



SIGGRAPH 2025
Vancouver+ 10-14 August

Sphere Carving: Bounding volumes for SDFs

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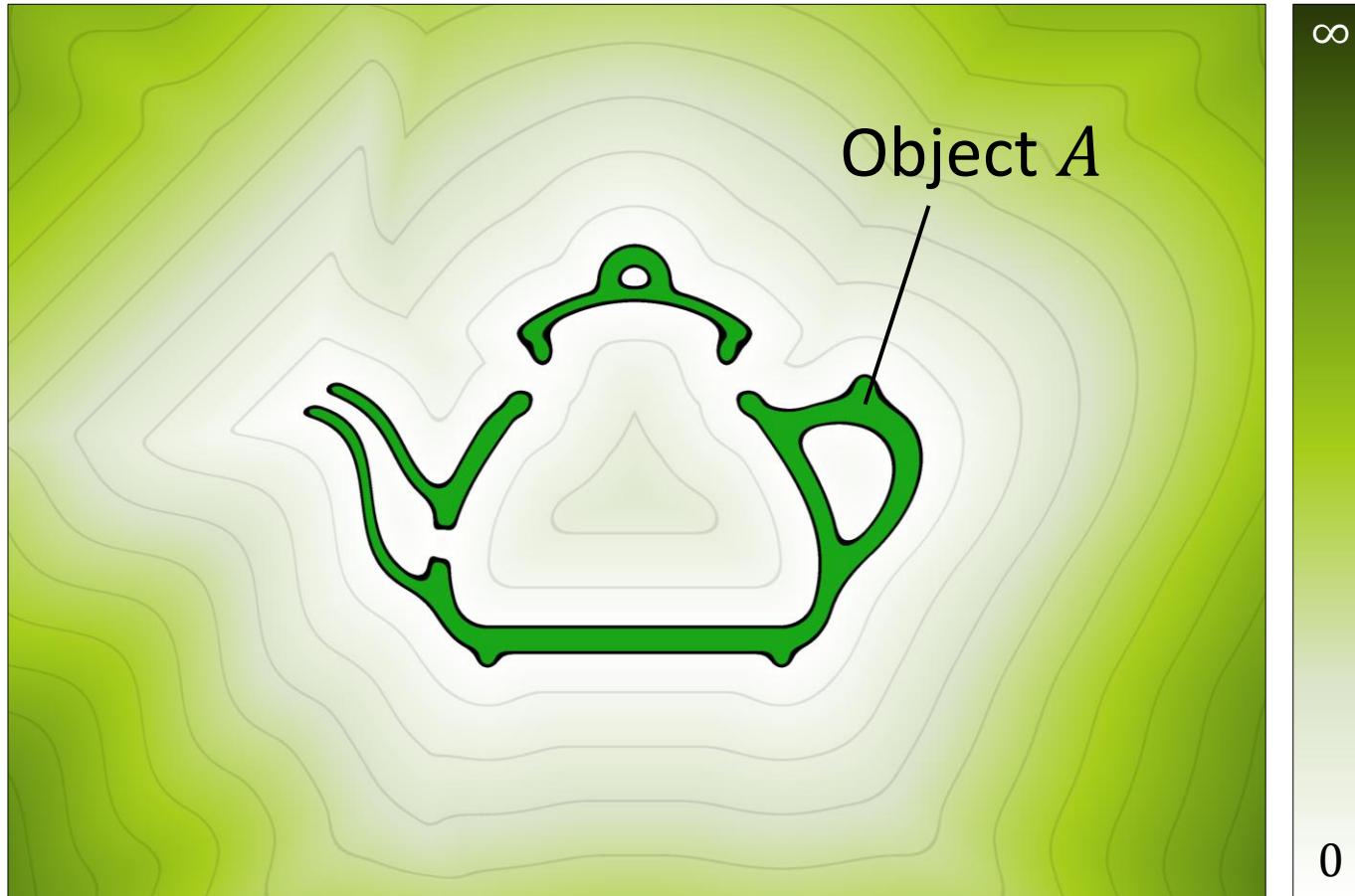
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 **Adobe**



Source code

Signed Distance Field



$$S = \{ \mathbf{p} \in \mathbf{R}^3 \mid f(\mathbf{p}) = 0 \}$$

$$|f(\mathbf{p})| \leq \text{distance}(A, \mathbf{p})$$

- Compact representation
- Infinite precision (as vector graphics)
- Most editing operations are very straightforward (union, intersection, ...)

[Reiner 2011] Interactive Modeling of Implicit Surfaces Using a Direct Visualization Approach with Signed Distance Functions

[Quilez 2008] 3D signed distance functions. <https://iquilezles.org/articles/distfunctions/>

How often do we make queries on f ?



Polygonization

Marching
cubes

[Wyvill 1986]

Dual
contouring

[Ju 2002]



Direct rendering

Ray
marching

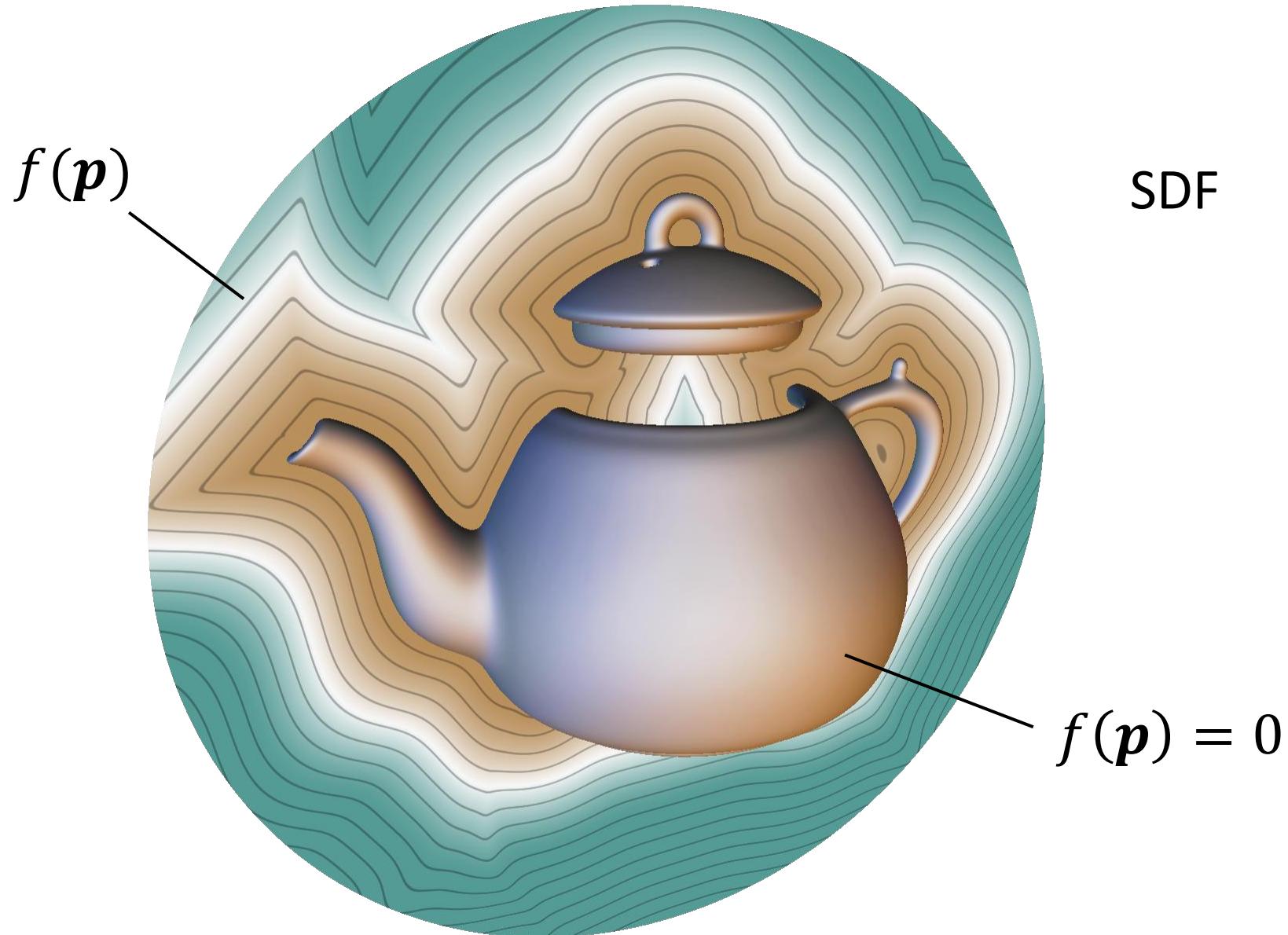
Sphere
tracing

[Hart 1996]



f is **expensive** to
compute and
queried **very often**

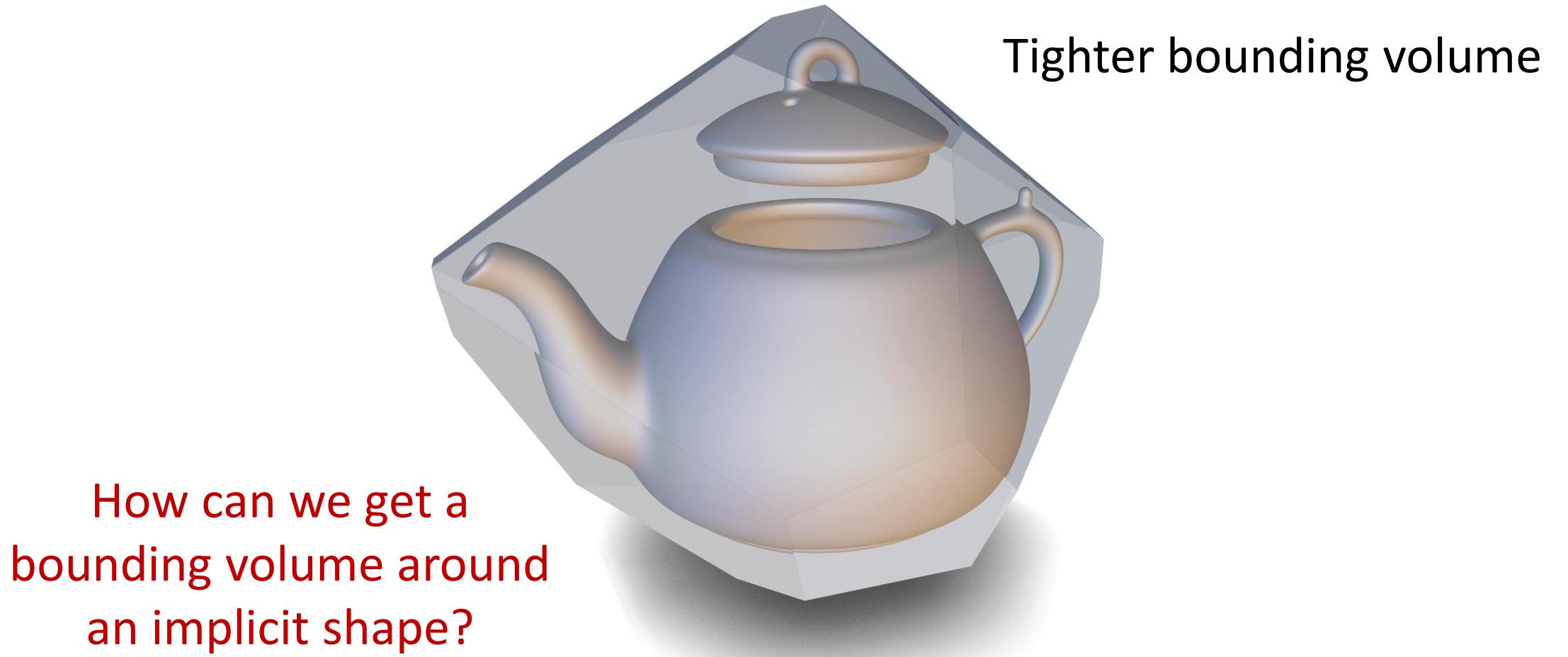
Bounding volumes



Bounding volumes



Bounding box



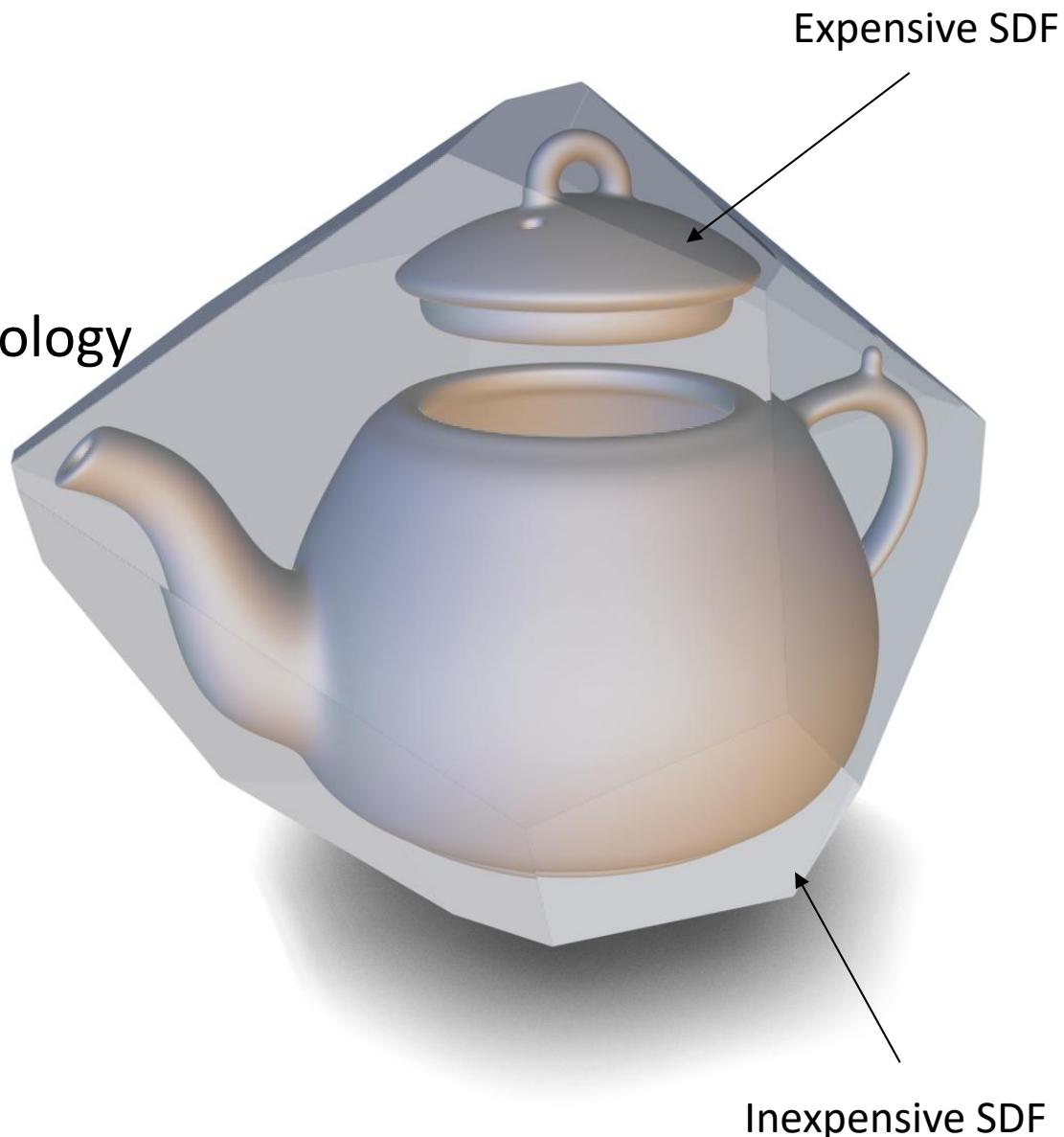
Convex hull generation for SDFs

Advantages:

