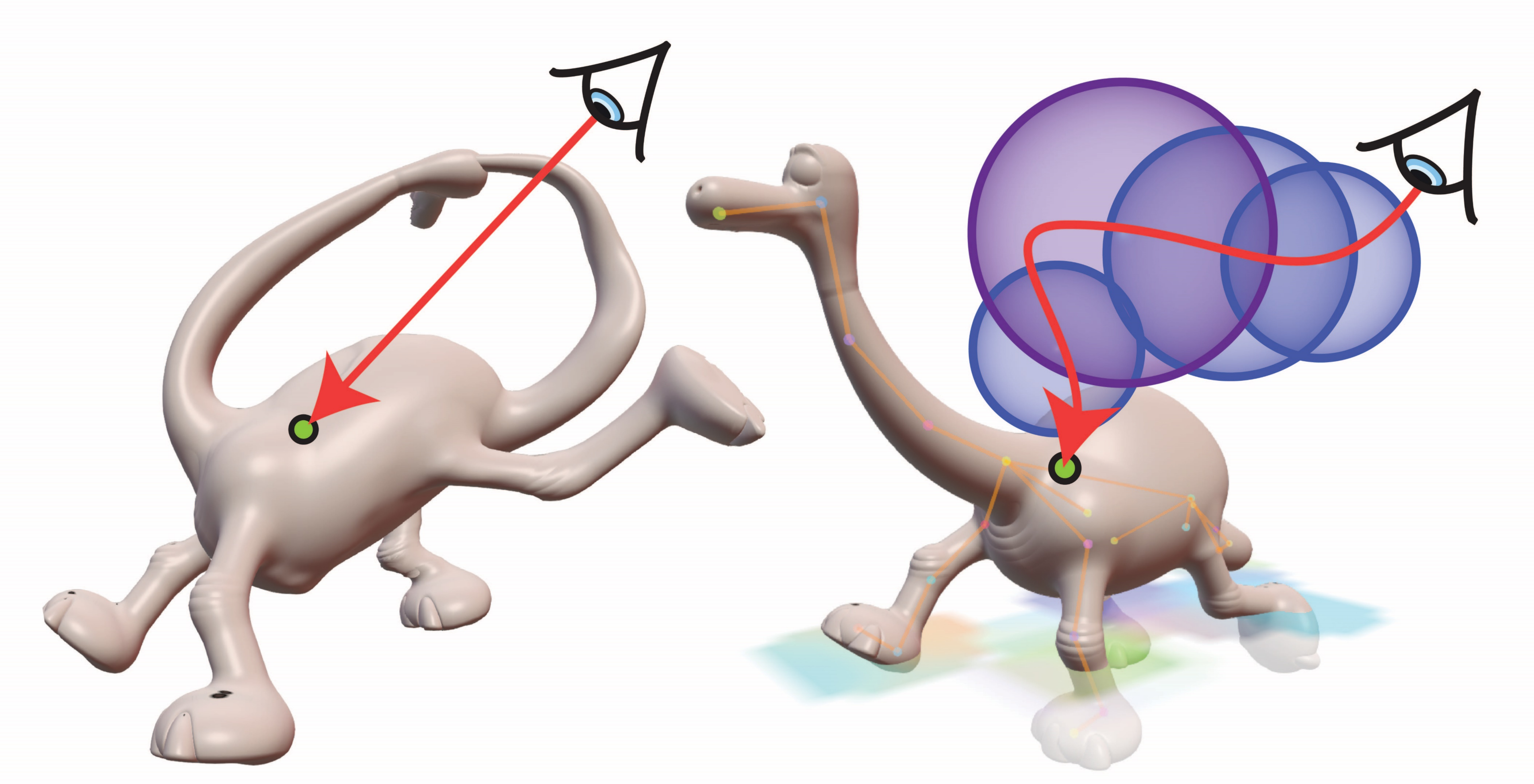
Non-linear Sphere Tracing for Rendering Deformed Signed Distance Fields



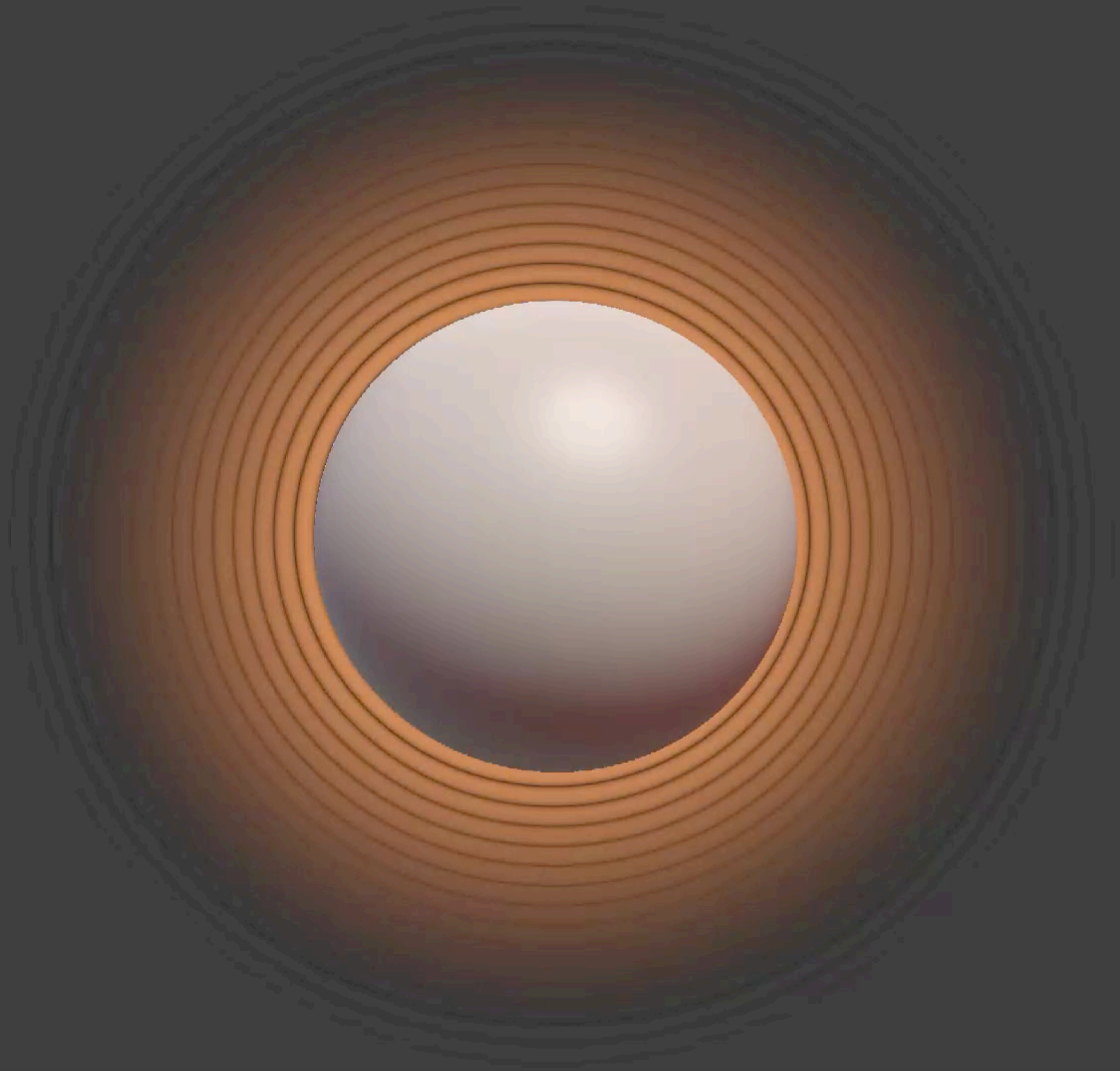
Dario Seyb[1] Alec Jacobson[2] Derek Nowrouzezahrai[3] Wojciech Jarosz[1]

[1] DARTMOUTH VISUAL COMPUTING LAB

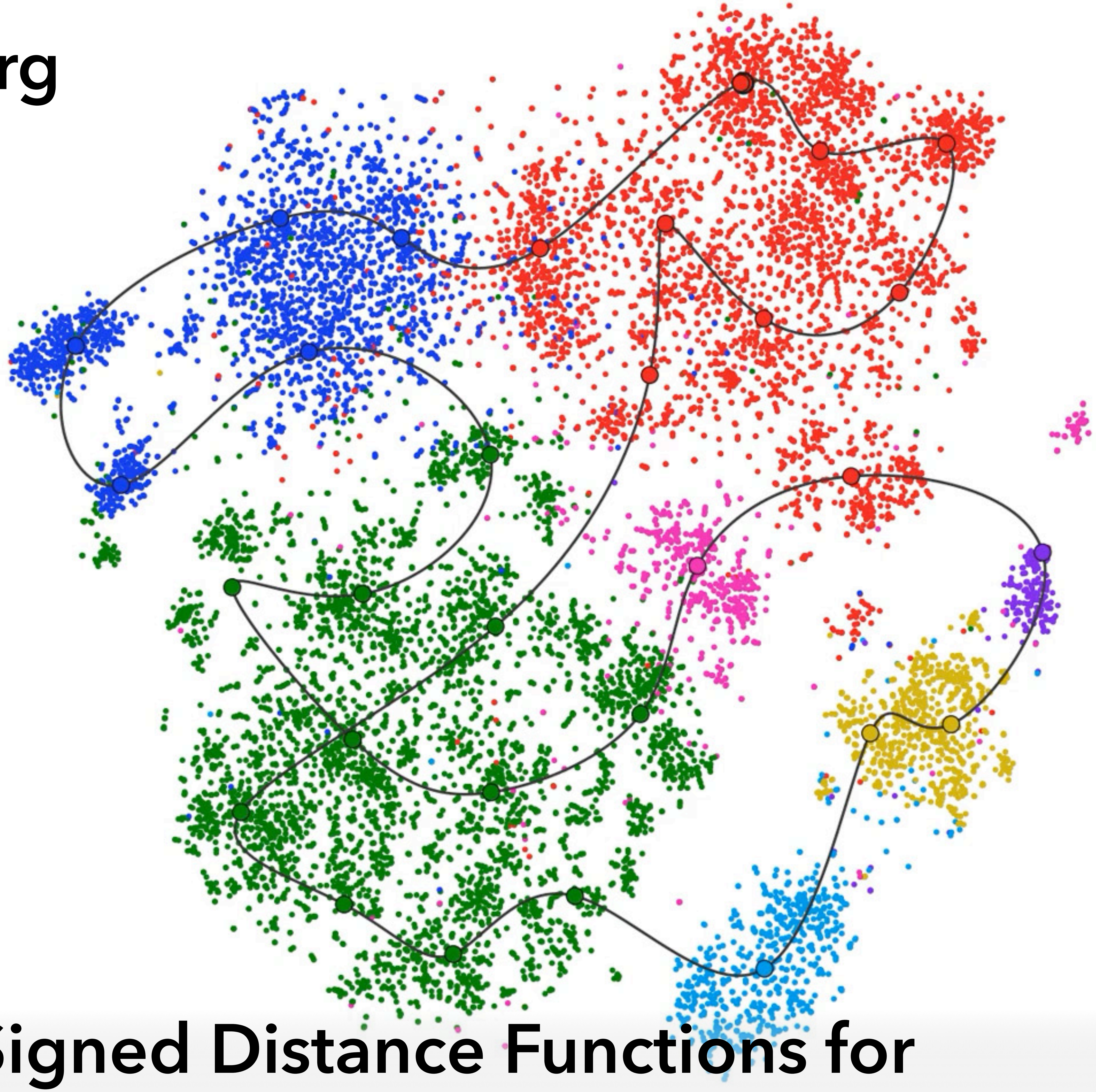
[2] Computer Science UNIVERSITY OF TORONTO

