Variable-width contouring for additive manufacturing

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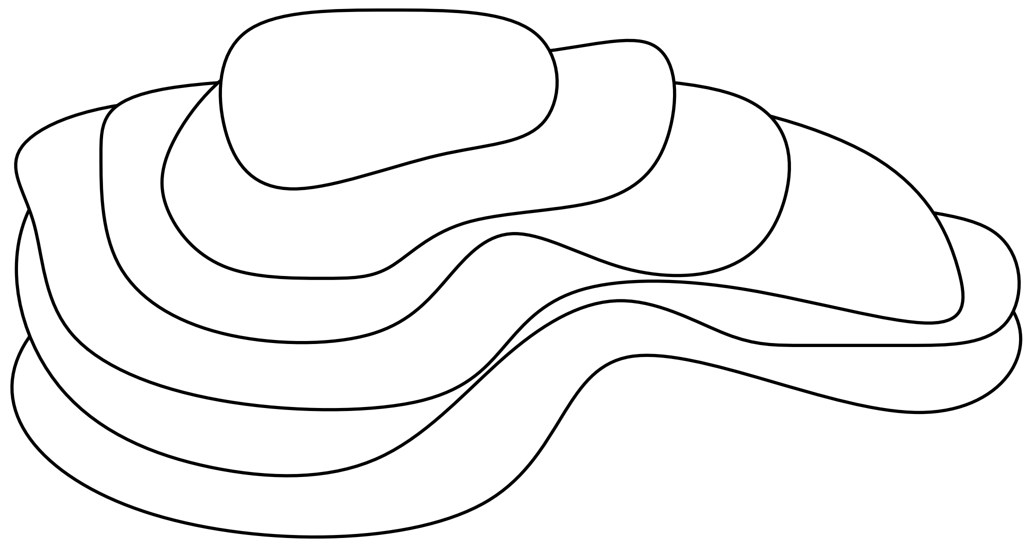
GTMG 2020

narrated by Samuel Hornus

Context: 3D printing

An object is fabricated as a stack of horizontal **layers**.



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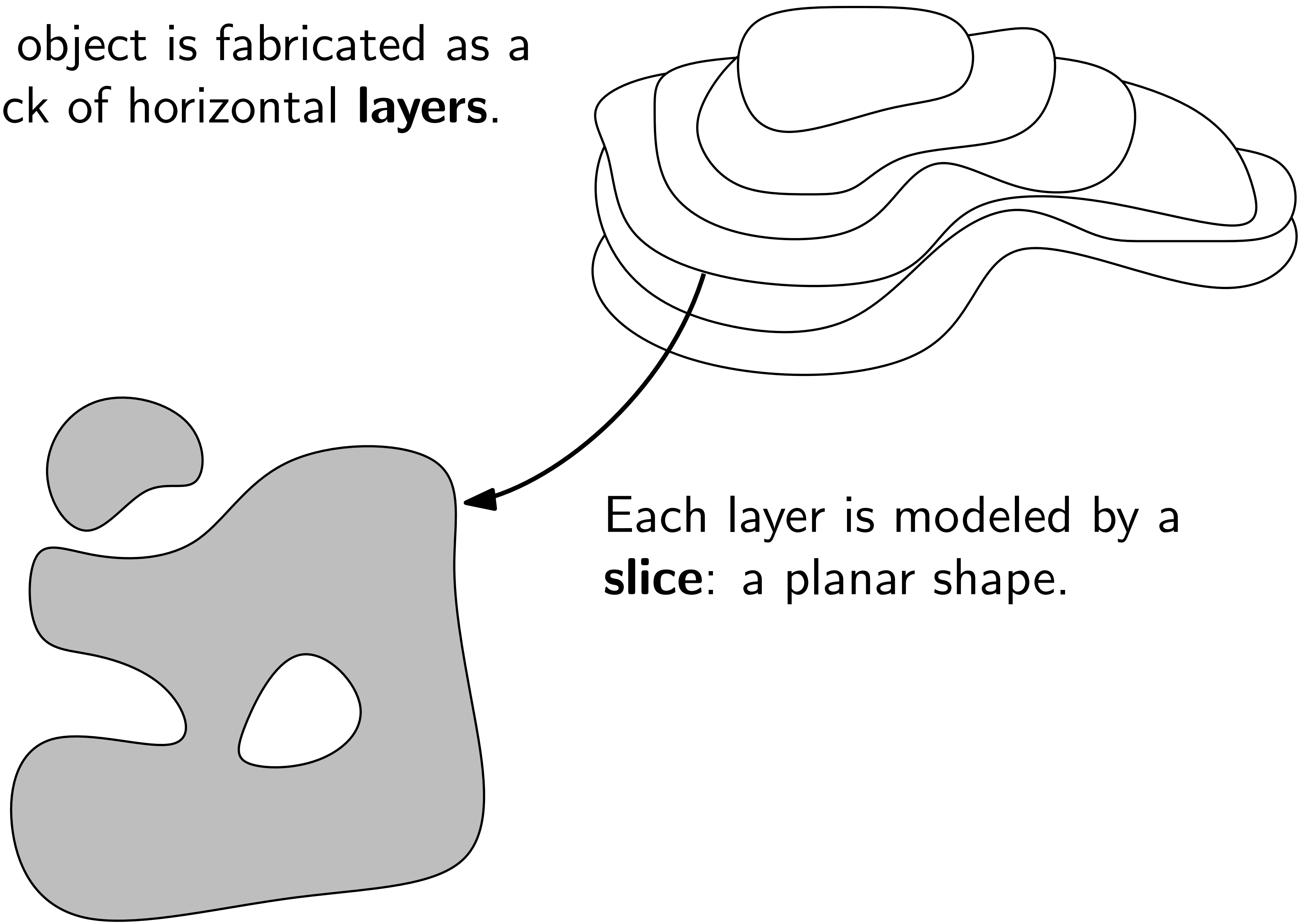
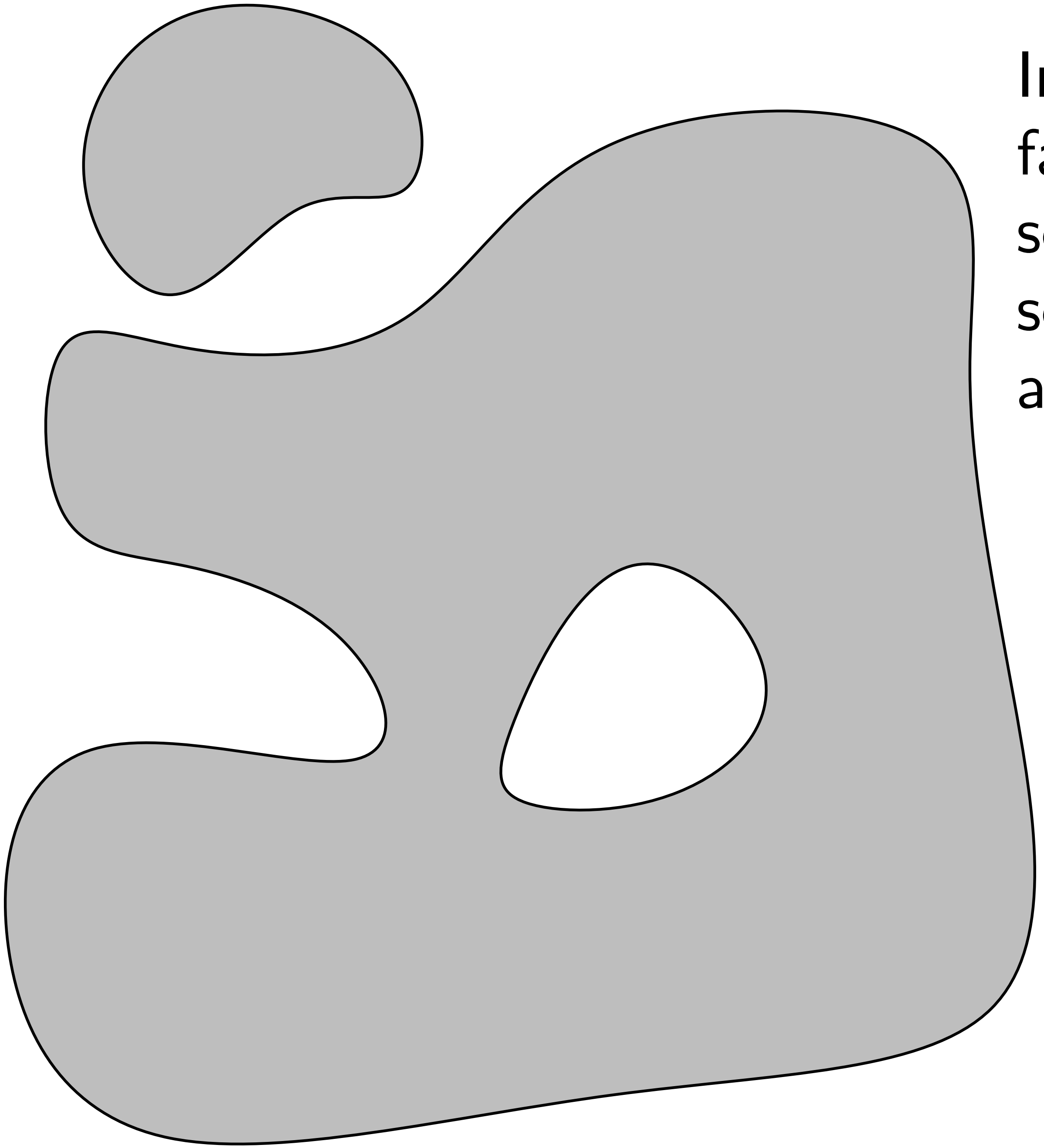


Each layer is modeled by a **slice**: a planar shape.

Context: 3D printing



In turn, each layer is fabricated by solidifying a **bead** of some material, along a **print path**

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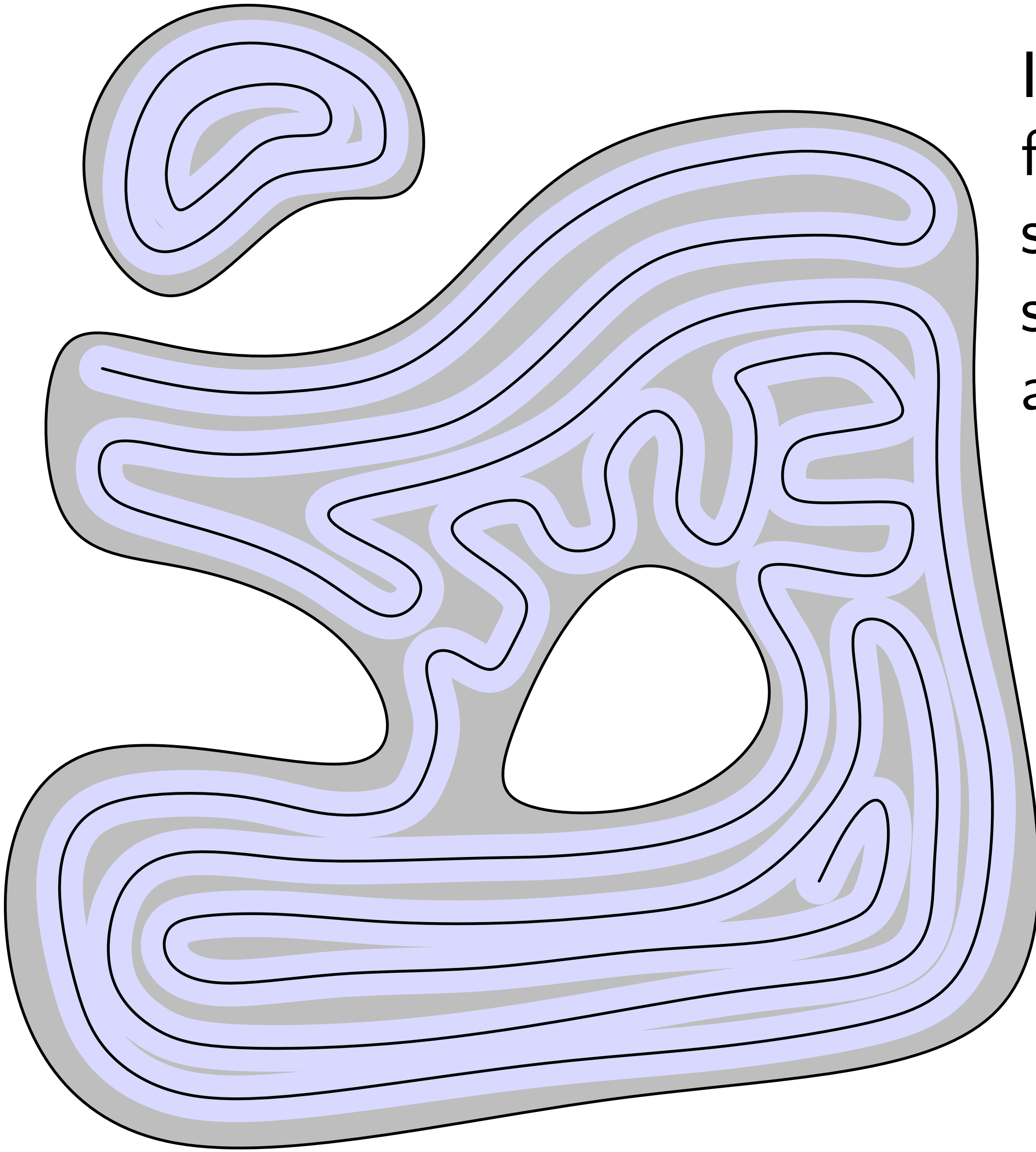

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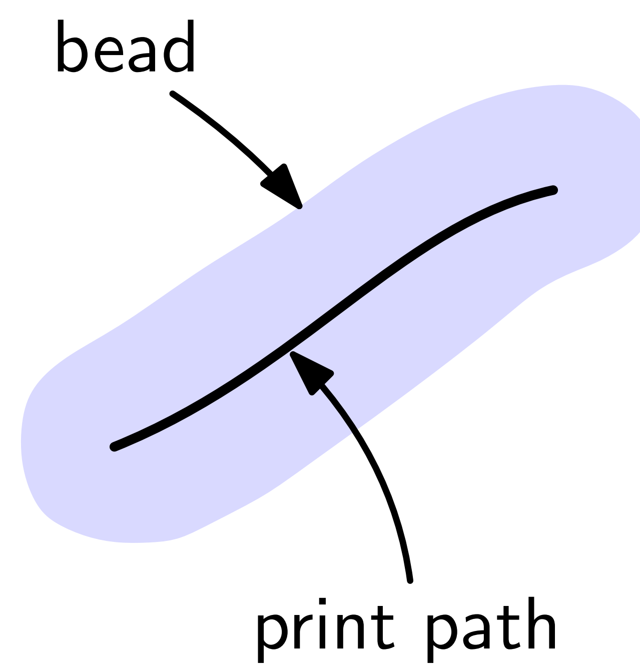
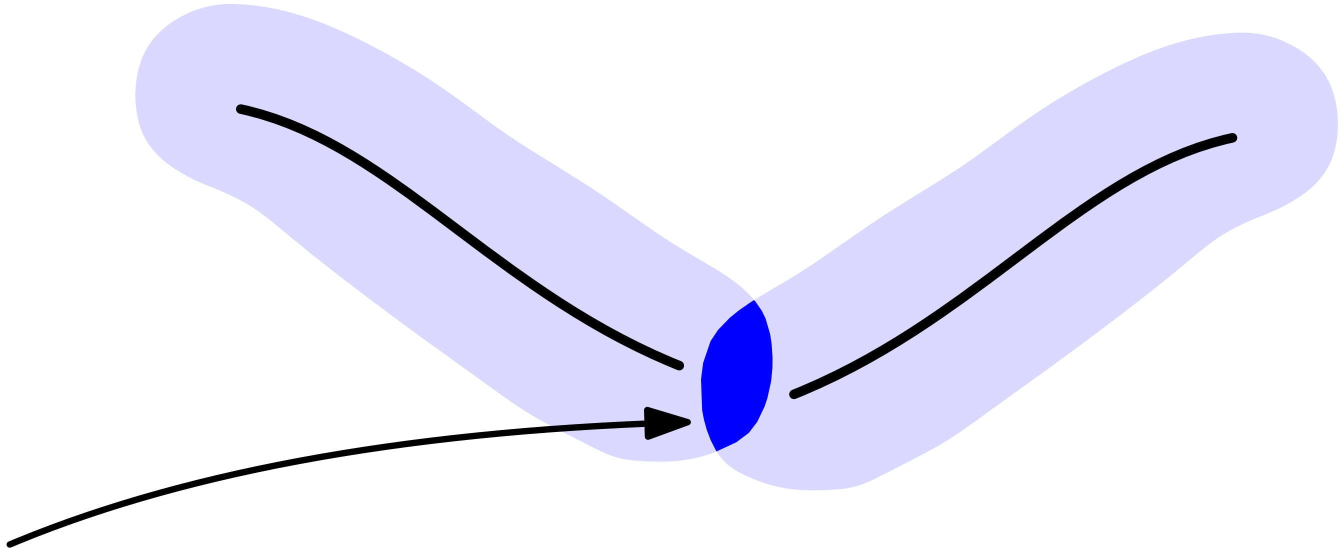
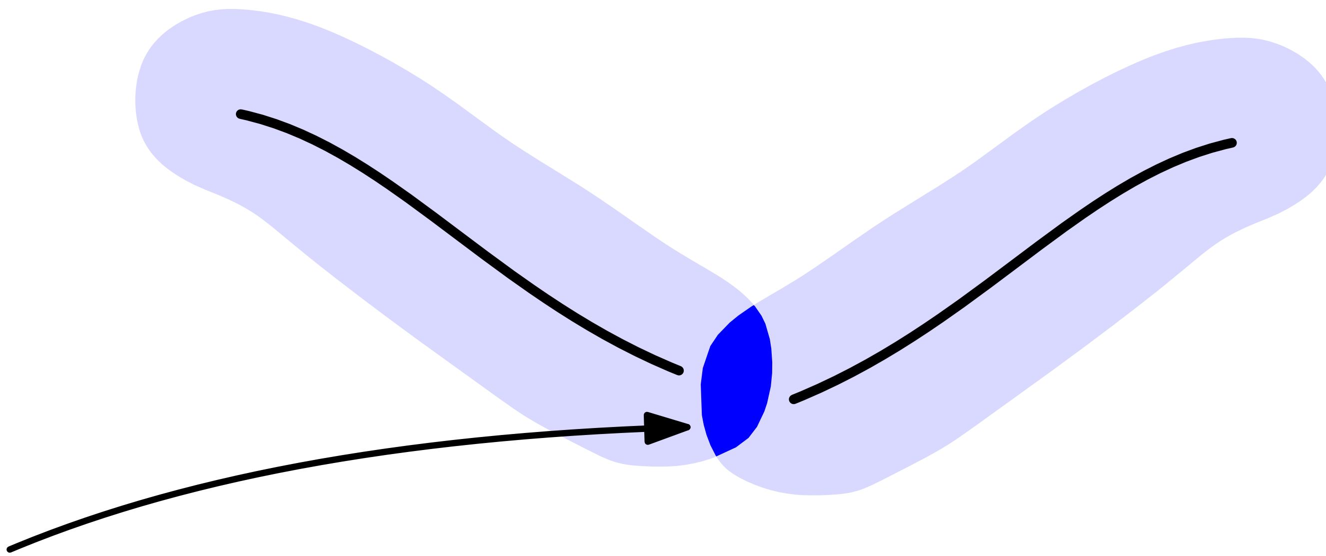


Overfill



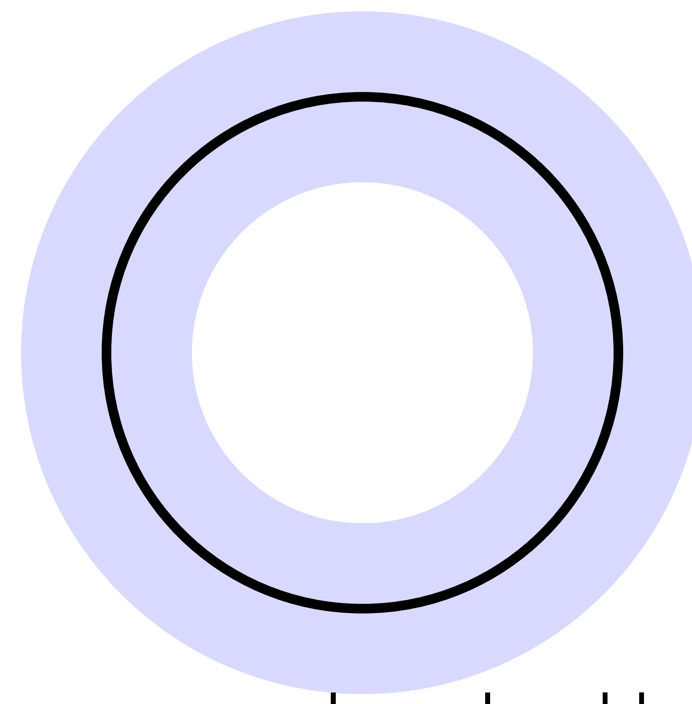
Overfill = forbidden...

Overfill



Overfill = forbidden...

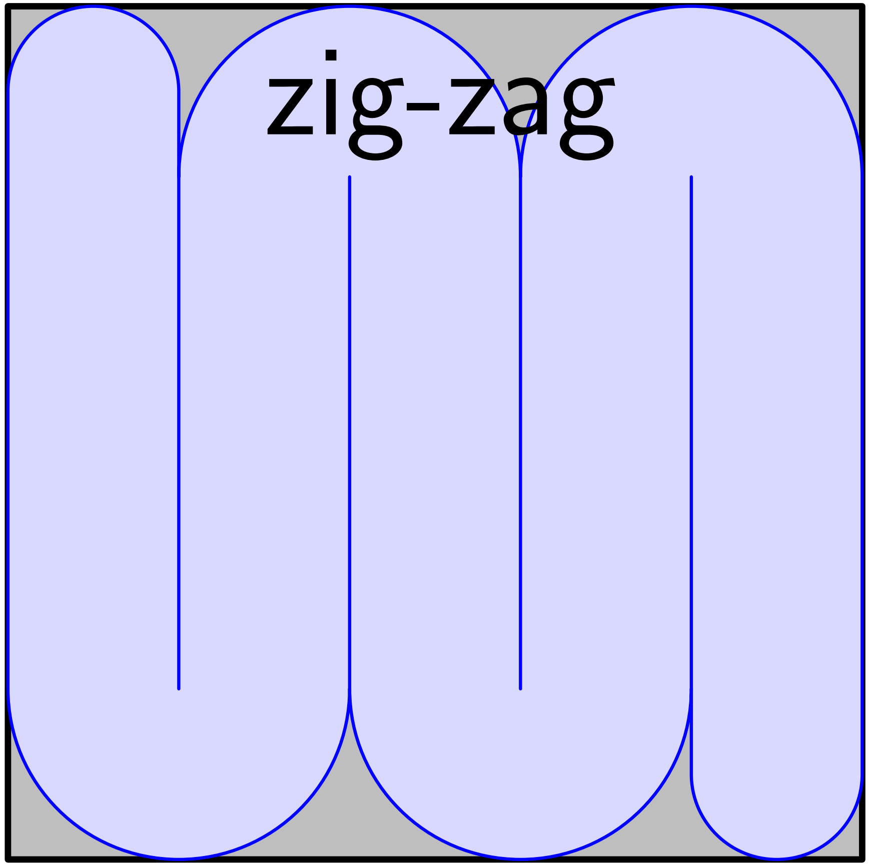
...except for closed beads, a
well controlled special case:

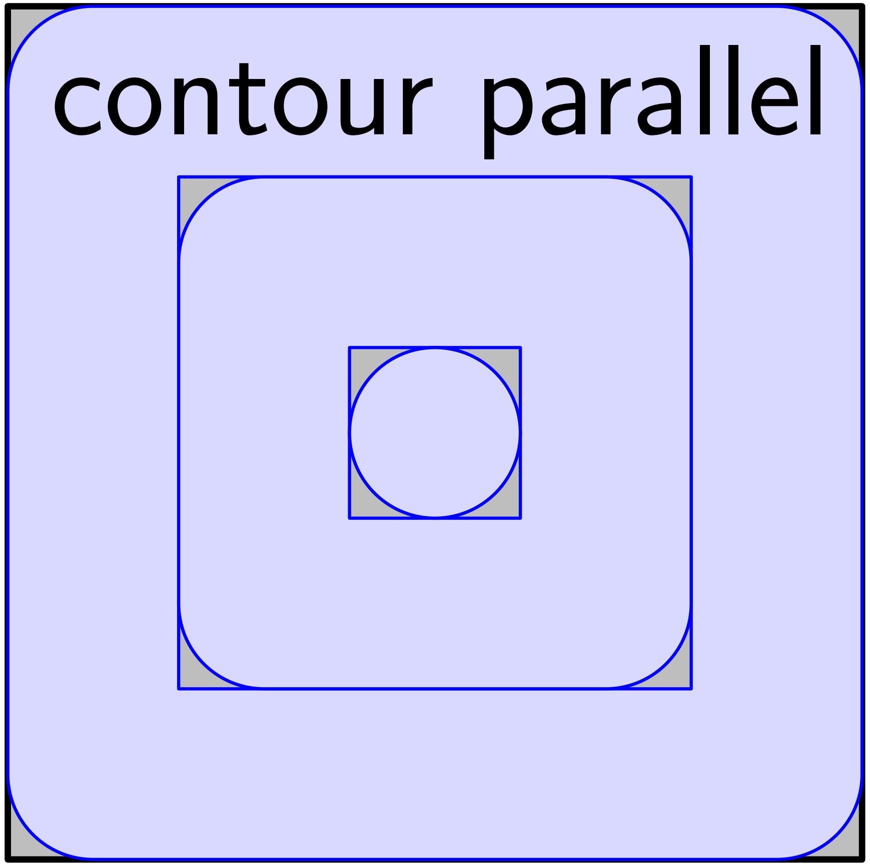


we love closed beads!

Underfill

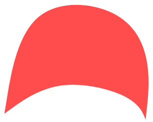
Example: two classic ways to fill a square with a **constant-width** bead.

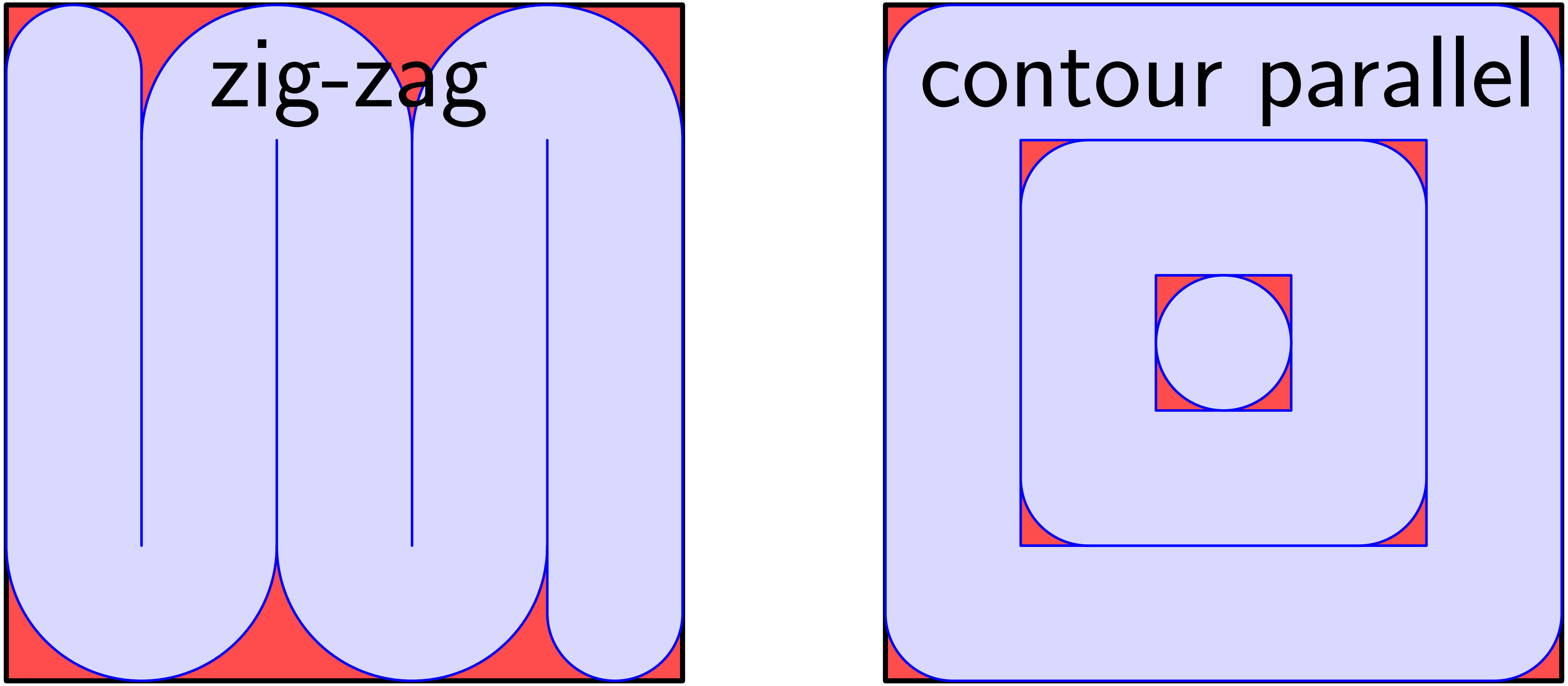




Underfill

Underfill is the existence of areas of the slice **not** covered by a solid bead.