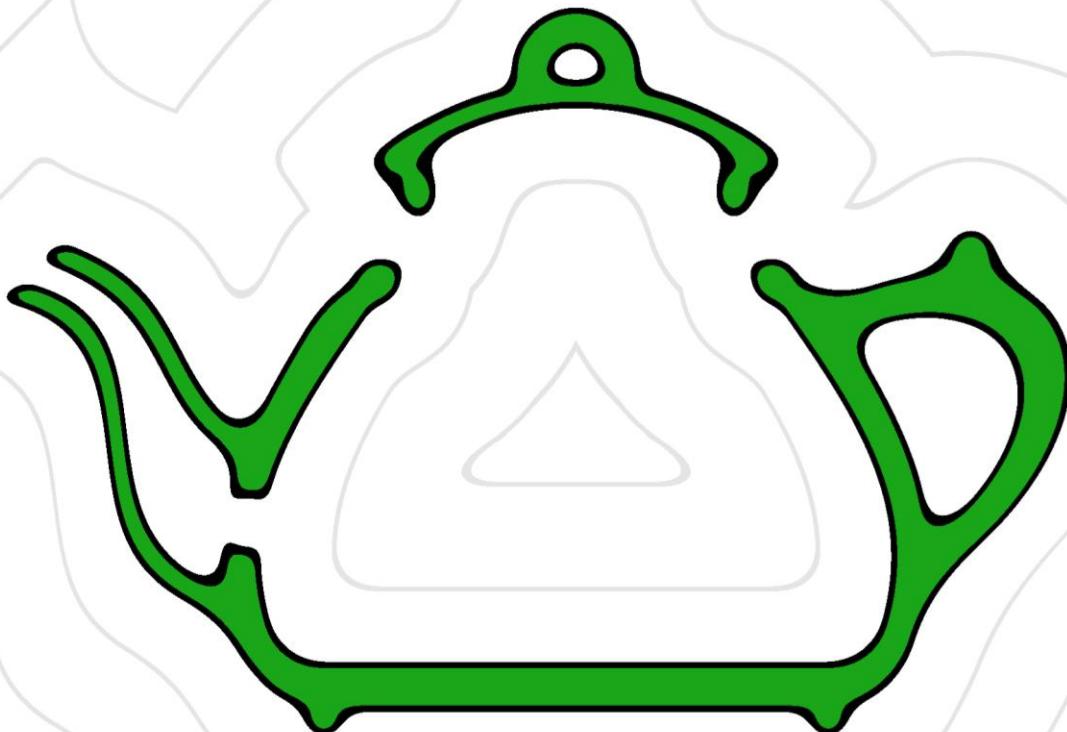
- Works on “black-box” sdfs, with any kind of topology
- Cheap to generate: < 10k queries on f
- Improve performance

Output result is a **convex hull** and can be:

- a cheap SDF: f_{bound}
- a low-res mesh



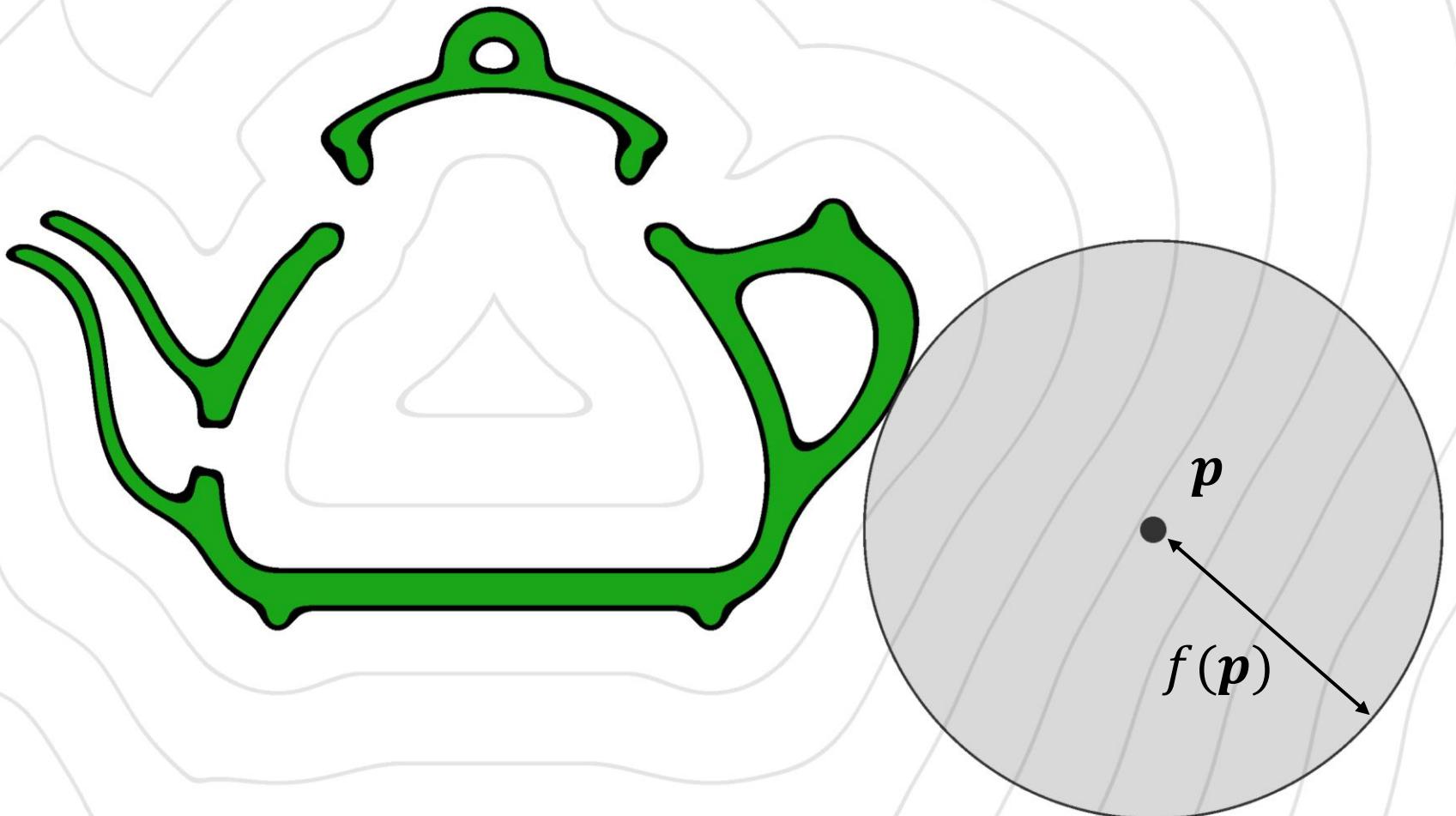
2D example



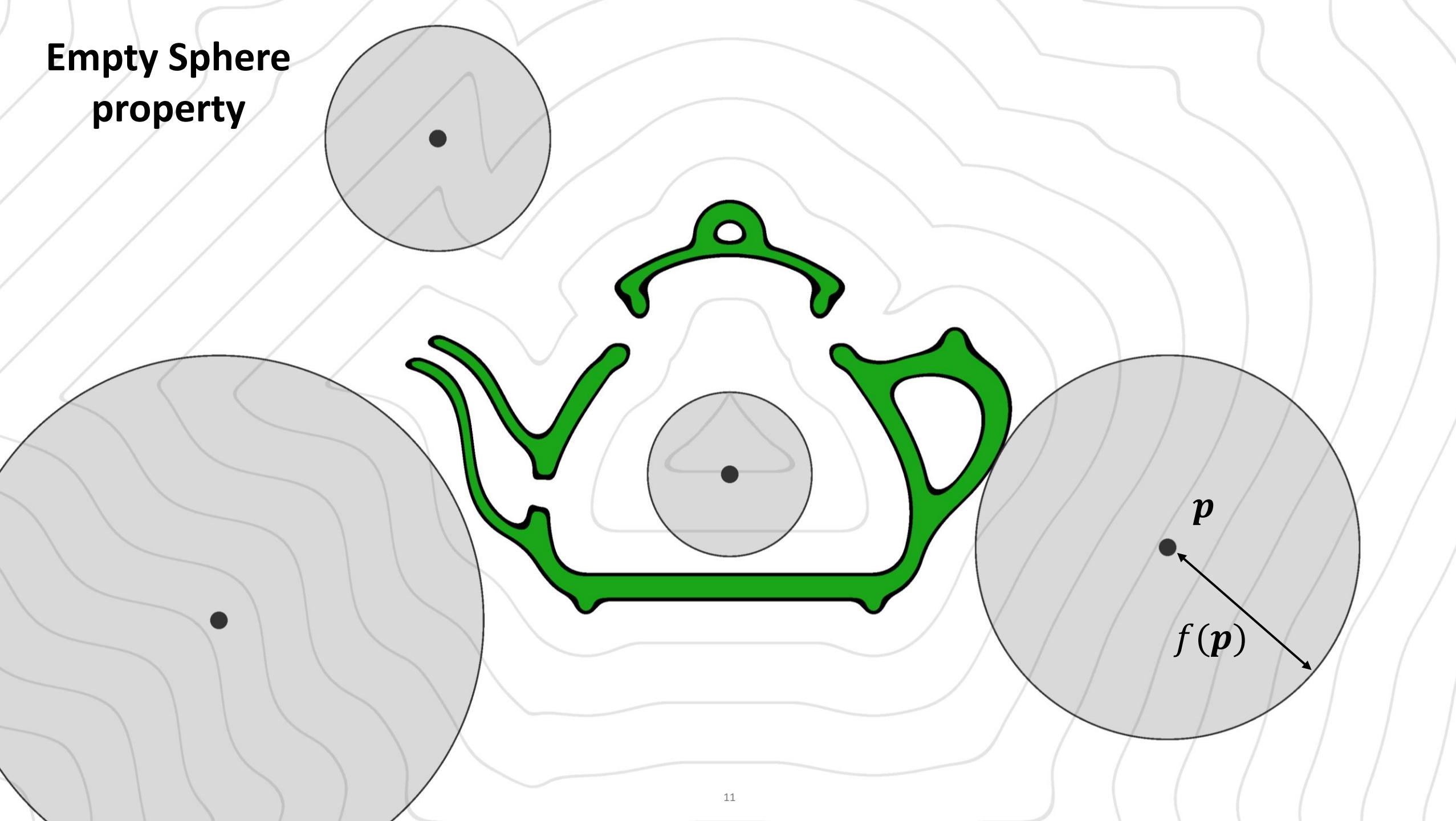
Our only tool: queries on f



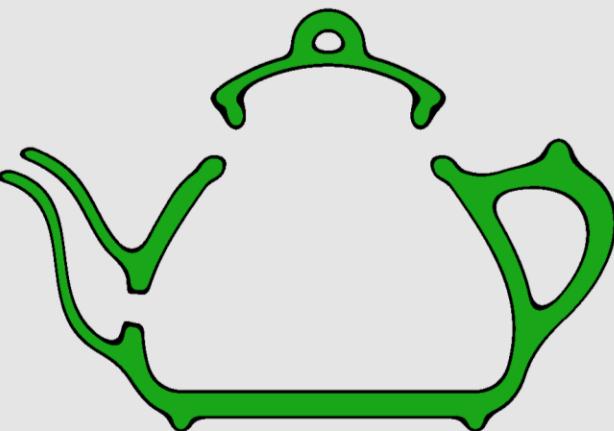
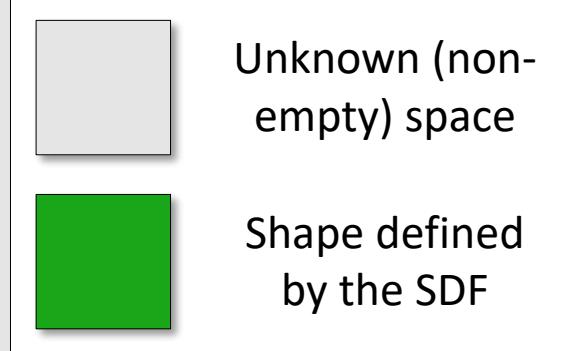
Empty Sphere property