[3] McGill


shadertoy.com/view/ldd3DX

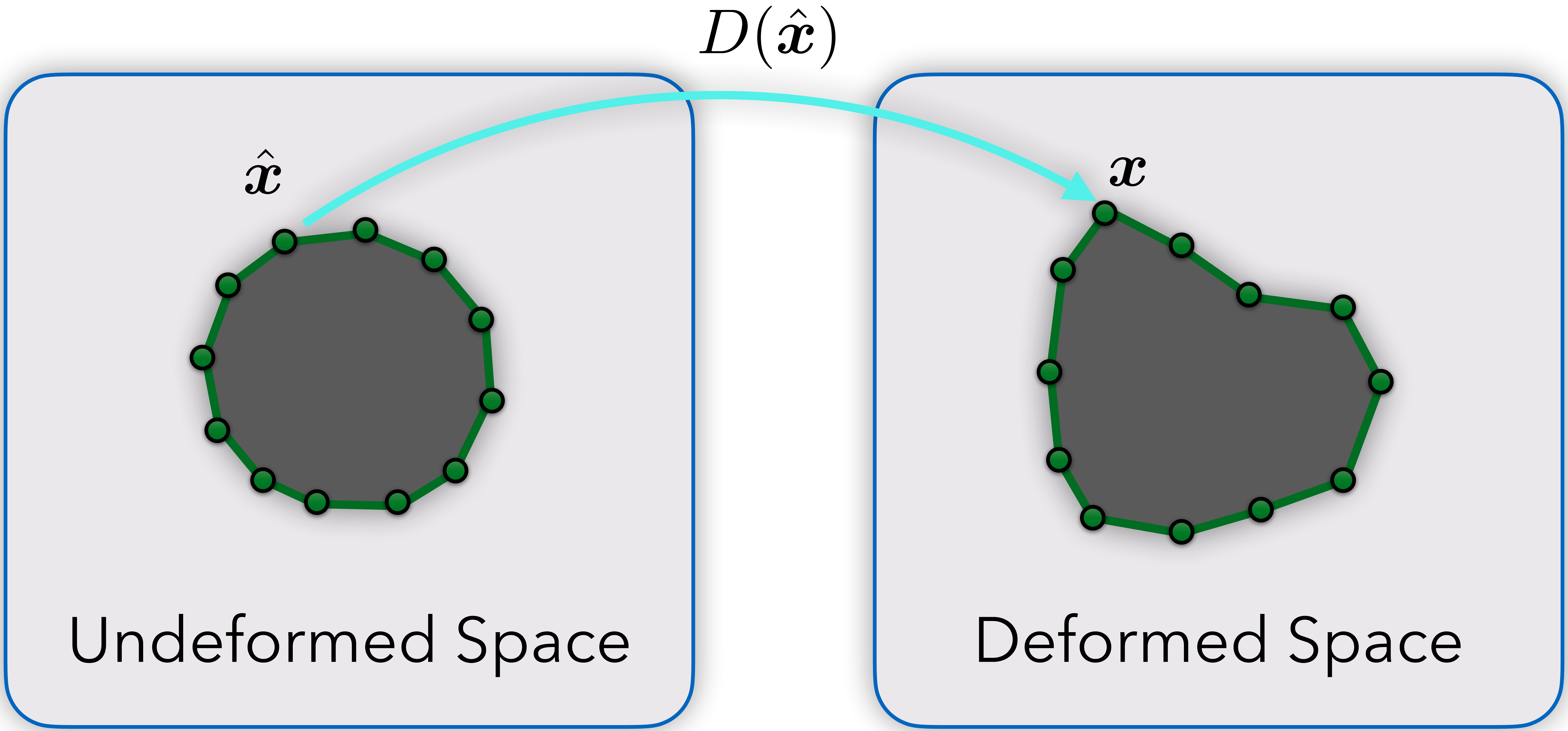


Visualization by Marian Kleineberg



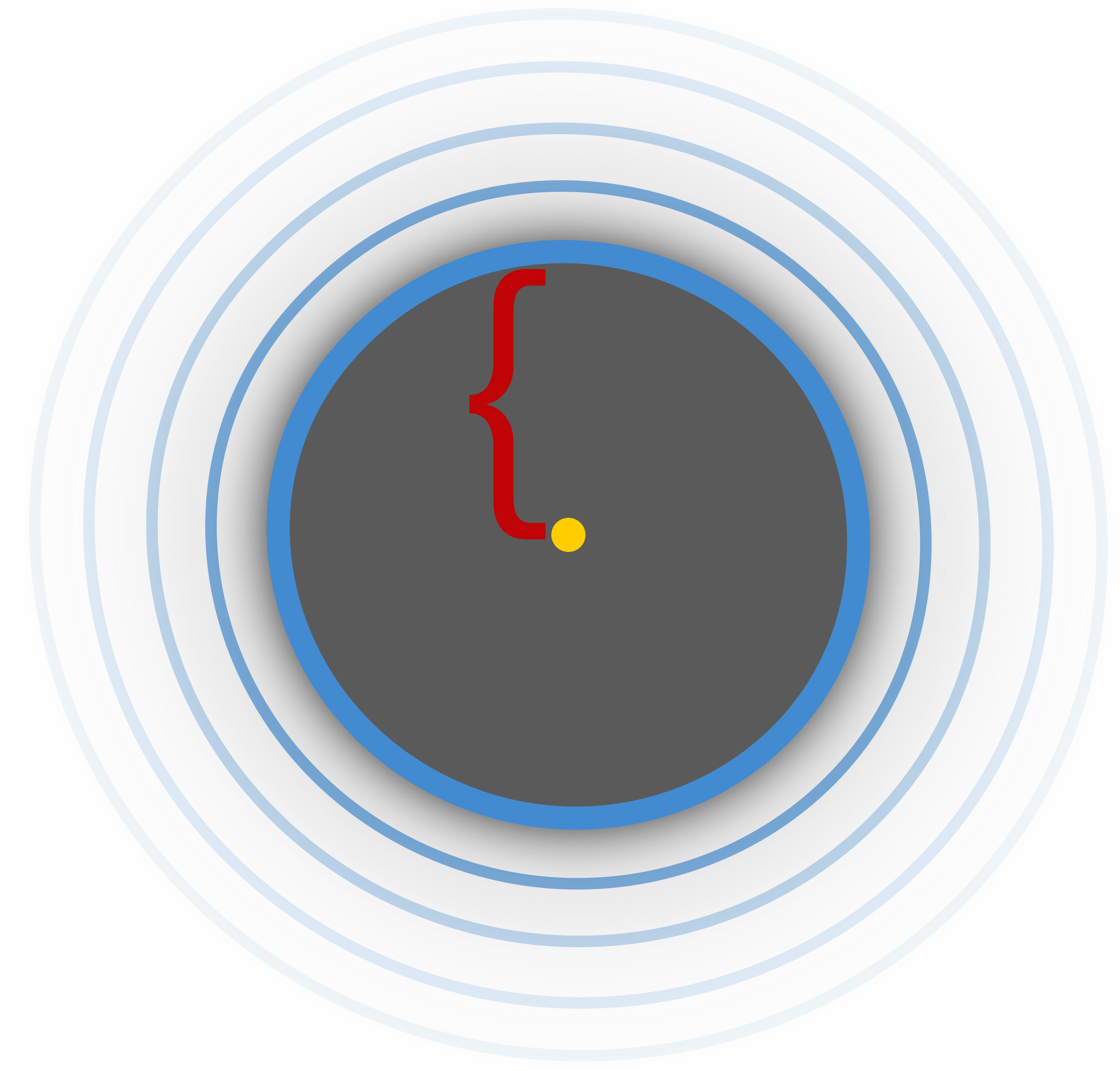
DeepSDF: Learning Continuous Signed Distance Functions for Shape Representation. Genova et. al, 2019