=underfill



Underfill

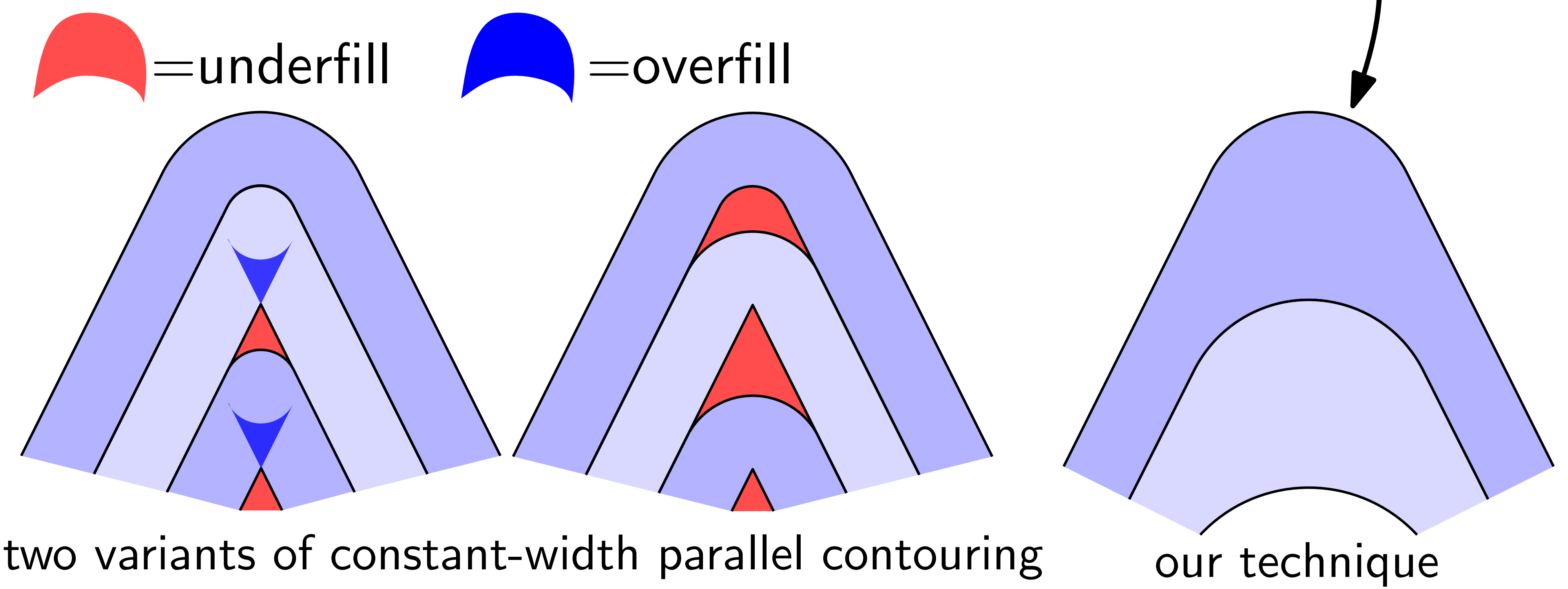
Underfill is bad.

We want to minimize underfill

What to do?

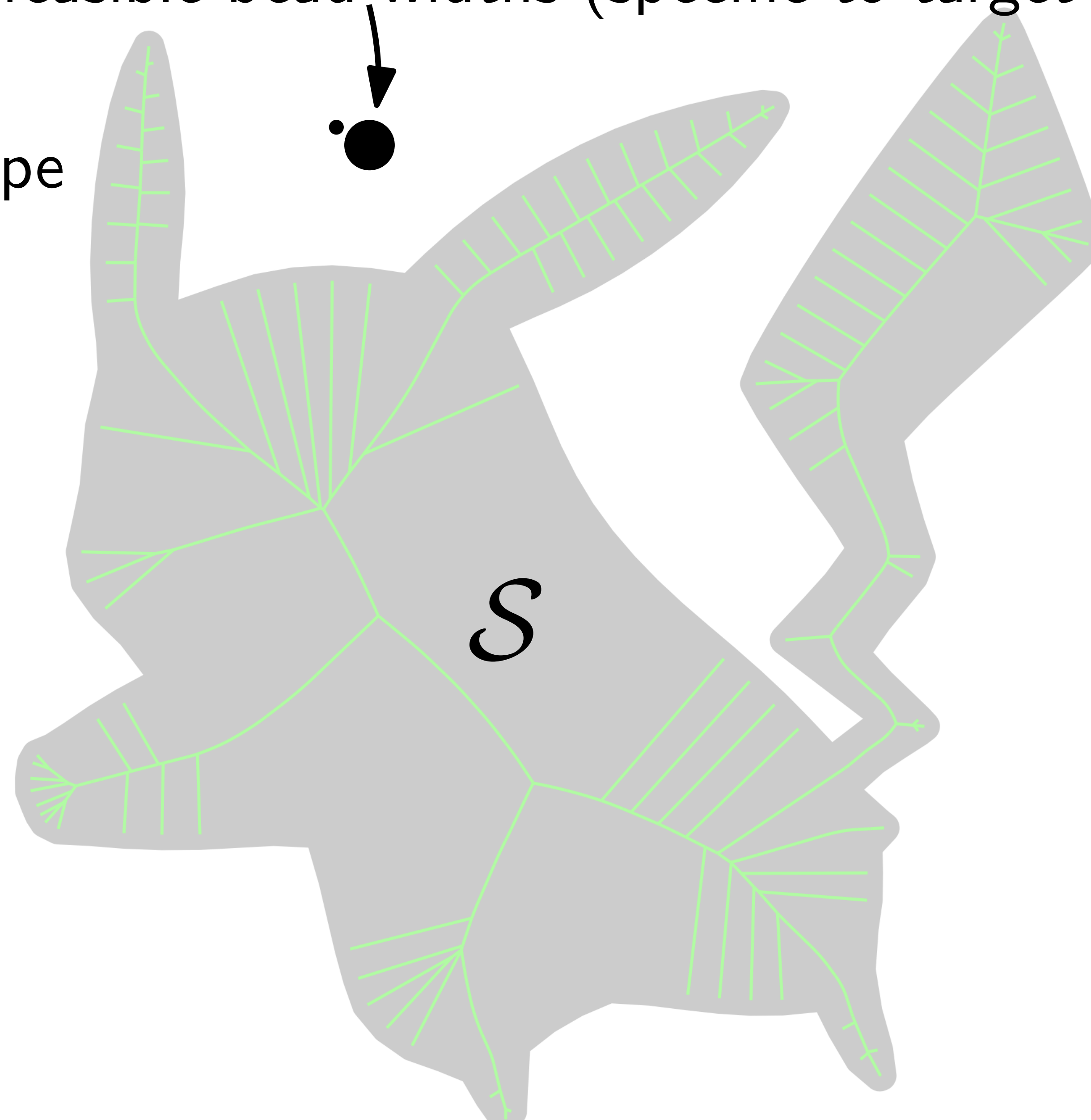
We follow earlier works suggesting to use variable-width beads.

We use **closed, variable-width beads**.
We try to minimize their number and curvature.



Inputs

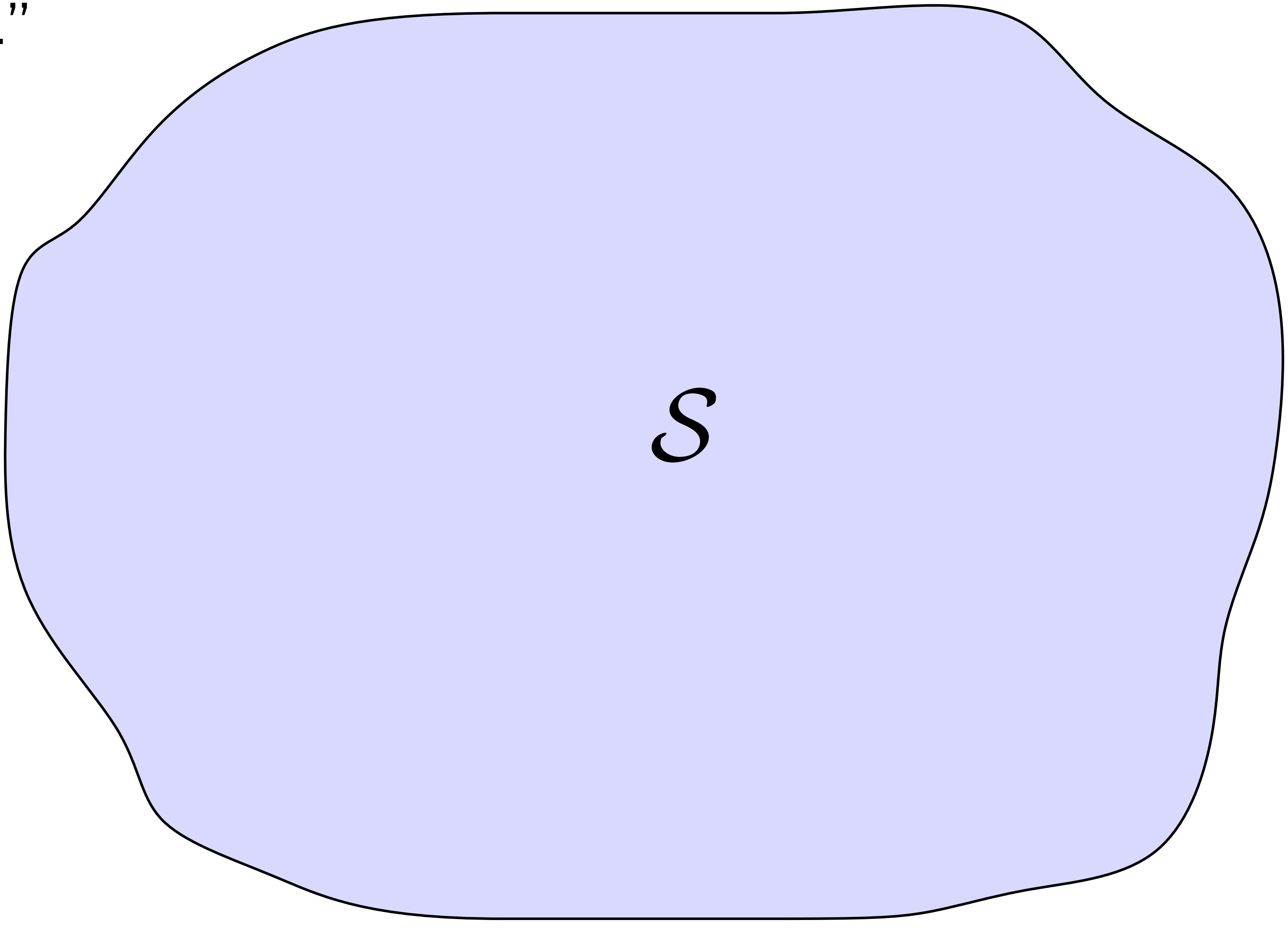
- A range $[2\gamma, 2\Gamma]$ of feasible bead widths (specific to target 3D printer).
- A $\mathbf{2}\gamma$-**fat** planar shape $\mathcal{S}$: all the maximal disks inside $\mathcal{S}$ have radius $\geq 2\gamma$. [1]



[1] In practice, slices are polygons. We process them into 2γ-fat shapes.

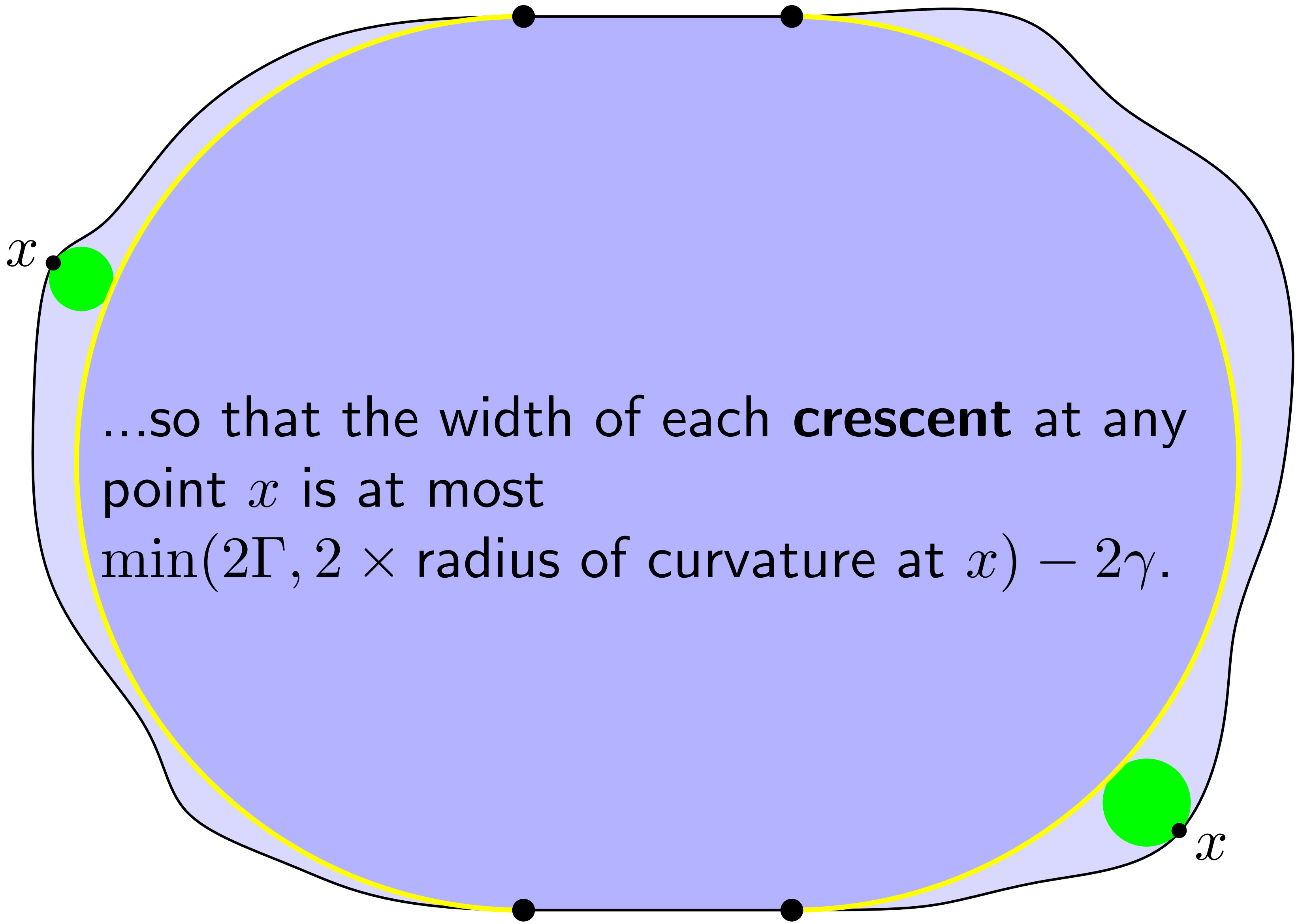
Variable-width contouring

Given a shape $\mathcal{S}$, we model a bead that stays in contact with the boundary of $\mathcal{S}$ and make the remaining inner shape "rounder."



Variable-width contouring

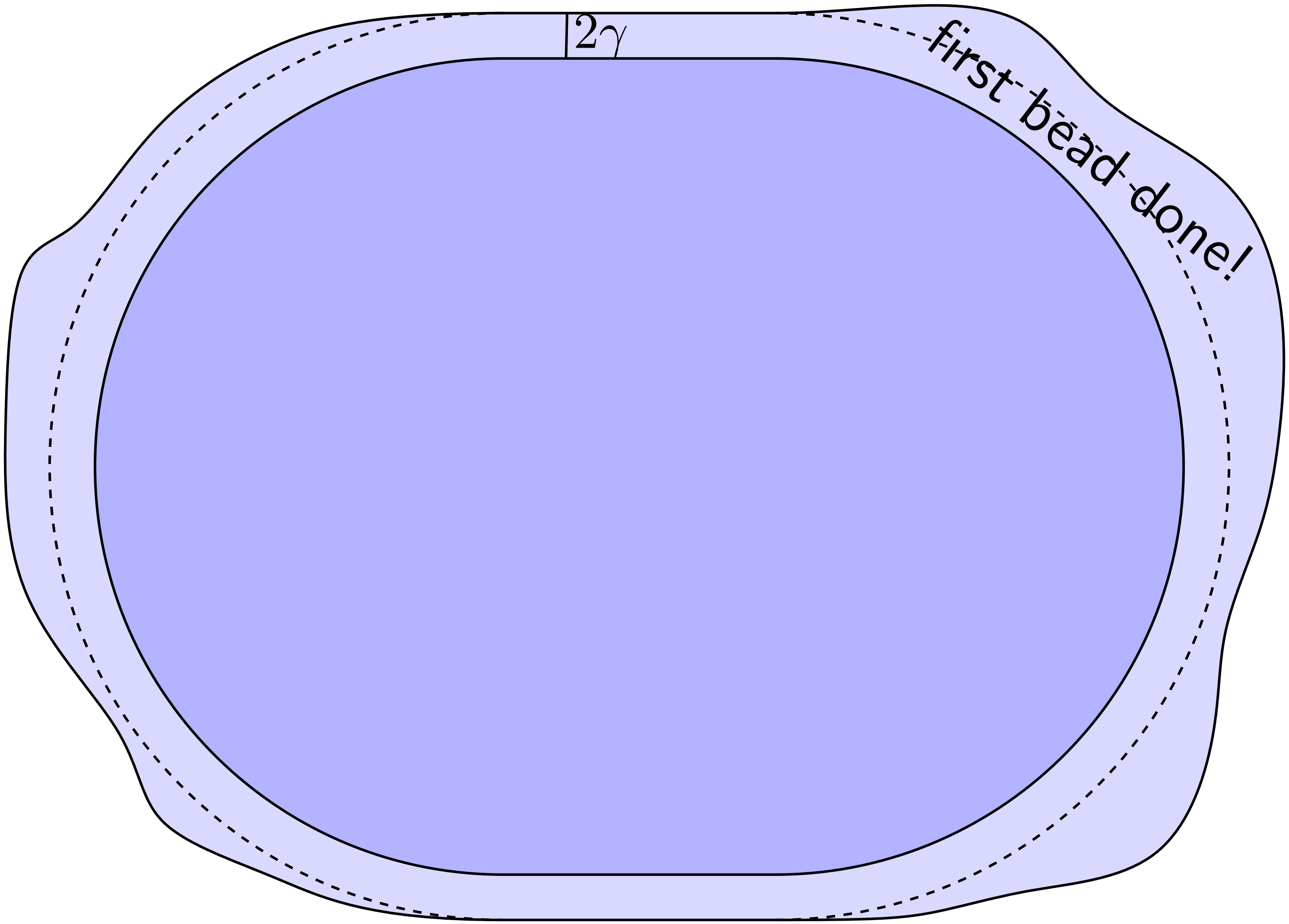
To do so, we replace parts of the boundary $\partial\mathcal{S}$ by inner tangent circular arcs (yellow)...



...so that the width of each **crescent** at any point x is at most $\min(2\Gamma, 2 \times \text{radius of curvature at } x) - 2\gamma$.

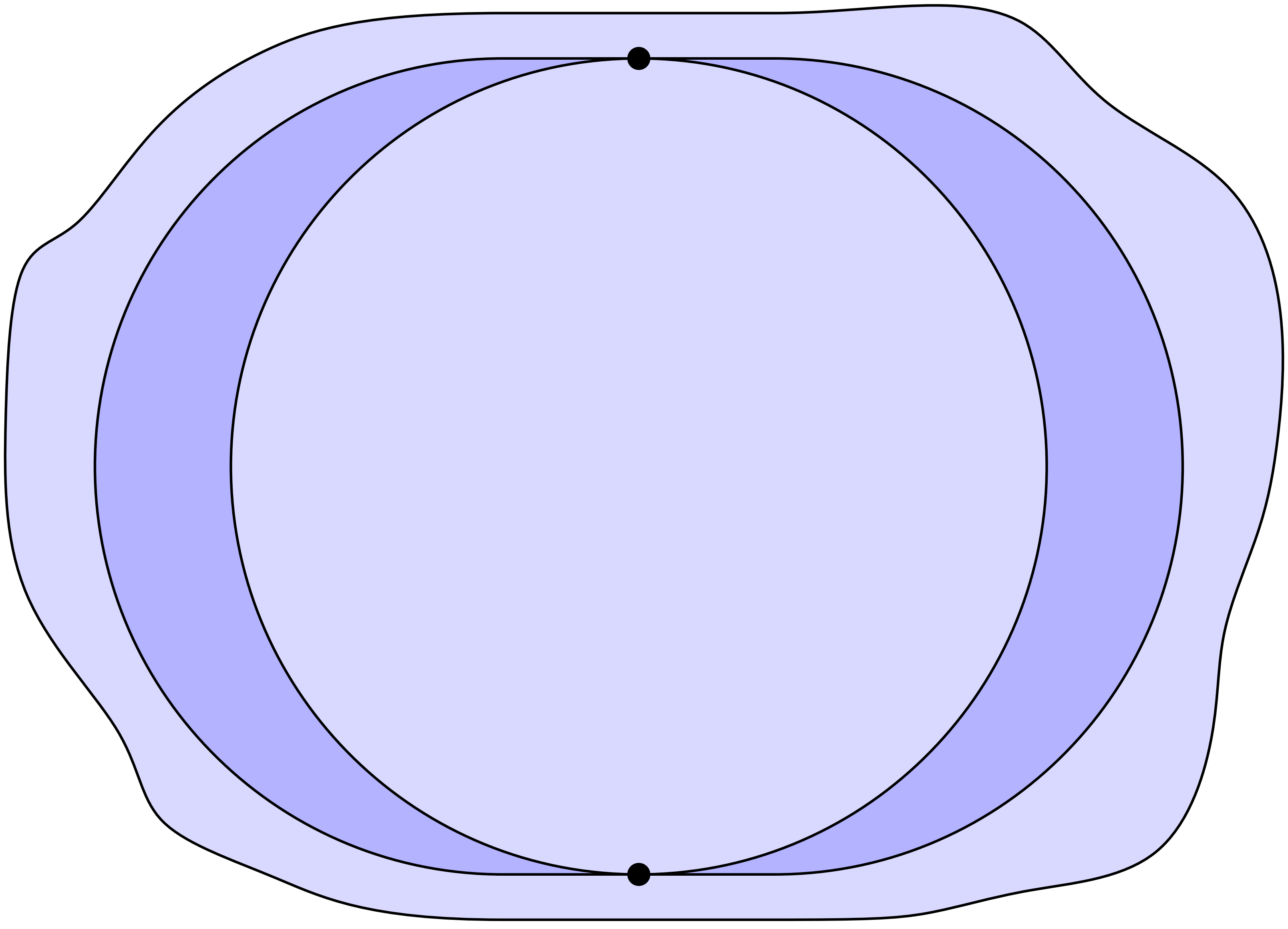
Variable-width contouring

Then we do a parallel offset of 2γ and obtain a bead of width within the allowed range.