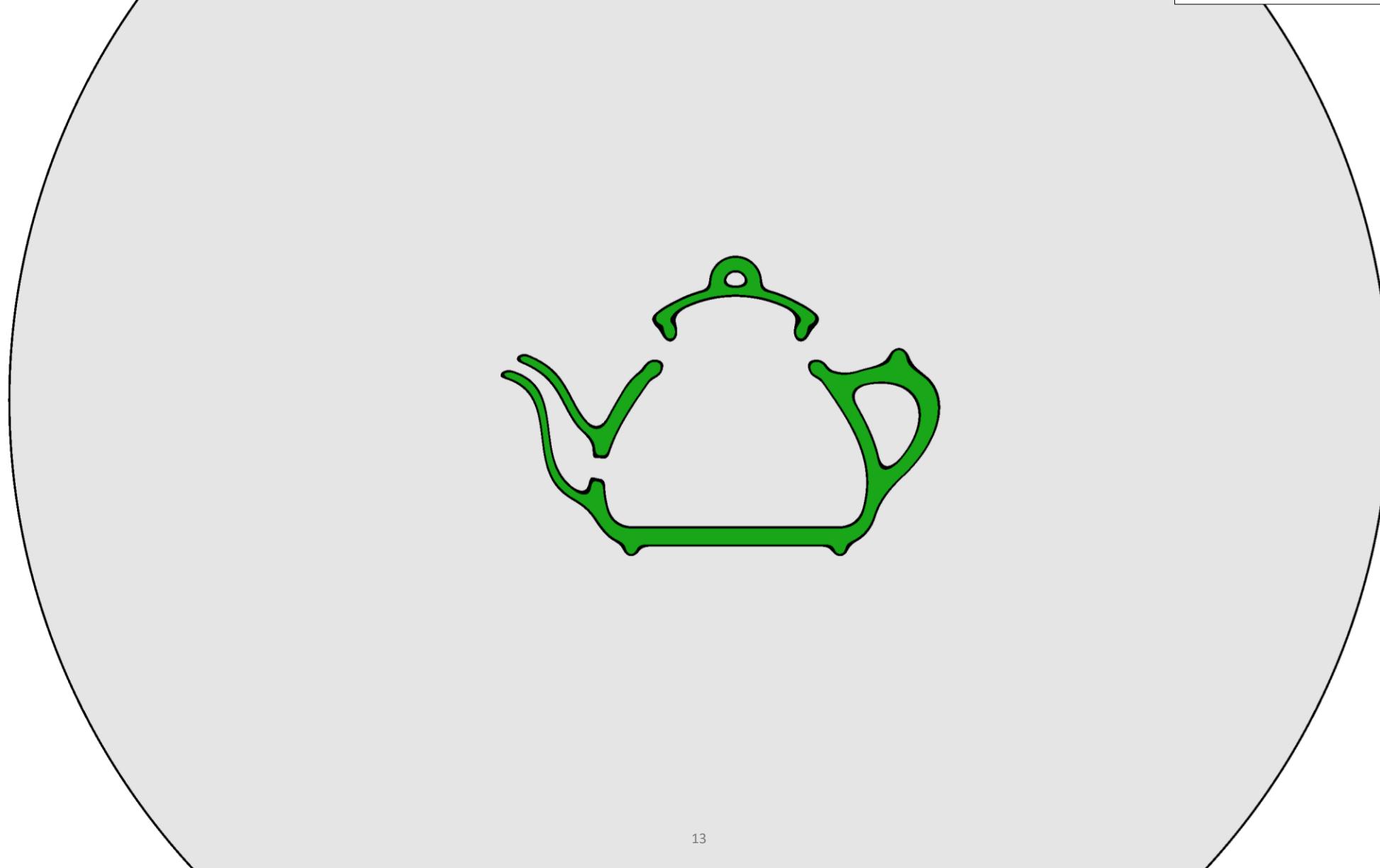
Empty Sphere property



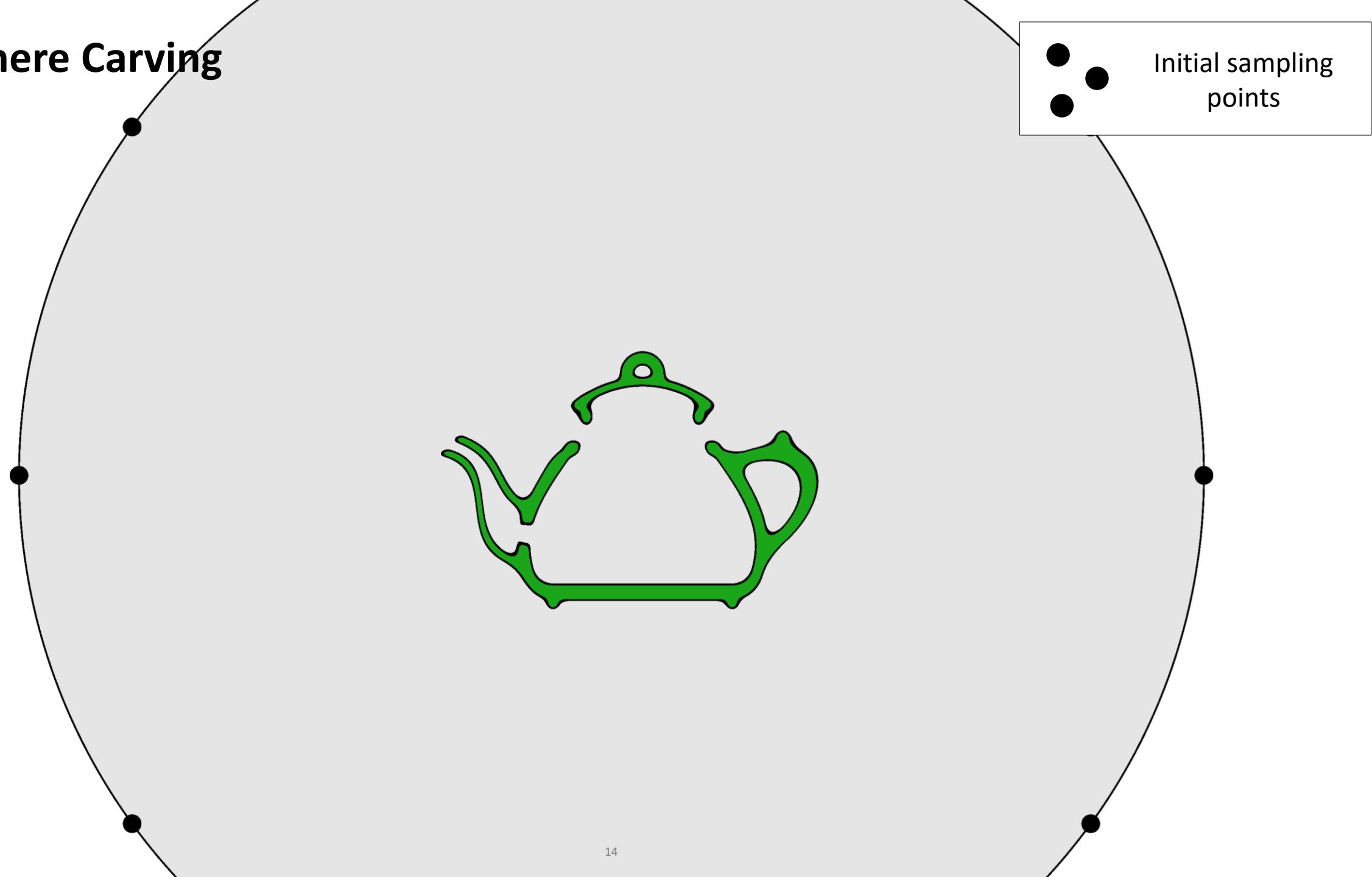
2D Sphere Carving



2D Sphere Carving

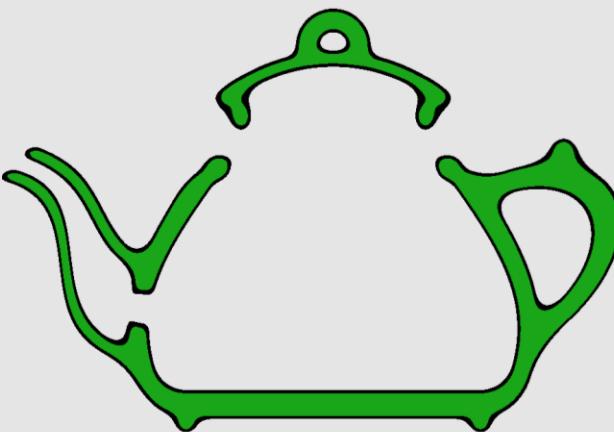
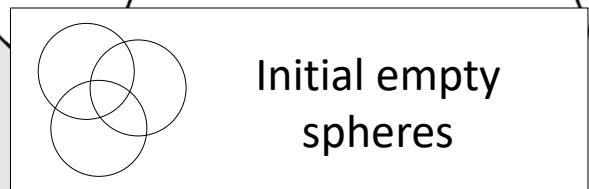


2D Sphere Carving

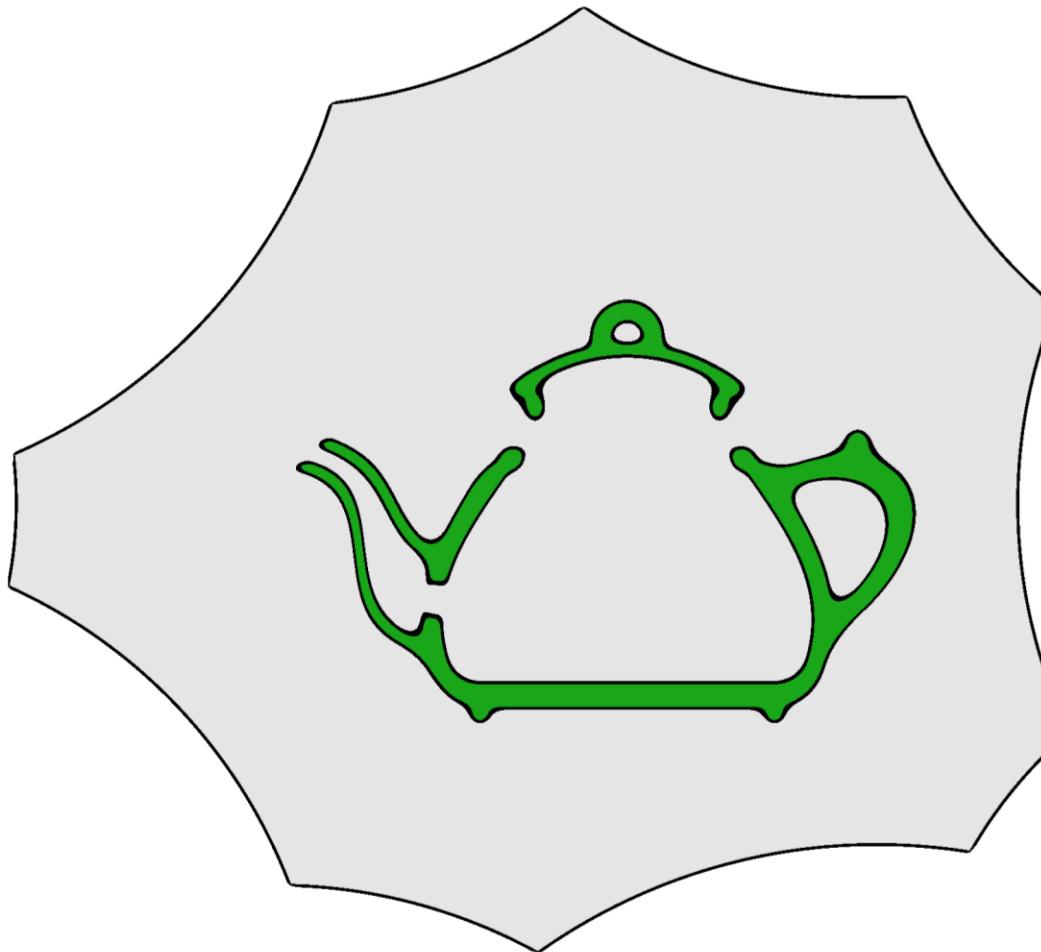


Initial sampling points

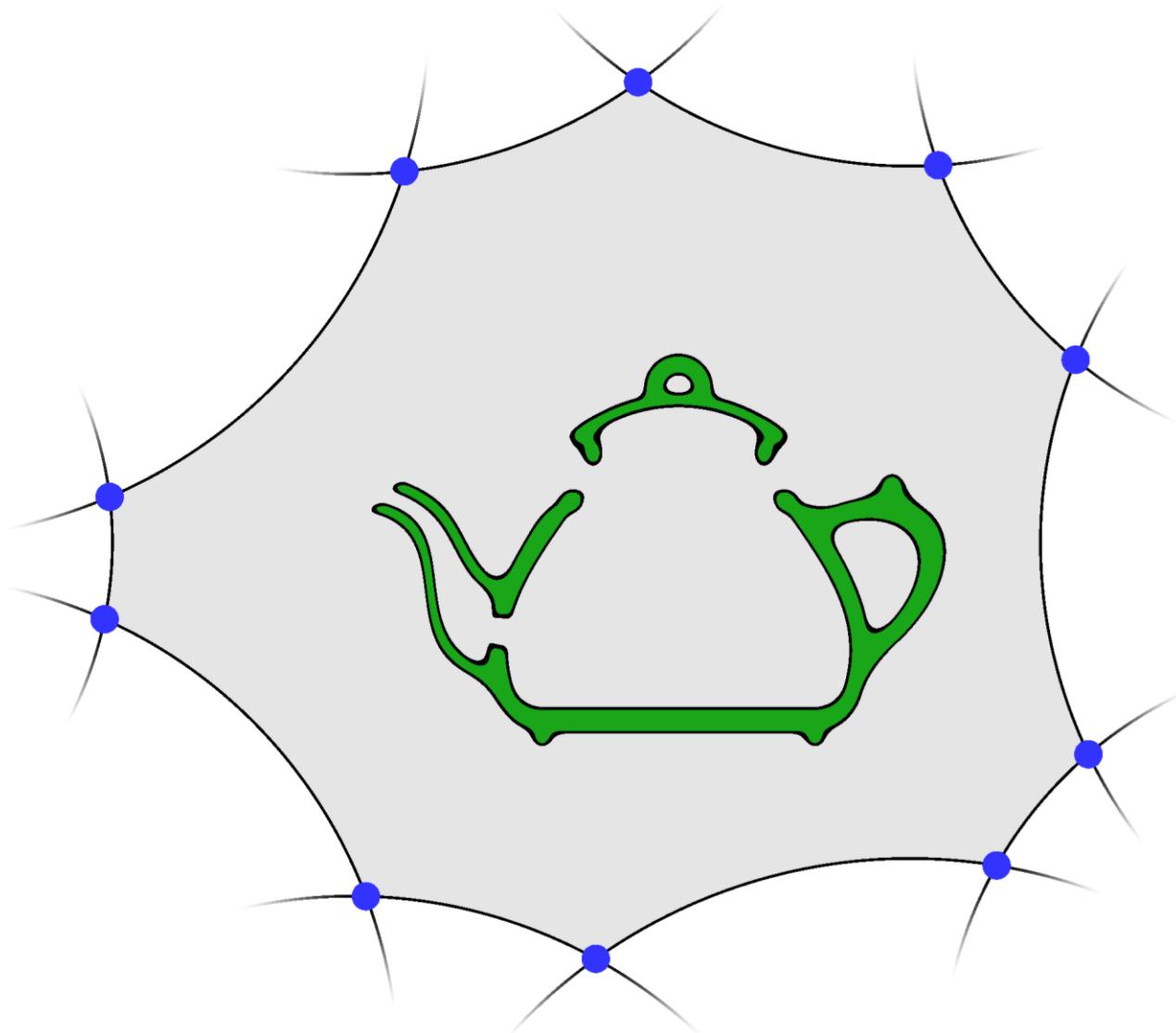
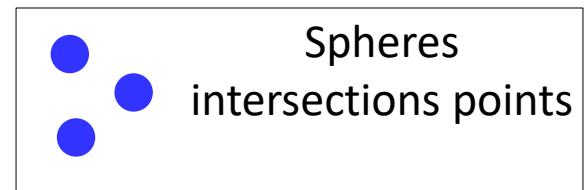
2D Sphere Carving



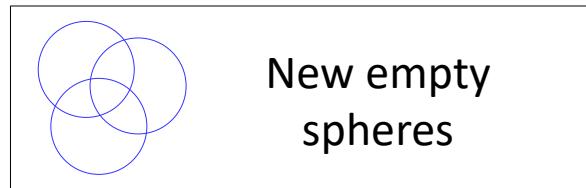
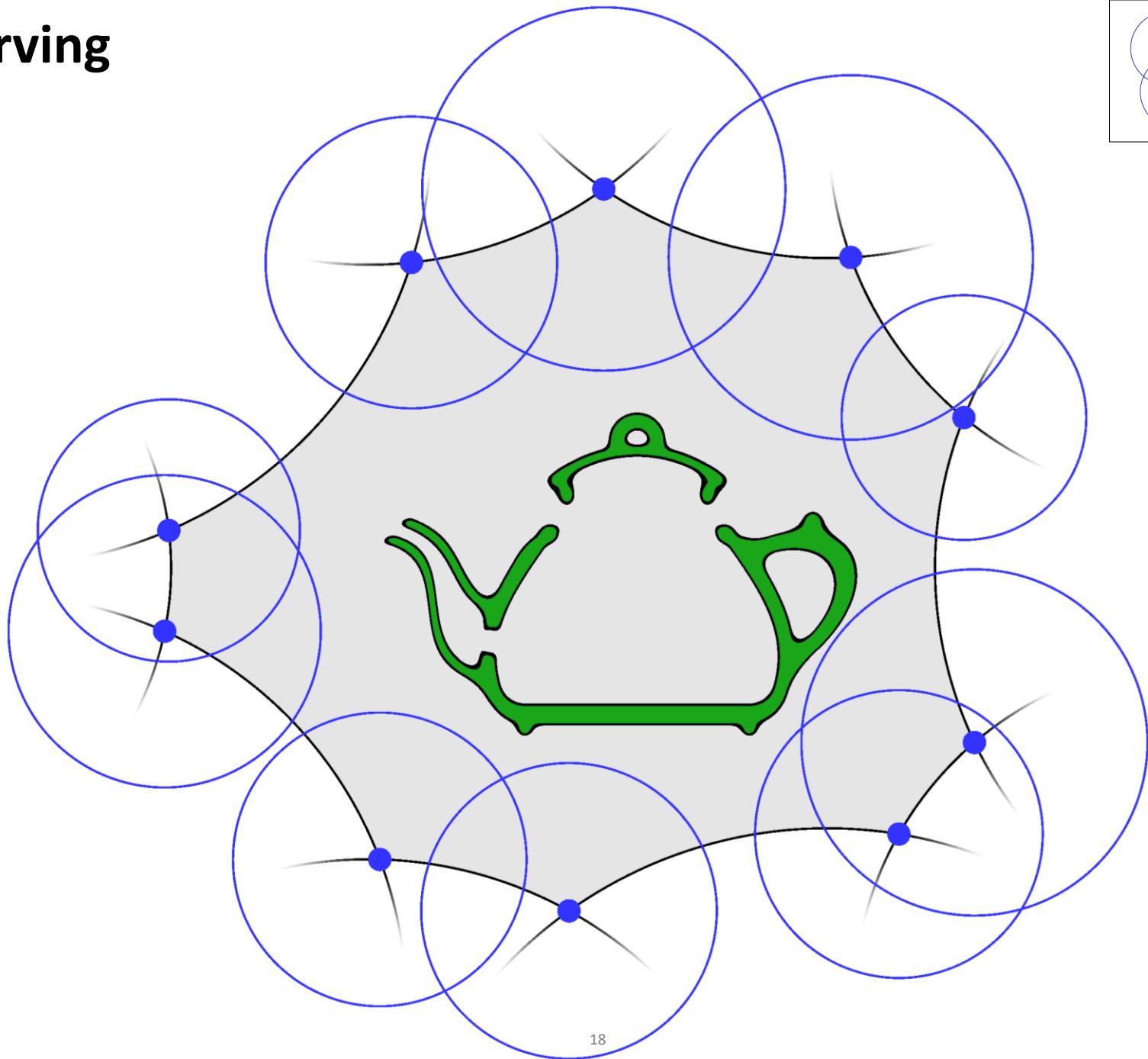
2D Sphere Carving