"Forward" Deformations

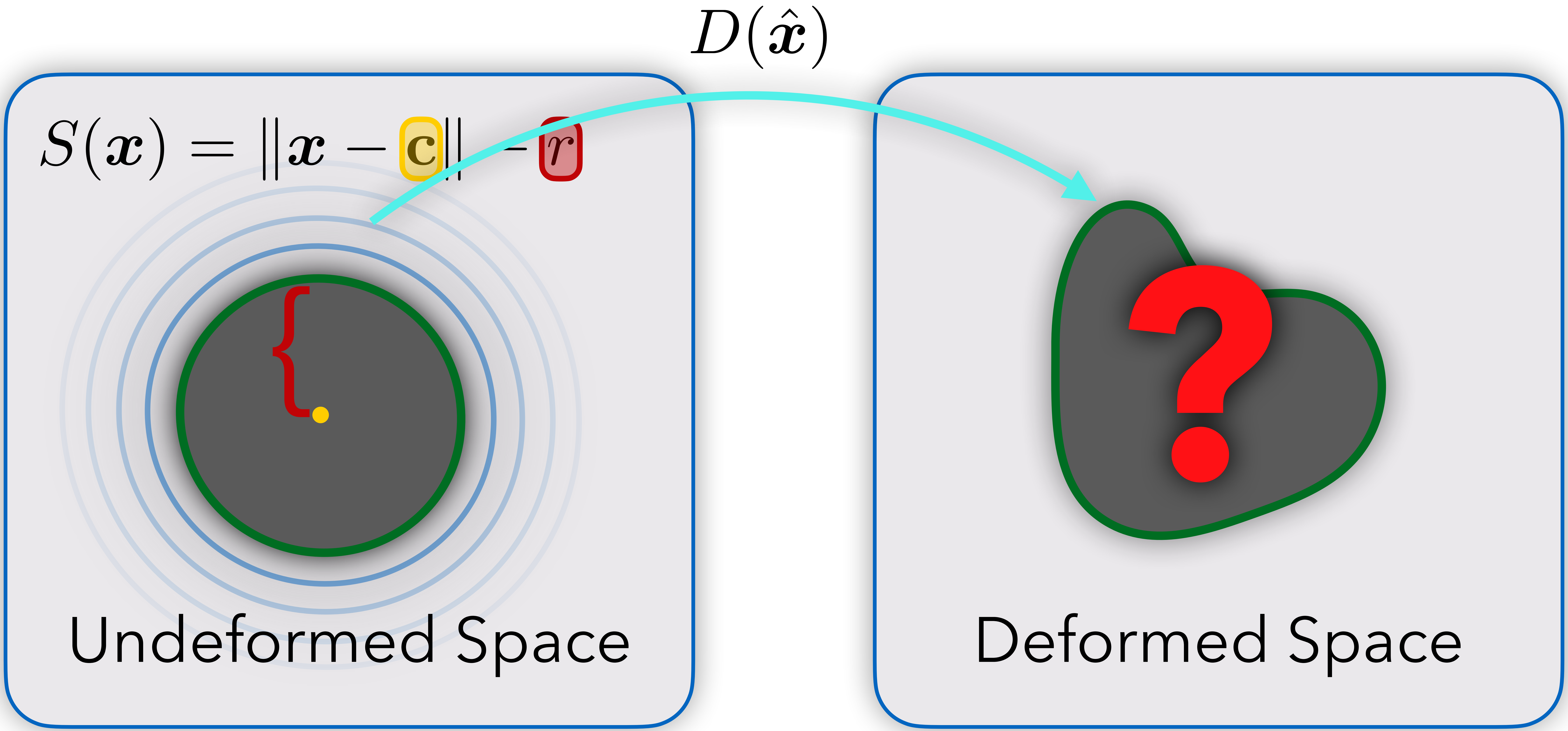


Implicit Surface Representations

$$S(x) = \|x - \mathbf{c}\| - r = 0$$



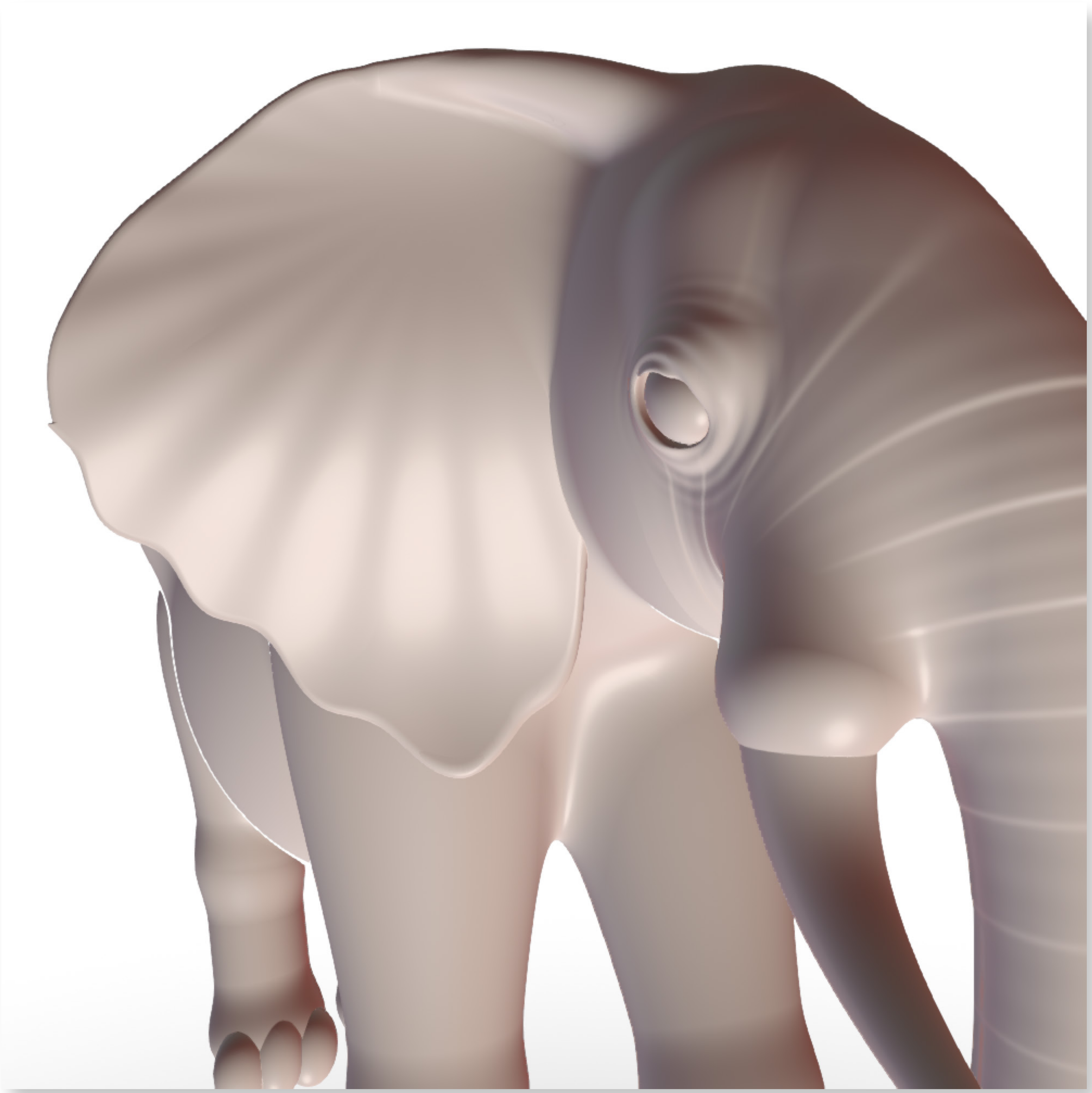
Implicit Surface Deformation



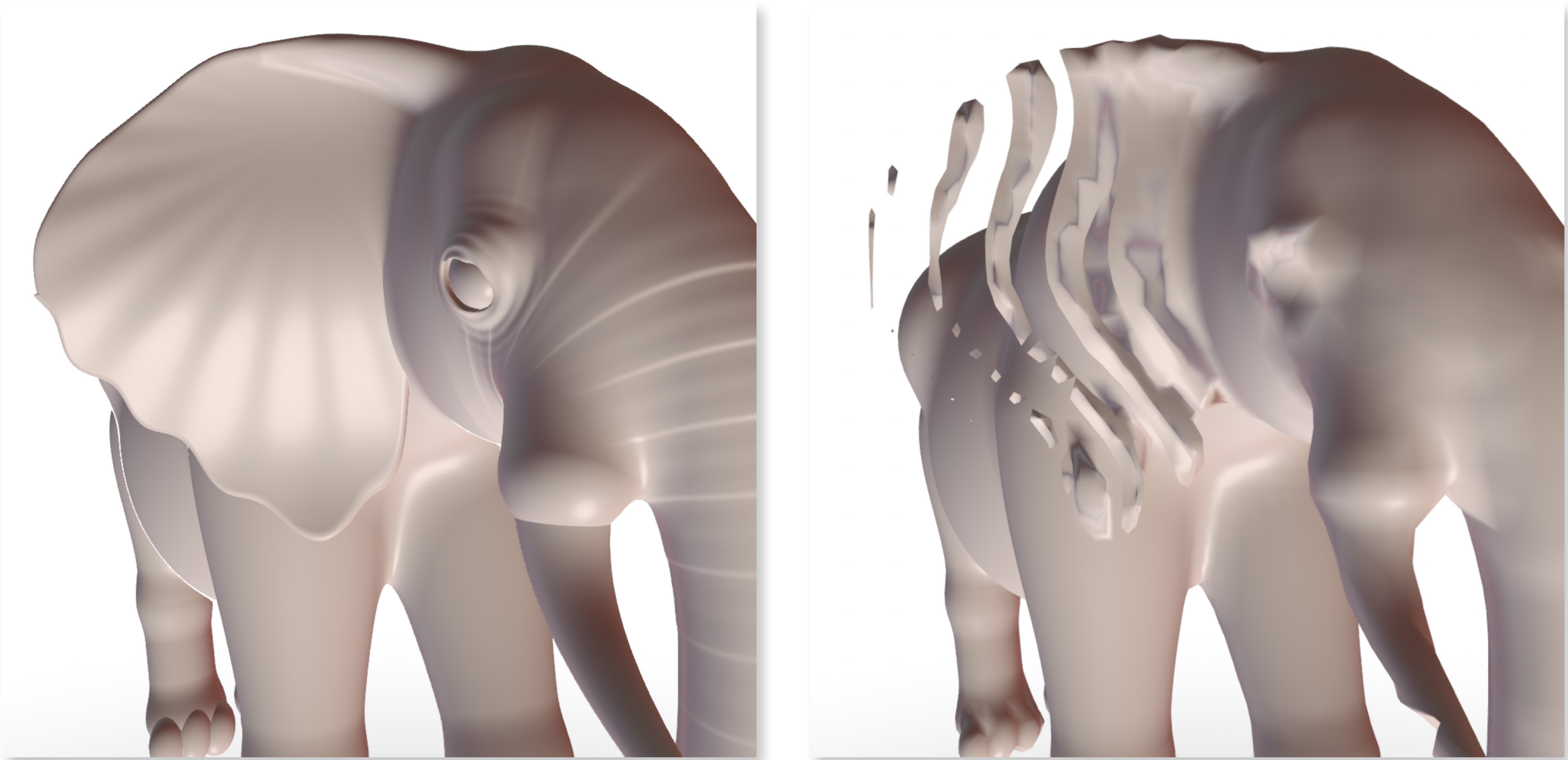
Problem Statement

Use **conventional deformation techniques** to directly render deformed **implicit surfaces**