Variable-width contouring

Now we repeat the process



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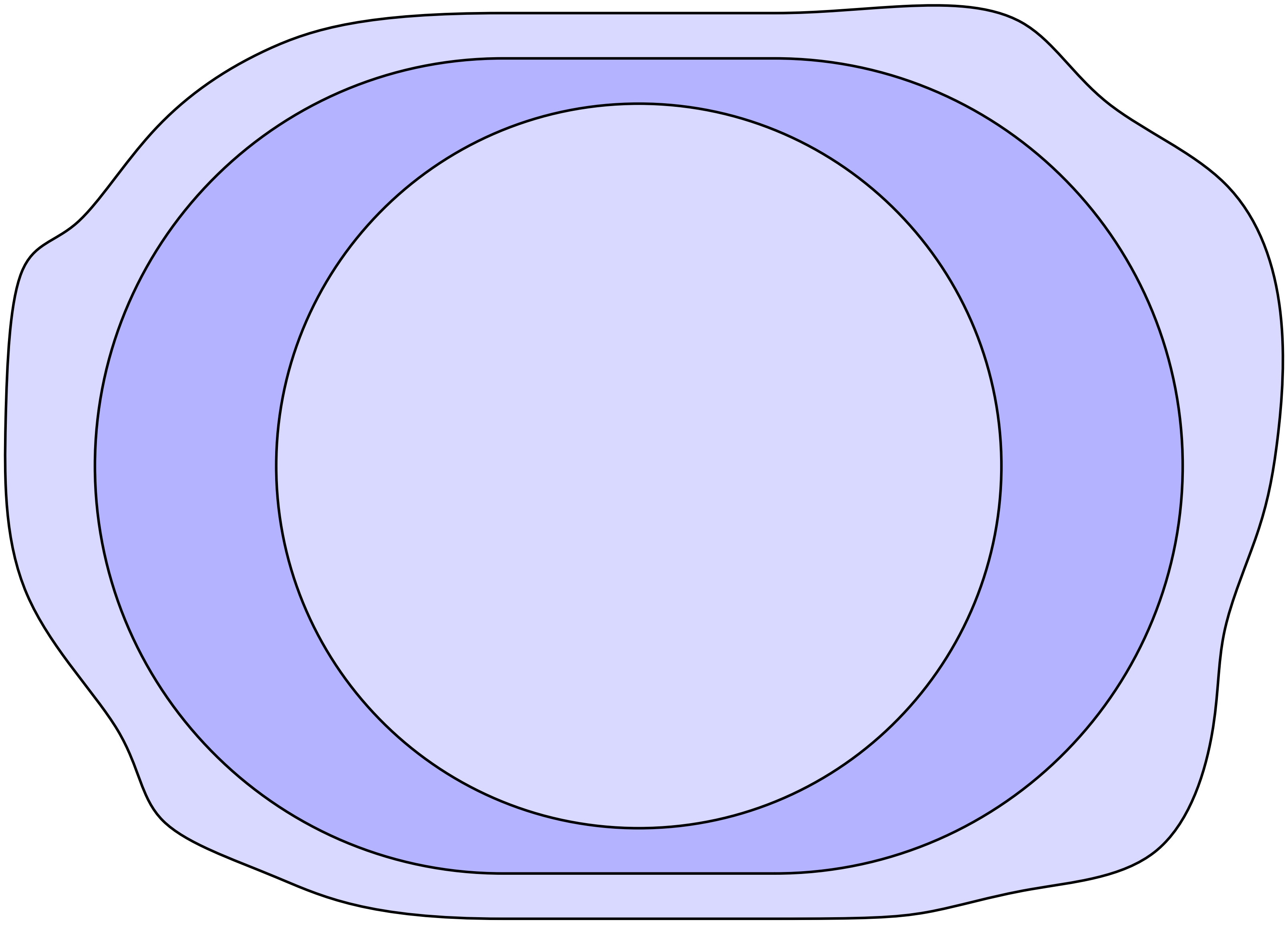
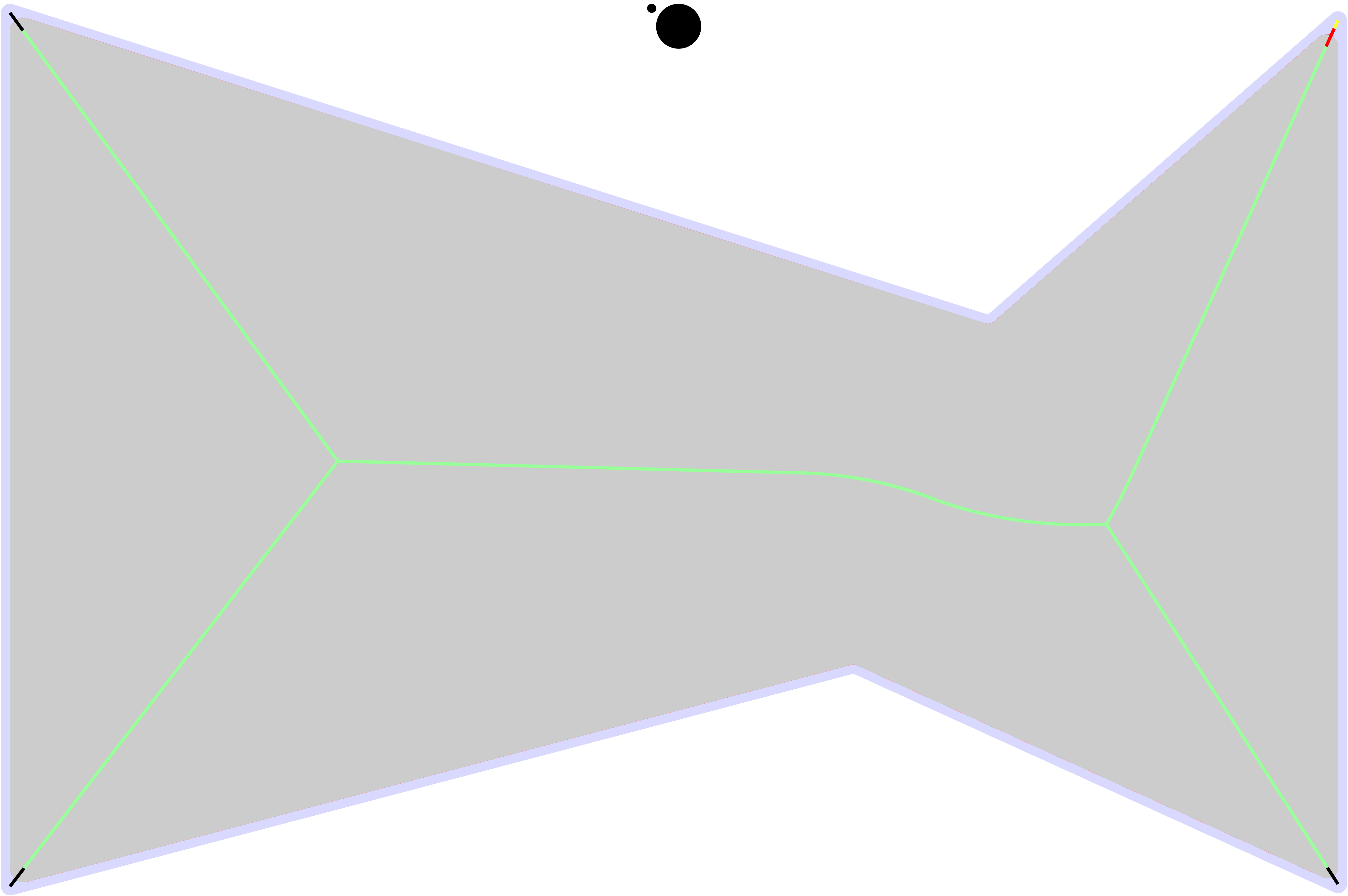
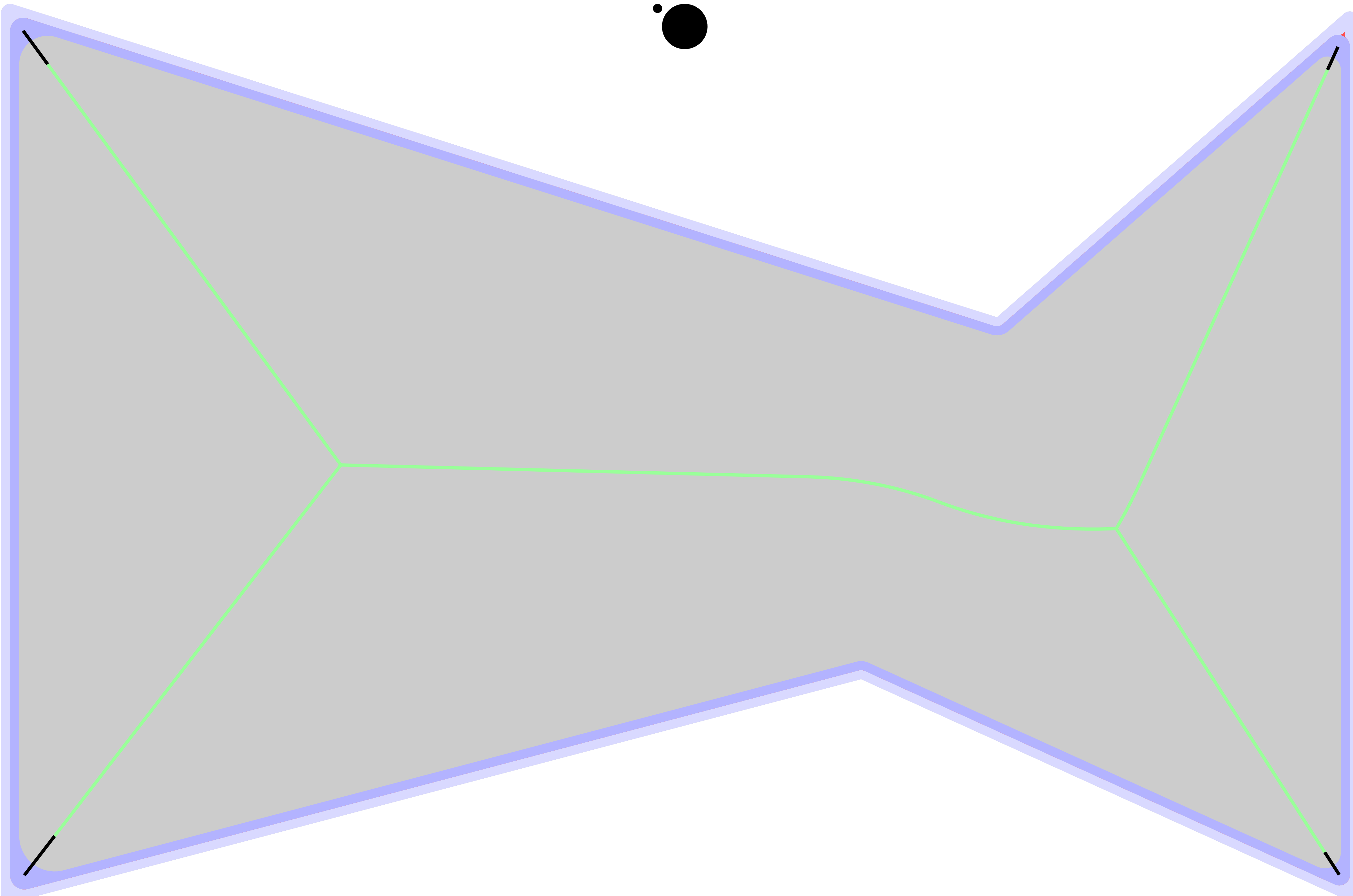
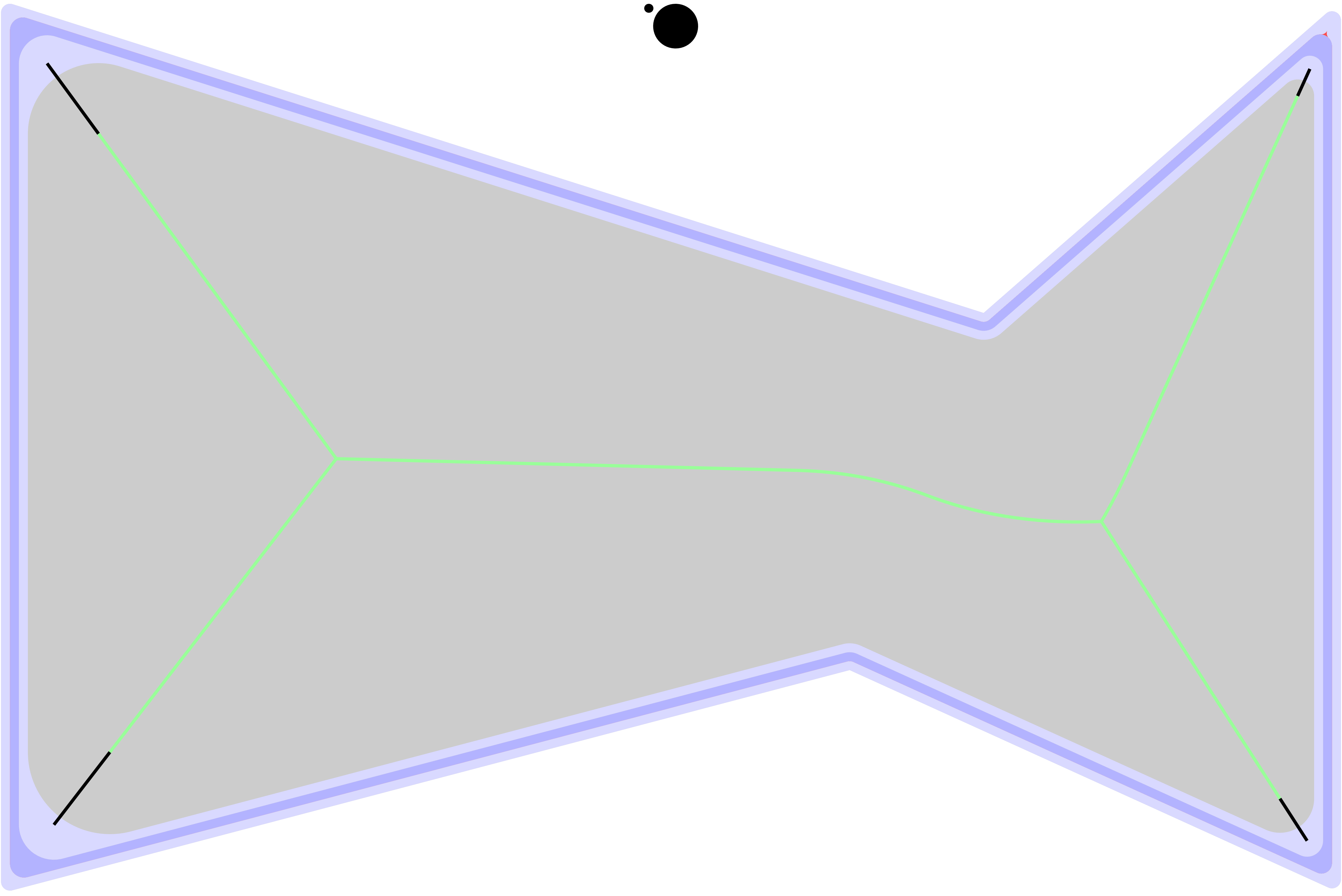
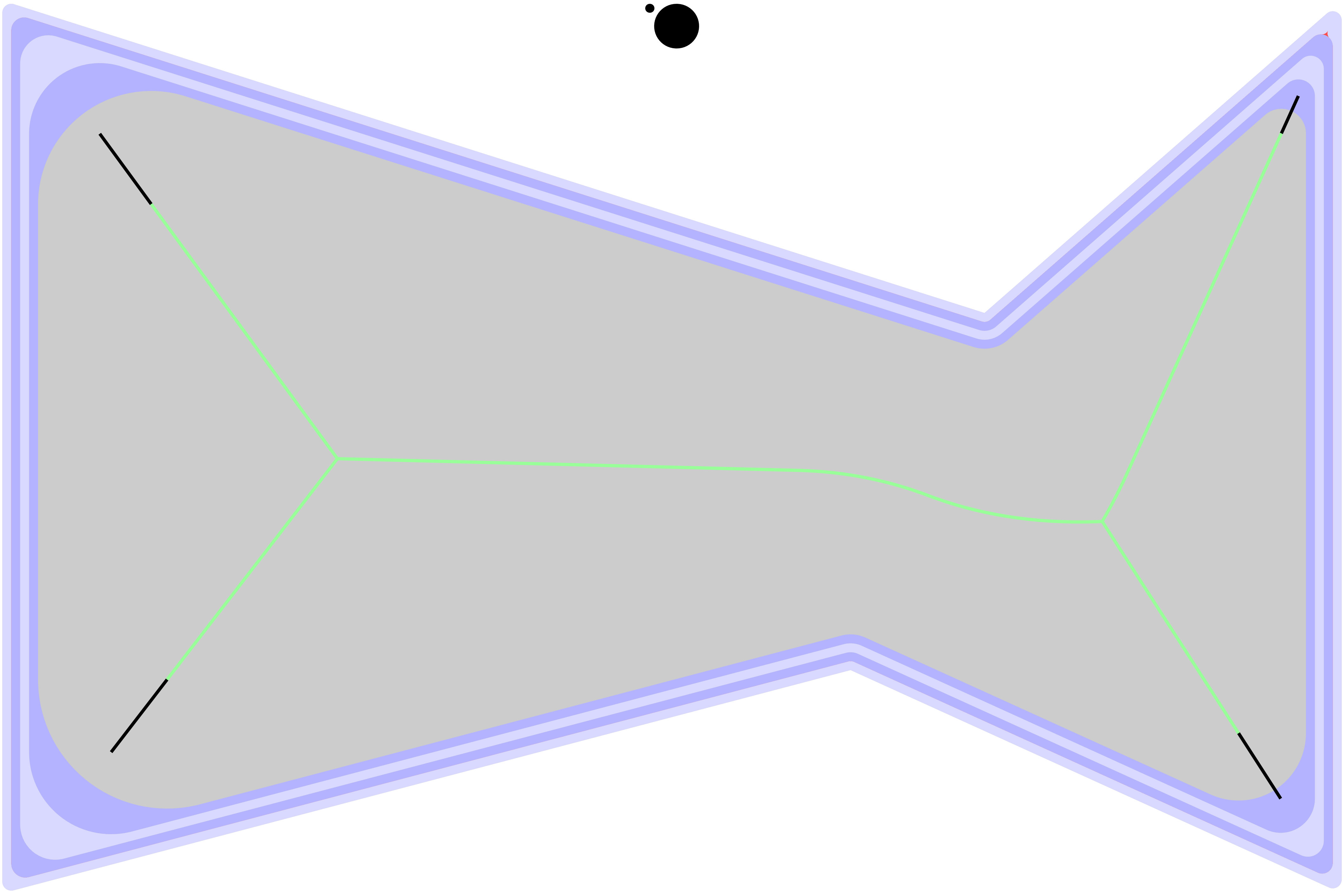
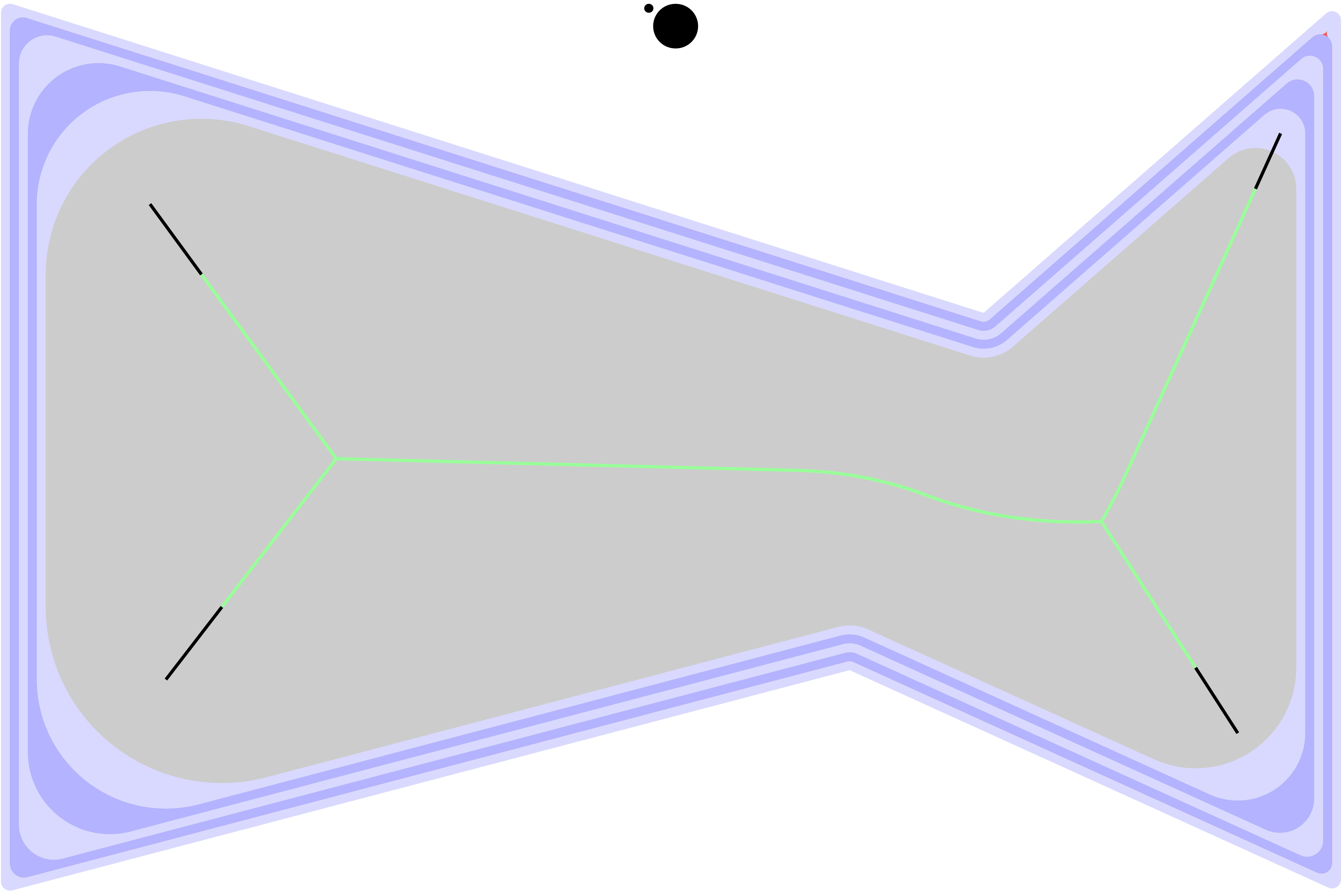