2D Sphere Carving

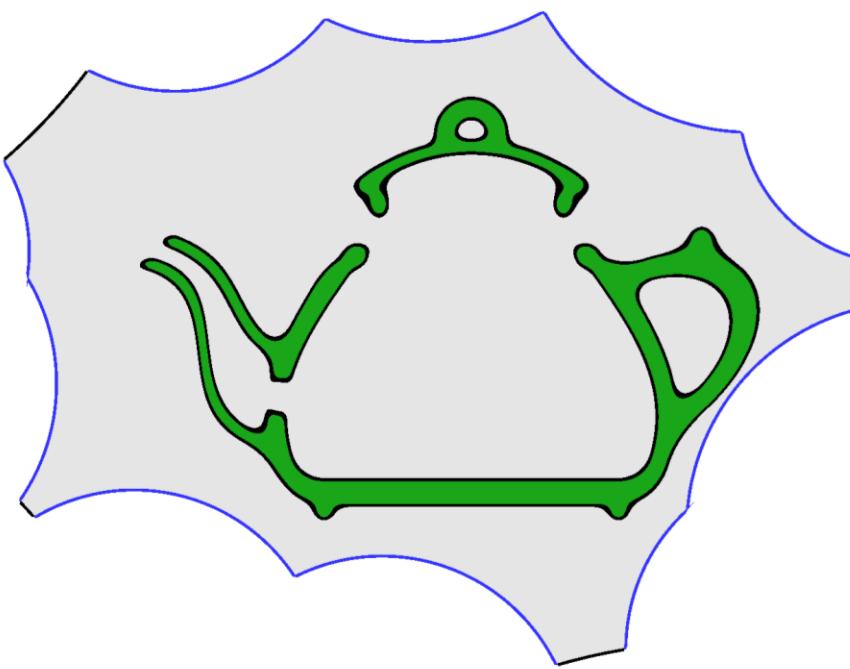


2D Sphere Carving

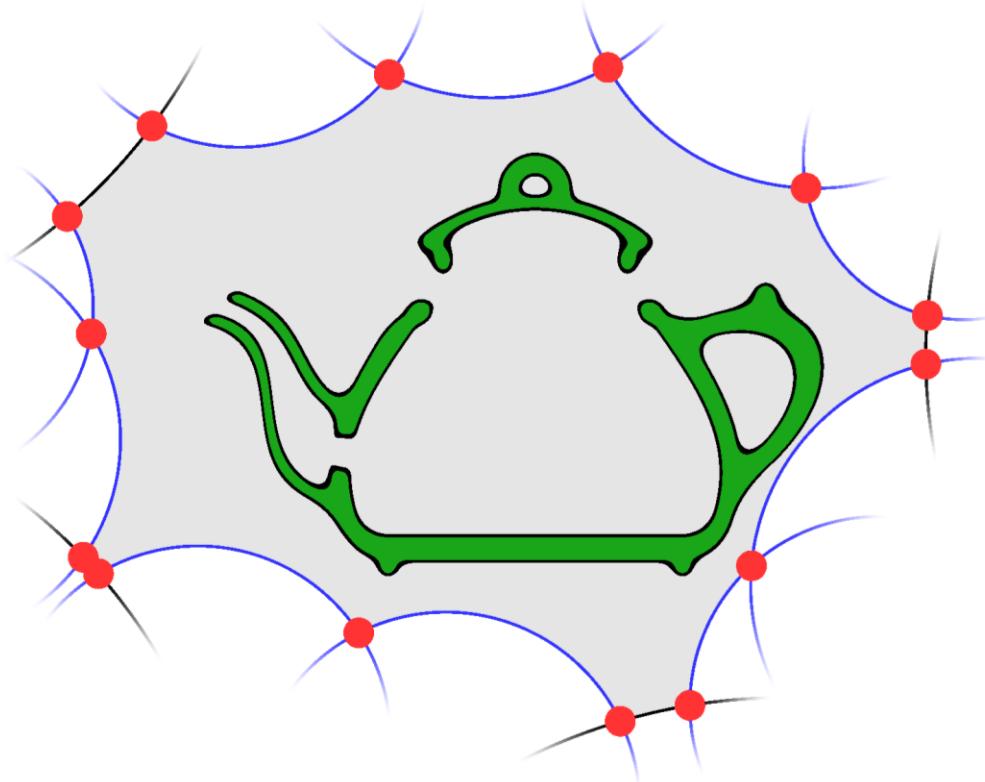
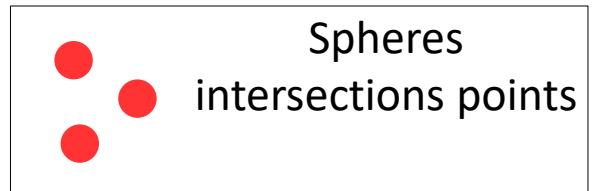


New empty
spheres

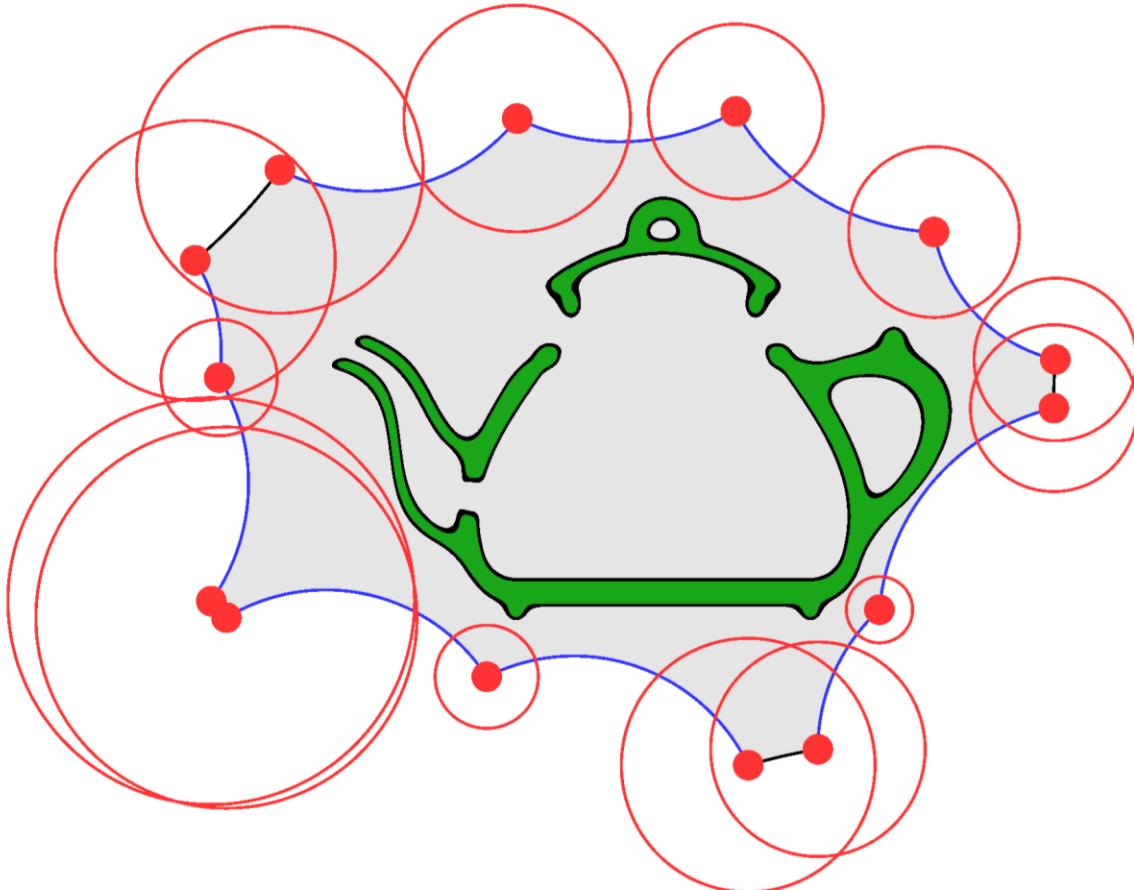
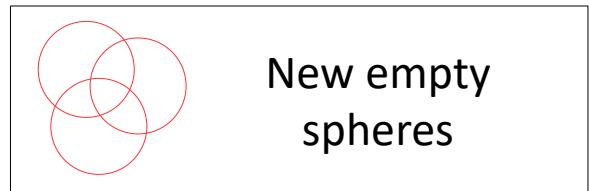
2D Sphere Carving