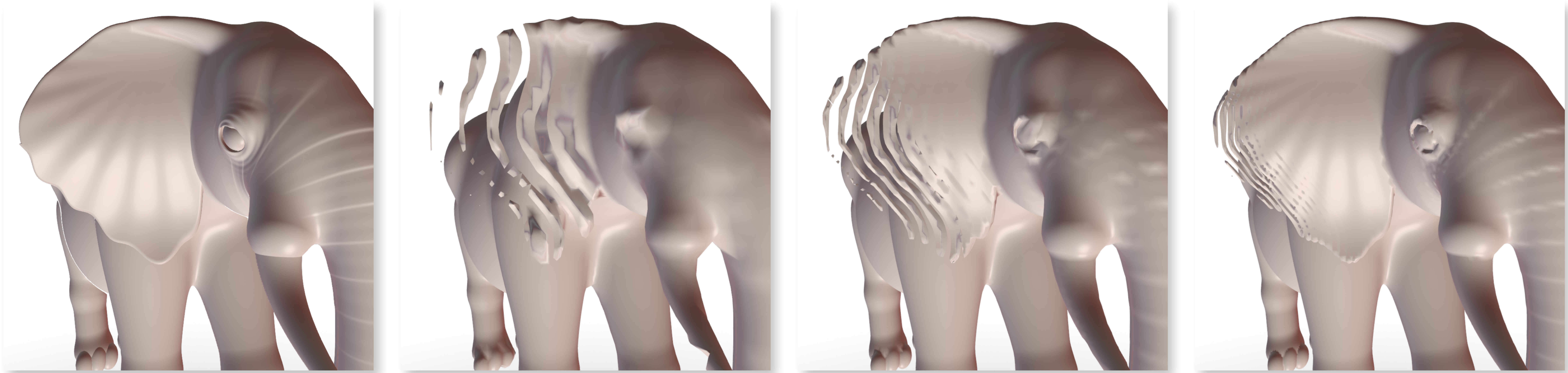
Conversion to Explicit Representation



Conversion to Explicit Representation

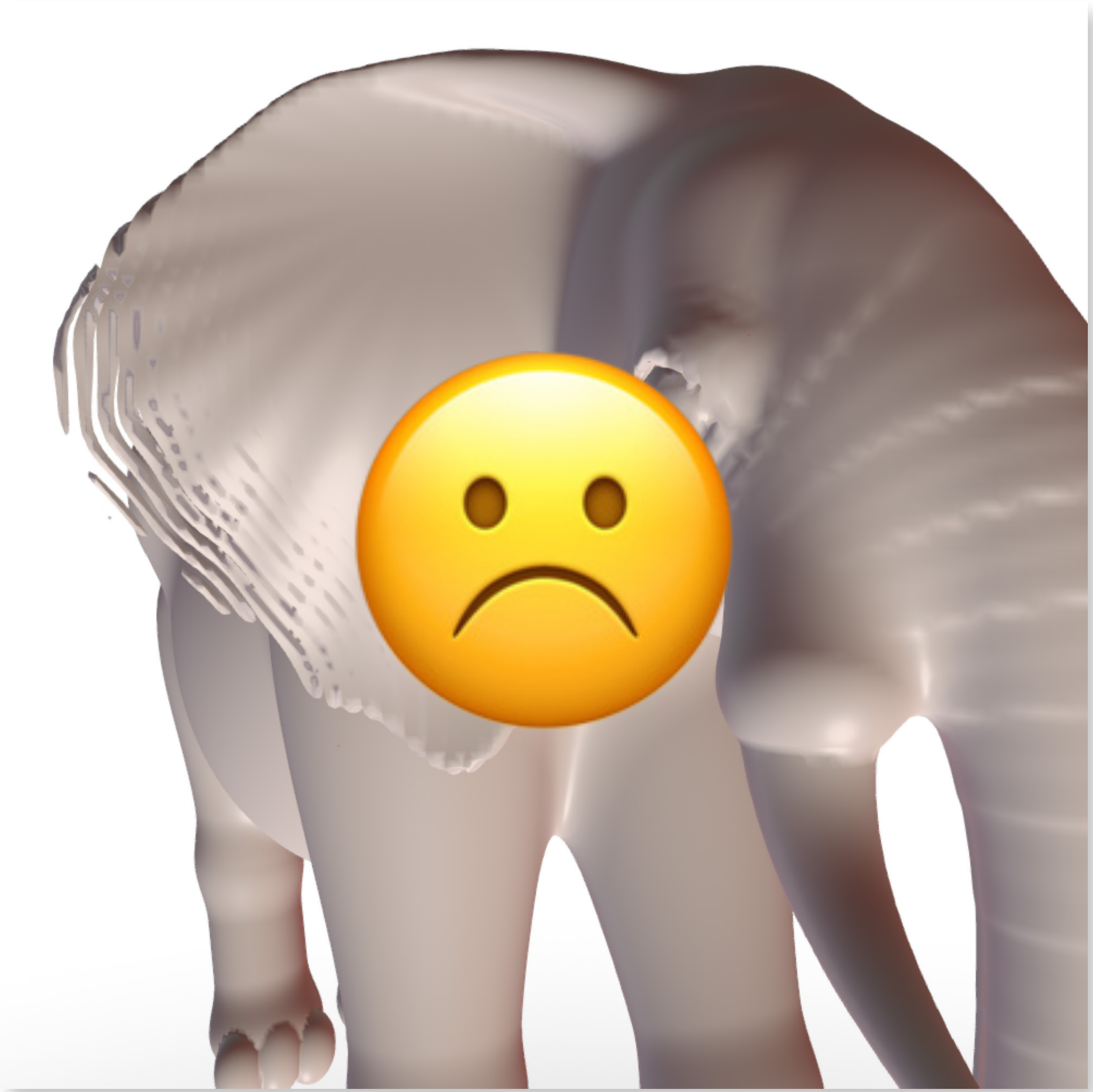


Increasing the resolution helps, but...



Ground Truth	128x128x128	256x256x256	512x512x512

Costly and still full of artifacts!



Conversion to Explicit Representation

- Data Structure for Soft Objects [Wyvill et al. 1986]

➡**Marching Cubes [Lorensen et al. 1987]**

- Dual Contouring [Ju et al. 2002]
- …

Problem Statement – Solved?

Use **conventional deformation techniques** to directly render deformed **implicit surfaces**

Implicit Surface Rendering

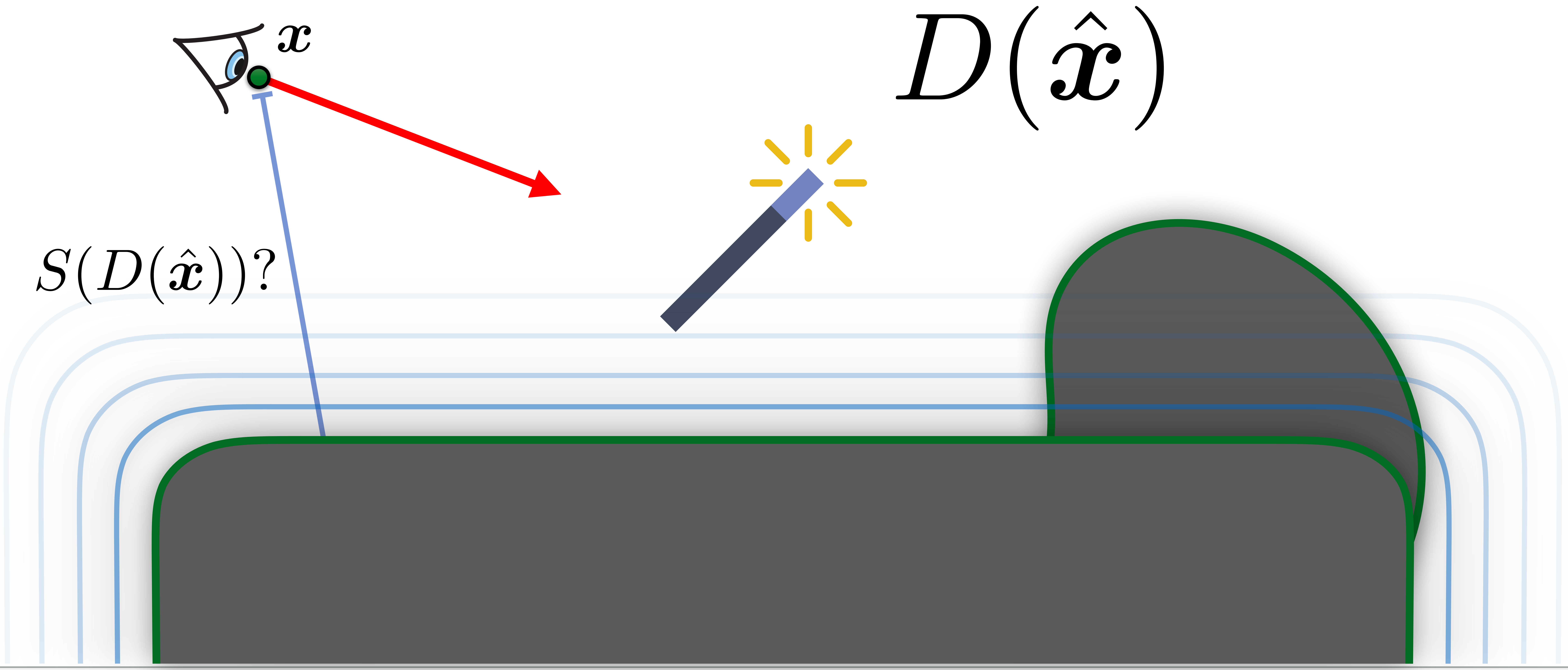
Sphere Tracing [Hart1996]

Sphere Tracing [Hart1996]

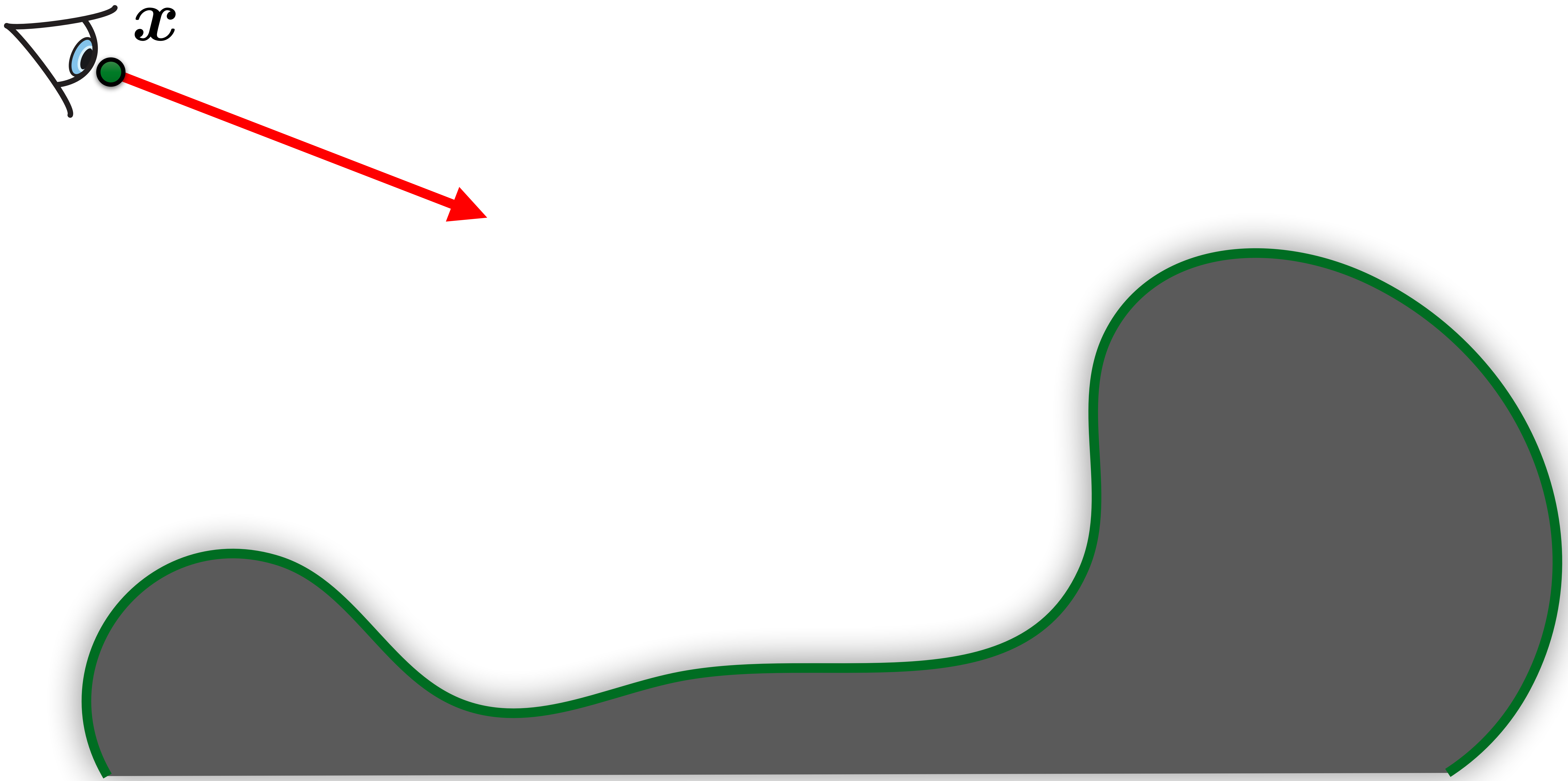
Sphere Tracing [Hart1996]

