction in motion commands

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Questions?

Charles Wade



This material is based upon work supported by the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, Office of Advanced Manufacturing, under contract number DE-AC05-00OR22725.

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