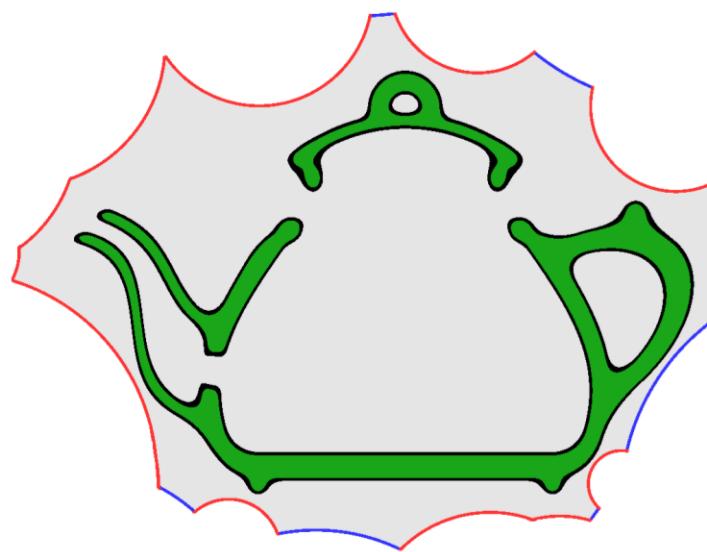
2D Sphere Carving



2D Sphere Carving

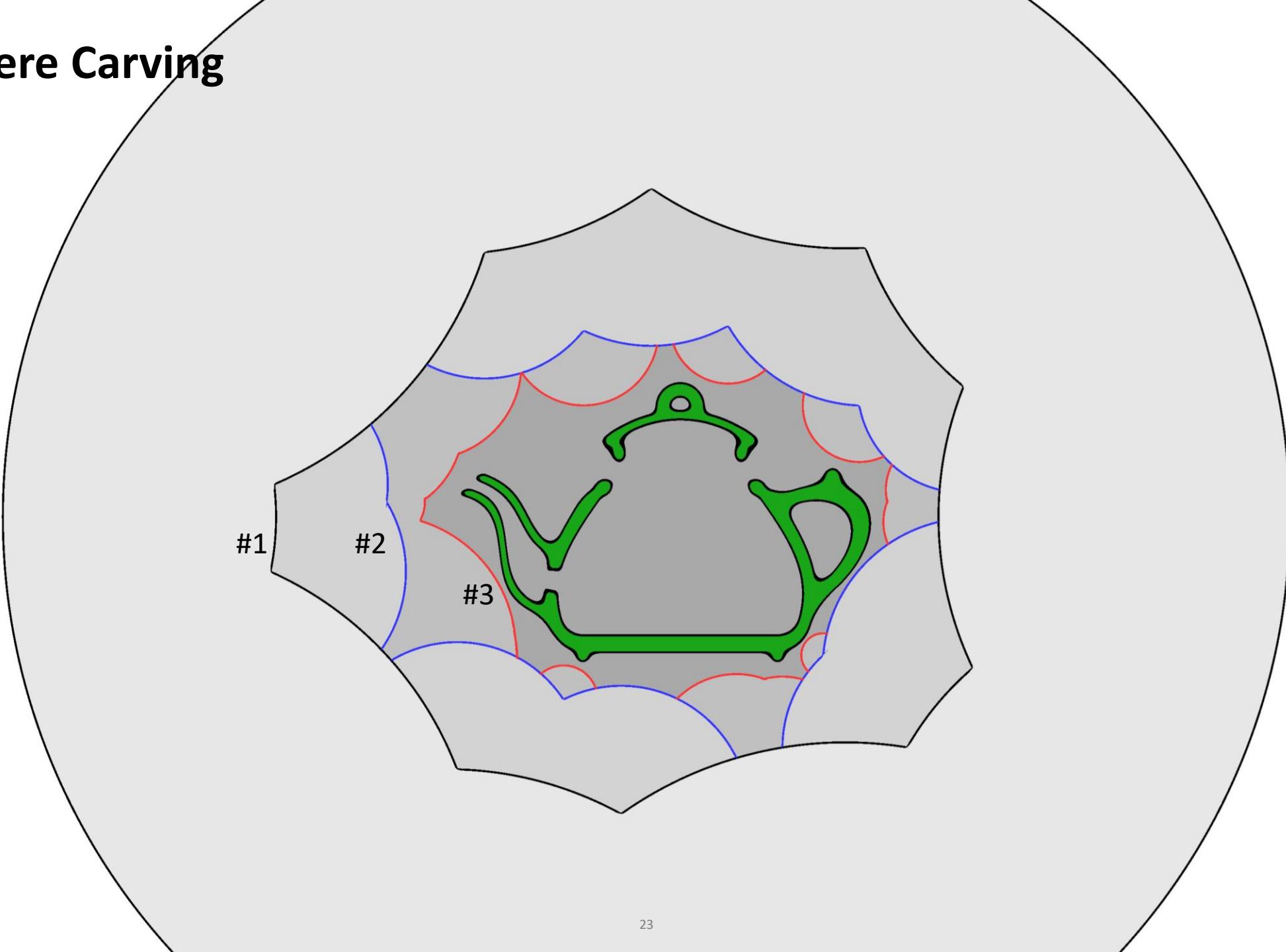


2D Sphere Carving

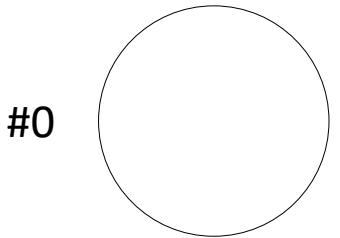


2D Sphere Carving

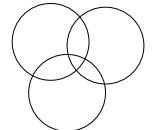
Iteration #0



2D Sphere Carving

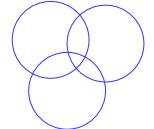


1



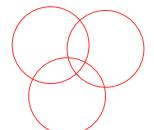
#1

10



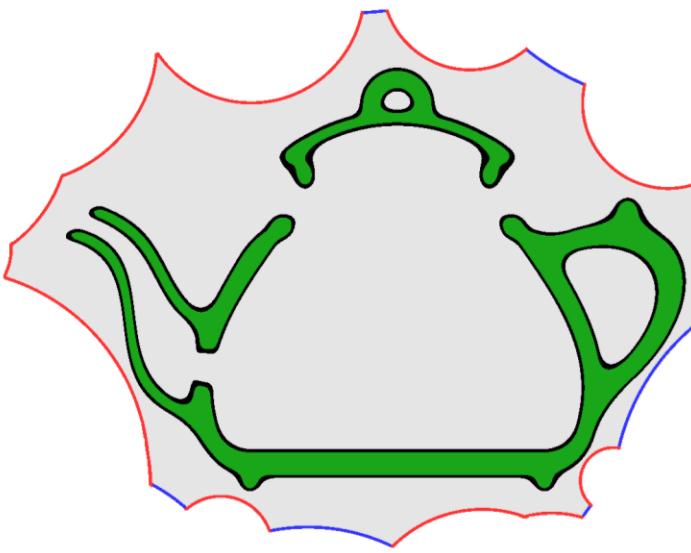
#2

10



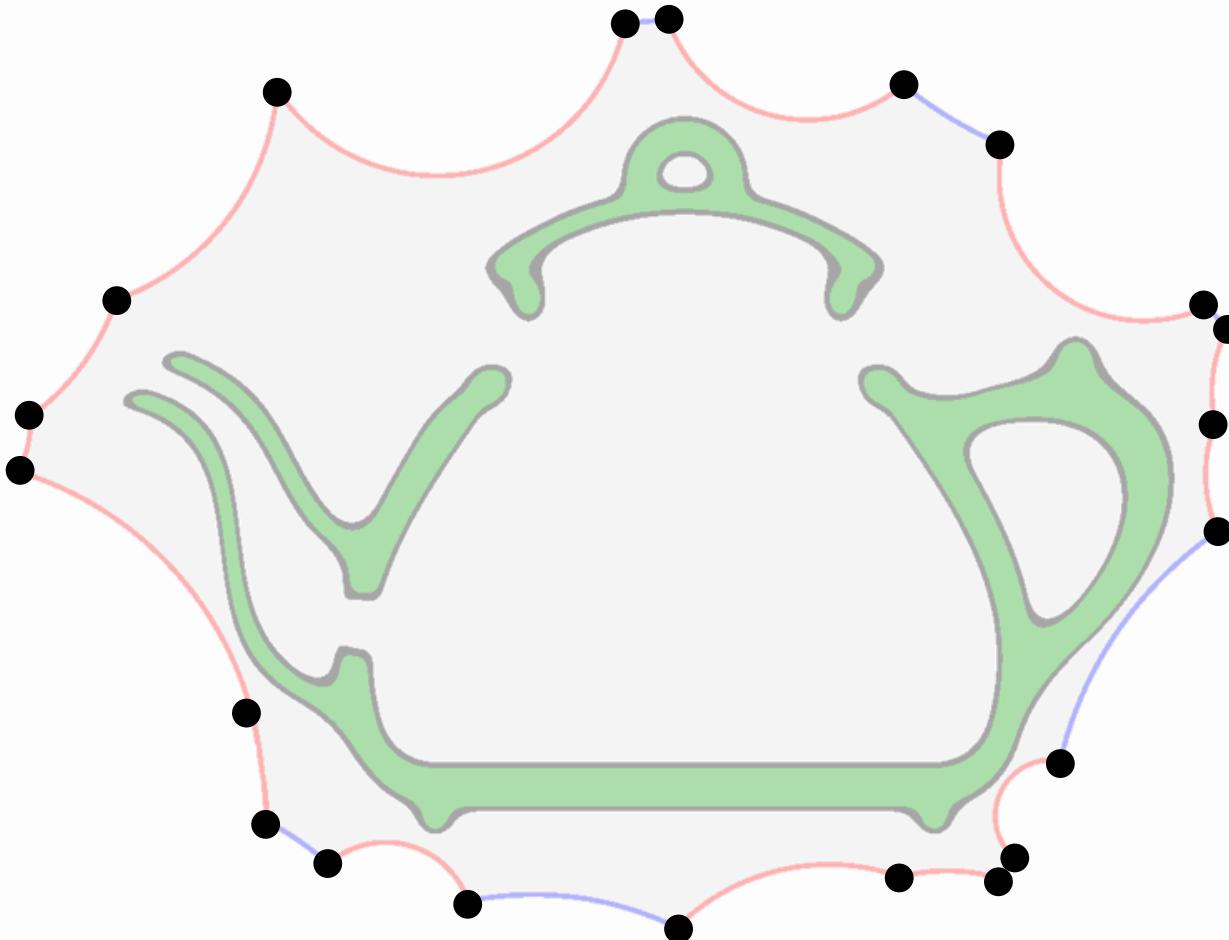
#3

14



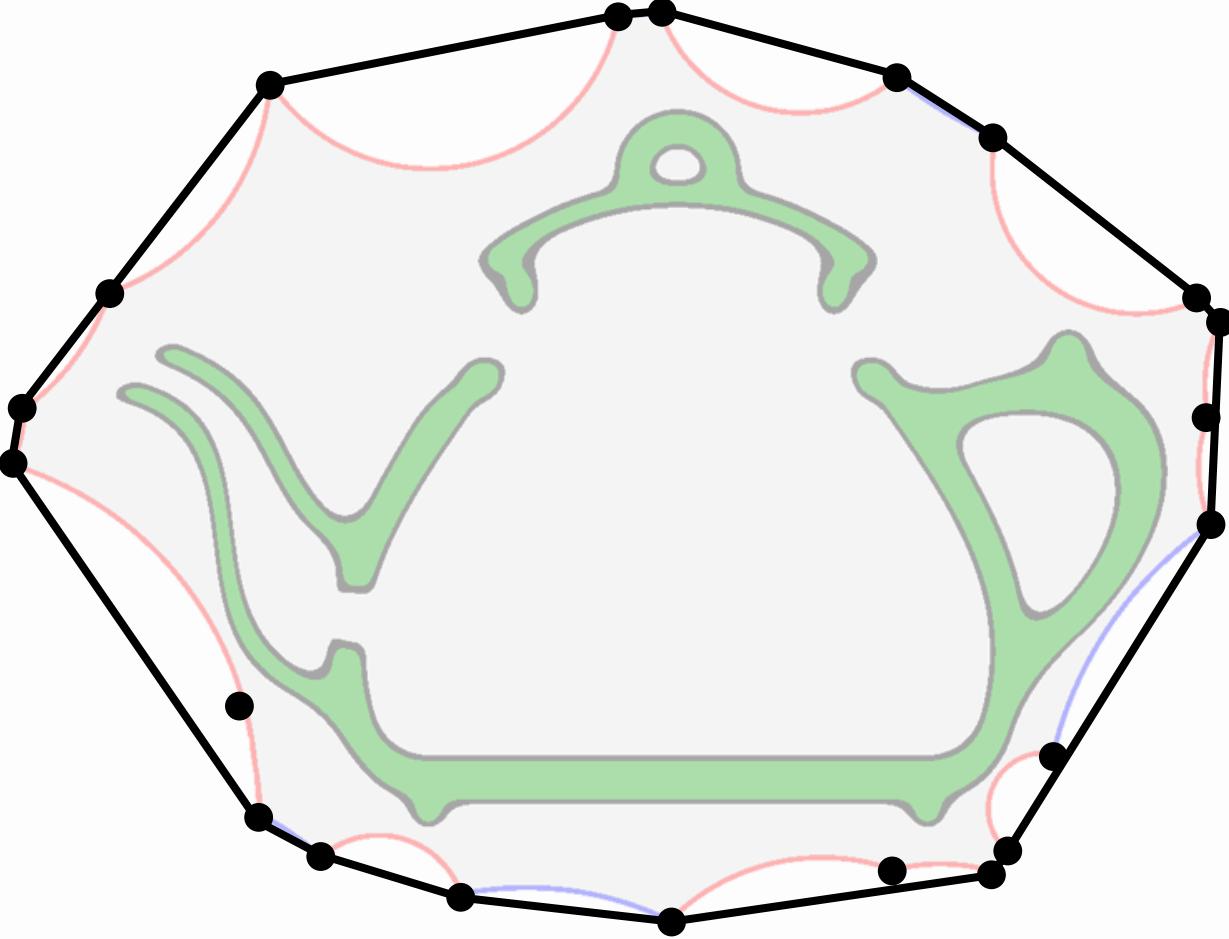
→ Carved space is already 35 spheres in 2D.
How to extract a more efficient bound?

2D Sphere Carving



Final point cloud

2D Sphere Carving

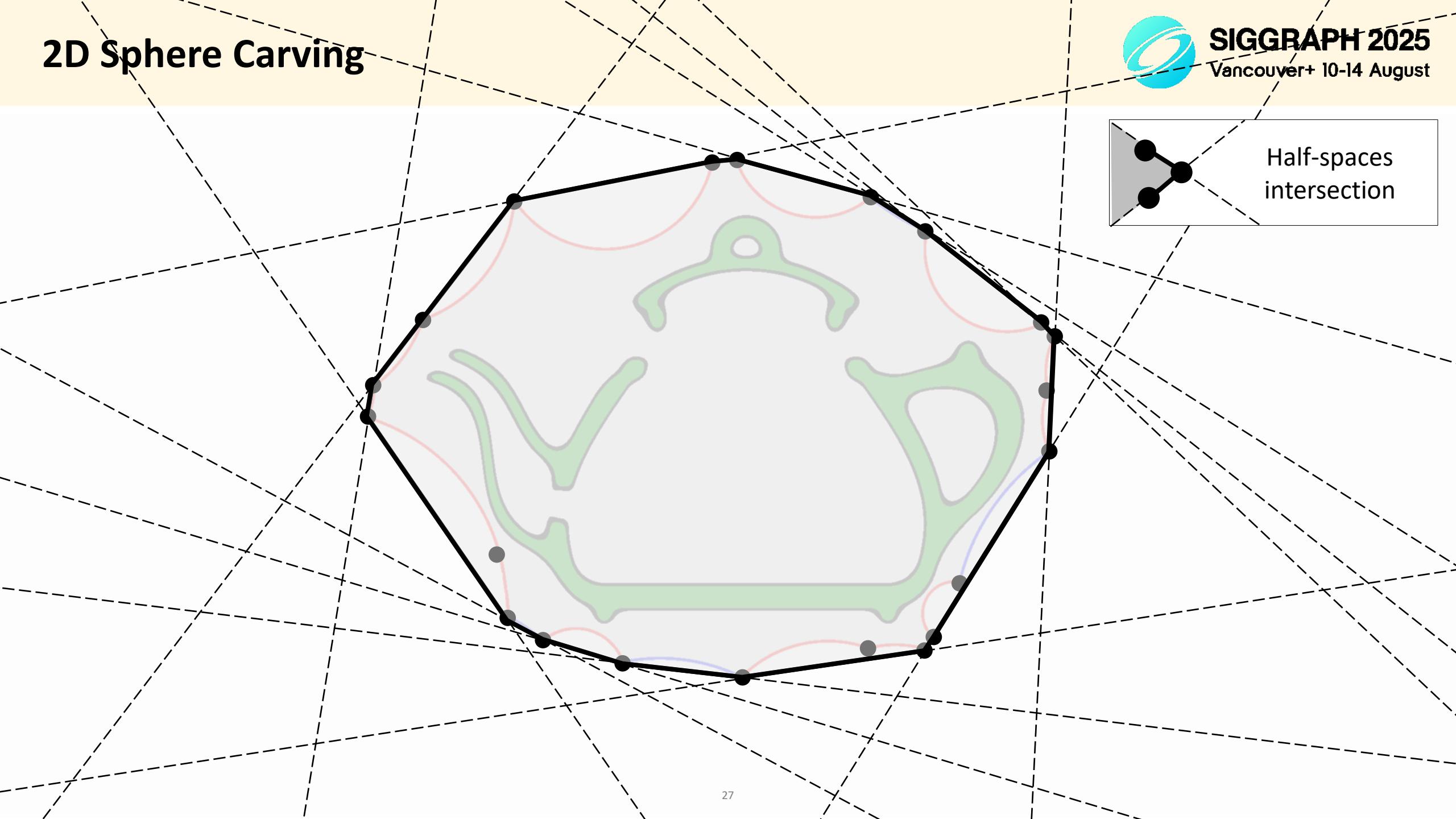
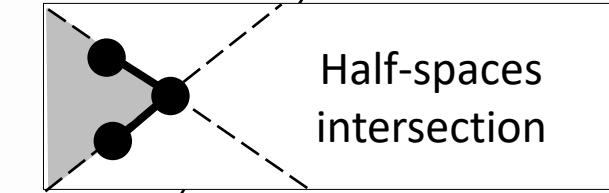


Convex hull

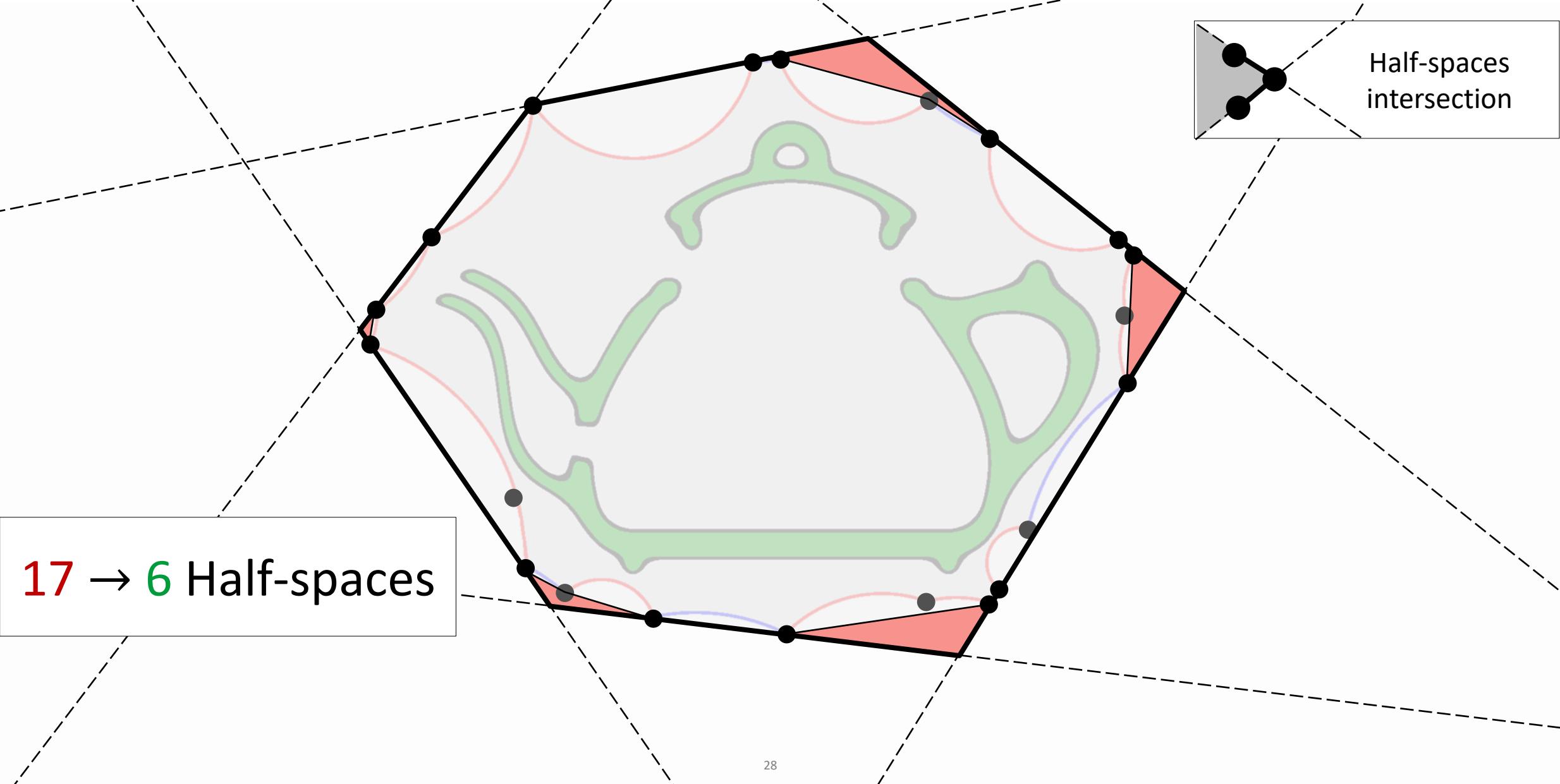
2D Sphere Carving



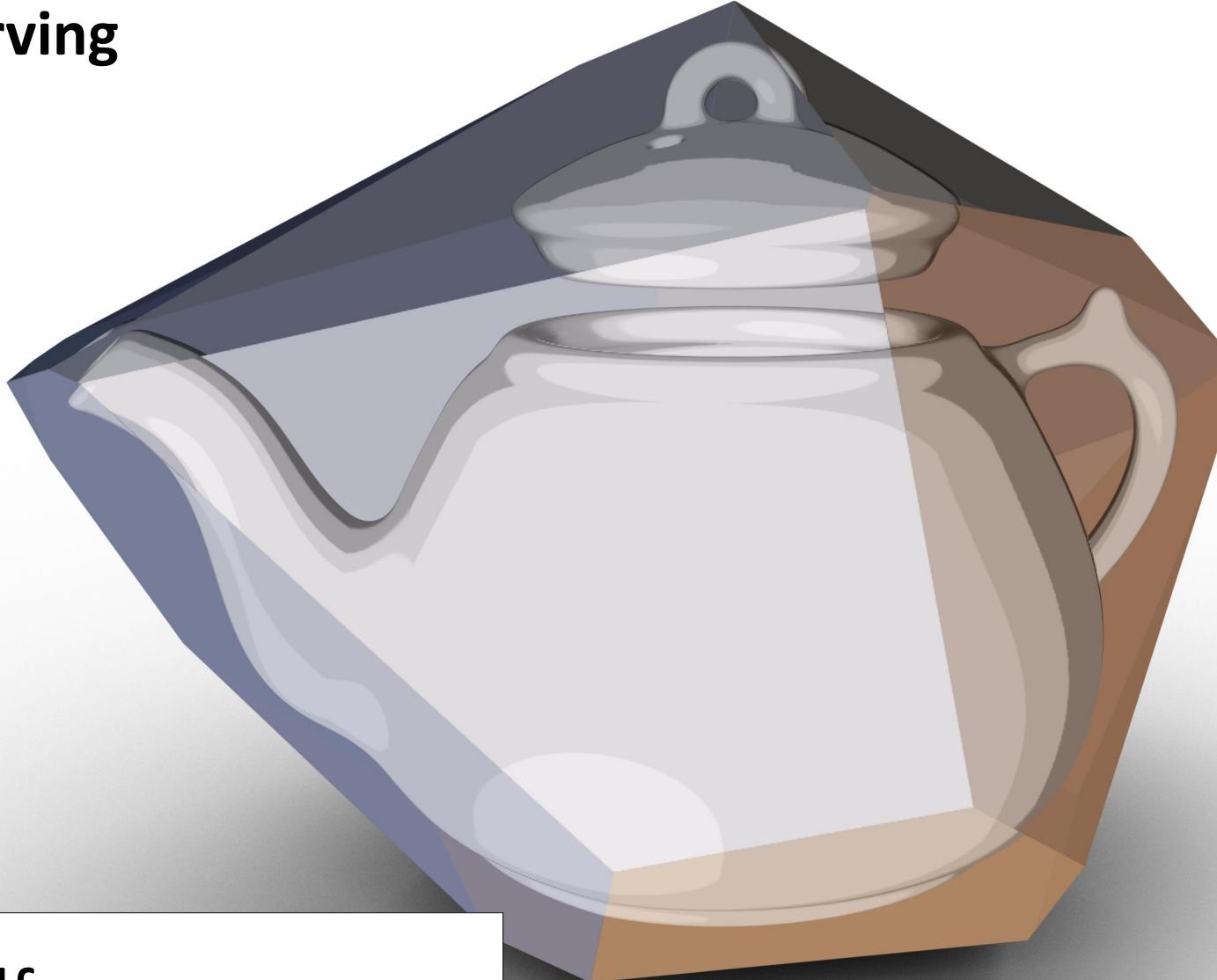
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2D Sphere Carving