- ✓ Fairly General
- ✓ Fast
- ✓ Low Error

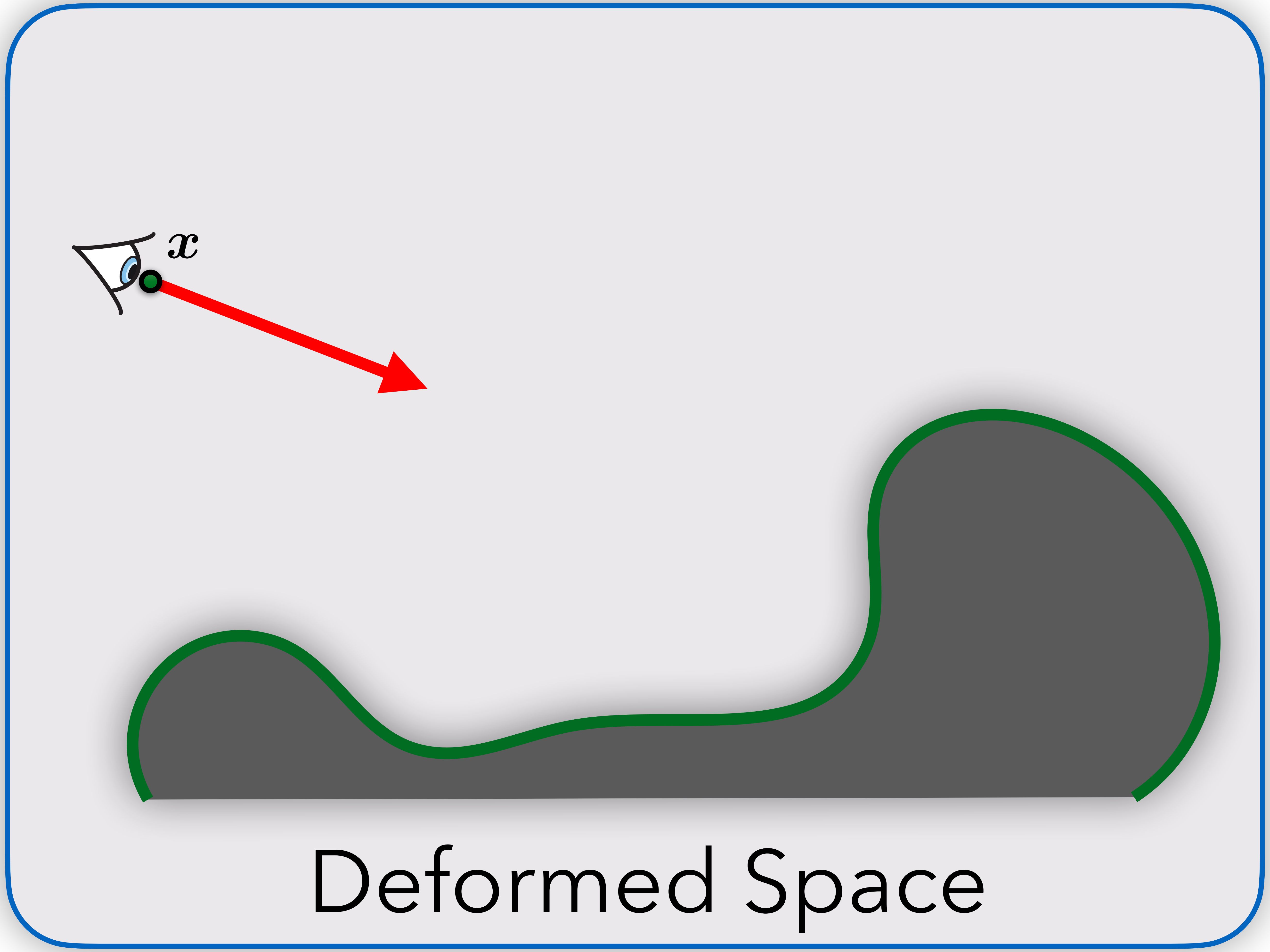
Sphere Tracing - Deformation



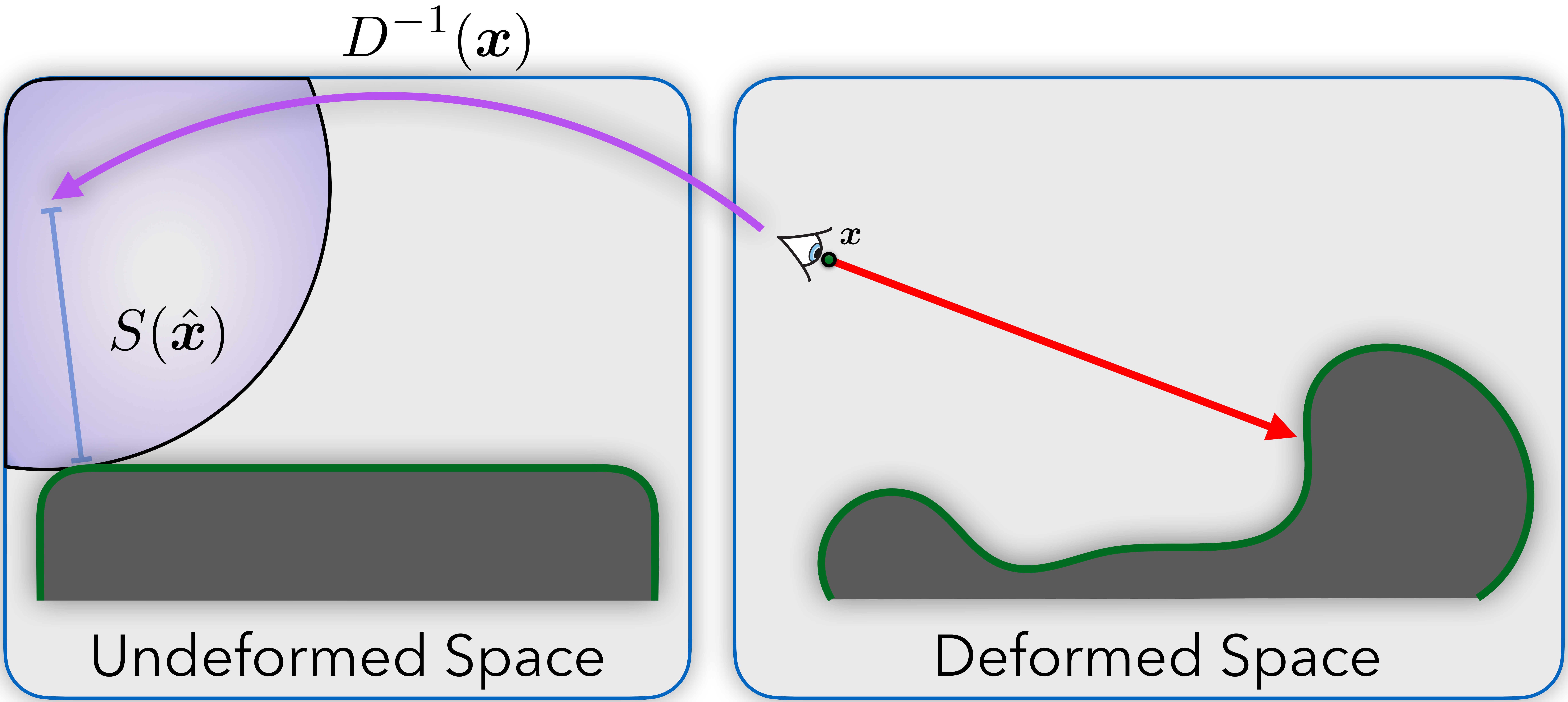
Sphere Tracing - Deformation



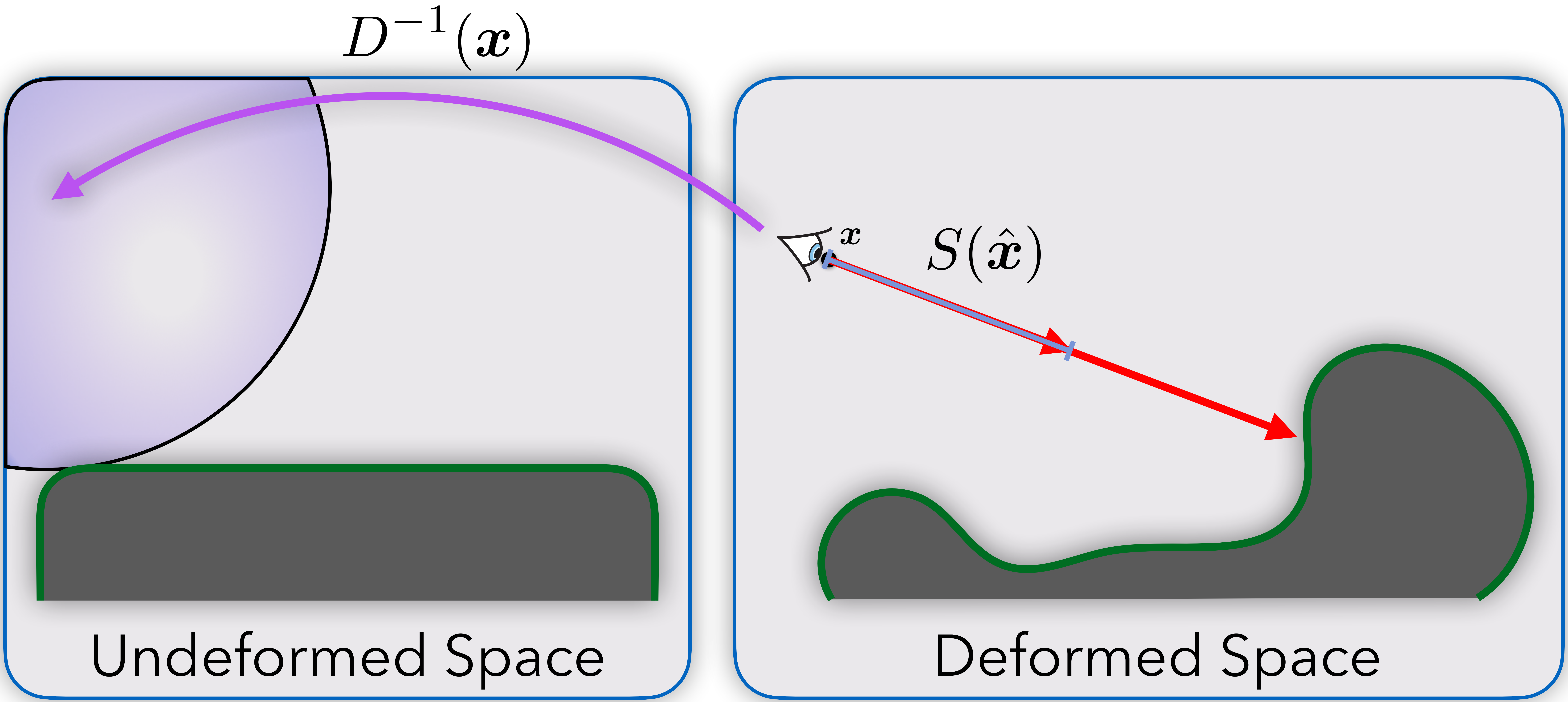
Sampling in Undeformed Space