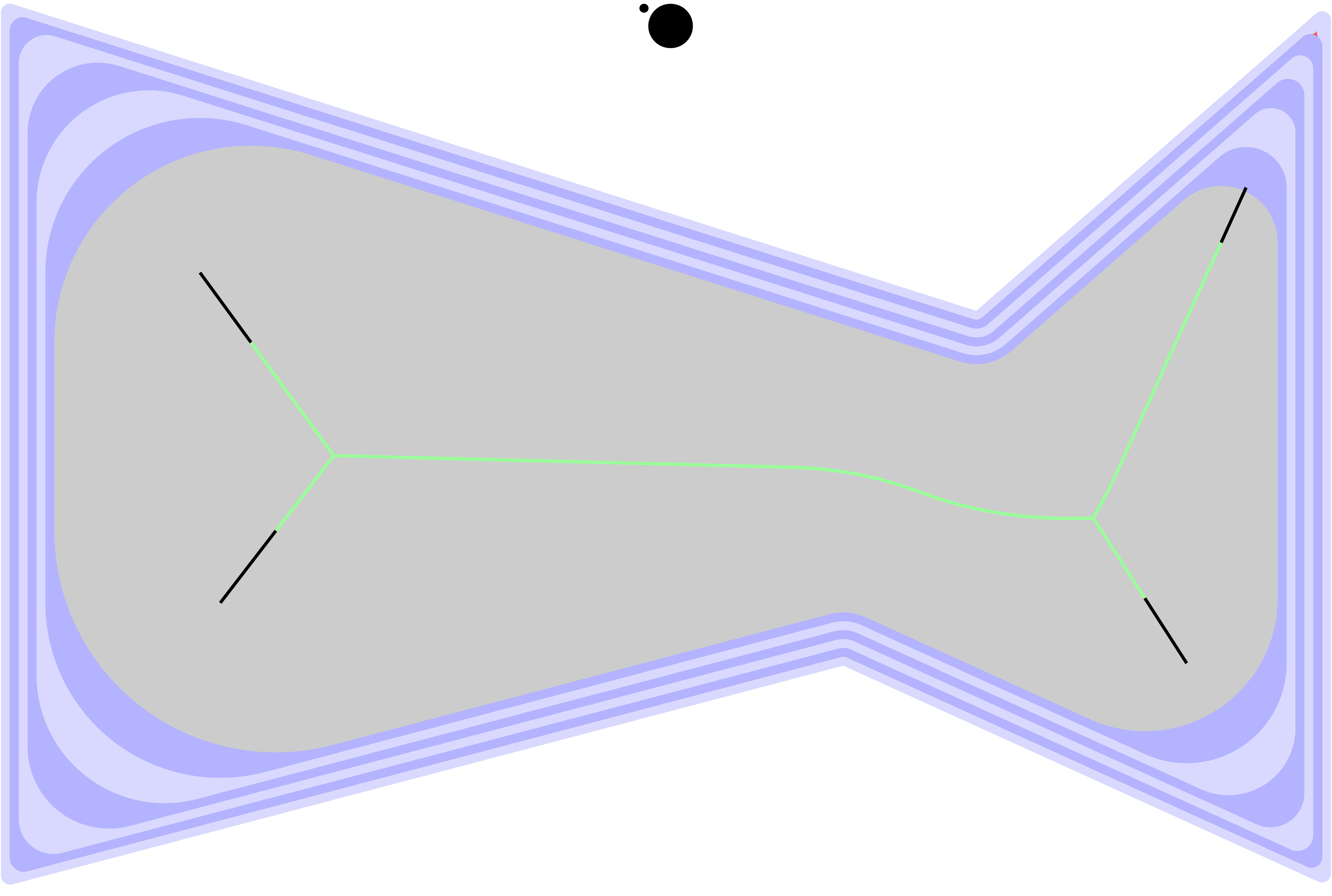


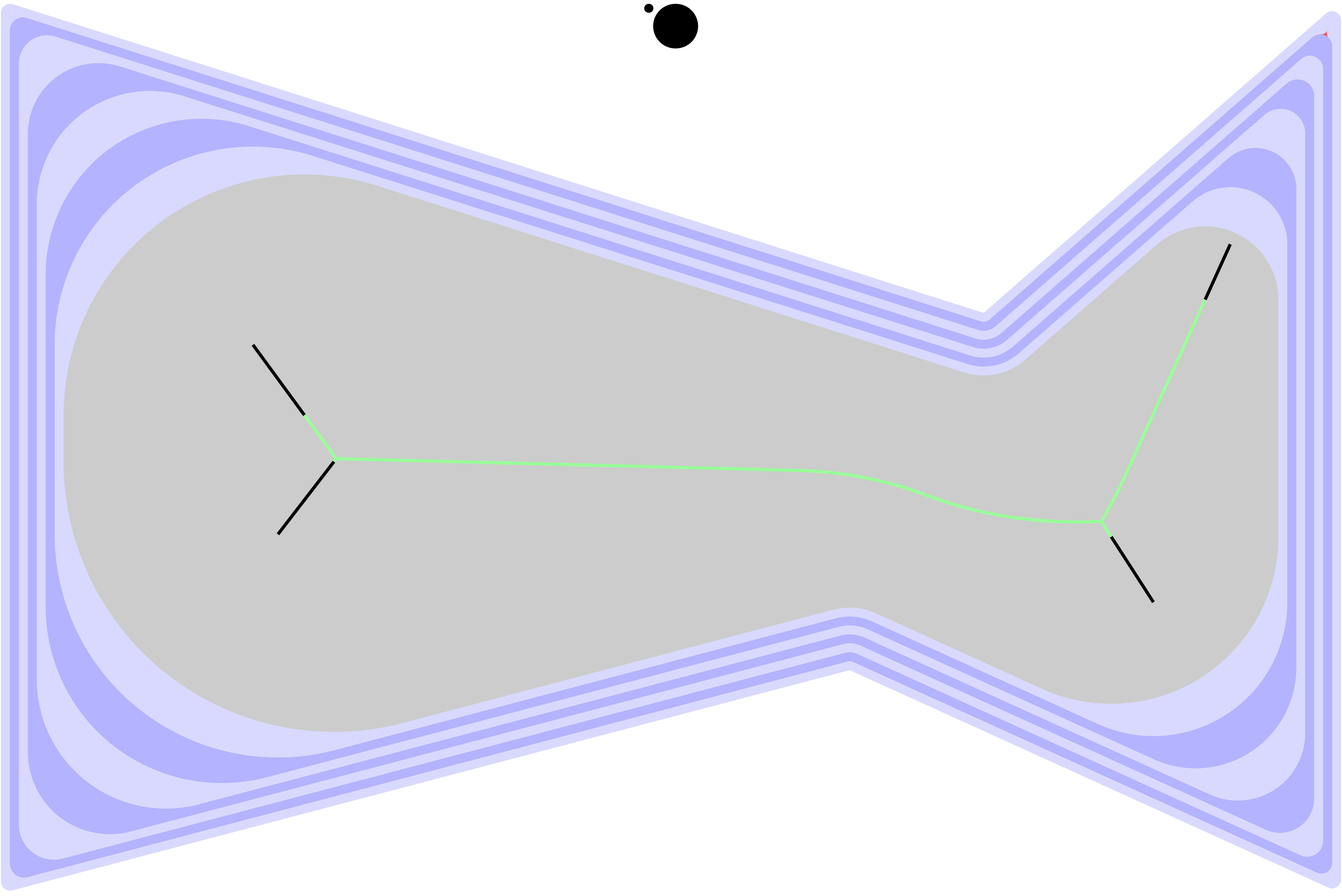


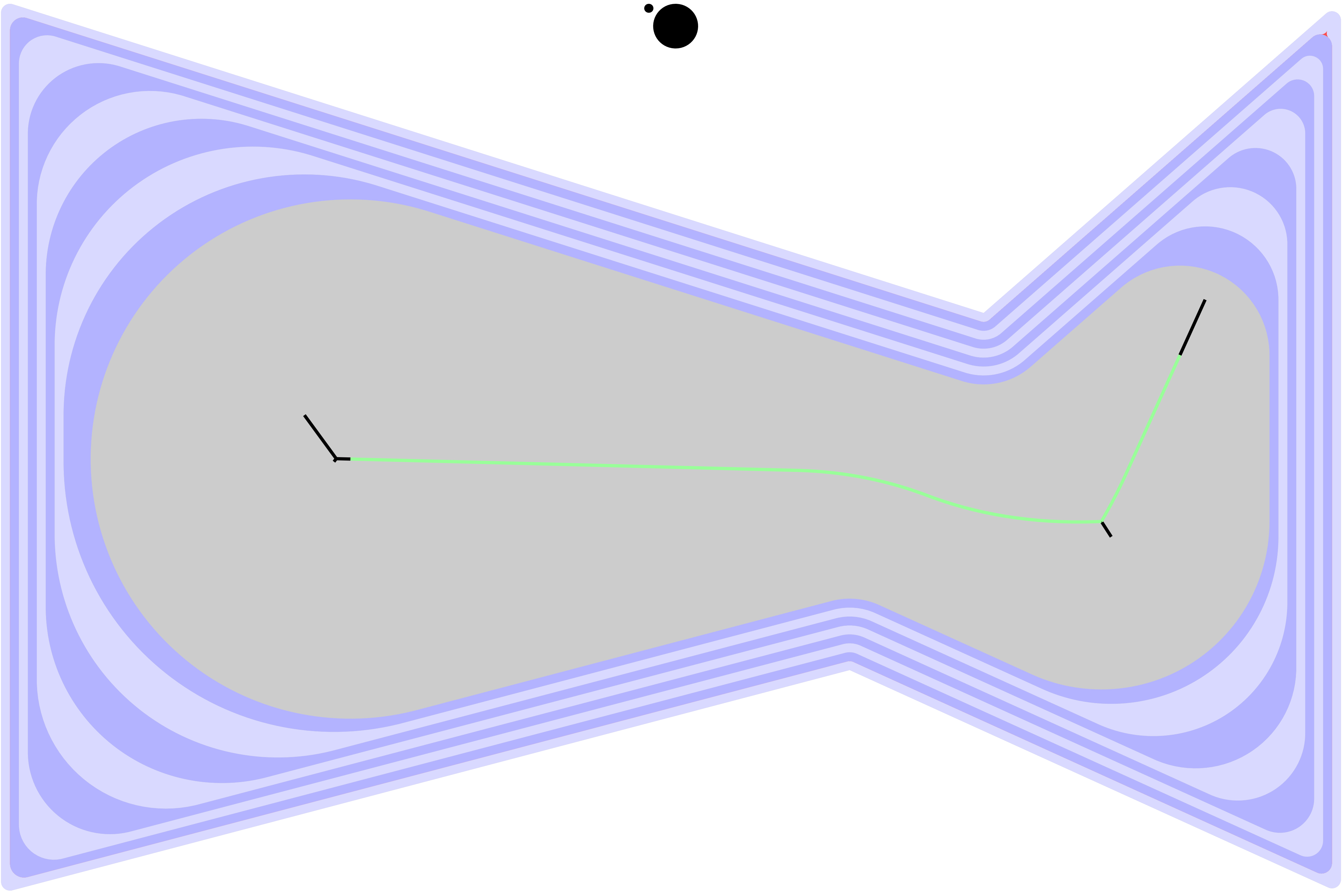


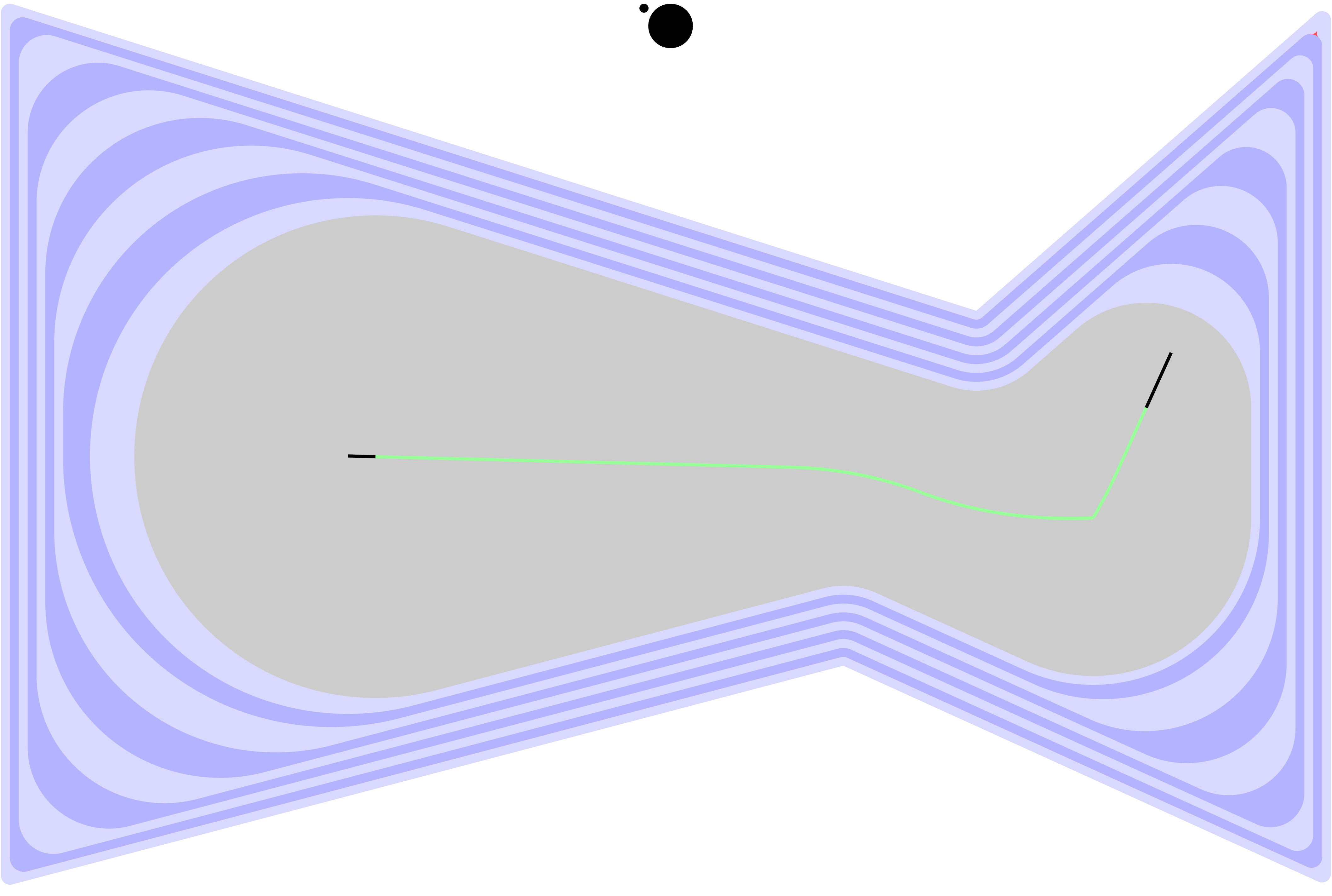


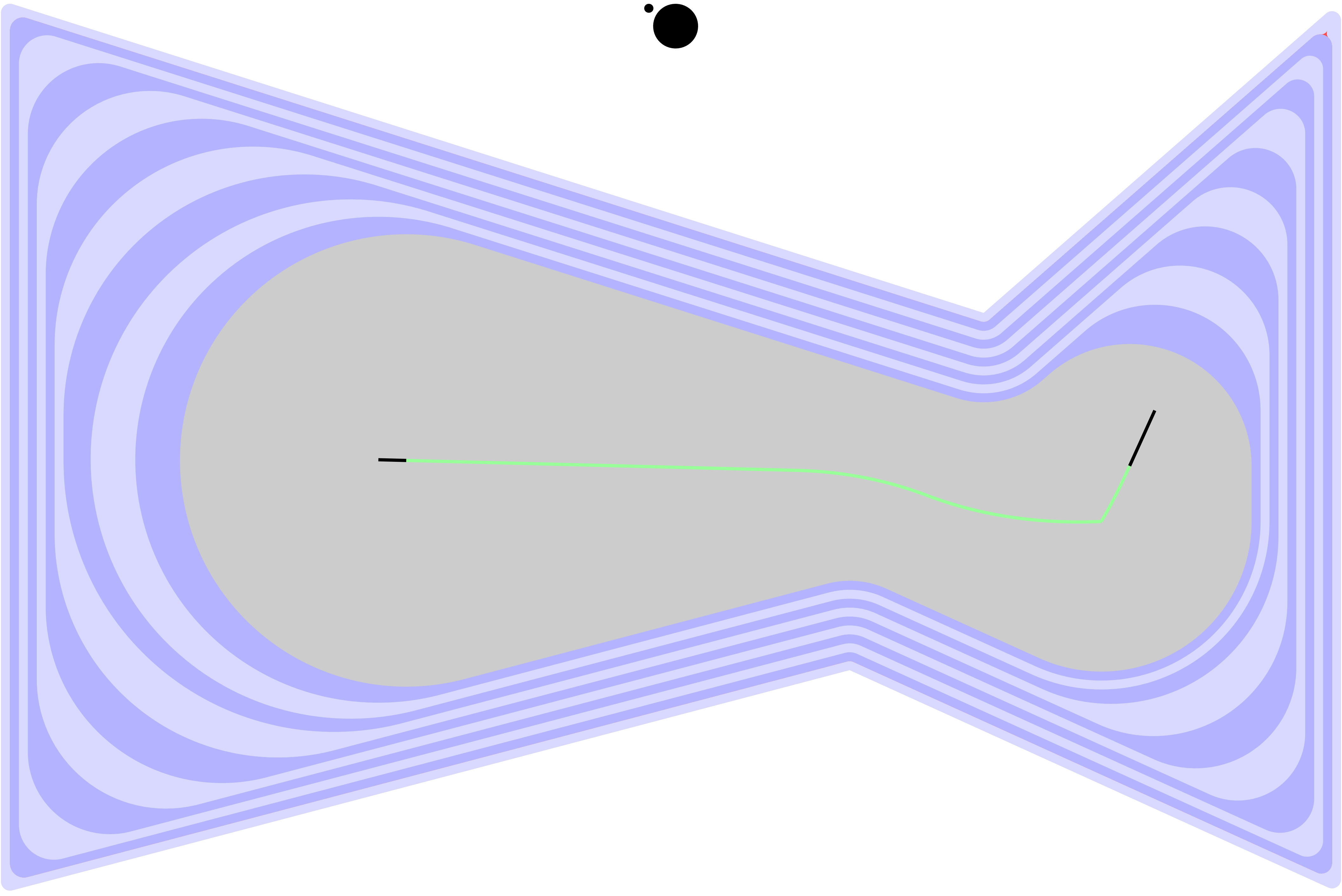


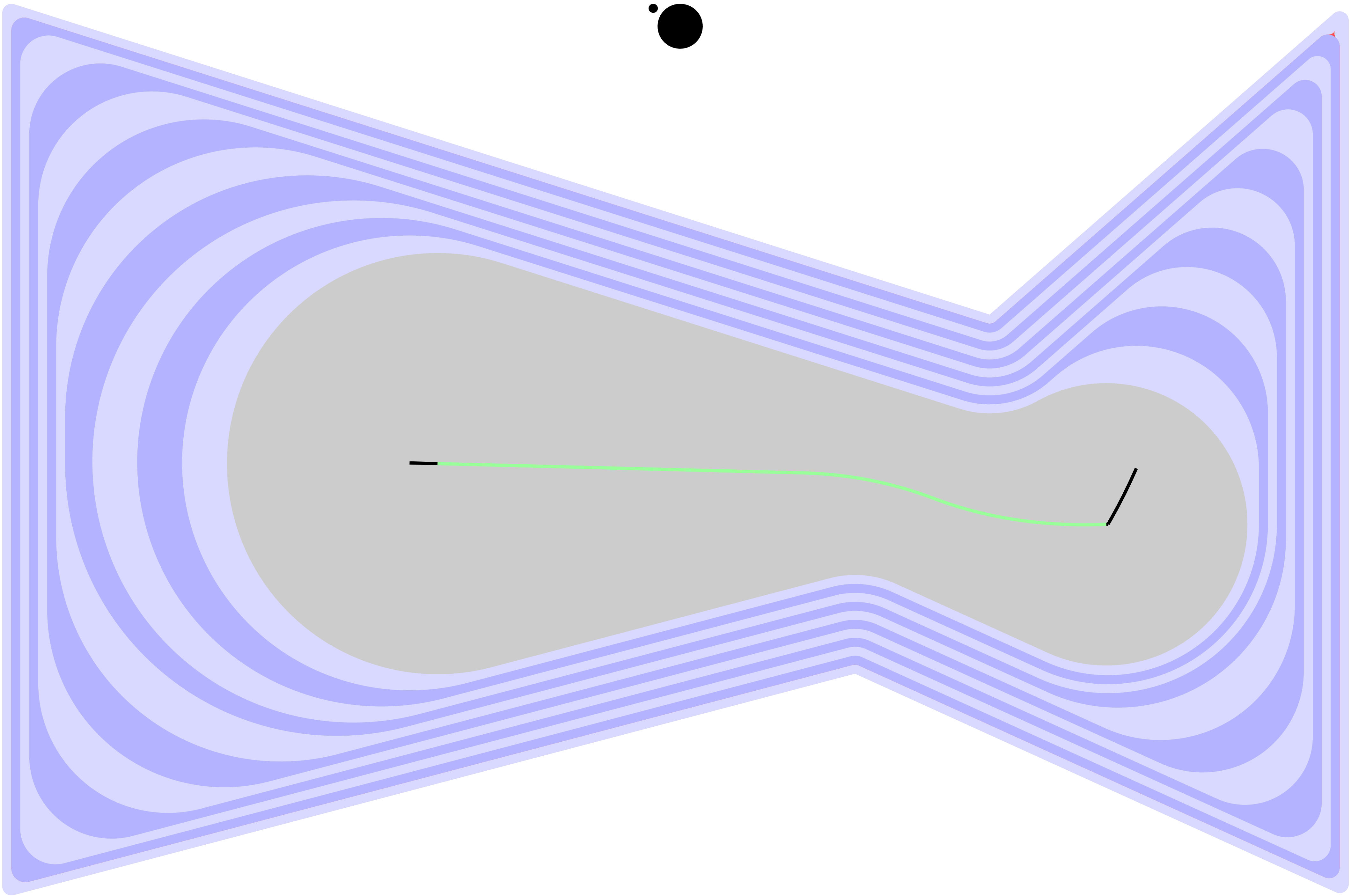


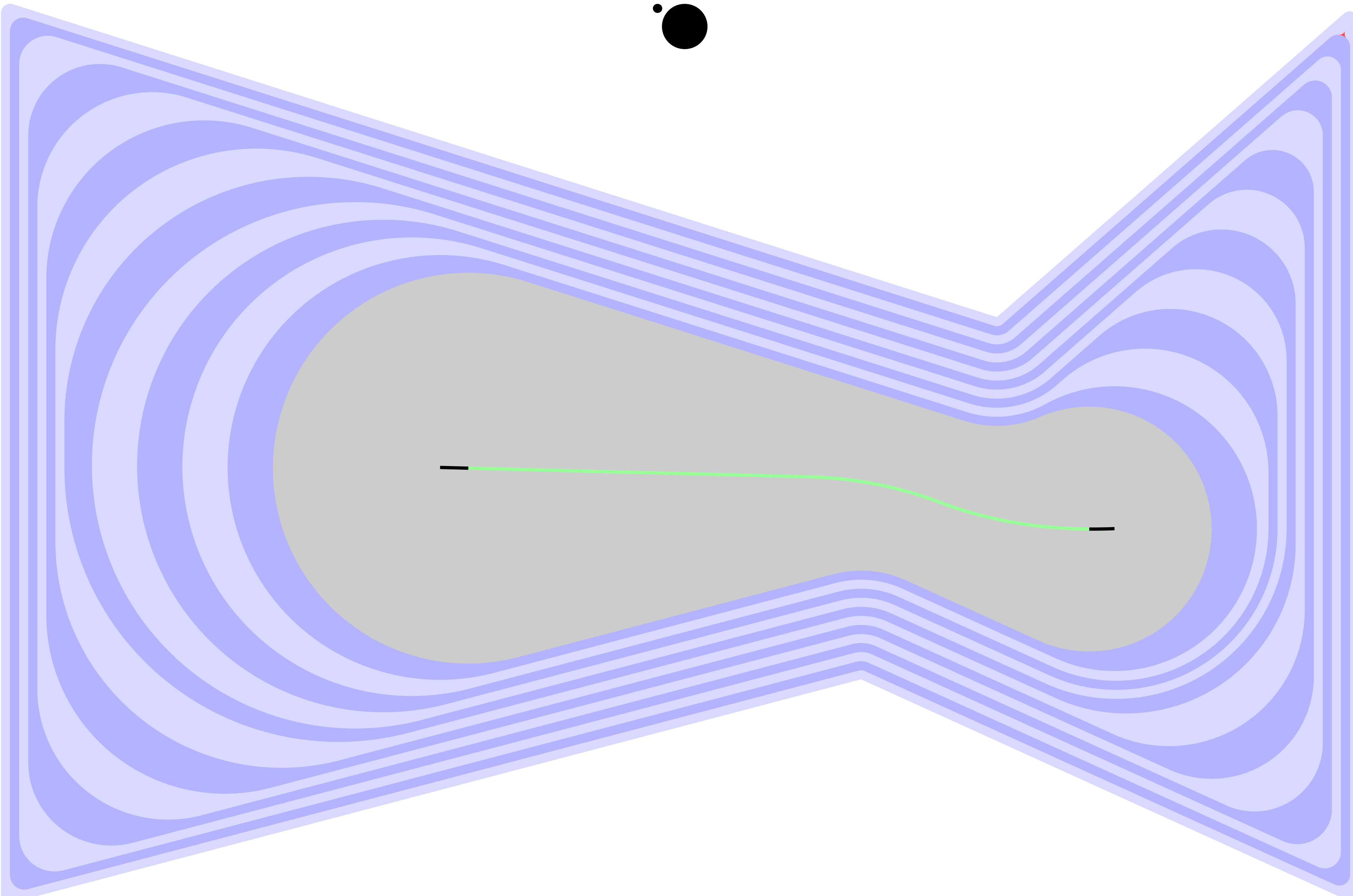


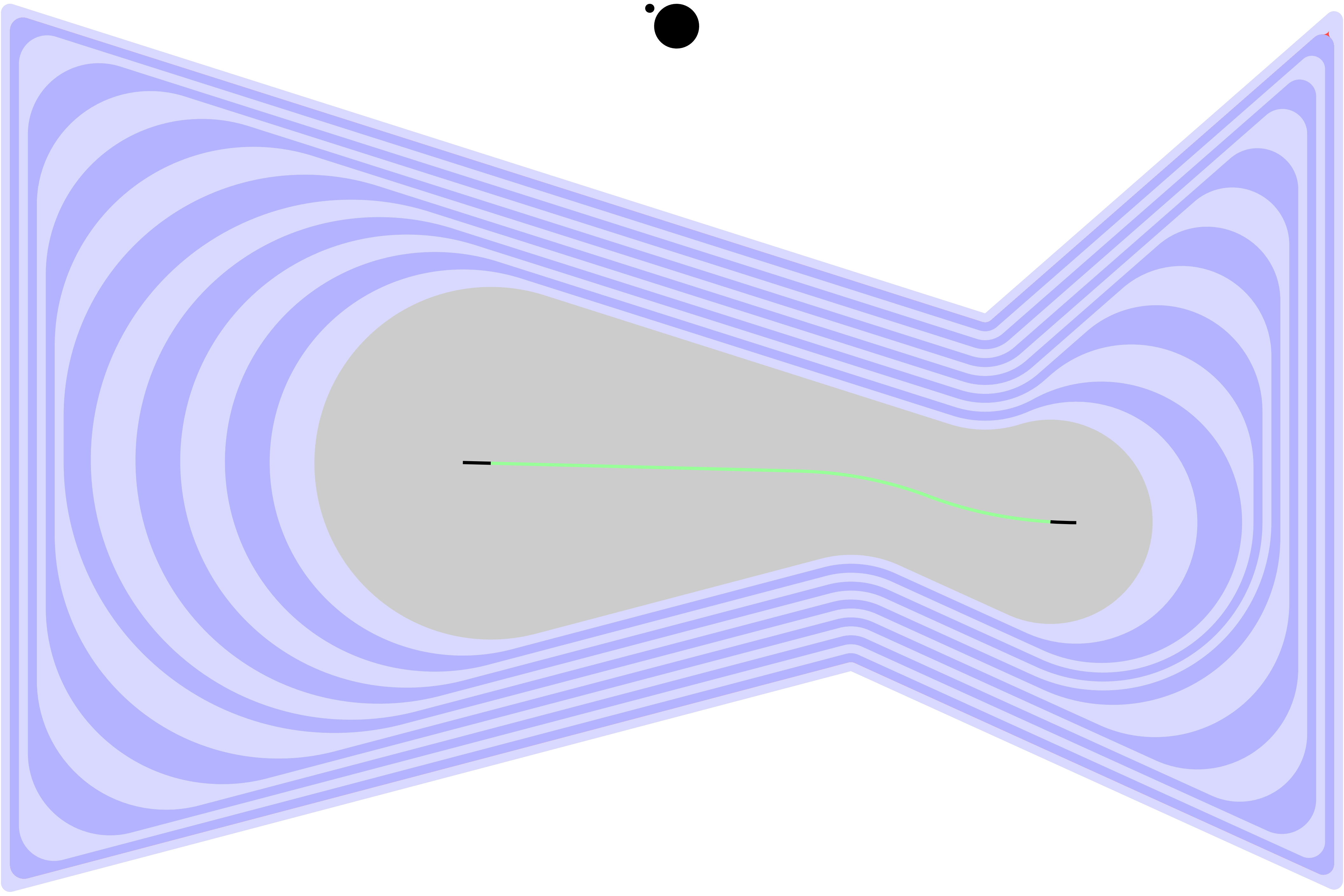


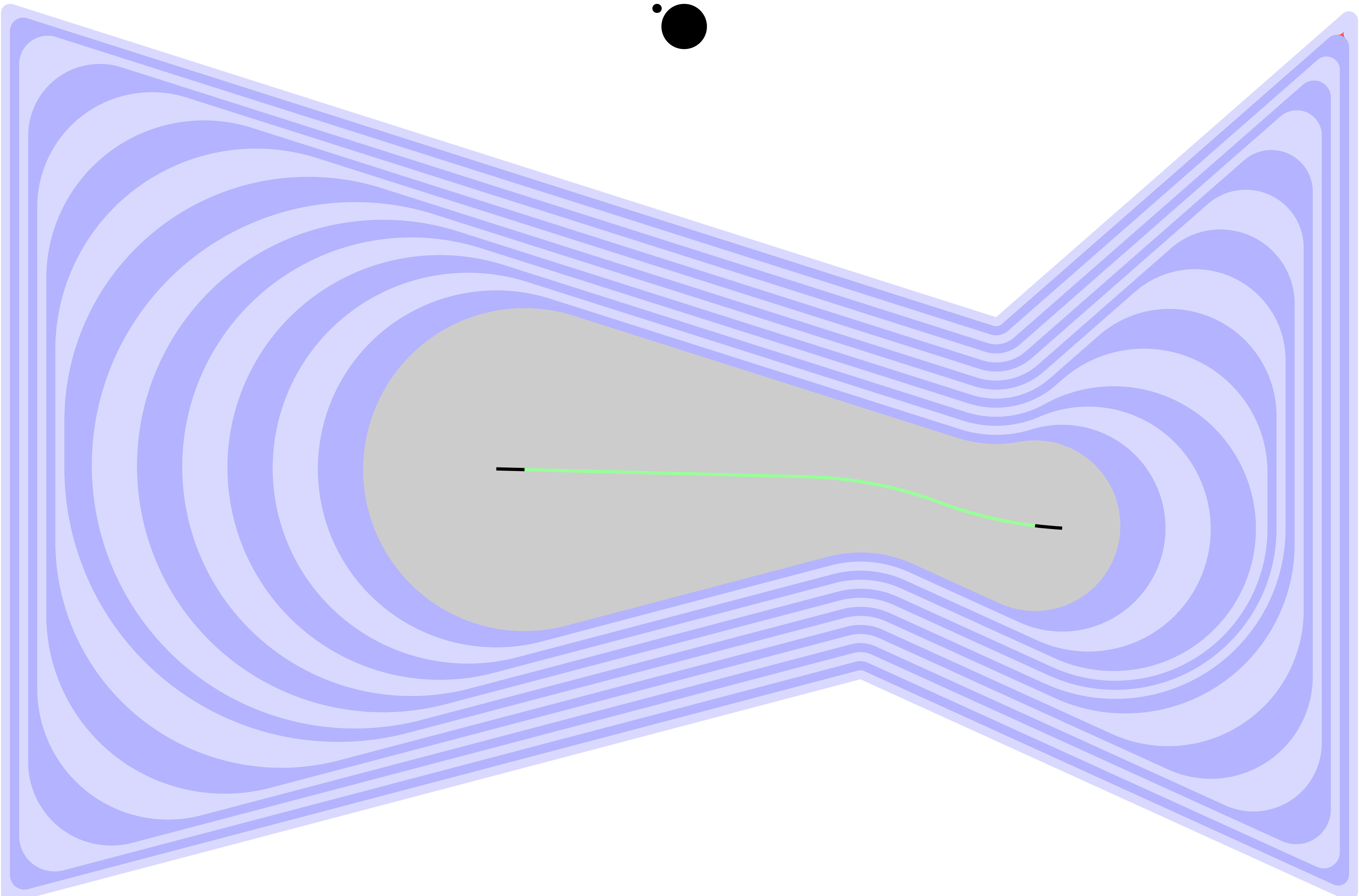


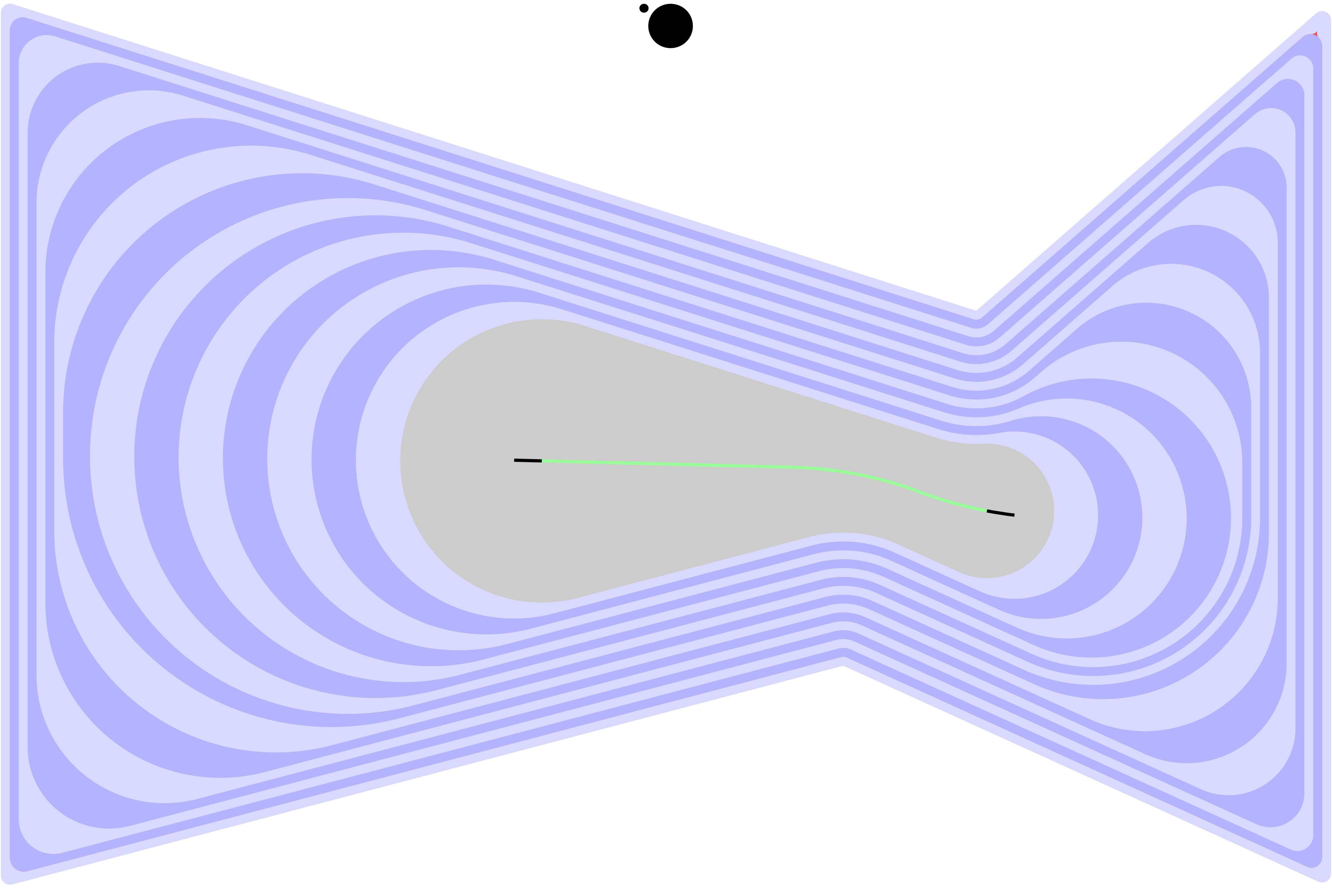


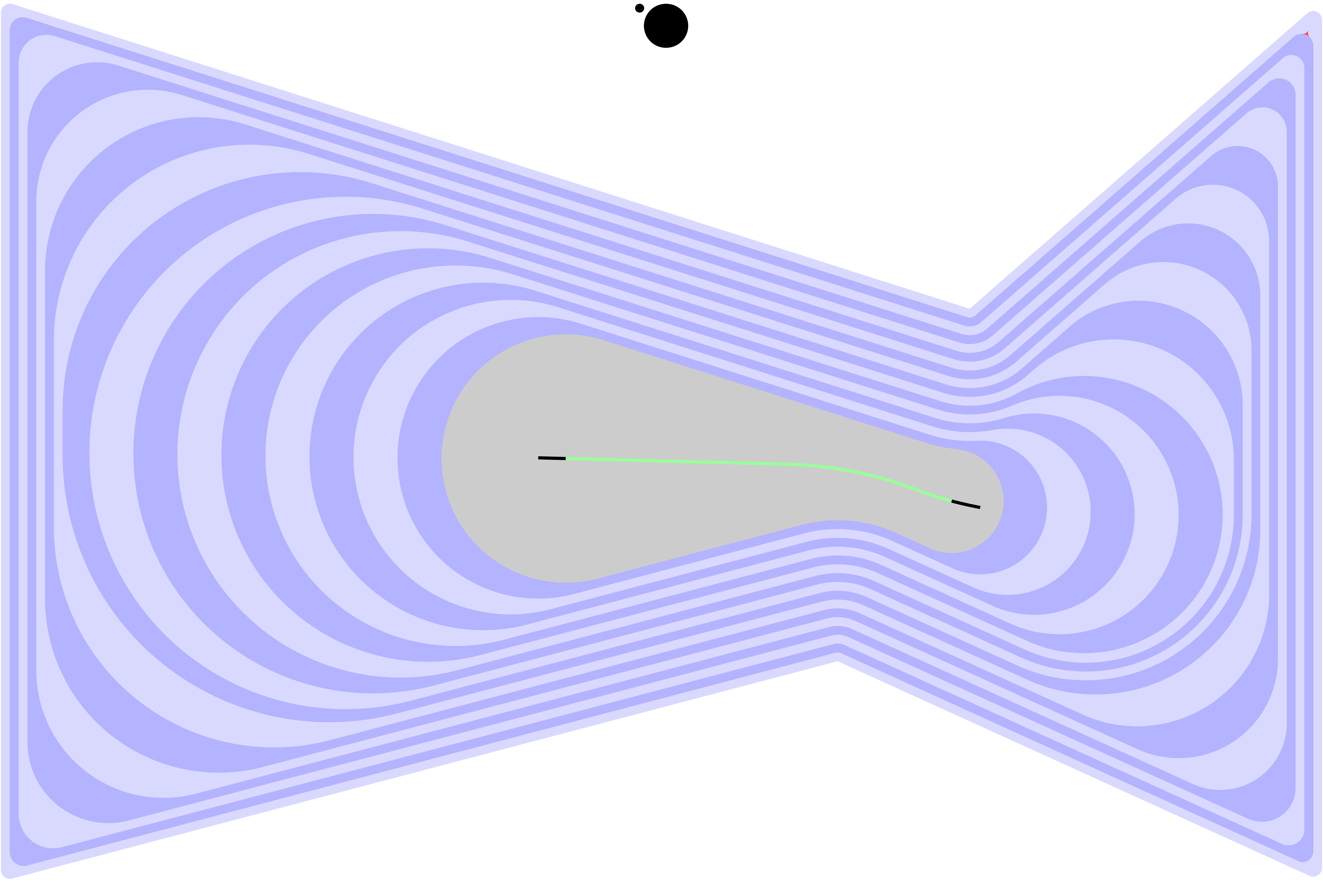


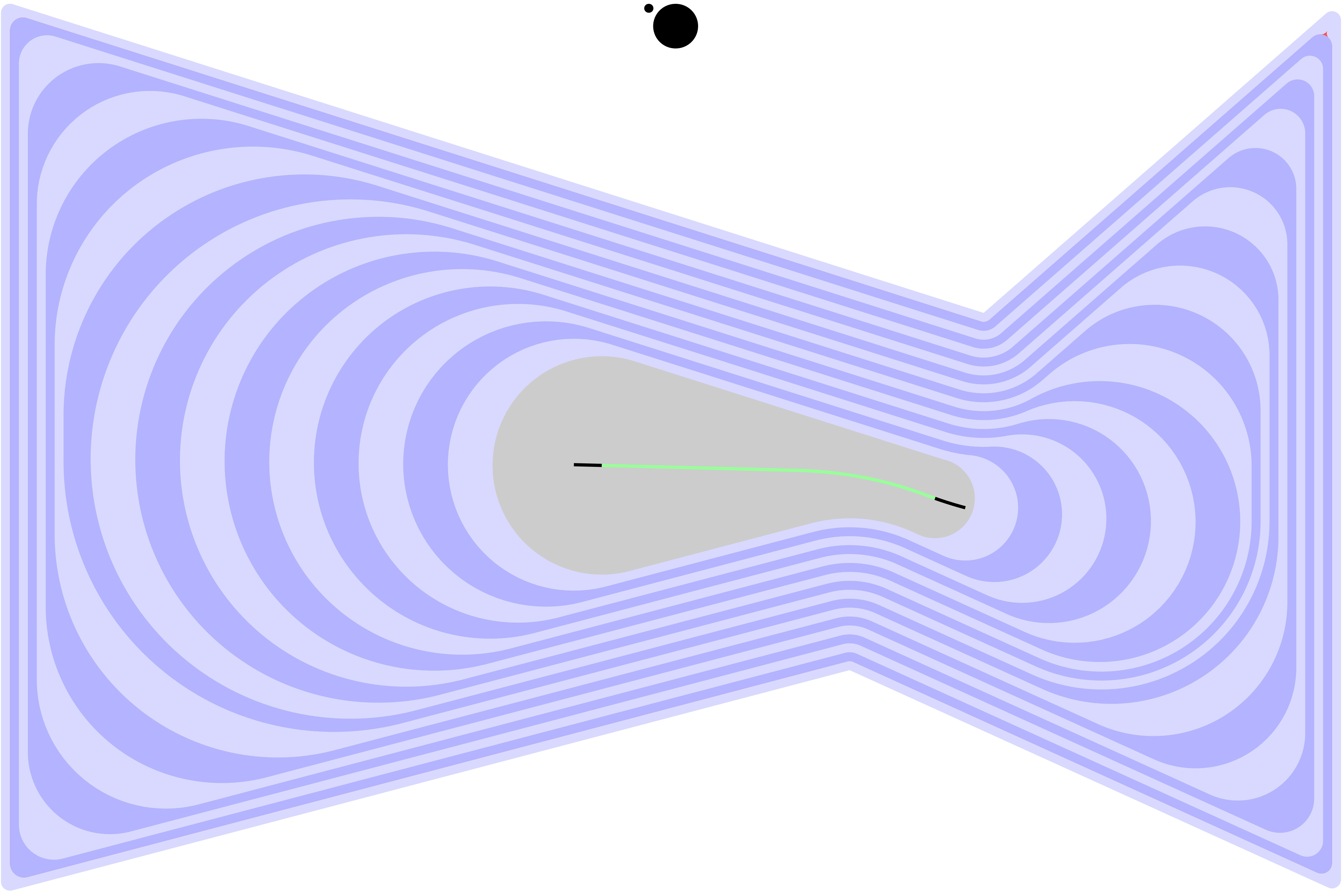


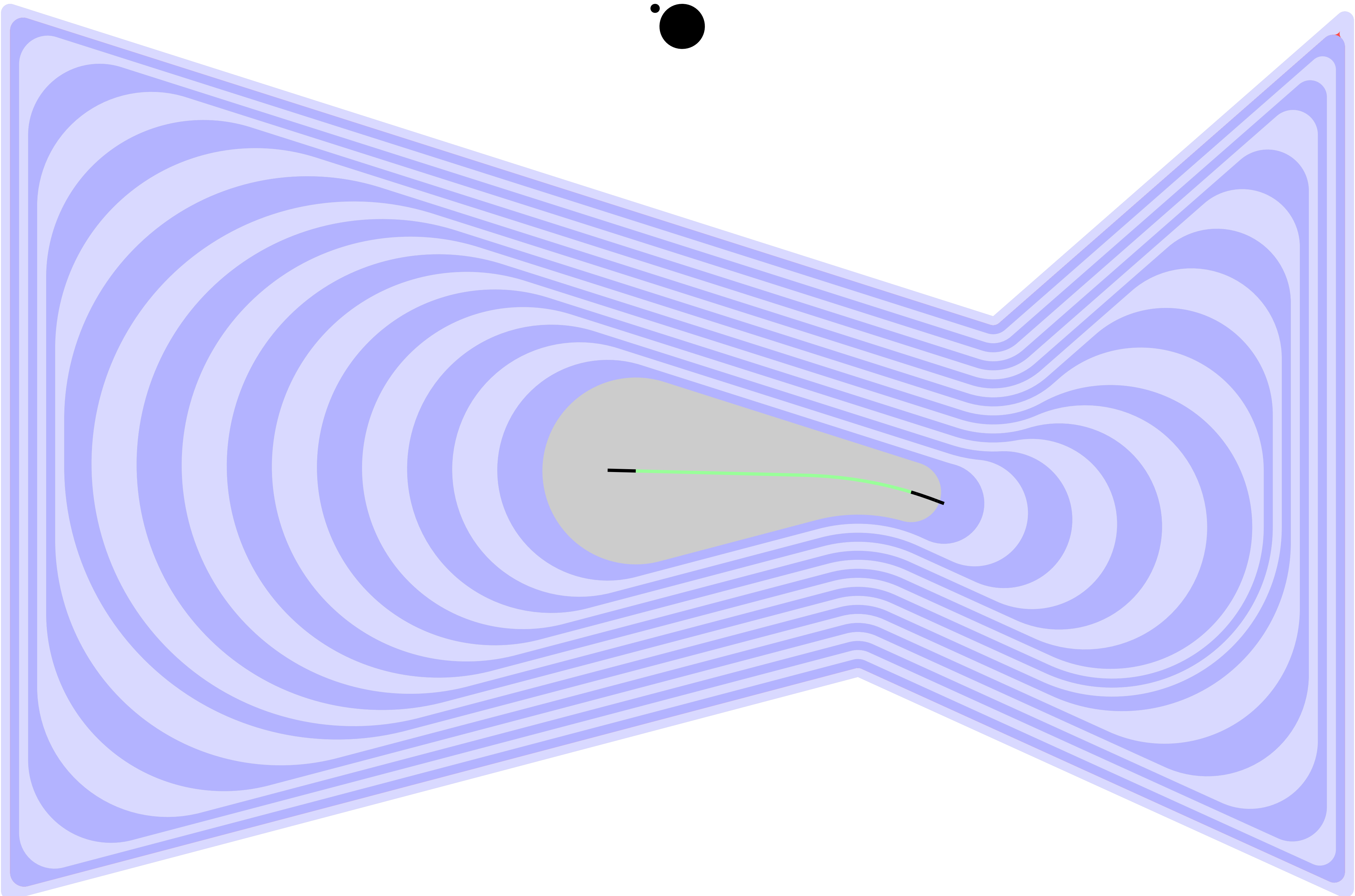


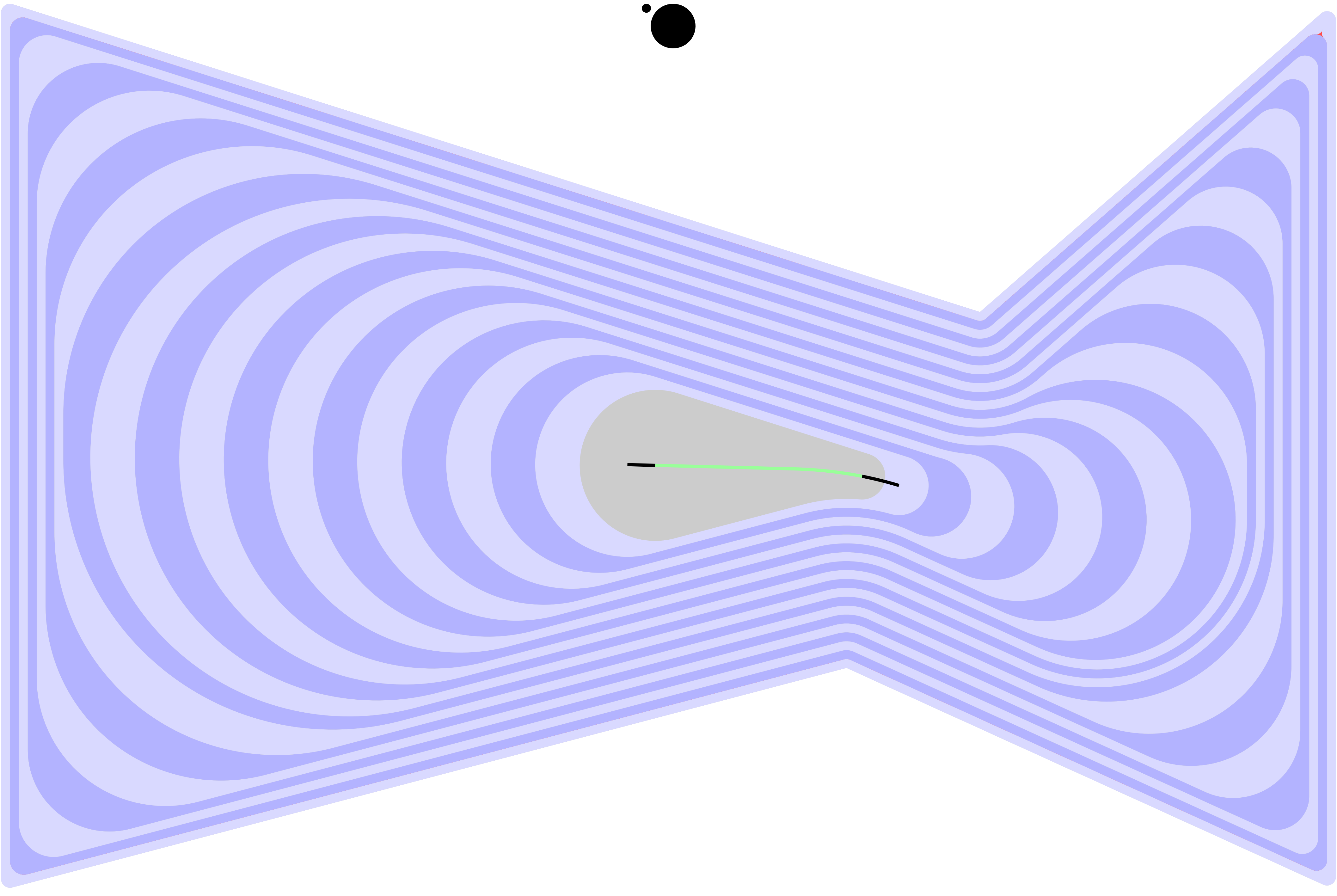


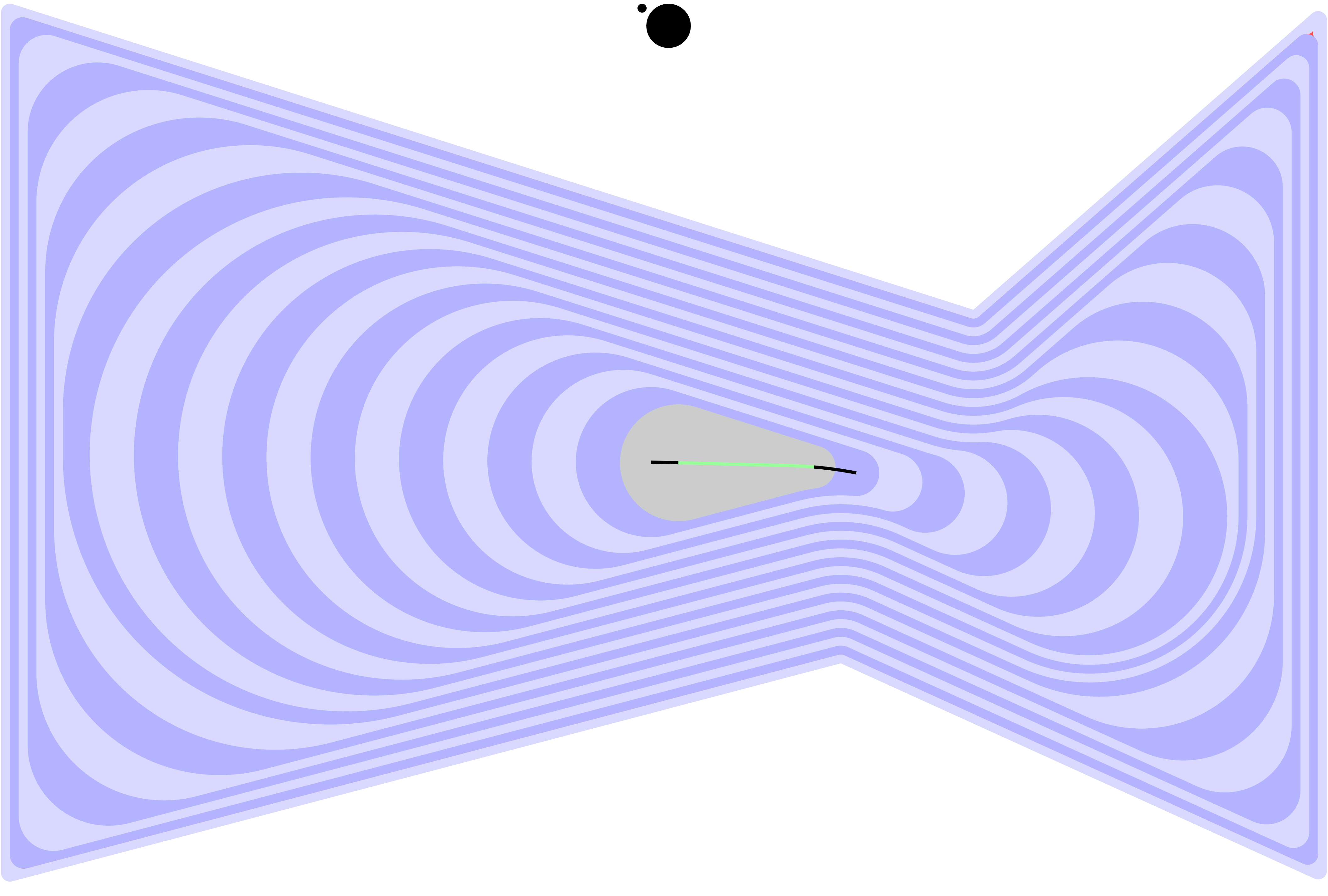


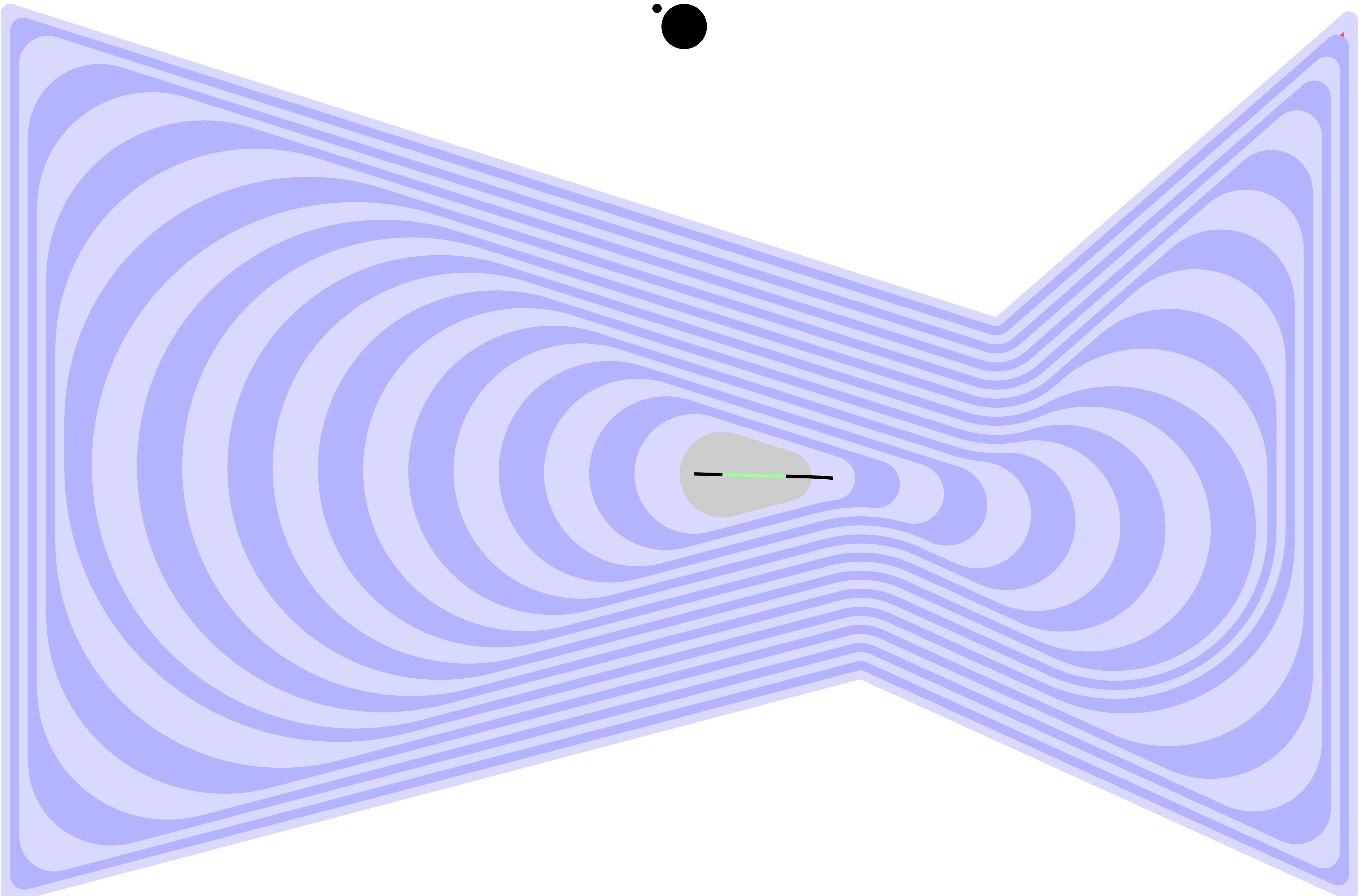