3D Sphere Carving



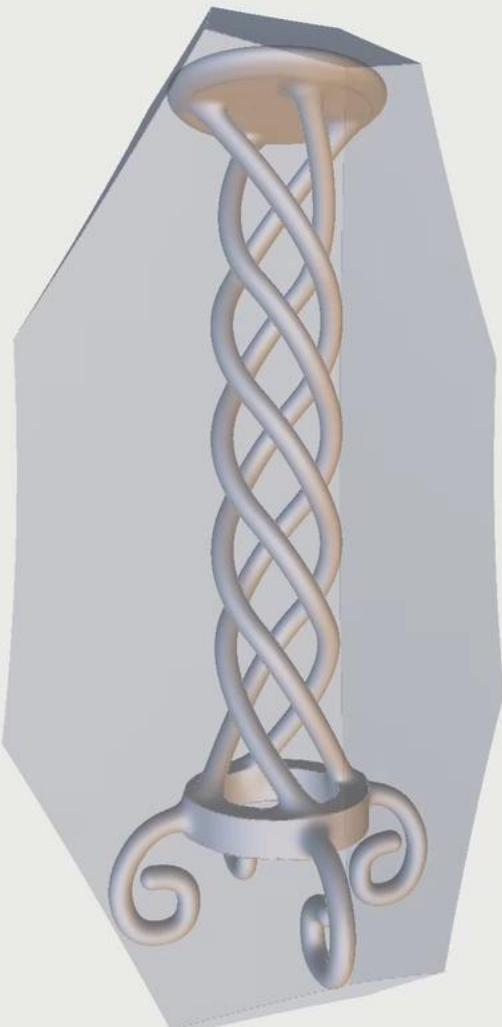
20 half-spaces

Computed using < 5k queries

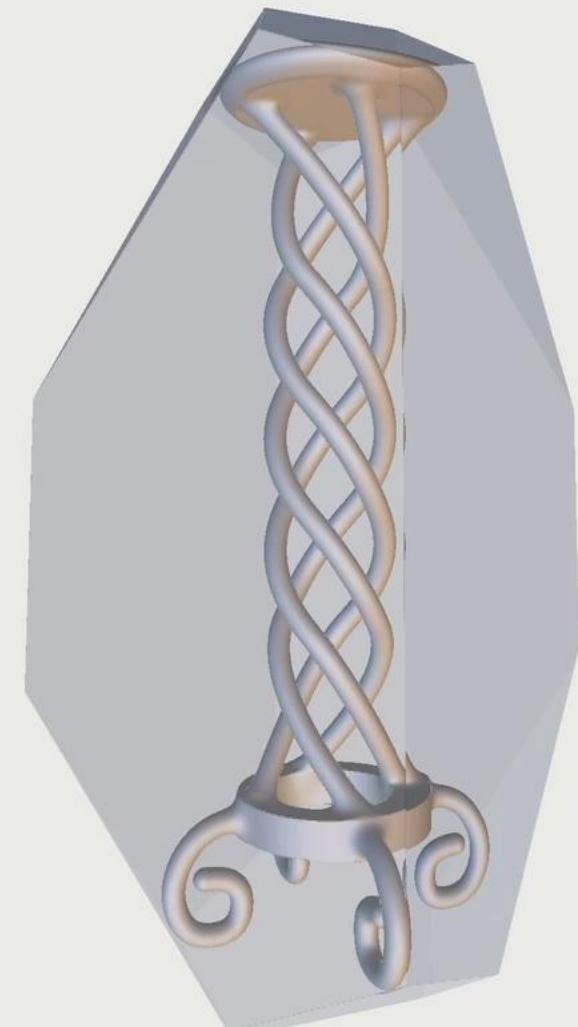
3D Sphere Carving



**Empty
Spheres**

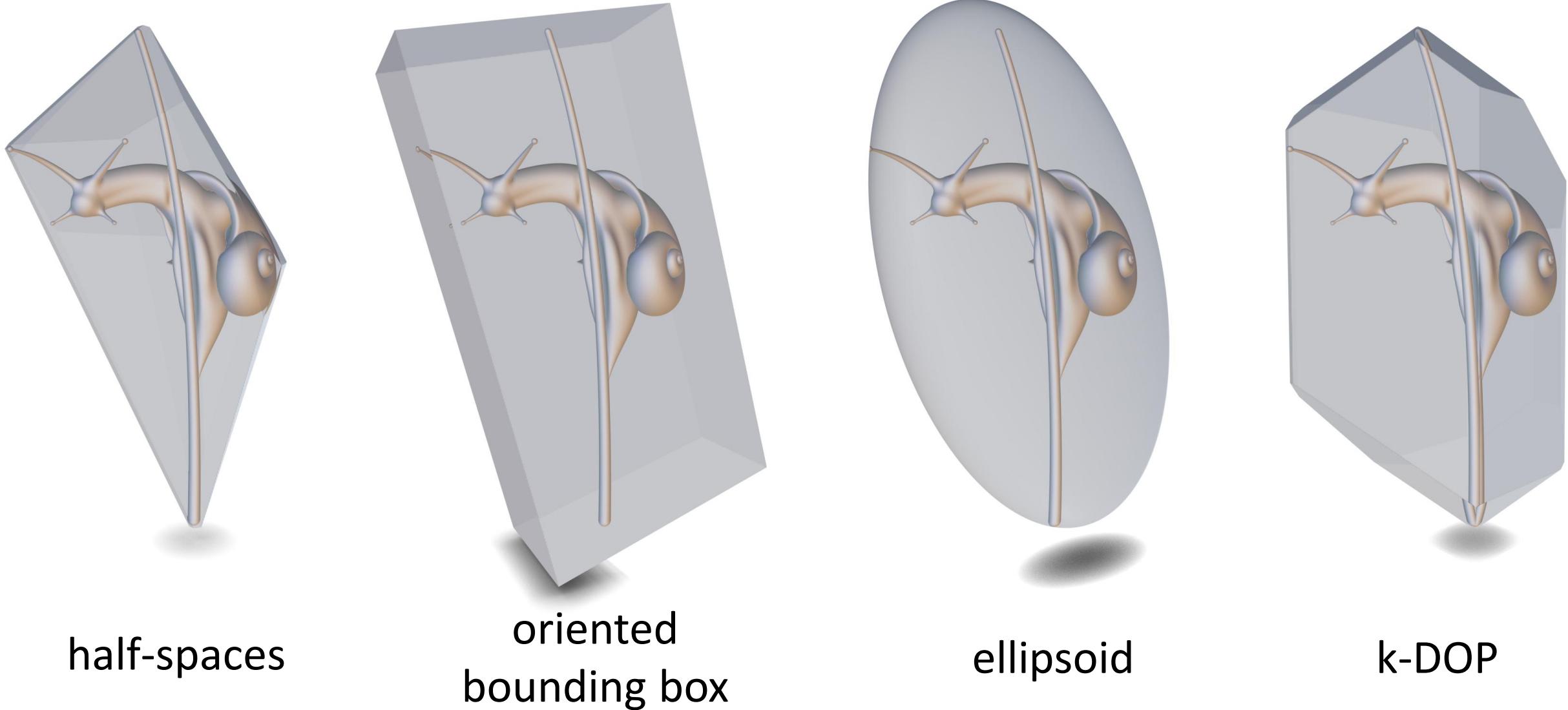


**Carved
Volume**



**Bounding
Volume**

Types of convex bound



half-spaces

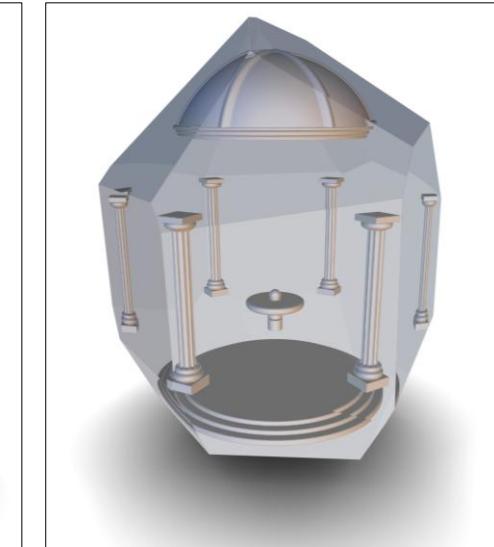
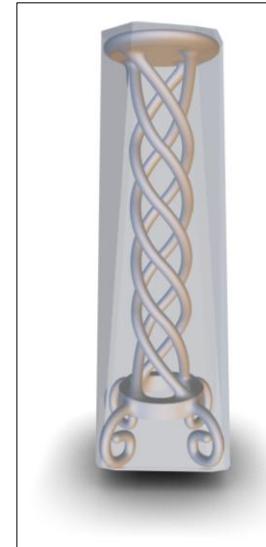
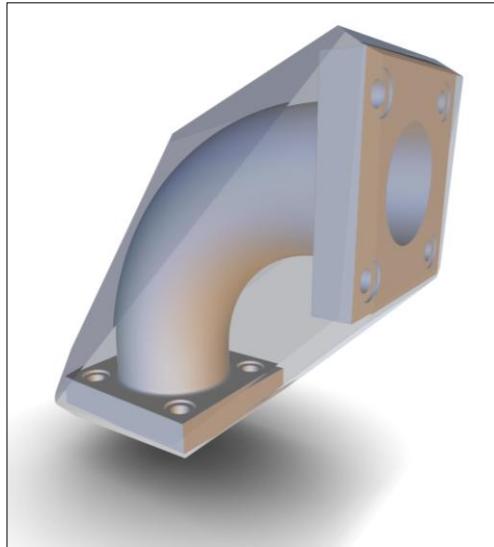
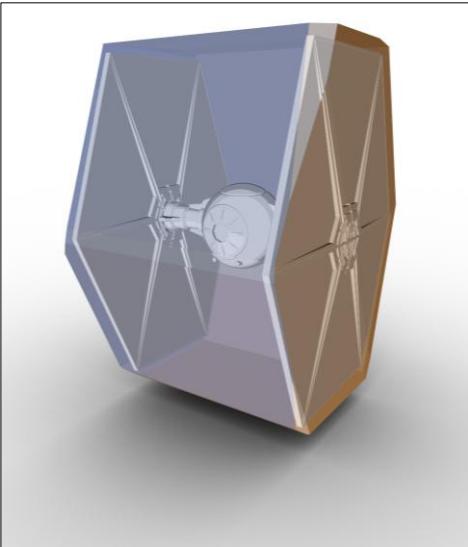
oriented
bounding box

ellipsoid

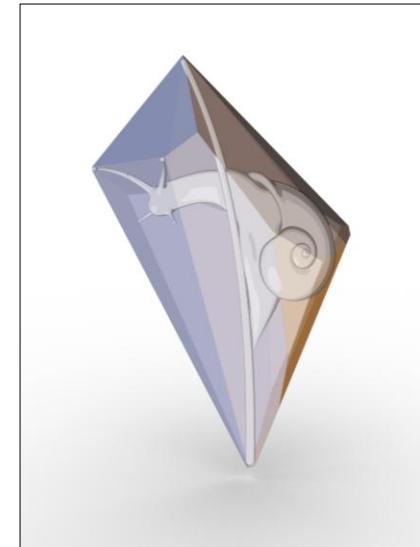
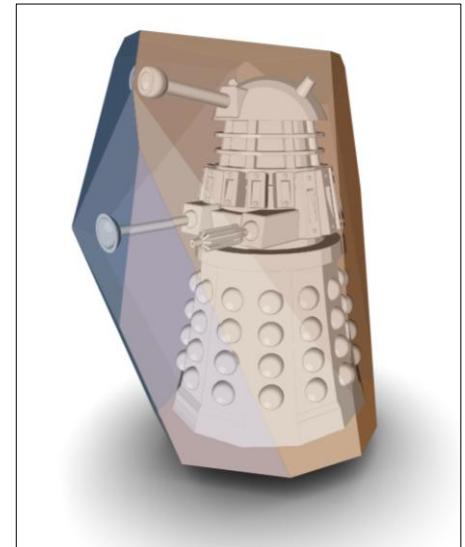
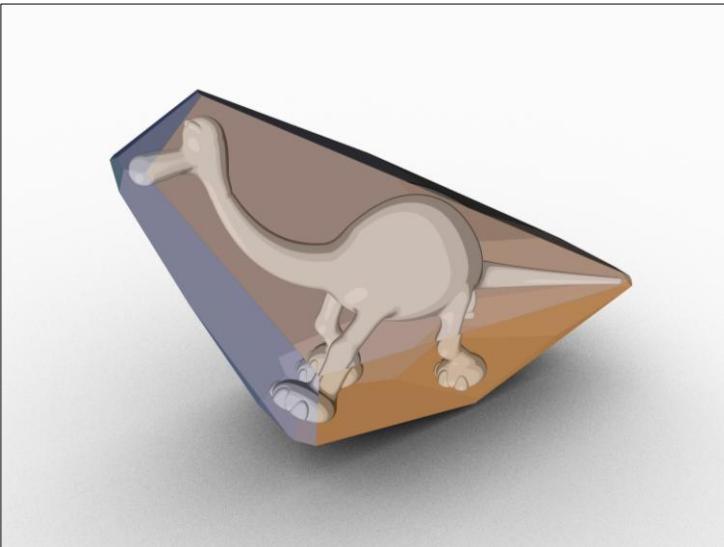
k-DOP

Works on any SDF!

Quasi Exact

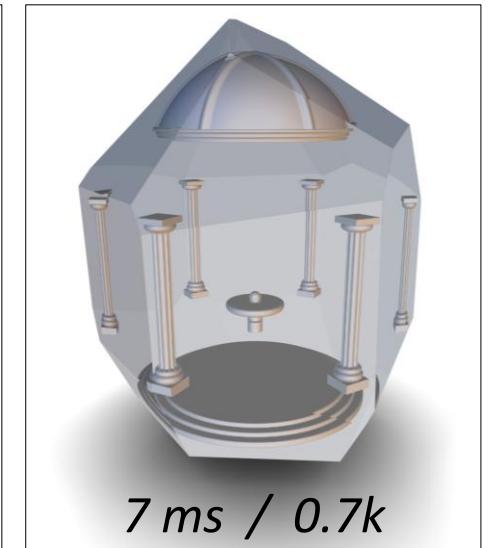
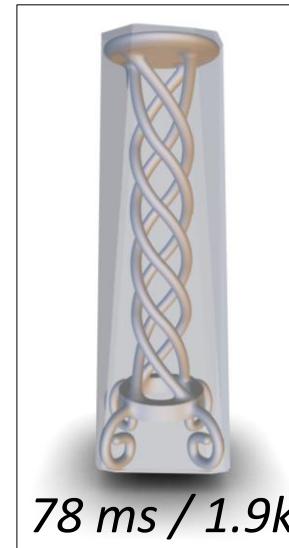
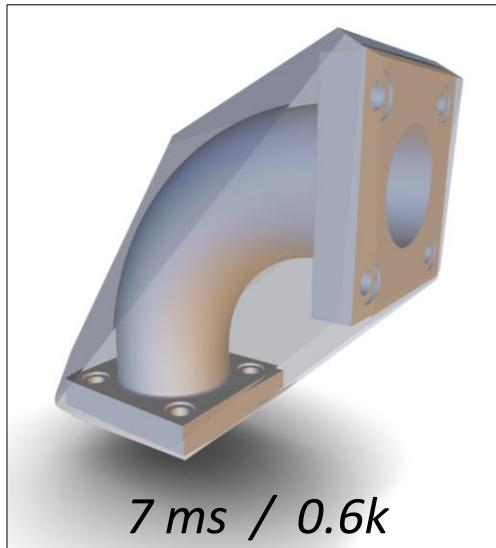
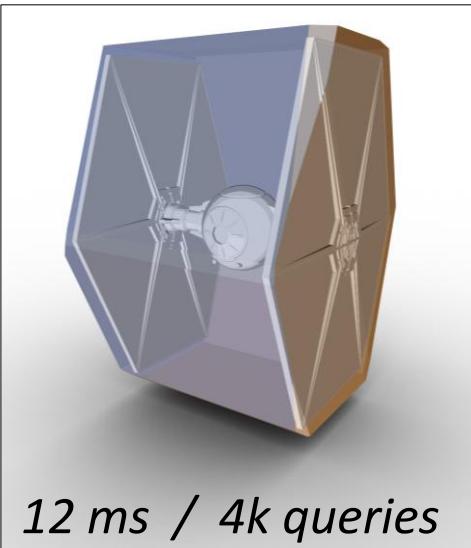