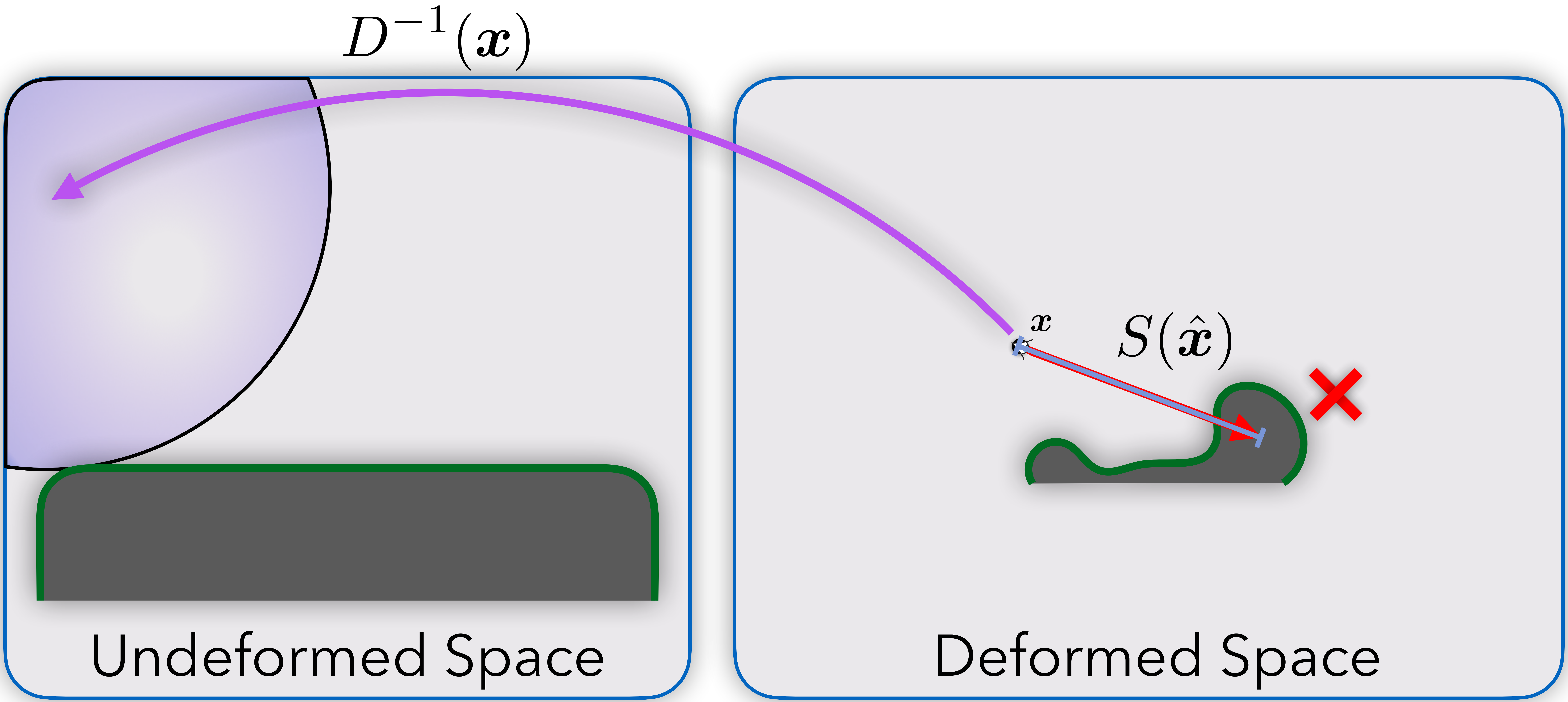
Sampling in Undeformed Space



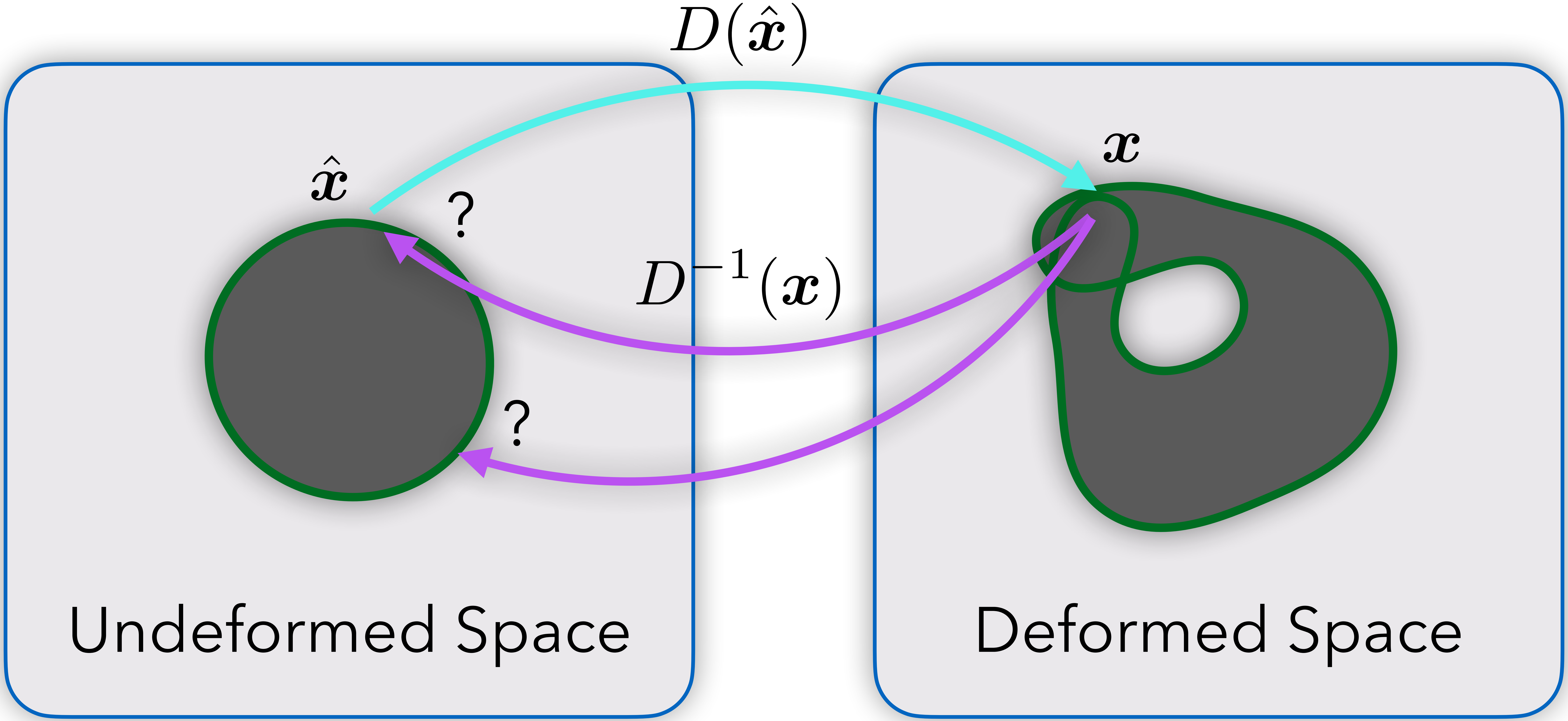
Sampling in Undeformed Space



Issue #1: Remapping the Distance



Issue #2: Non Invertible Deformations

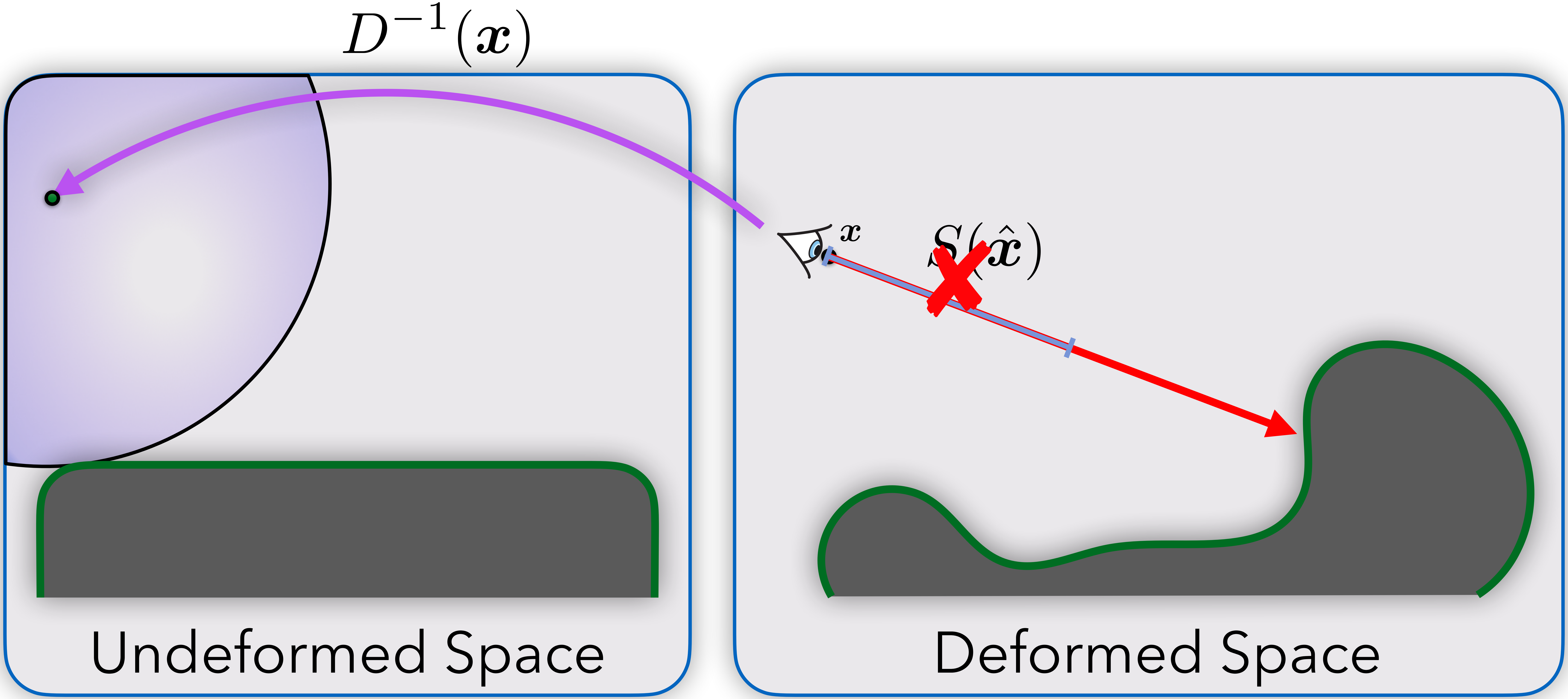


Problem Statement – Solved?