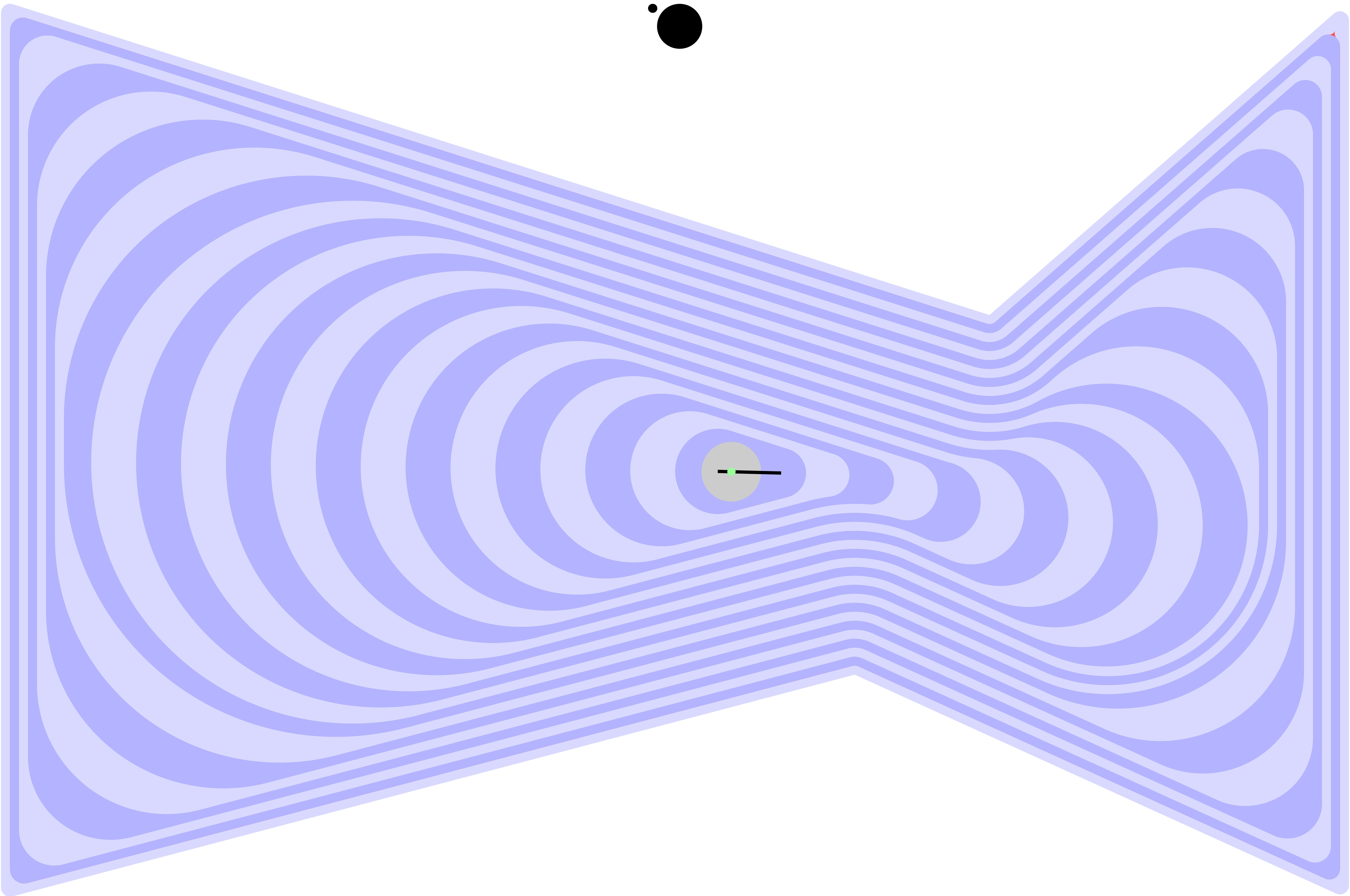


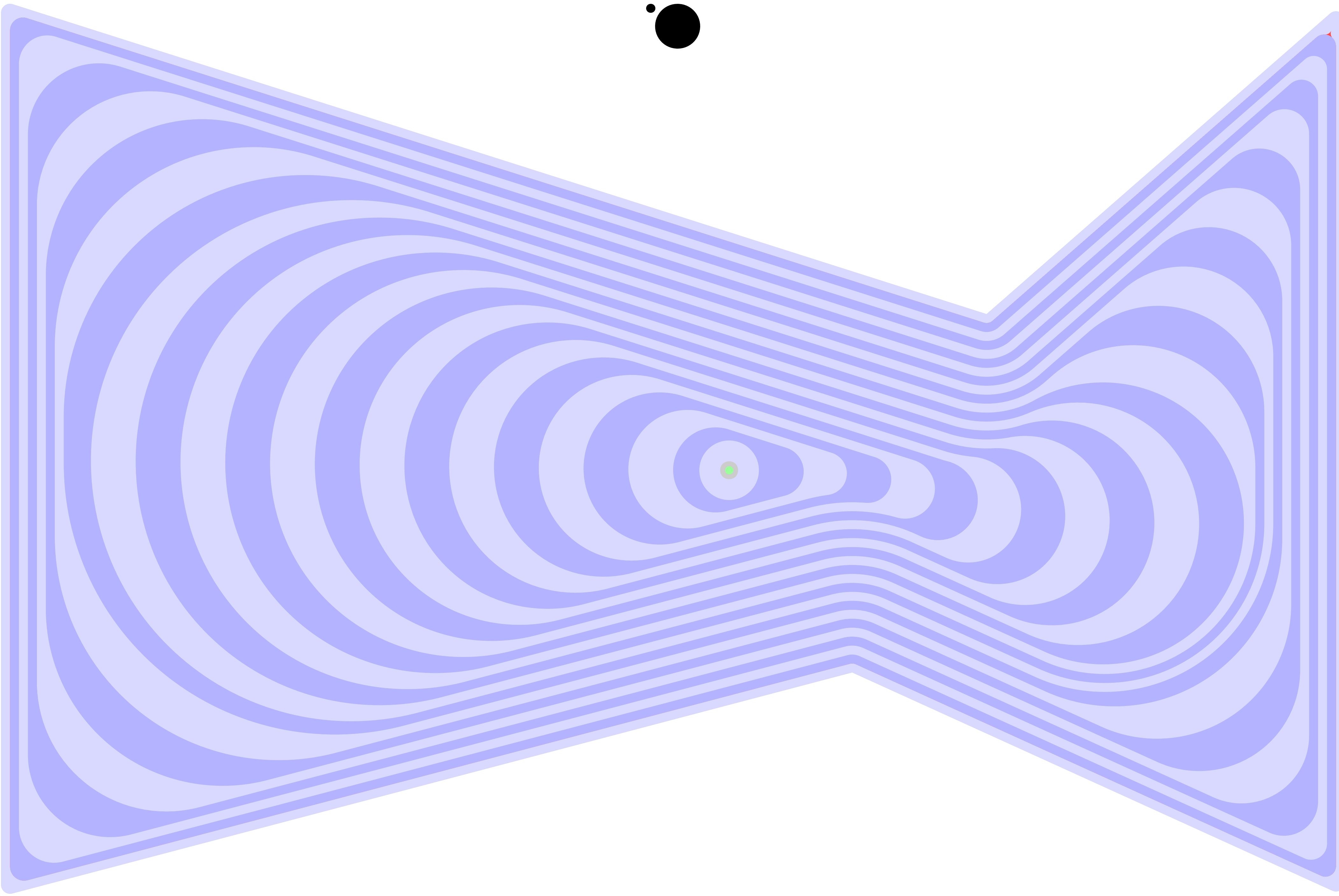


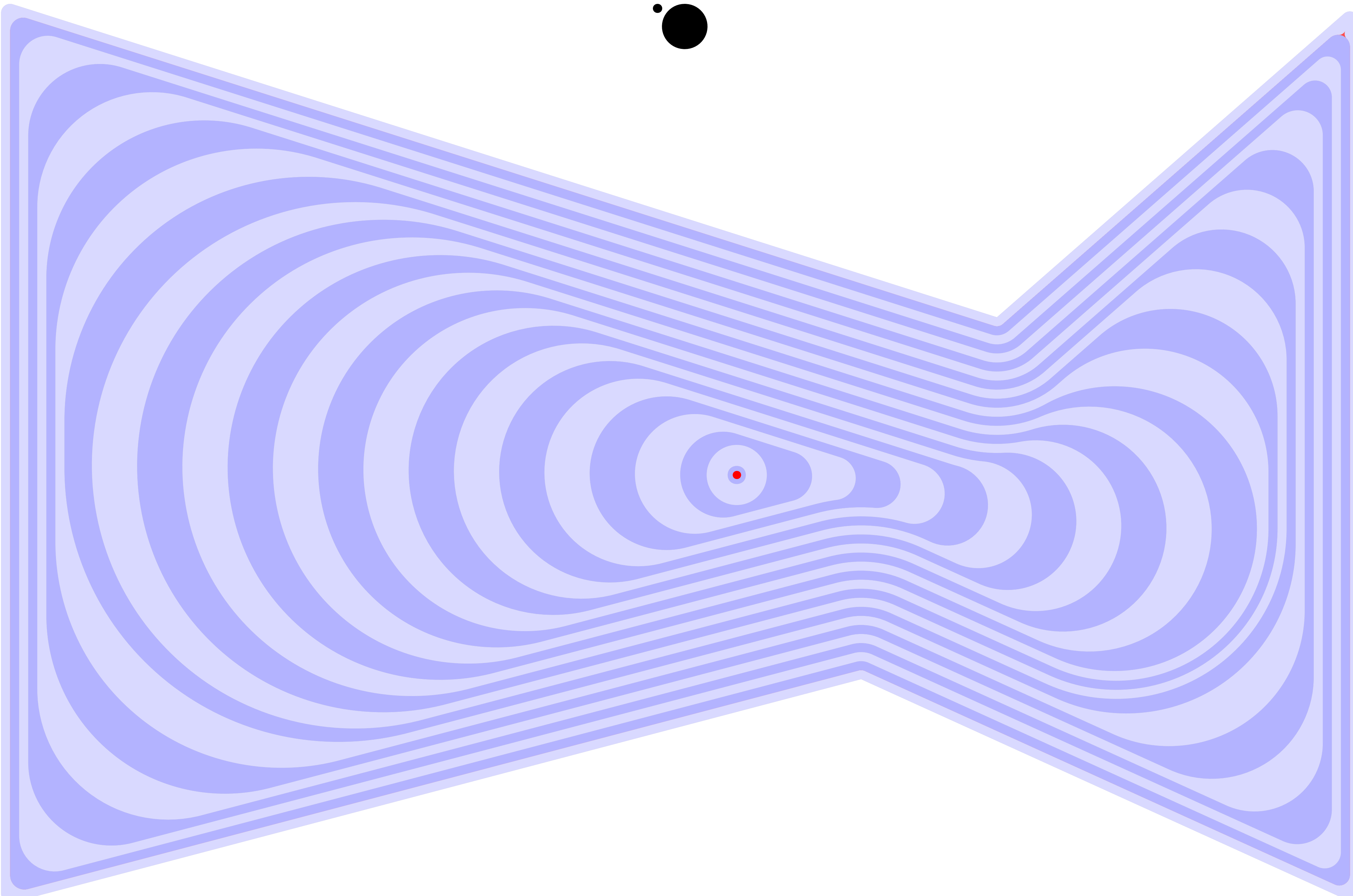


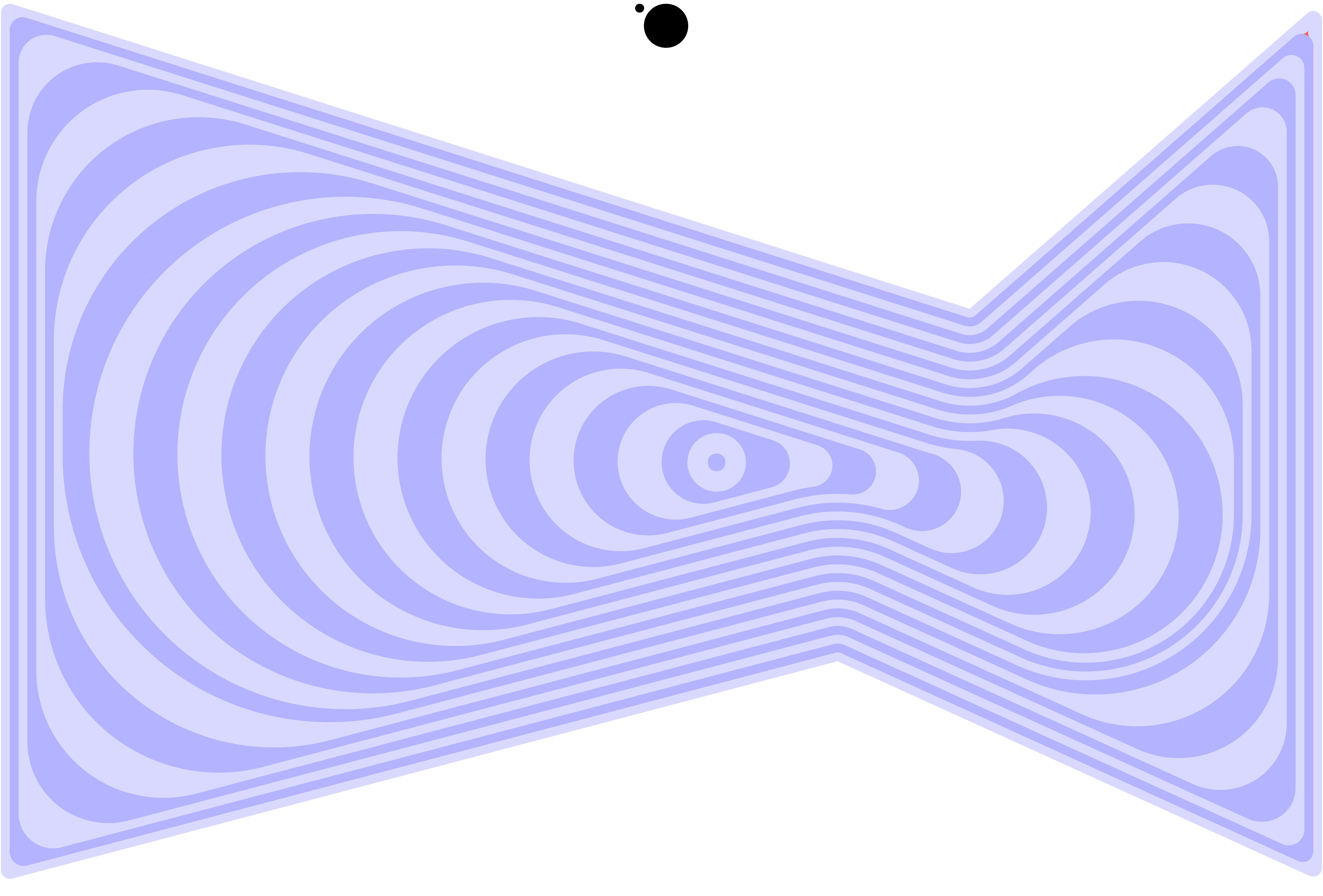






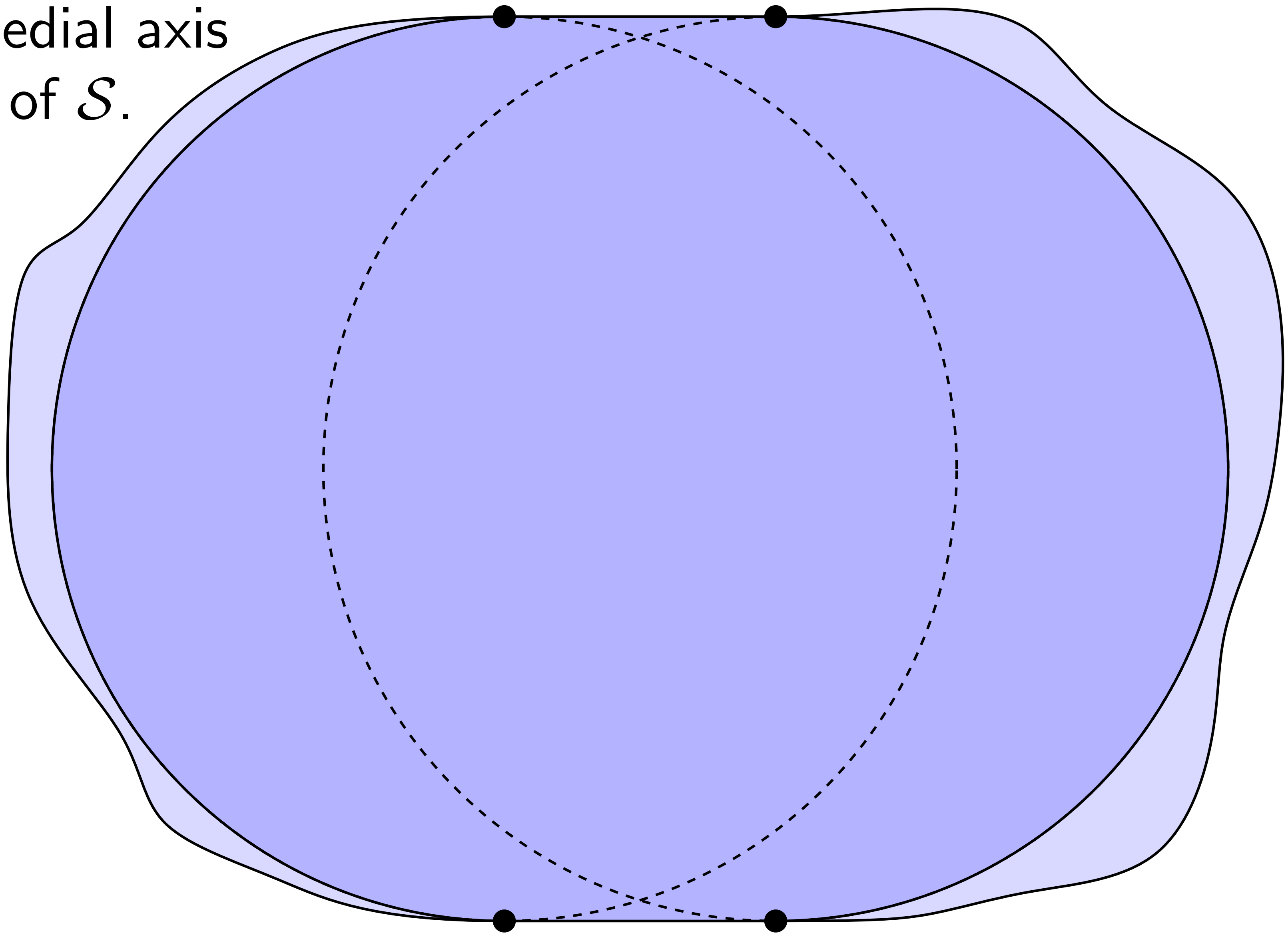






Variable-width contouring

The circles supporting the tangent circular arcs are chosen as the boundary of maximal disks in $\mathcal{S}$. Hence, their center lies on the medial axis $\mathbf{MA}(\mathcal{S})$ of $\mathcal{S}$.



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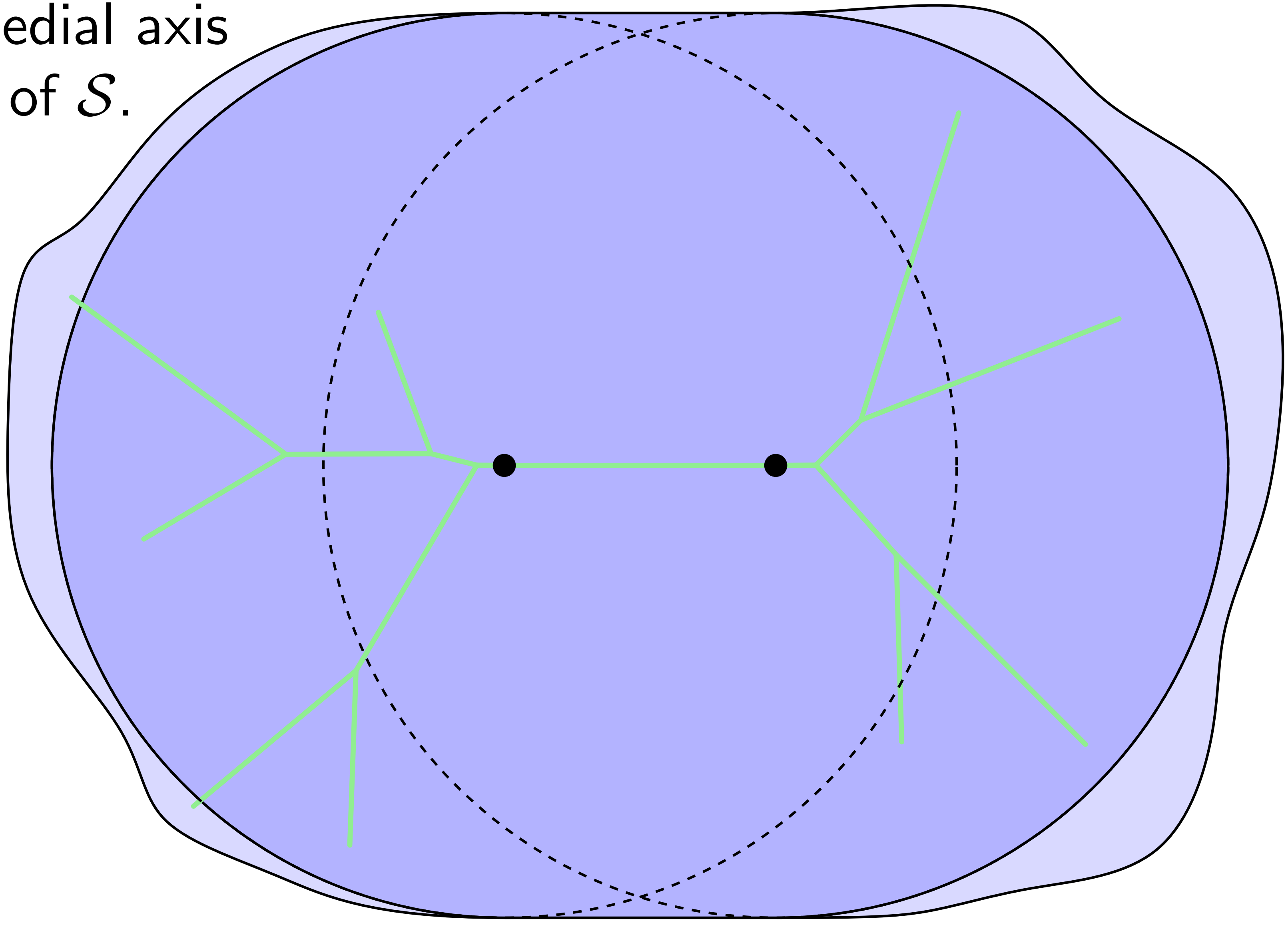
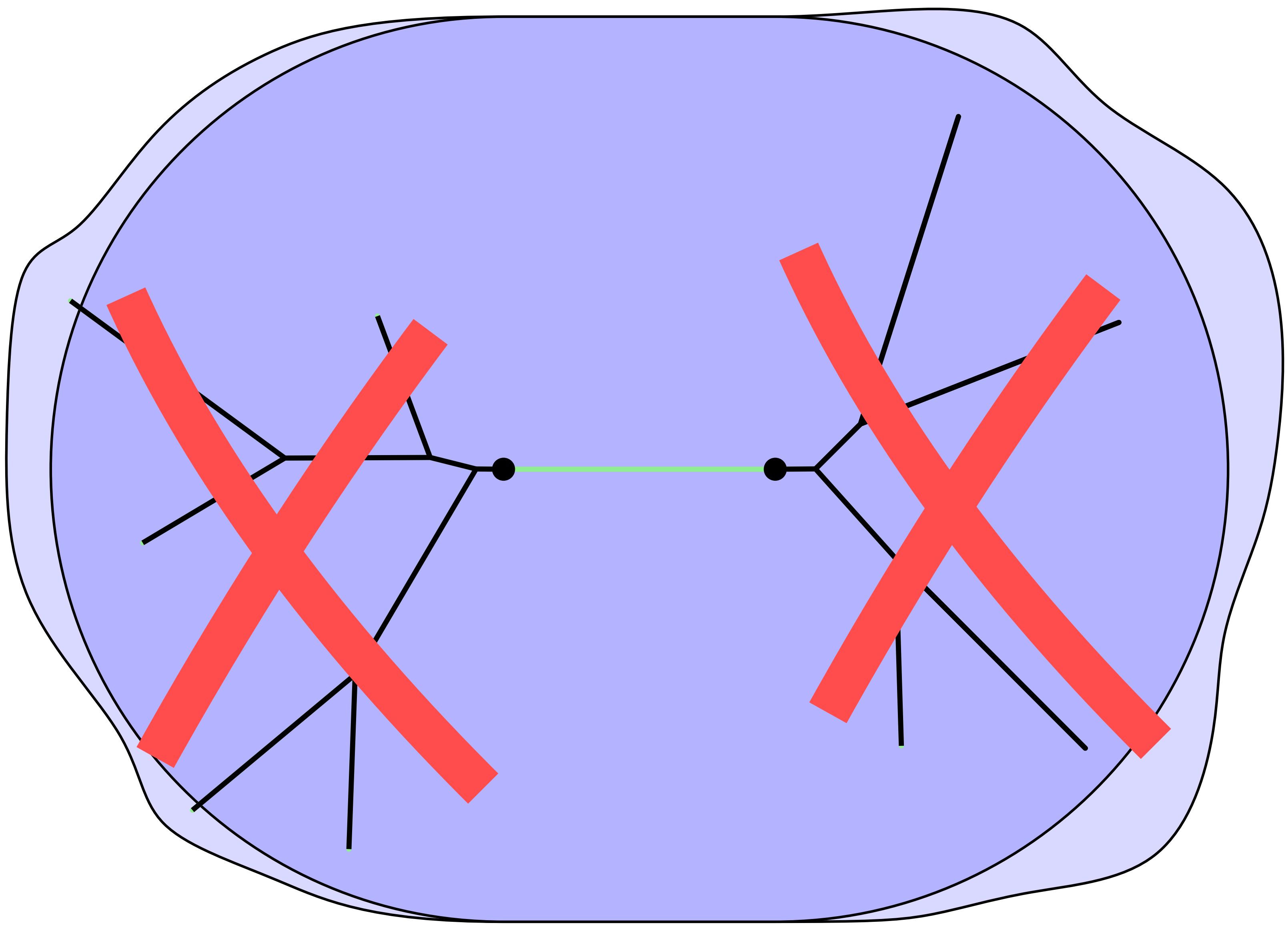


Variable-width contouring

Replacing by circular arc = **trimming** the medial axis!