Underestimated

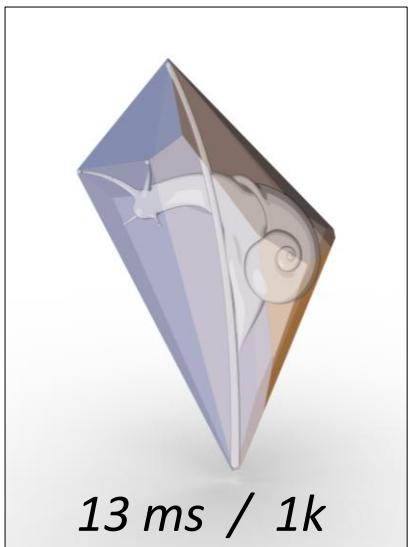
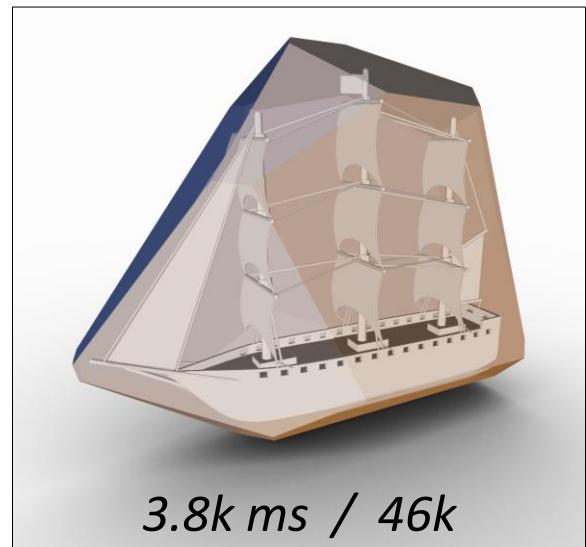
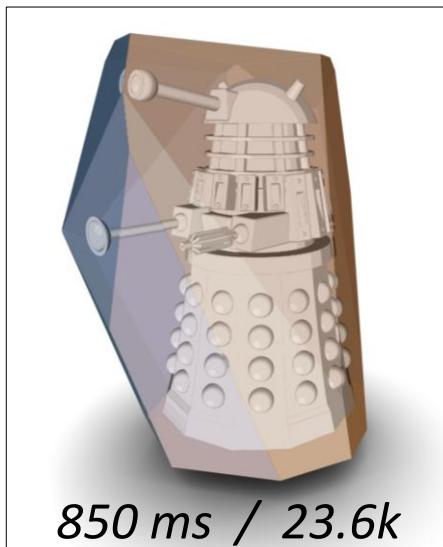
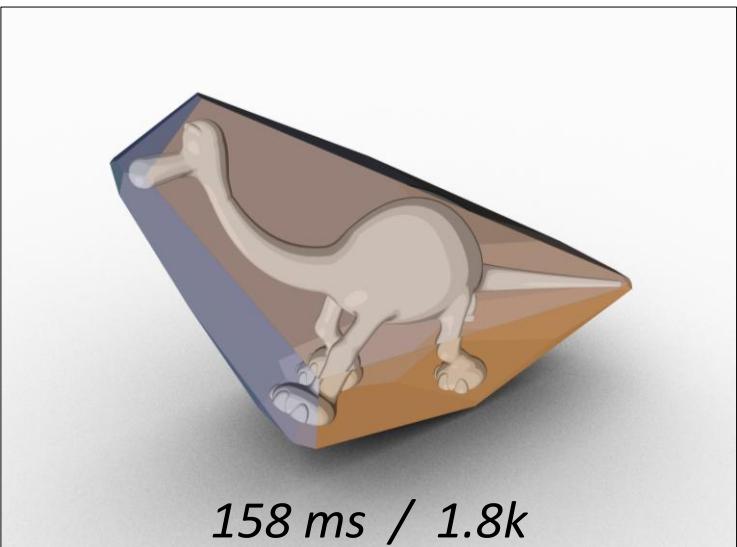


Sphere Carving – Results on CPU

Quasi Exact



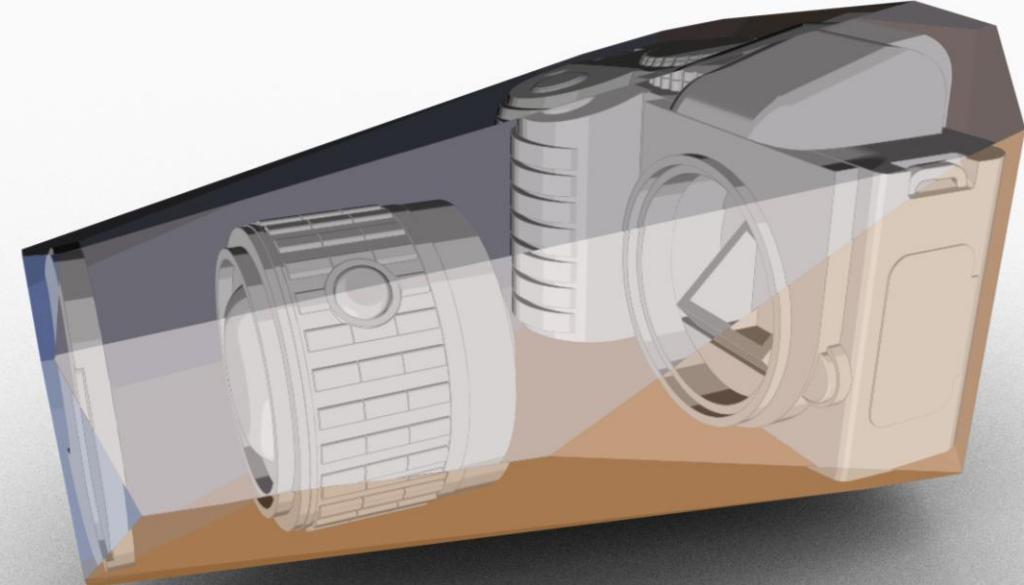
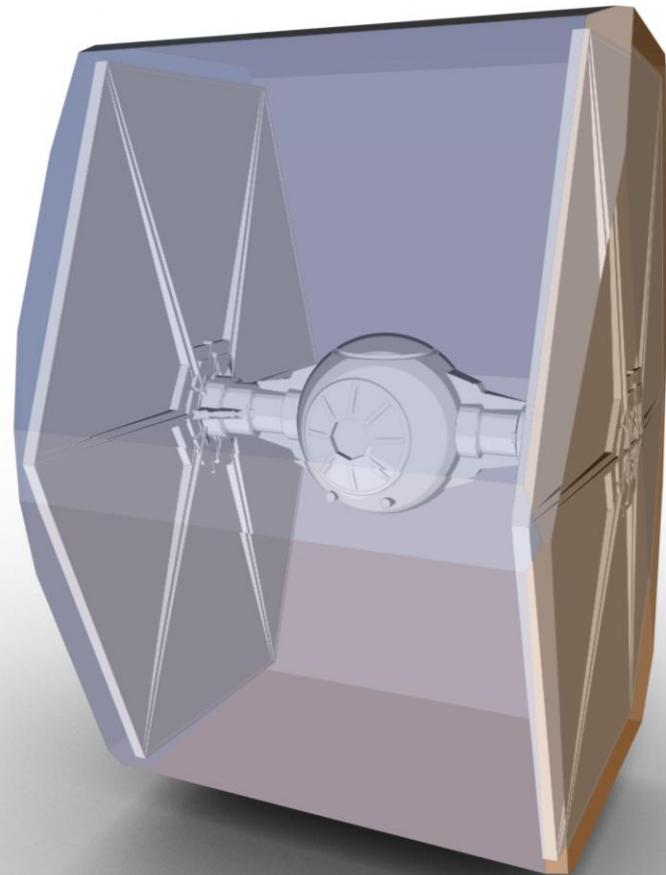
Underestimated



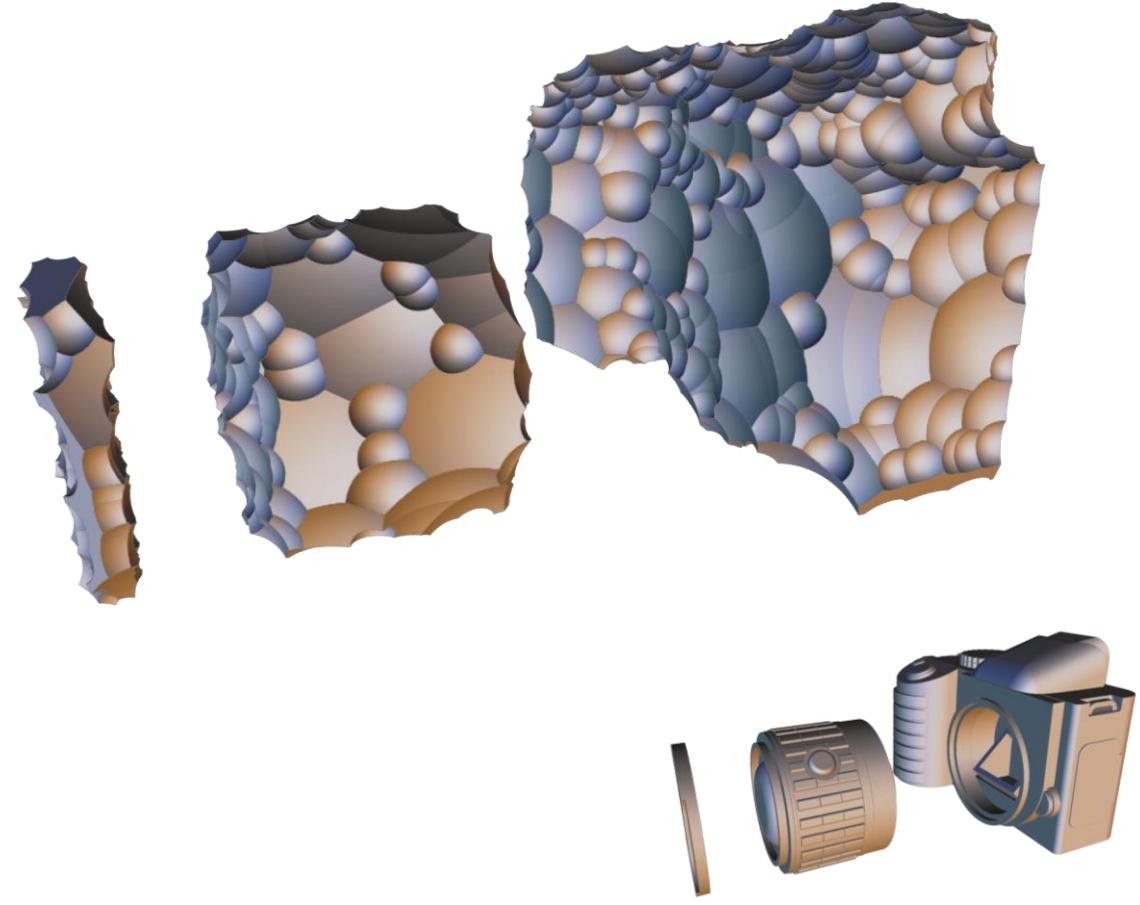
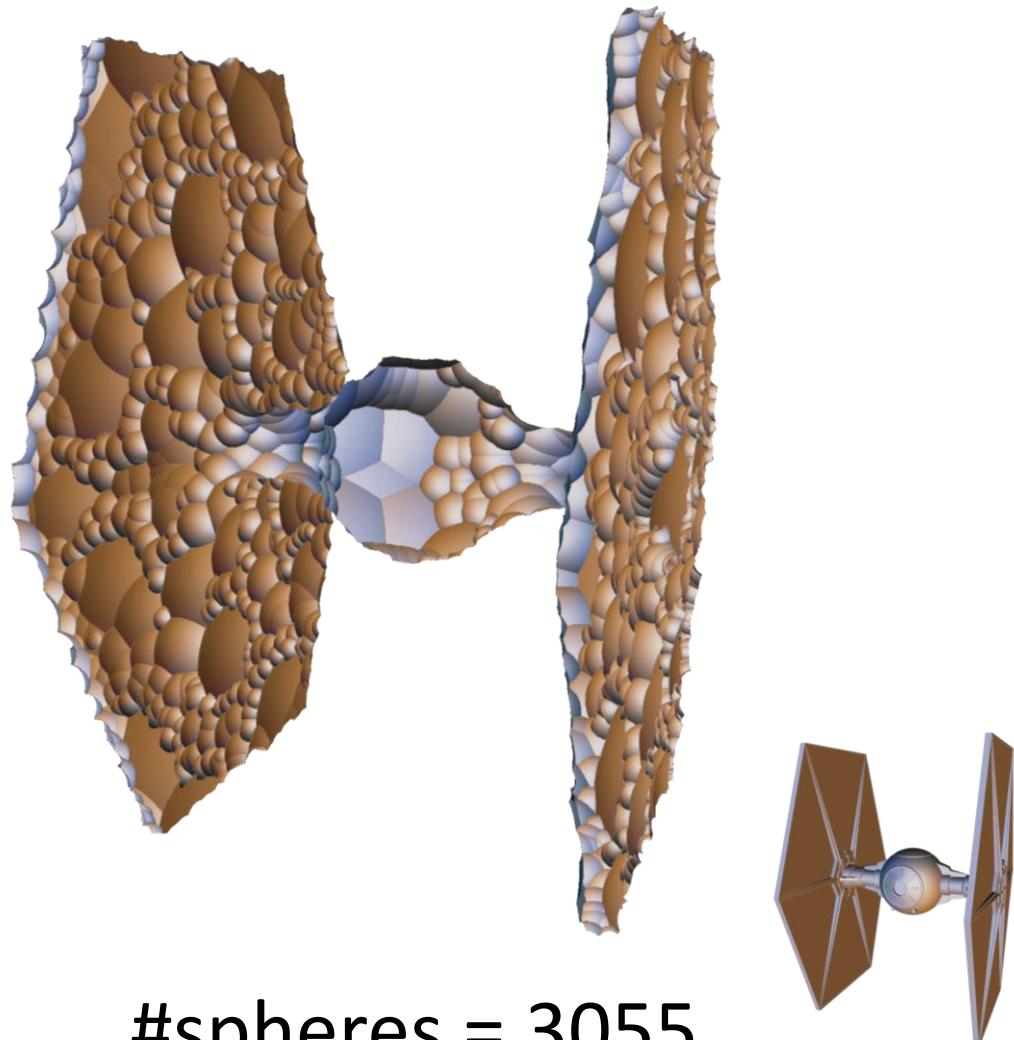
One convex bound?

A single convex bound can include a lot of **empty space**.

Can we extract **multiple convex bounds** for one shape/scene?