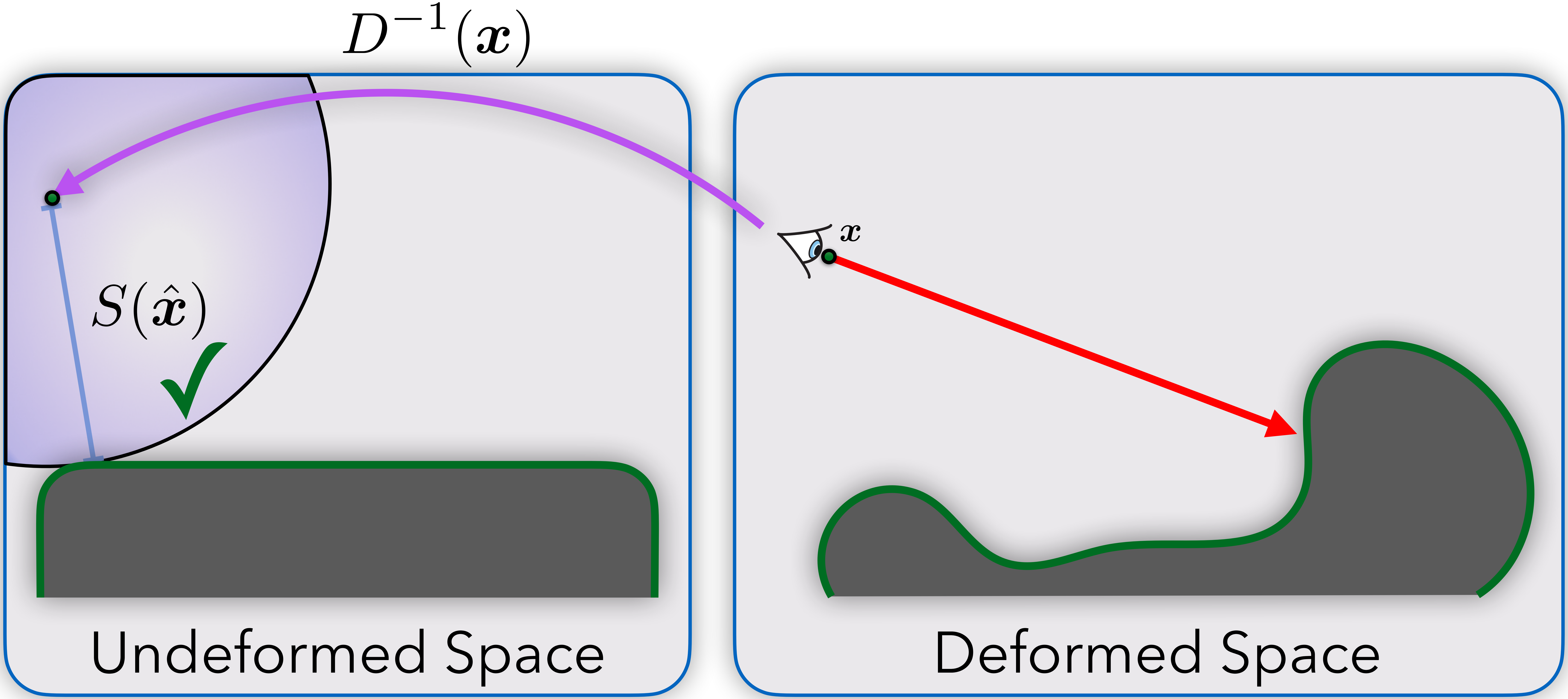
Use ~~conventional~~ **deformation techniques** to directly render deformed **implicit surfaces** ✓

Non-linear Sphere Tracing

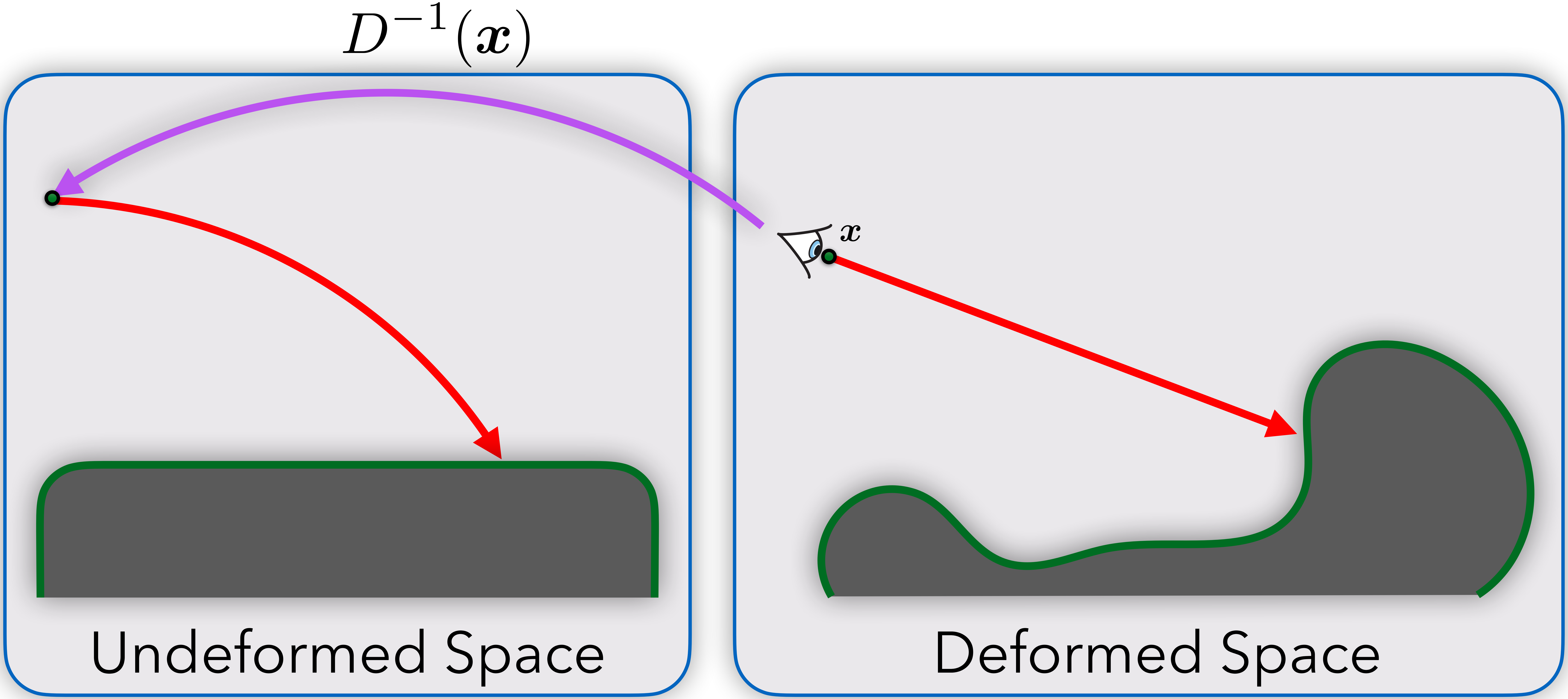
The distance isn't valid here…



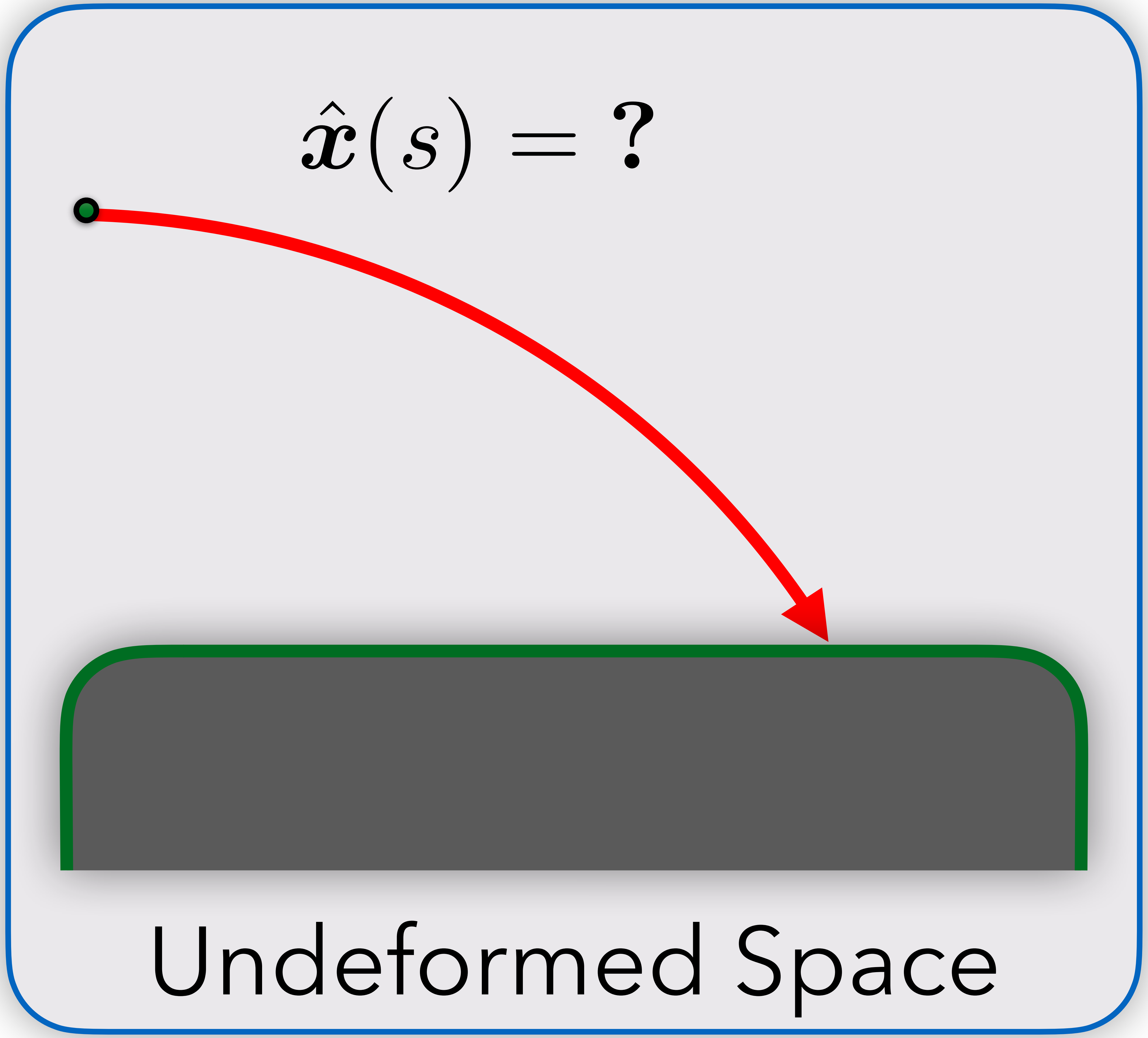
But it is here!