Variable-width contouring: basics

1. Trimming the medial axis: removes crescents of width $\leq 2\Gamma - 2\gamma$ from the shape.

2. Parallel offset : removes a band of width exactly 2γ, which together with the crescents, form a bead of width varying within $[2\gamma, 2\Gamma]$.

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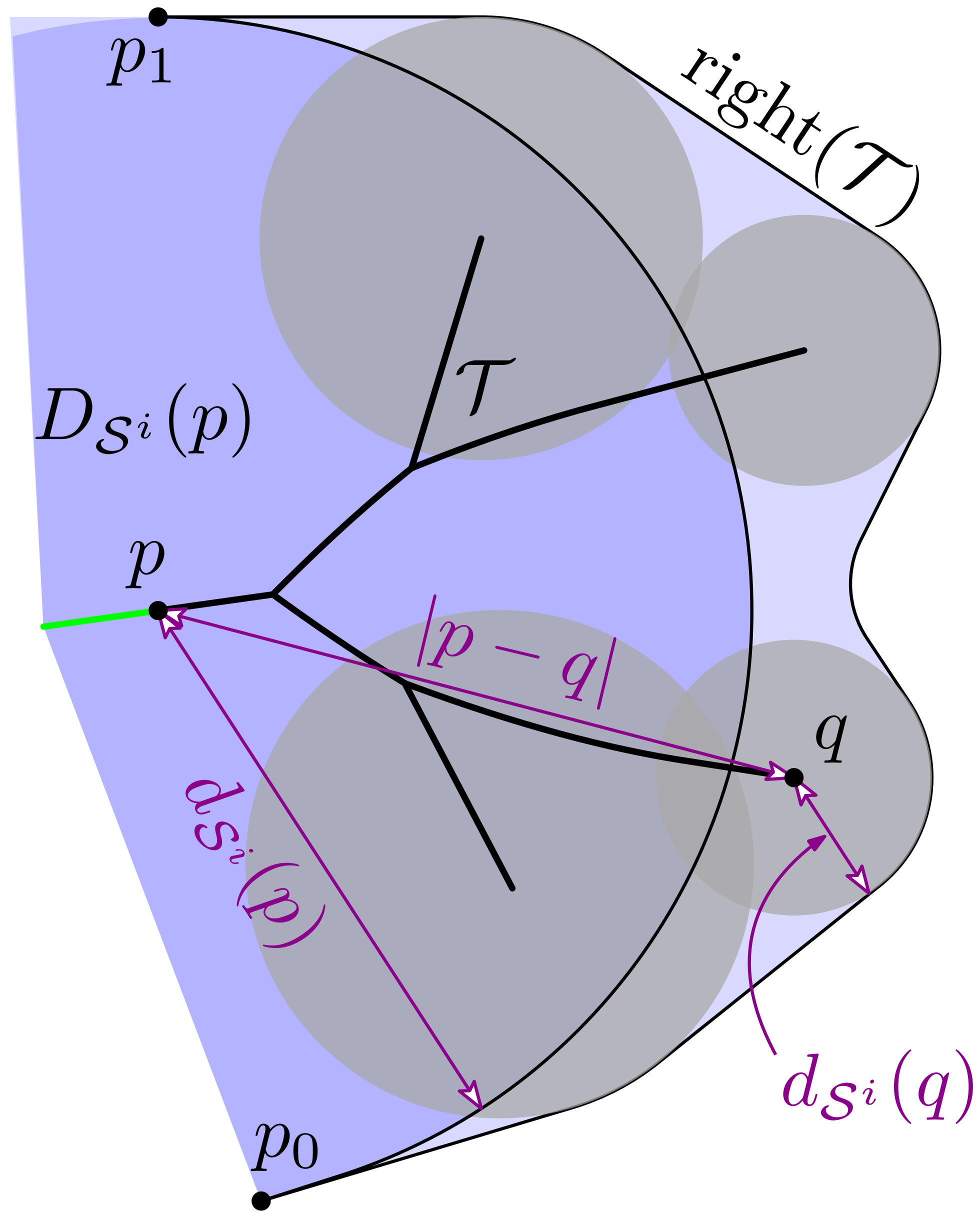
If the input is a "polygon," the medial axis is computable (CGAL, BOOST) and the two operations above produce shapes with **linear** or **circular** boundary arcs only.

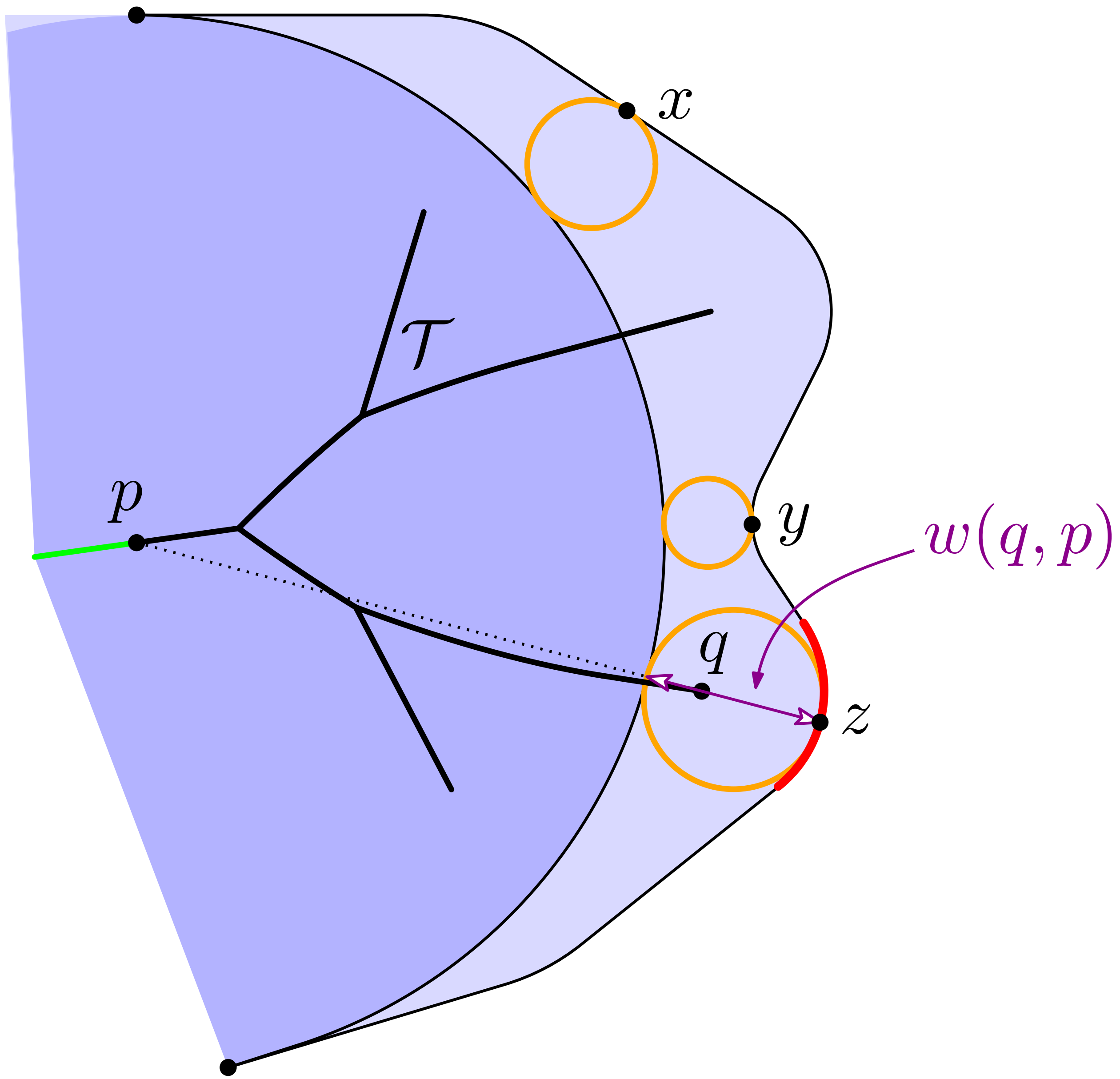
Corollary: in that case, each bead is bounded by linear or circular arcs only.