Sphere Carving – Carved volume

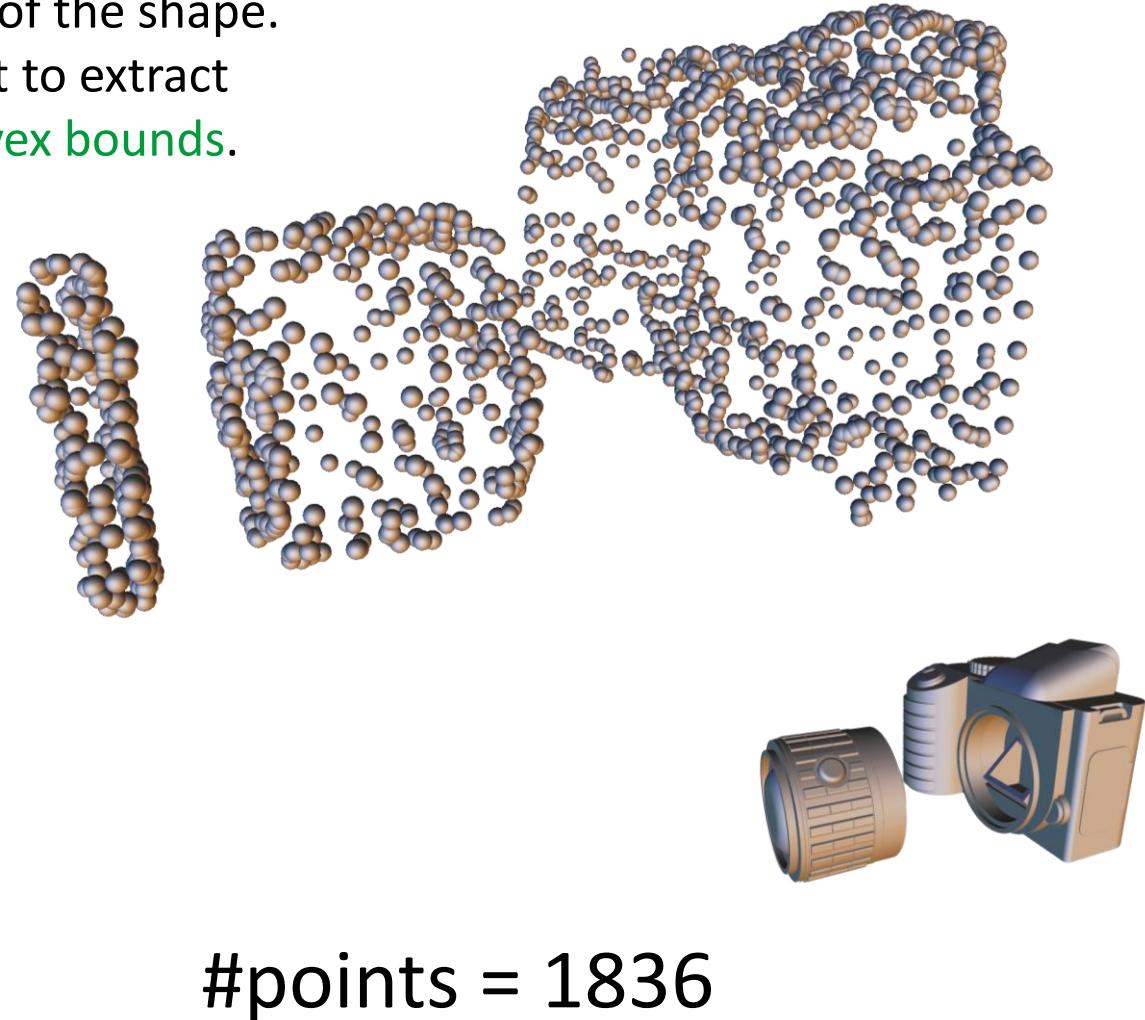


Sphere Carving – final point cloud

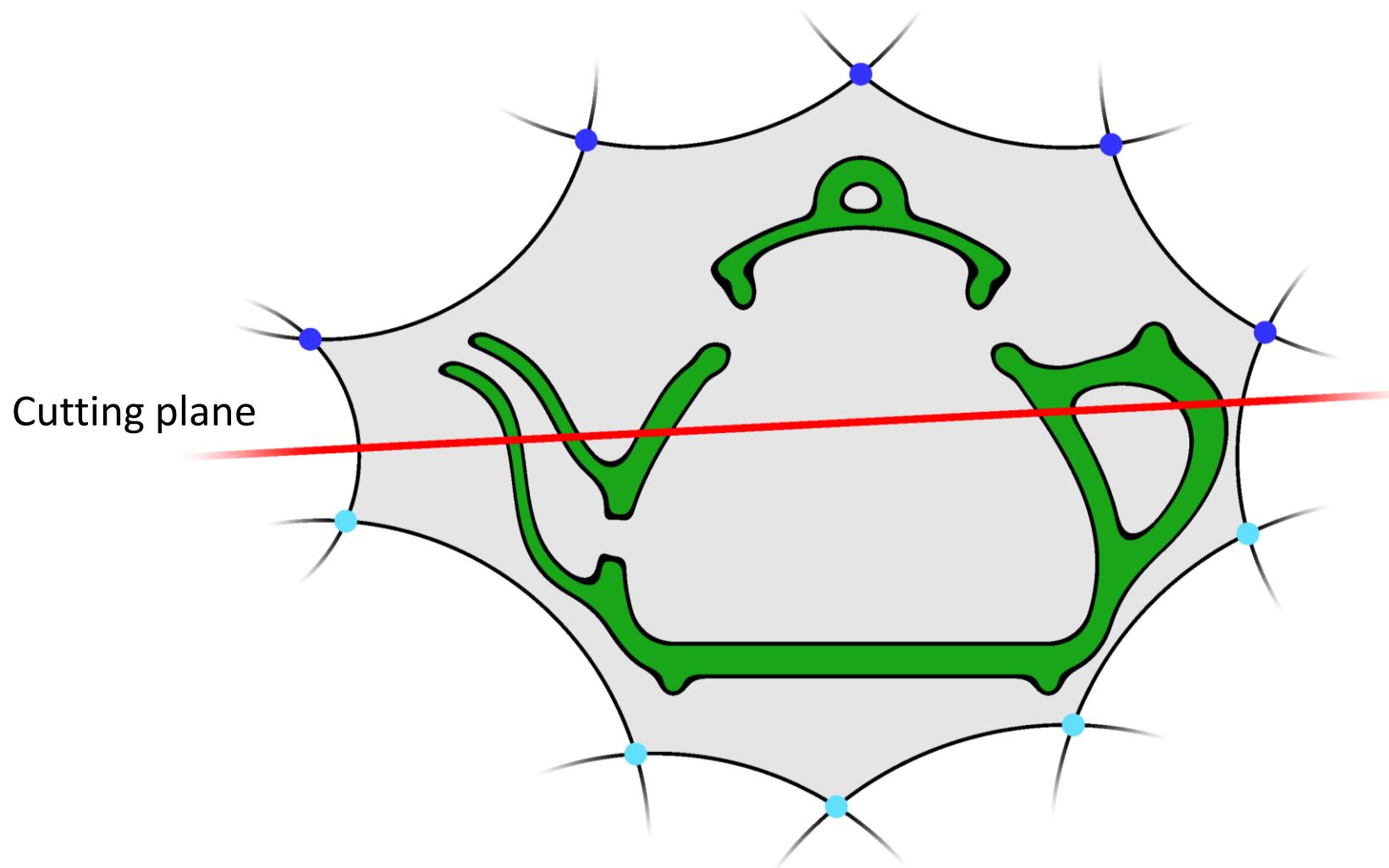


The final point cloud is already a good approximation of the shape.

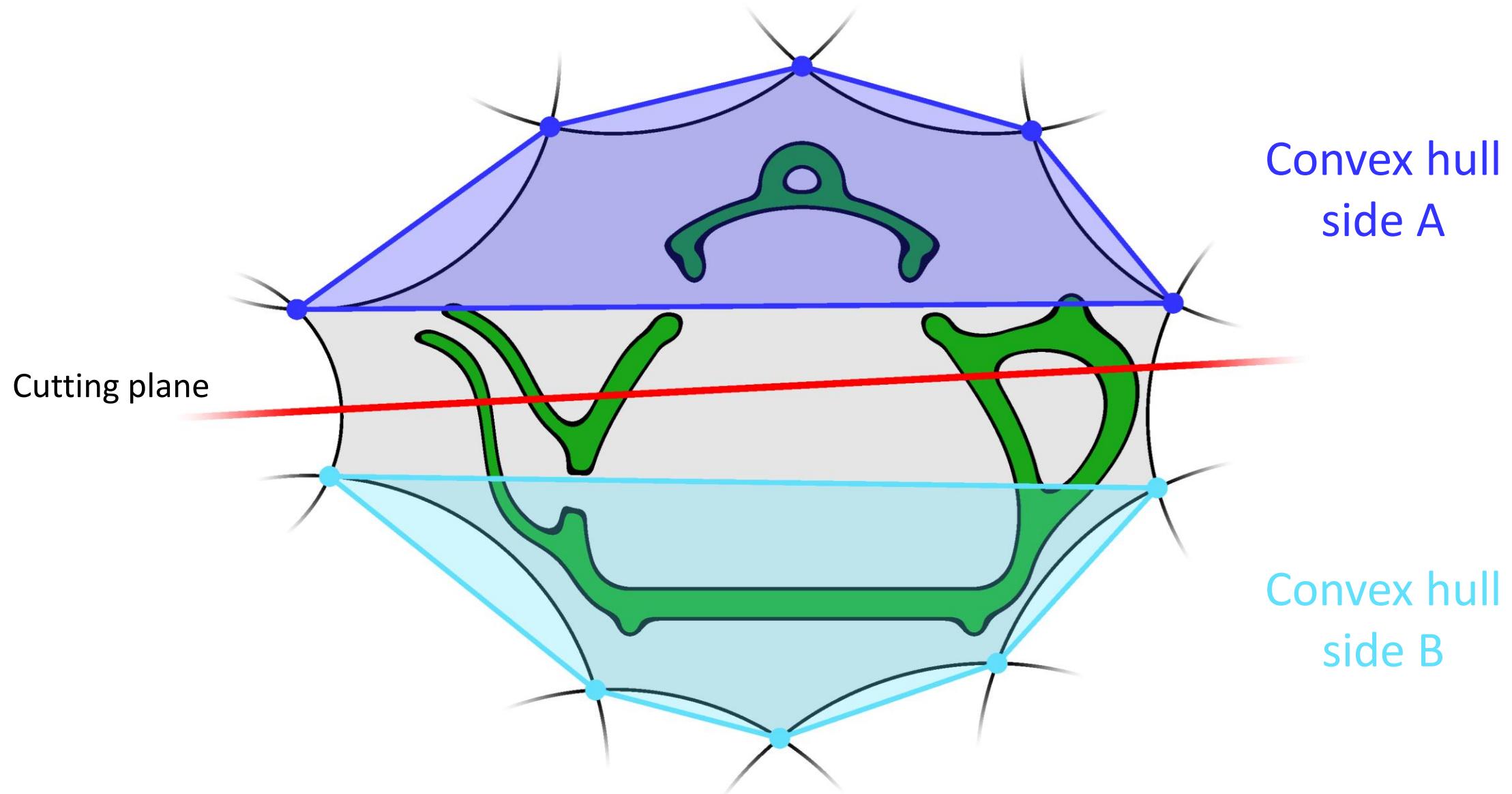
We can use it to extract multiple convex bounds.



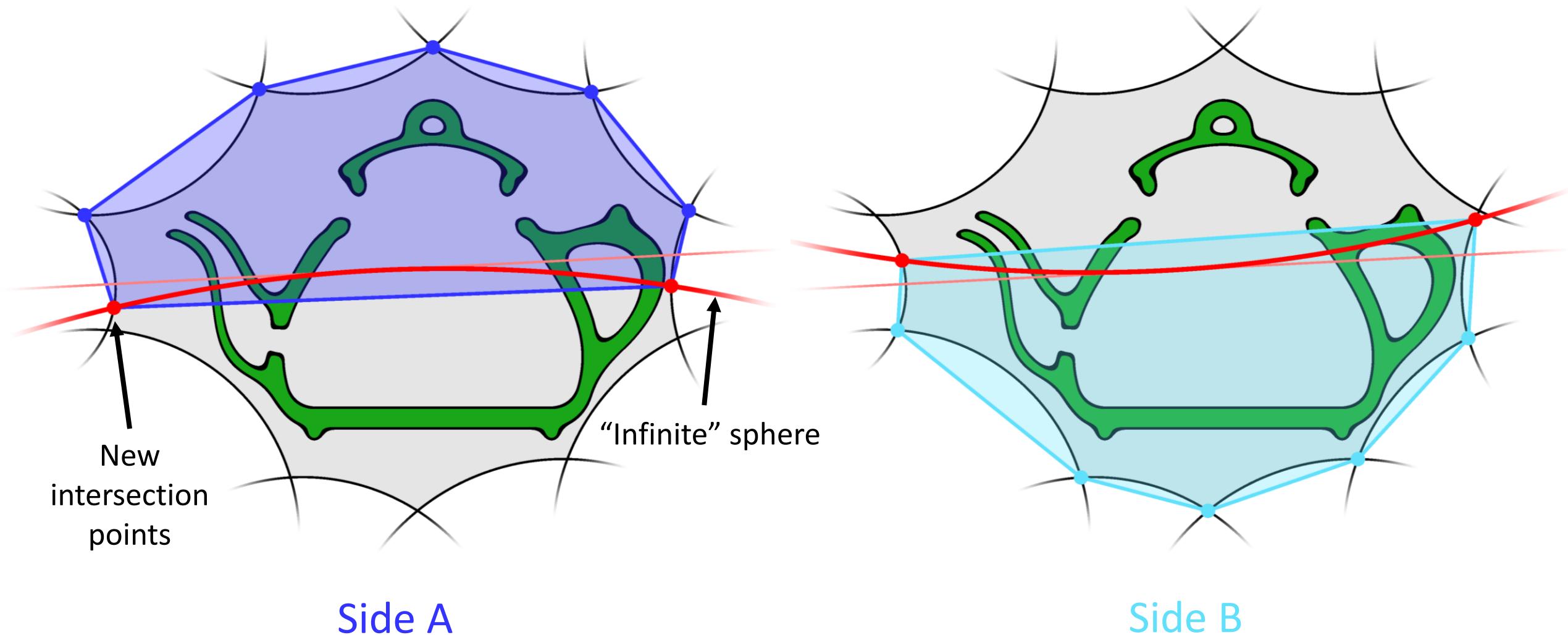
Use convex decomposition techniques [*Thul 2018*] on the point cloud!



Sphere Carving – ACD splitting

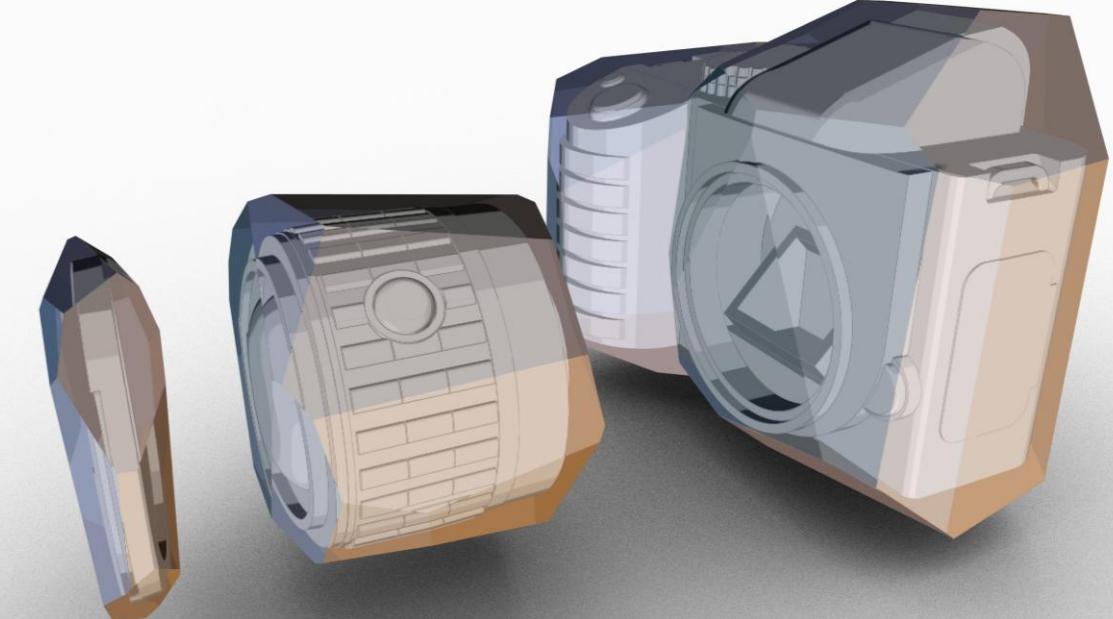
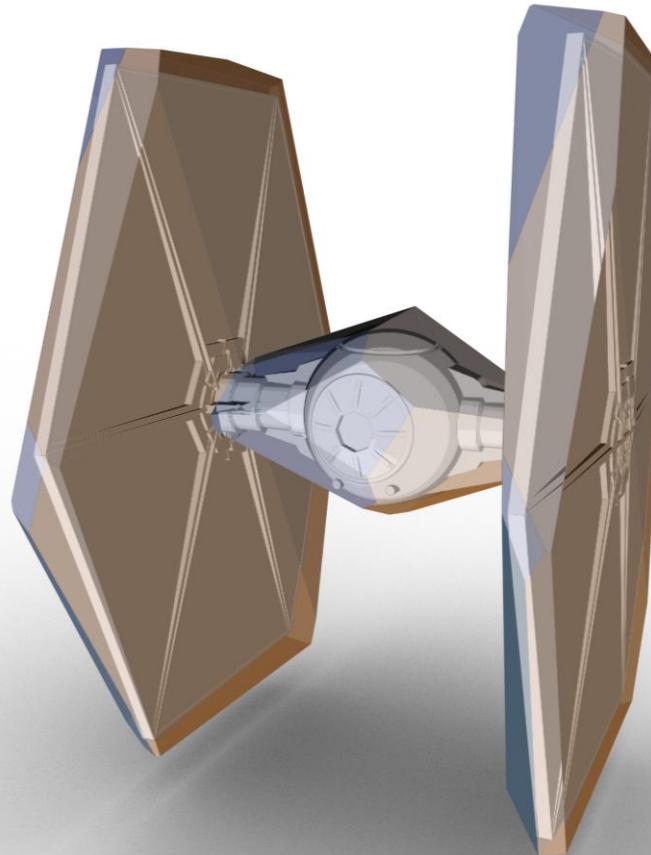


Sphere Carving – Approximating cutting planes



Sphere Carving – Full ACD

The new bounds discard more empty space and separate different components.



Sphere Carving generates bounding volumes around SDFs

- Robustness / Bounding guarantees
- Fast generation for most SDFs
- Compatible with convex decomposition methods
- Provides speedups for popular methods (Marching Cubes, Sphere Tracing)

Future work perspectives

- Acceleration structure to speed-up the sphere intersections
- More precise meshing of the carved volume
- Bound update after local shape editing
- Interior Sphere Carving



Source code available

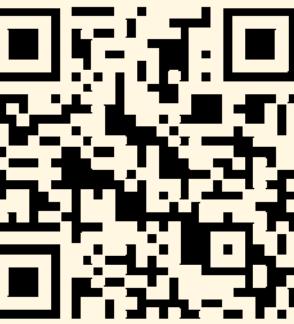
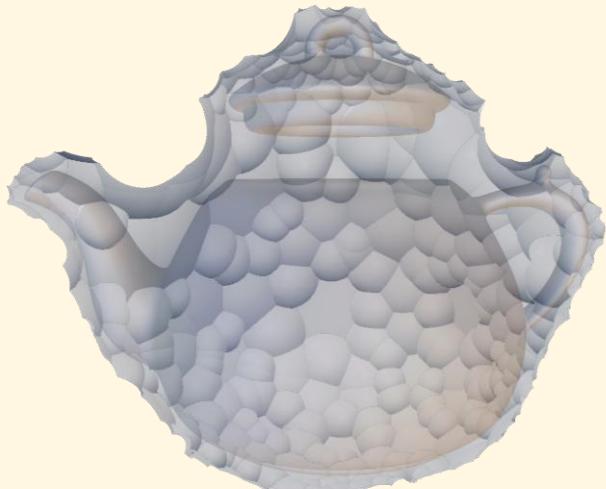


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Thank you

Merci



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