Trimming

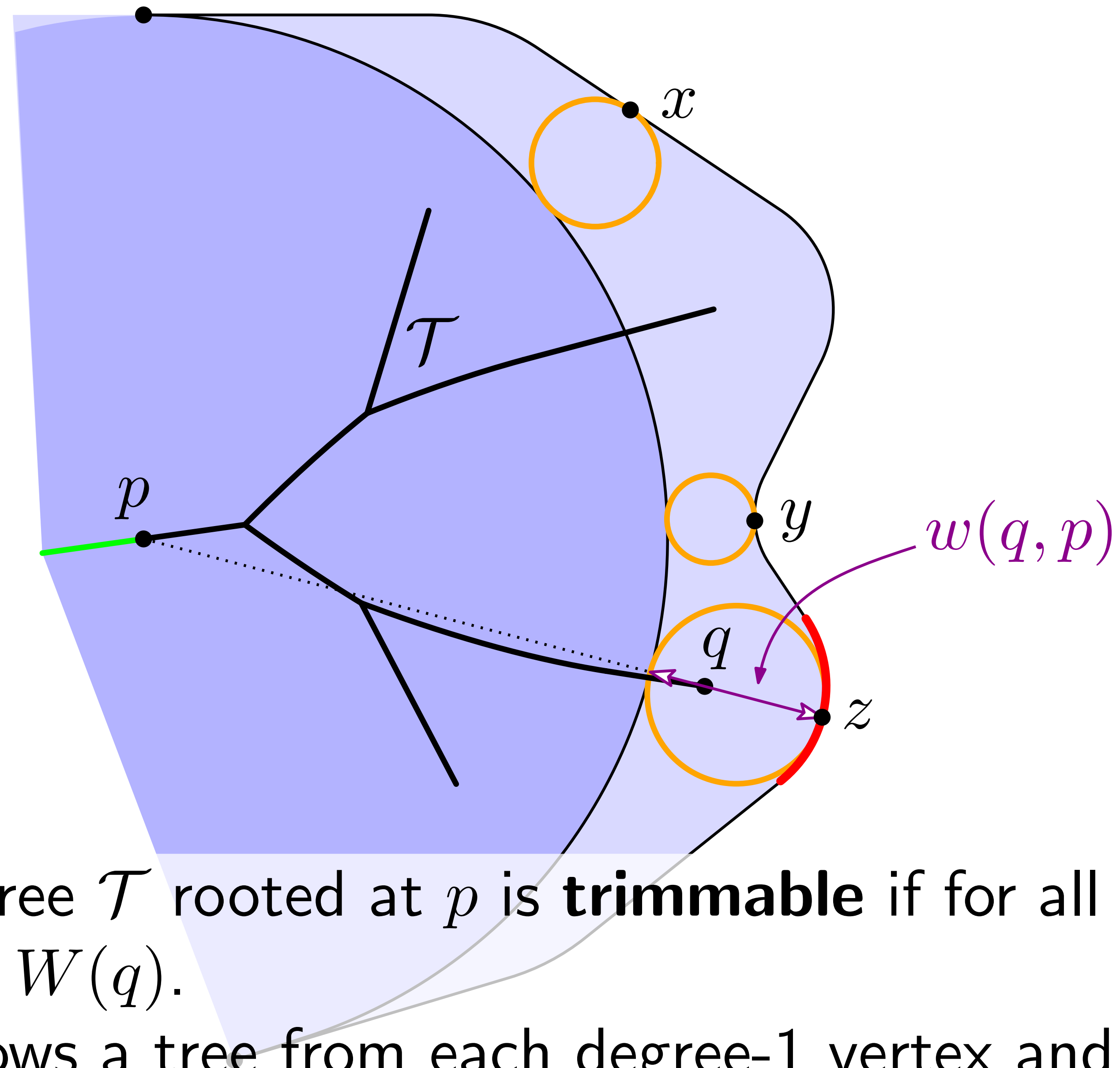


p_1
right($\mathcal{T}$)
$\mathcal{T}$
$D_{\mathcal{S}^i}(p)$
p
$|p - q|$
q
$d_{\mathcal{S}^i}(p)$
$d_{\mathcal{S}^i}(q)$
p_0

Trimming

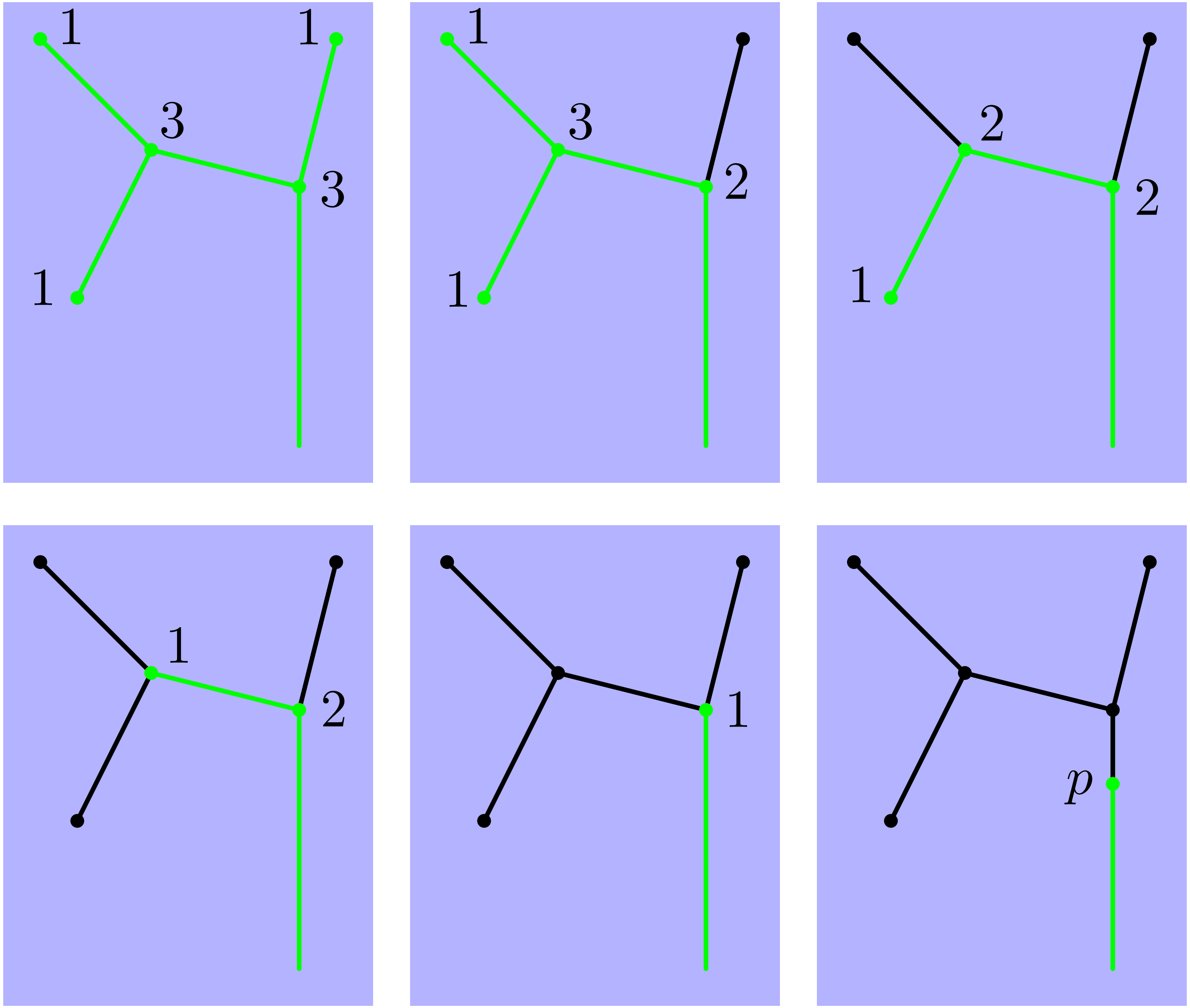


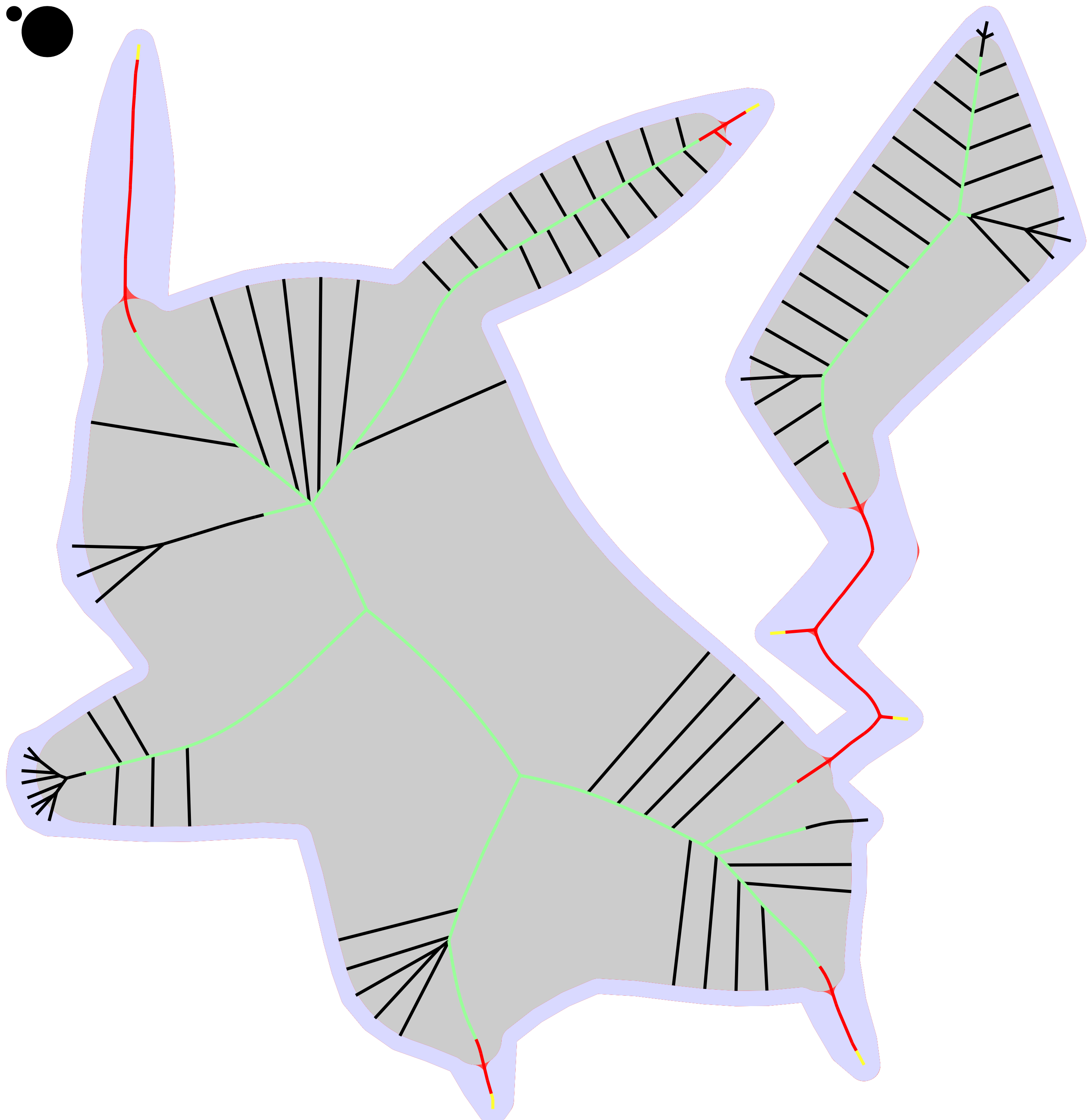
Trimming

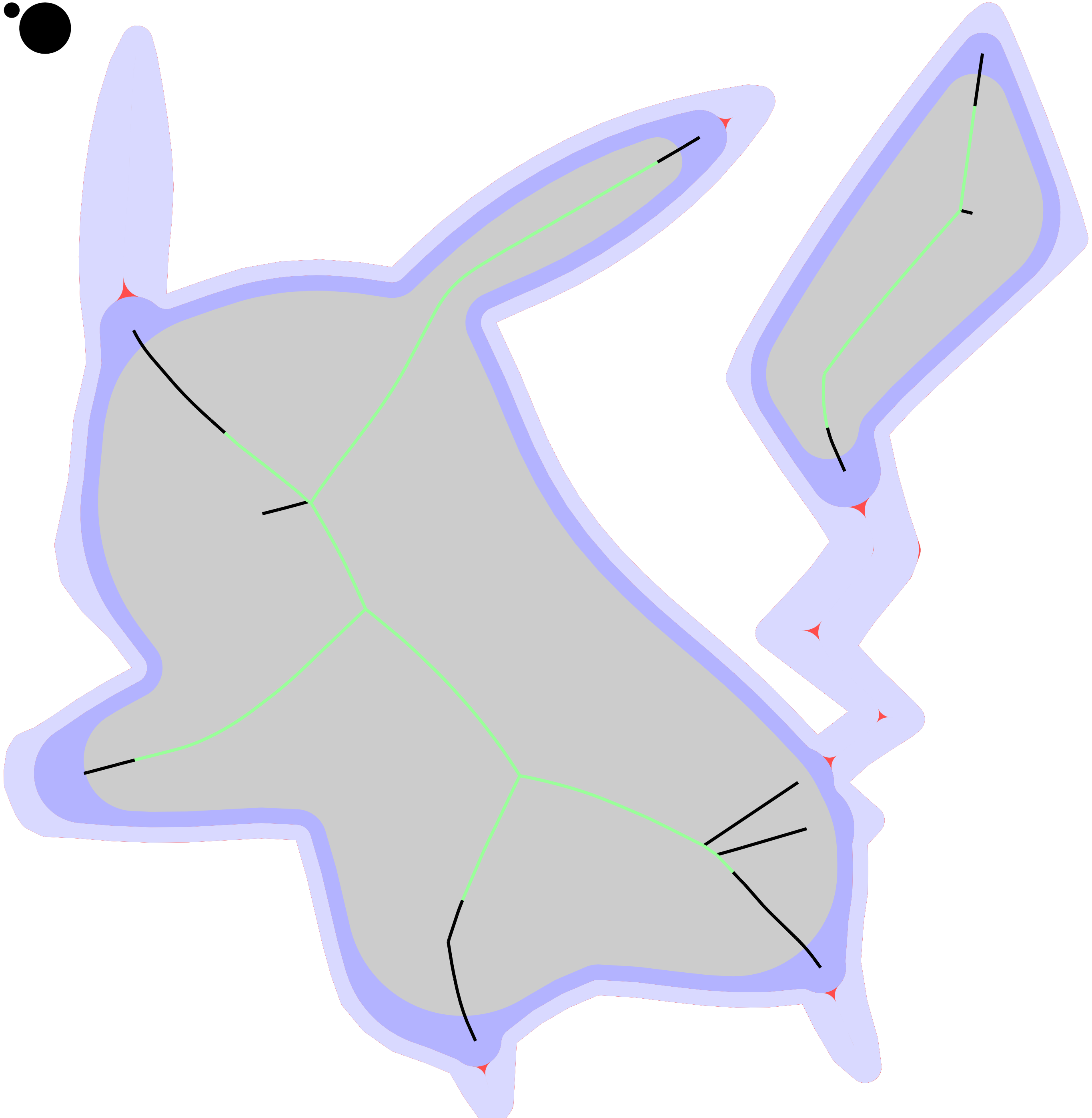


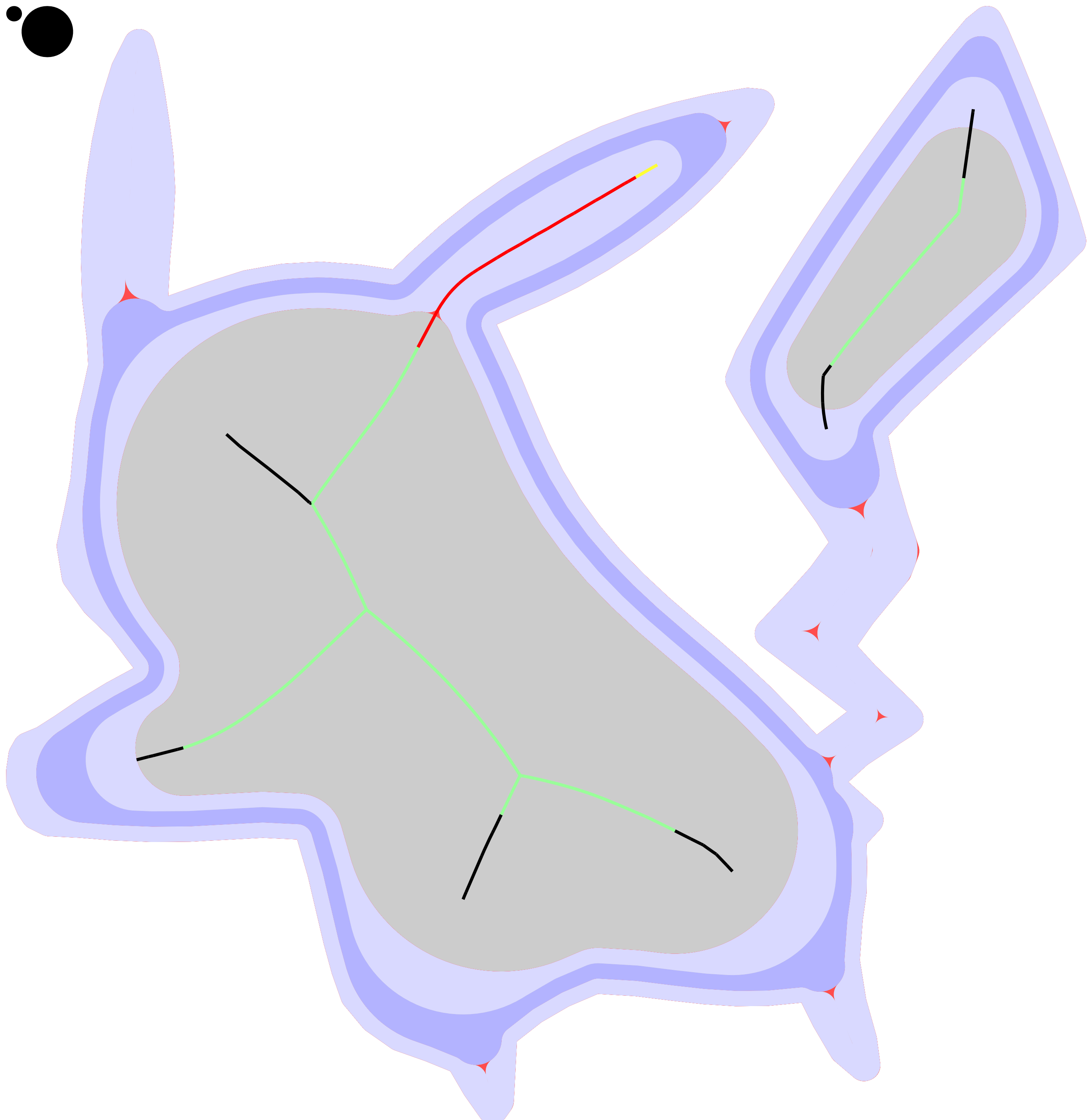
We say that the tree $\mathcal{T}$ rooted at p is **trimmable** if for all leaf q of $\mathcal{T}$, $w(q,p) \leq W(q)$.
The algorithm grows a tree from each degree-1 vertex and finds all **maximal trimmable** trees.

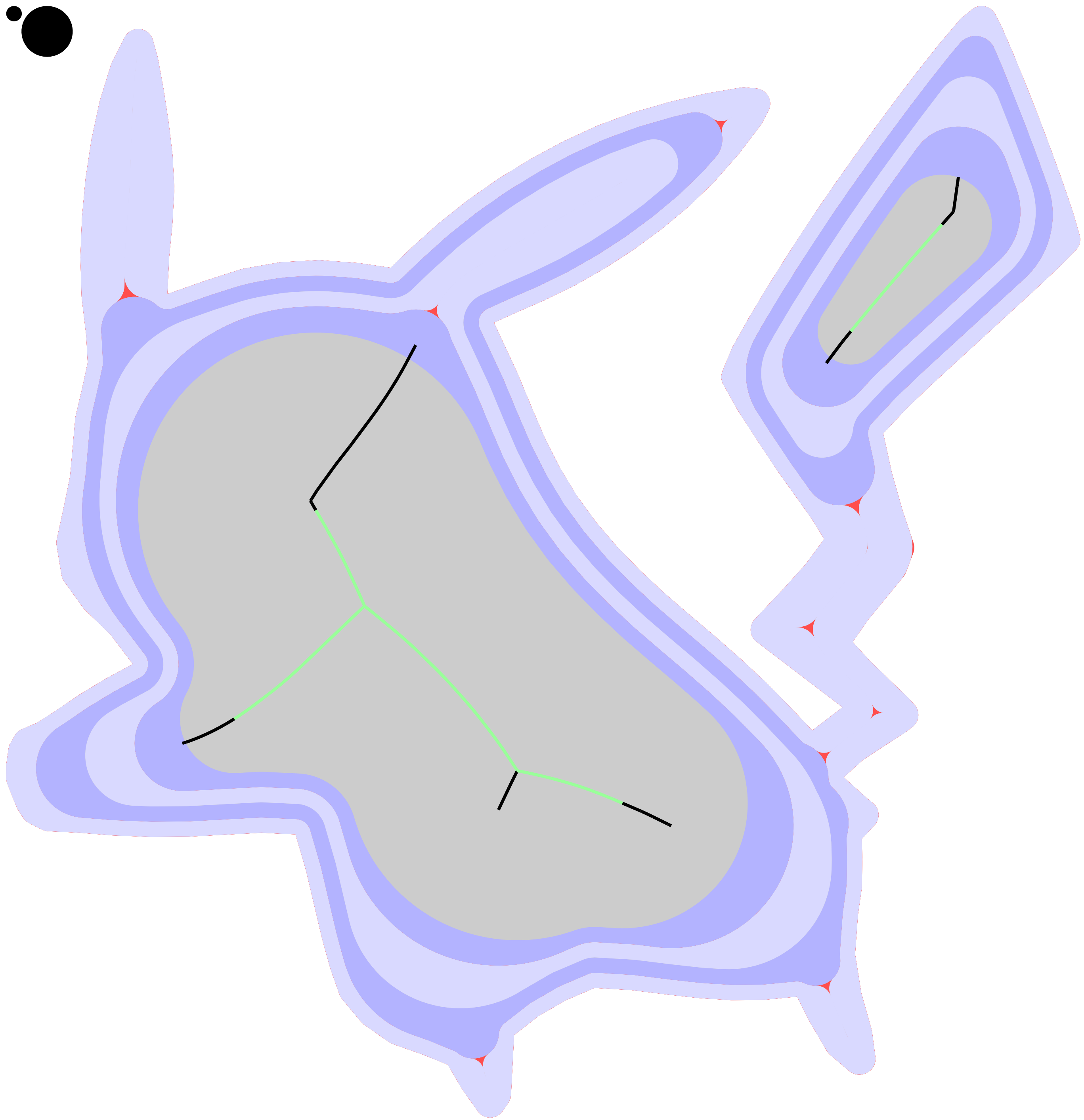
Trimming

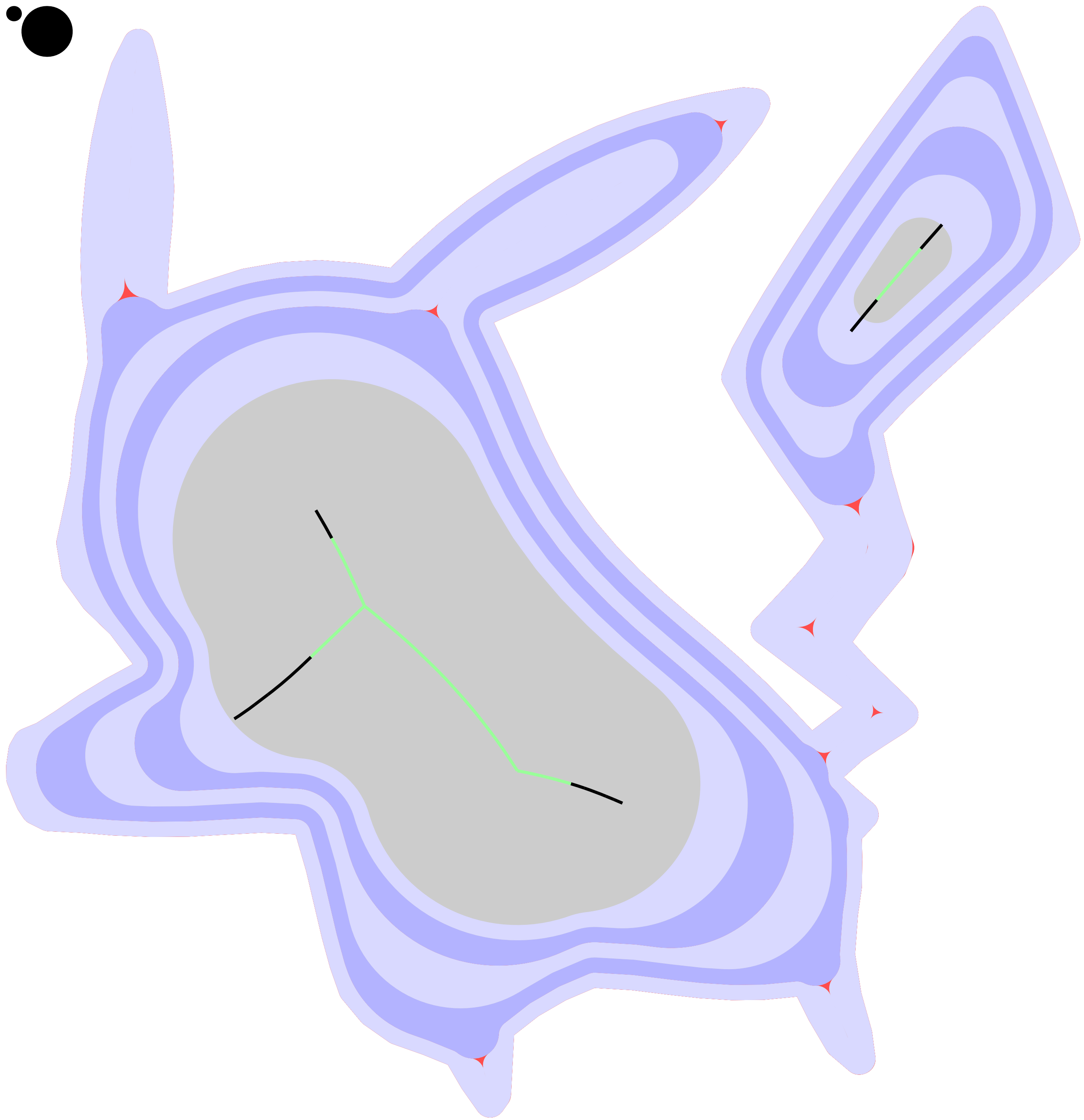


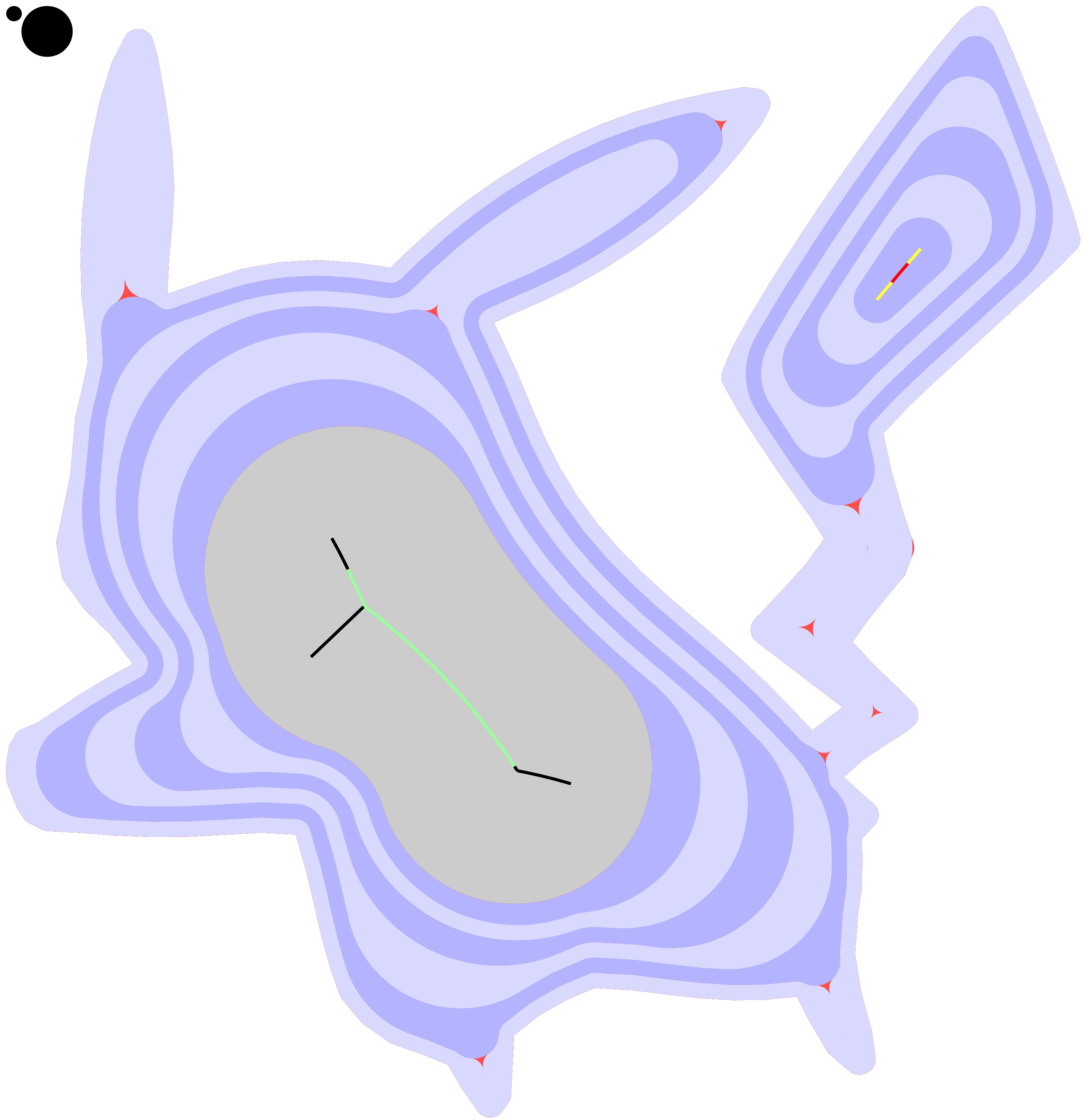


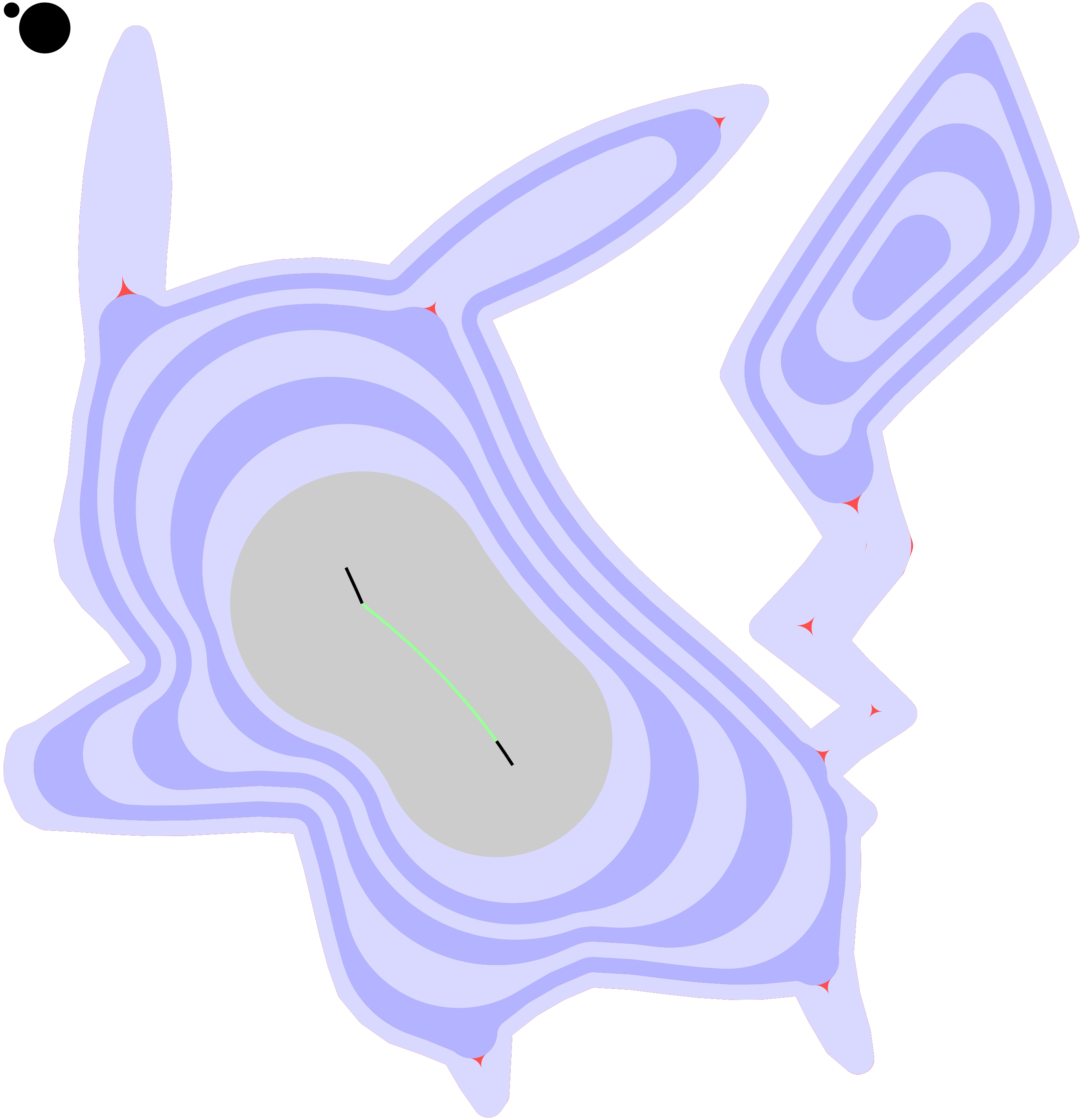


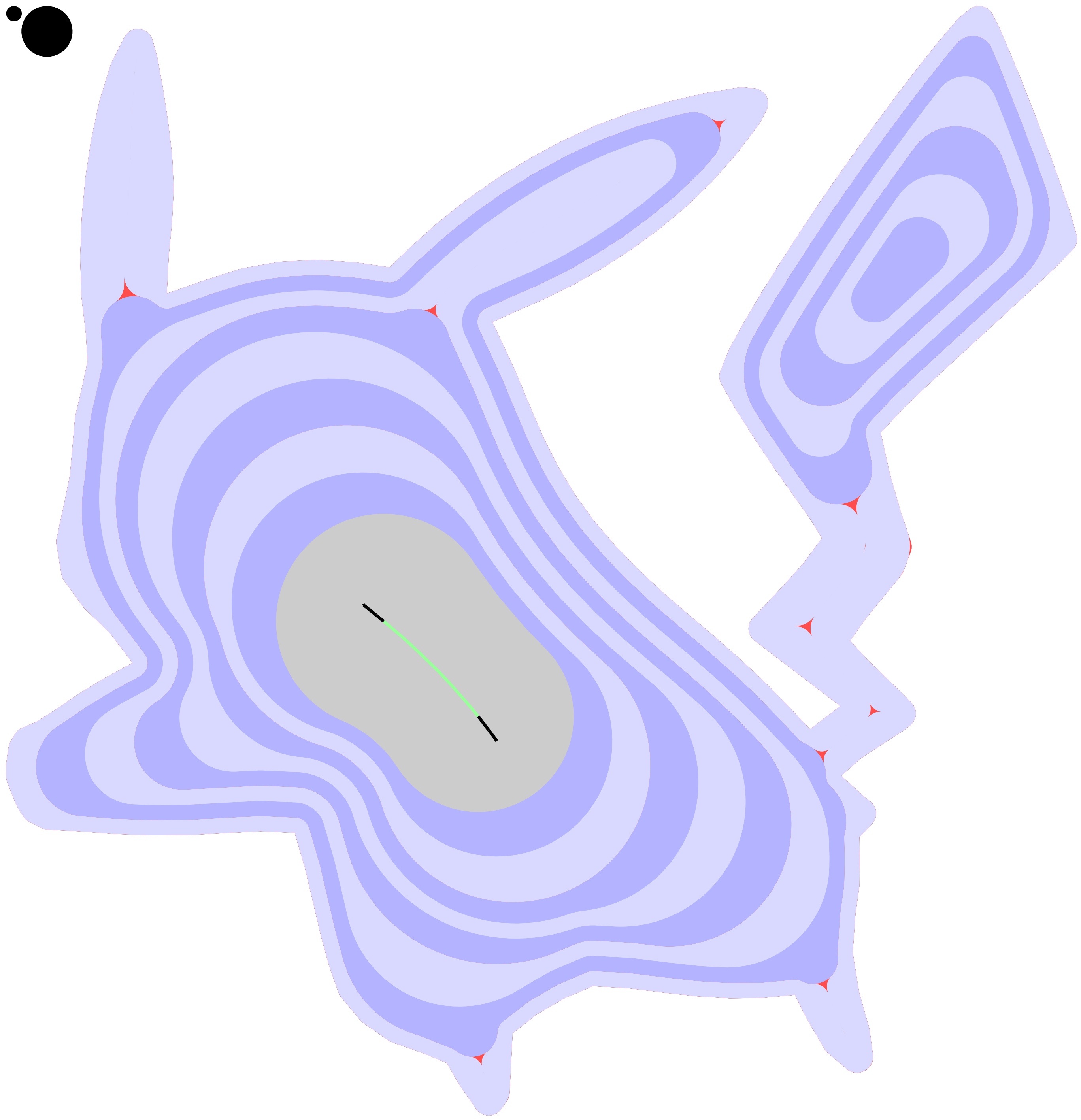


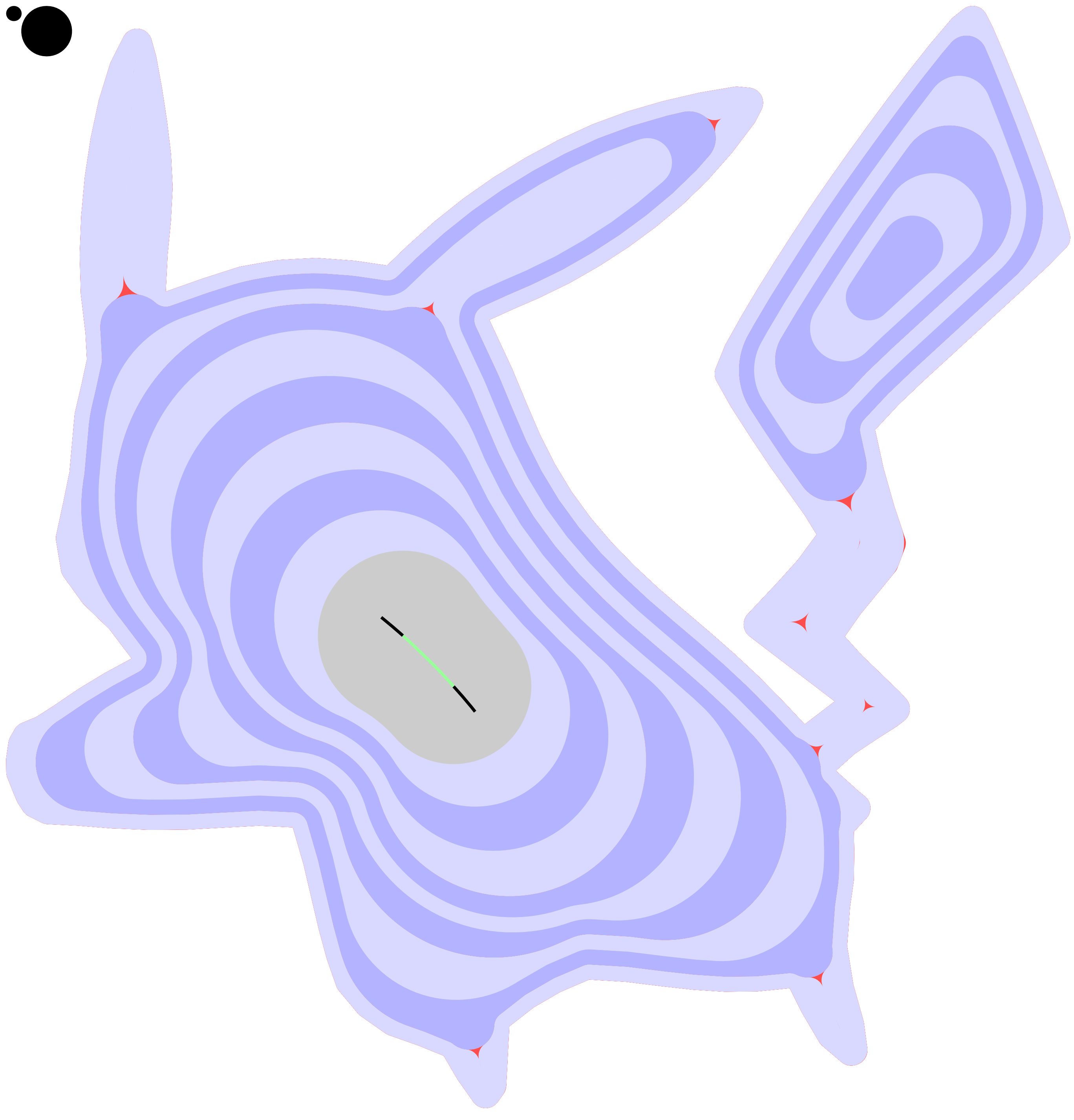


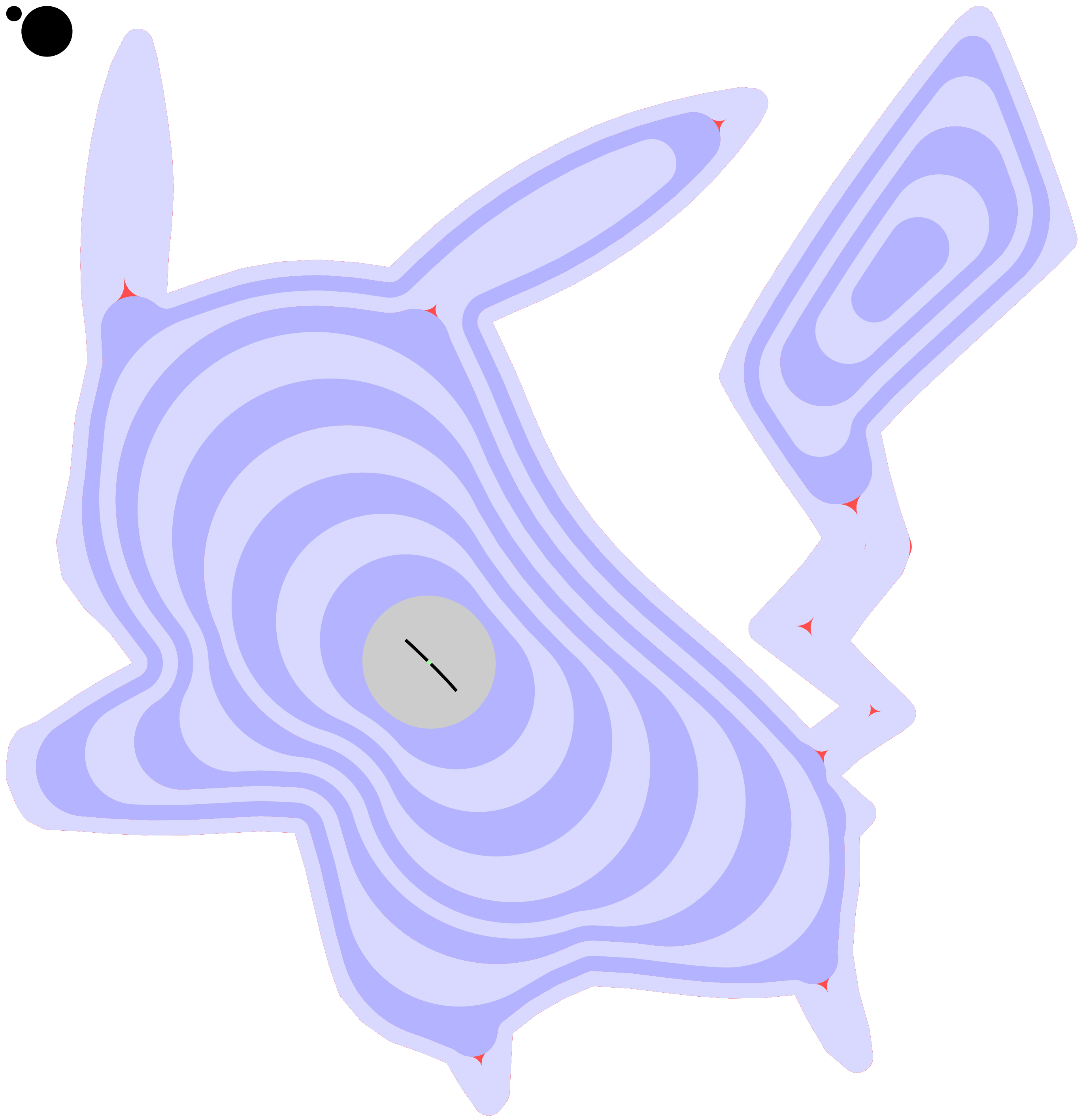


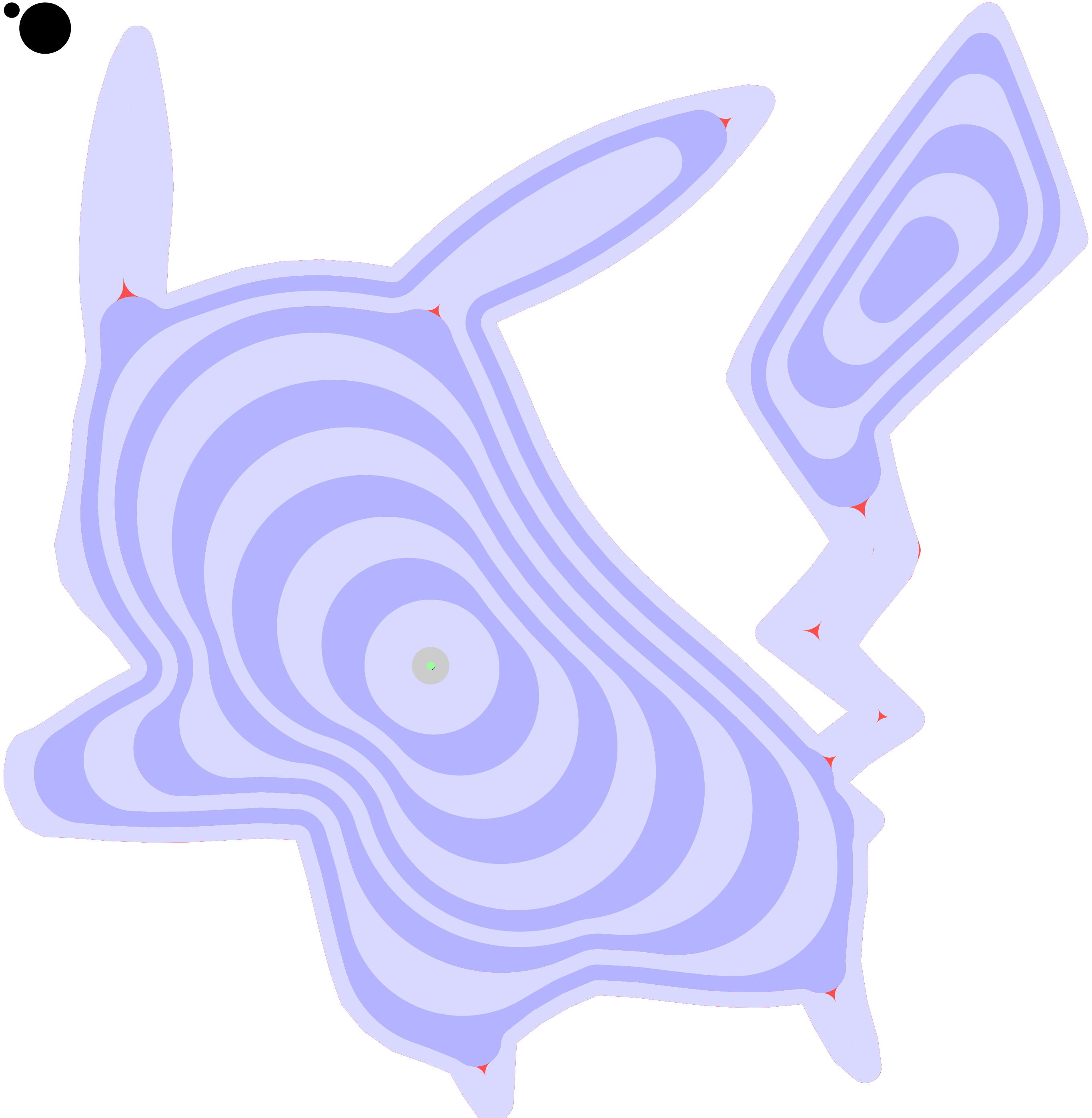


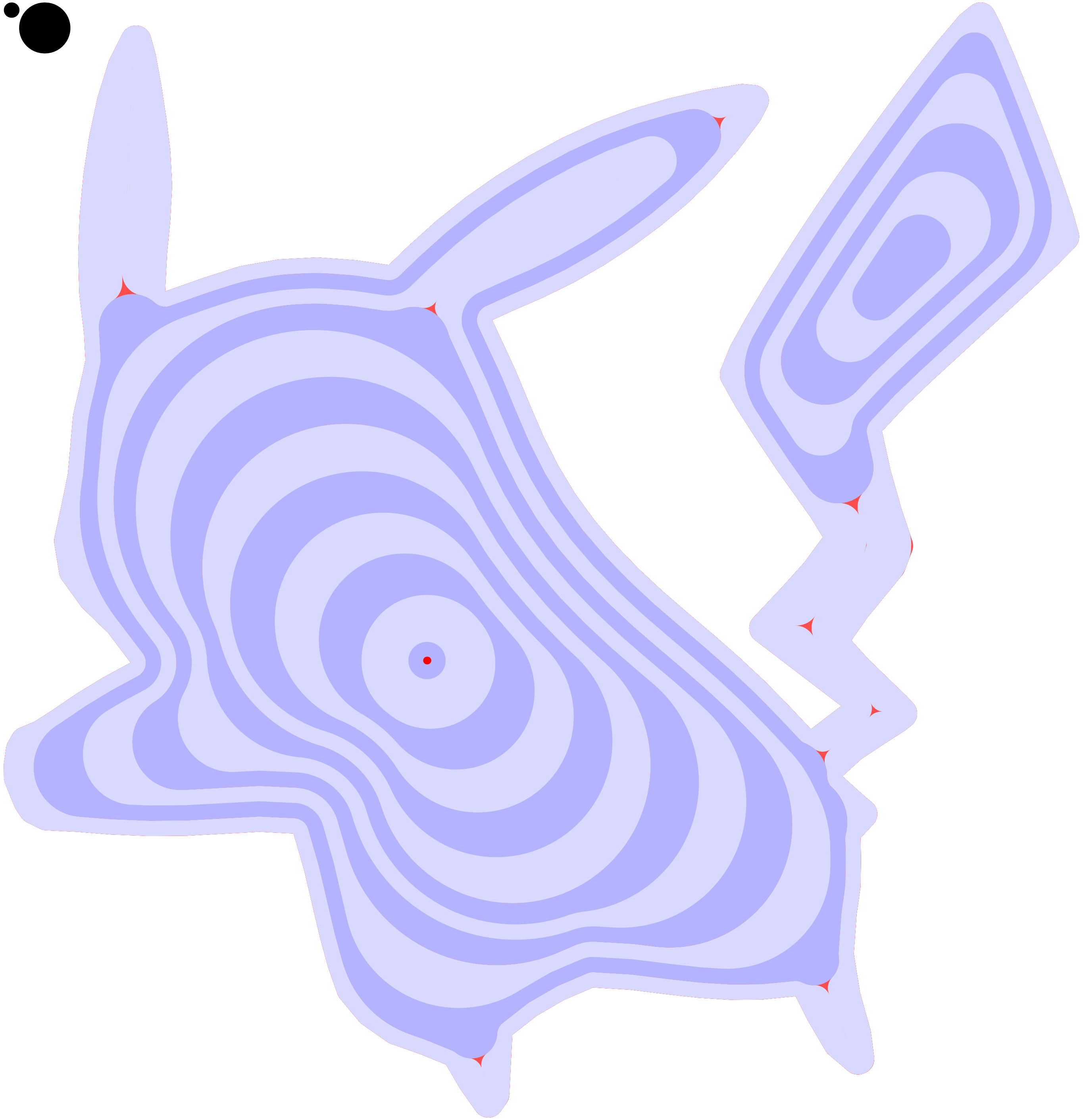


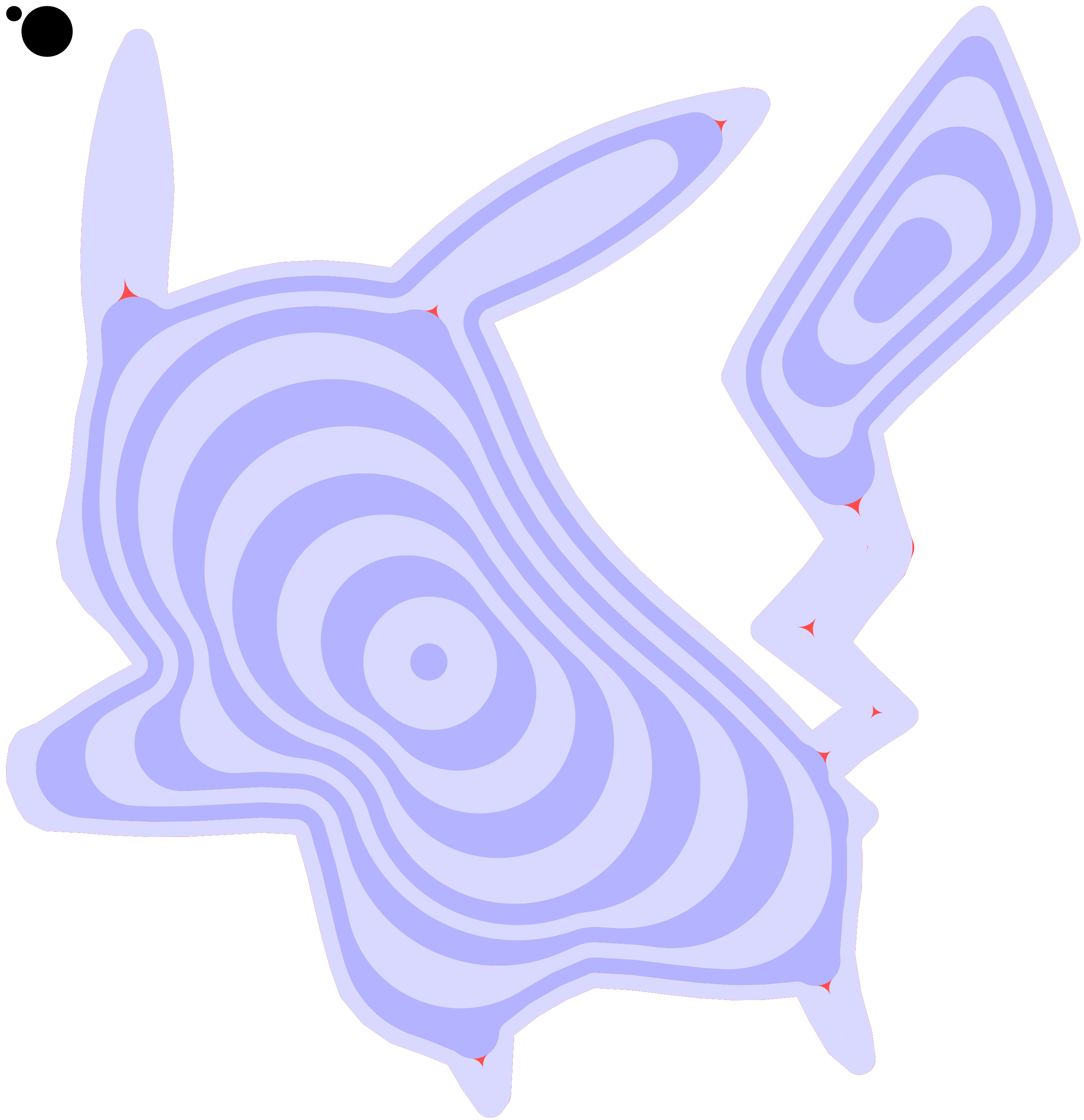












End of this presentation

See the paper for more about

- Collapsing
- Shaving
- Print-path sampling (center curve of each bead)
- Actual 3D-printed tests
- Comparison with state-of-the-art (almost 10x less underfill)
- Proof of no overfill

Thank you