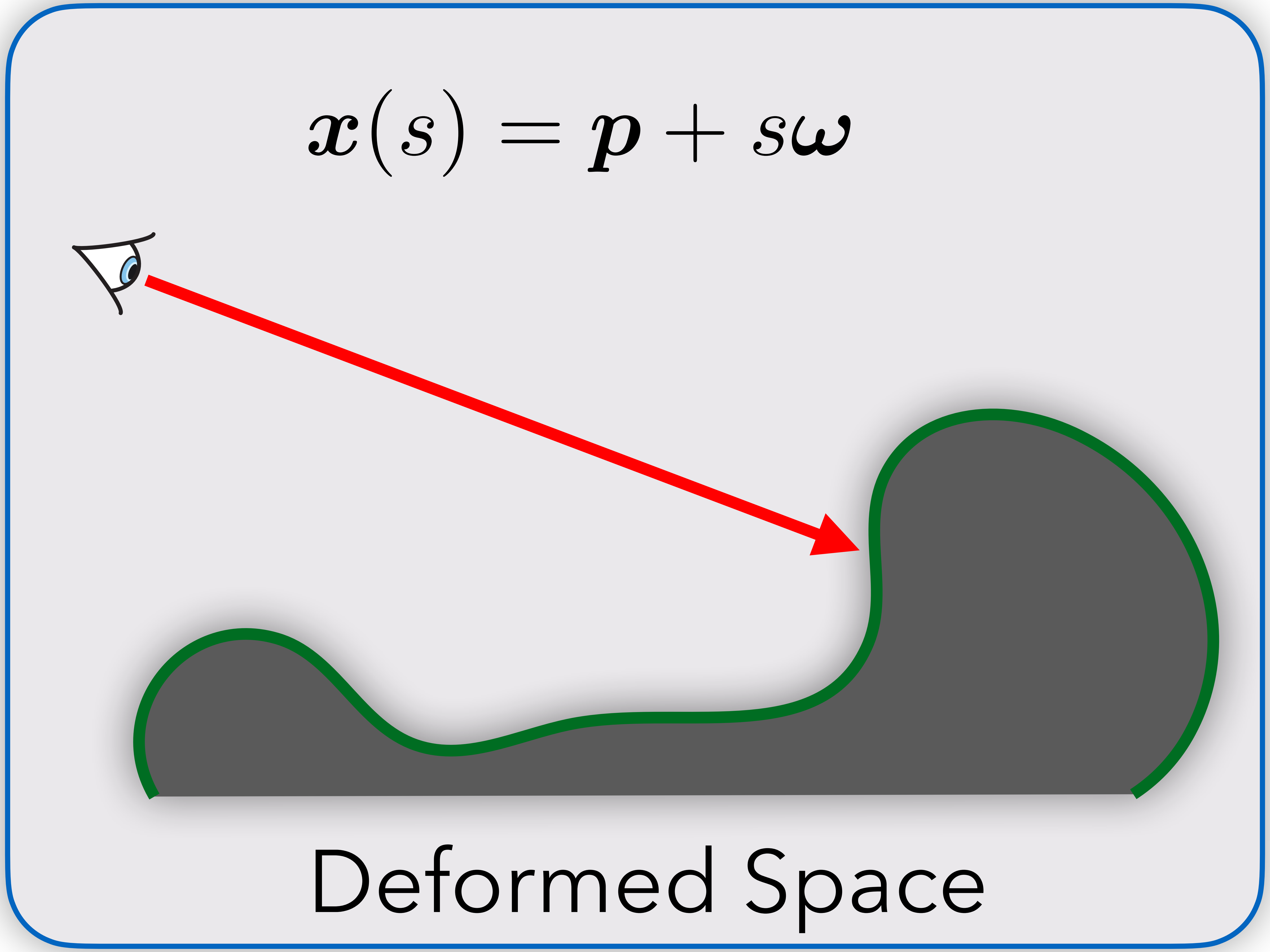


Idea: Trace in Undeformed Space

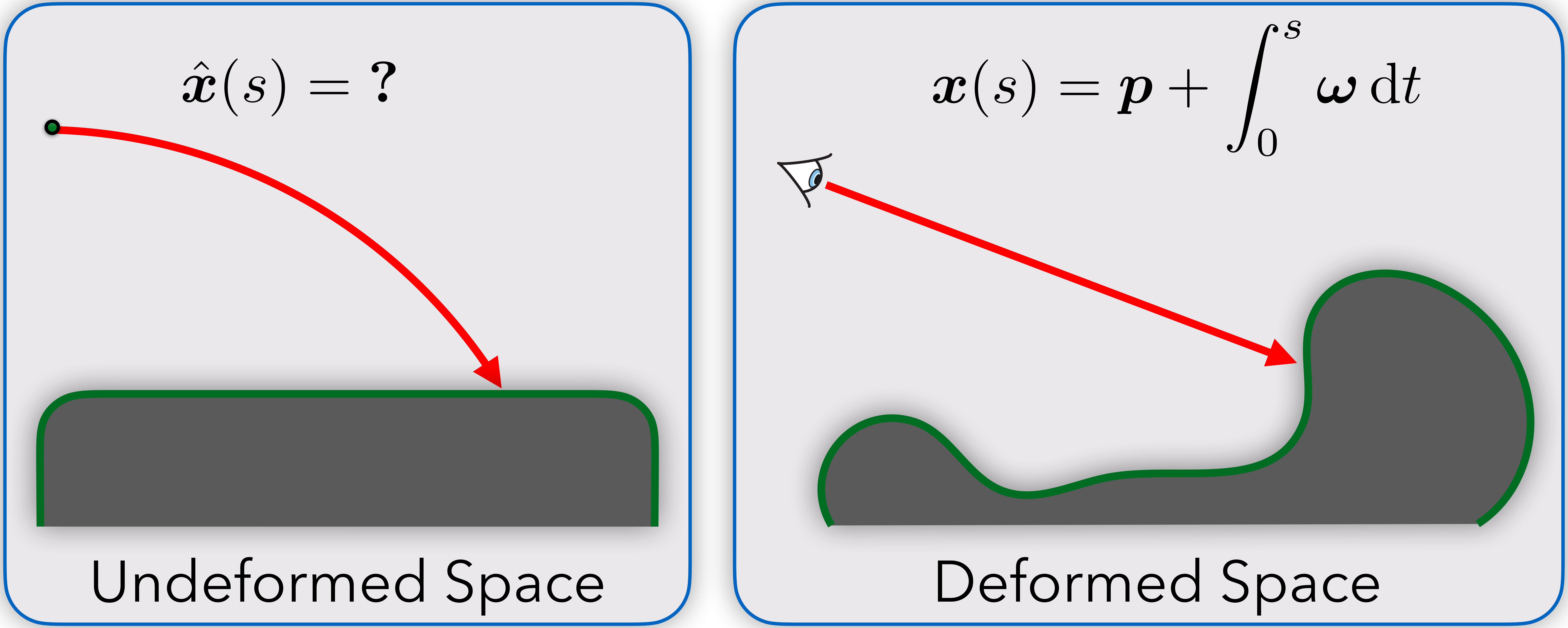


What is the *deformed* ray equation?



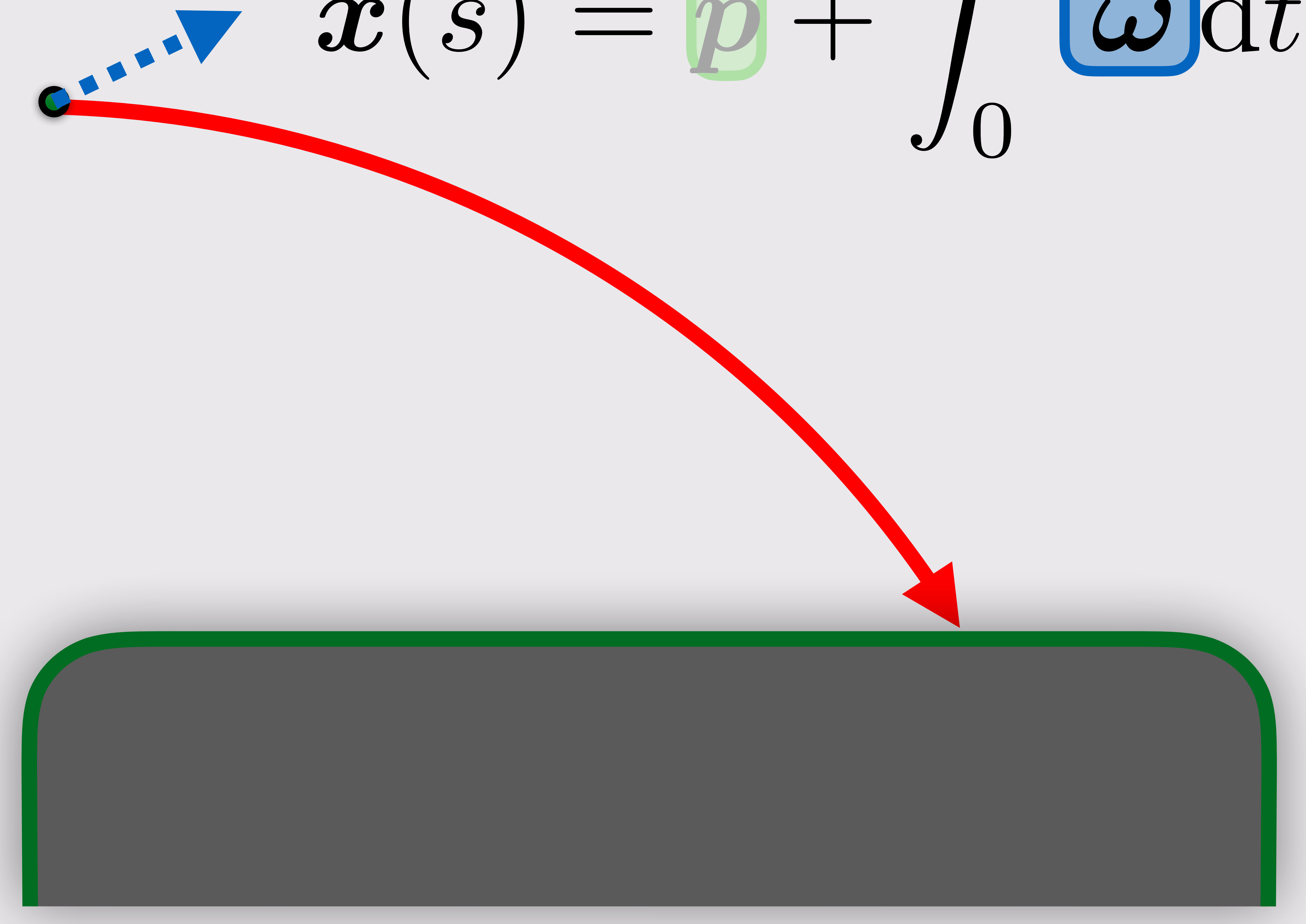


Line integrals to the rescue!



Line integrals to the rescue!

$$\hat{\boldsymbol{x}}(s) = \hat{\boldsymbol{p}} + \int_0^s \hat{\boldsymbol{\omega}}\, \mathrm{d}t$$

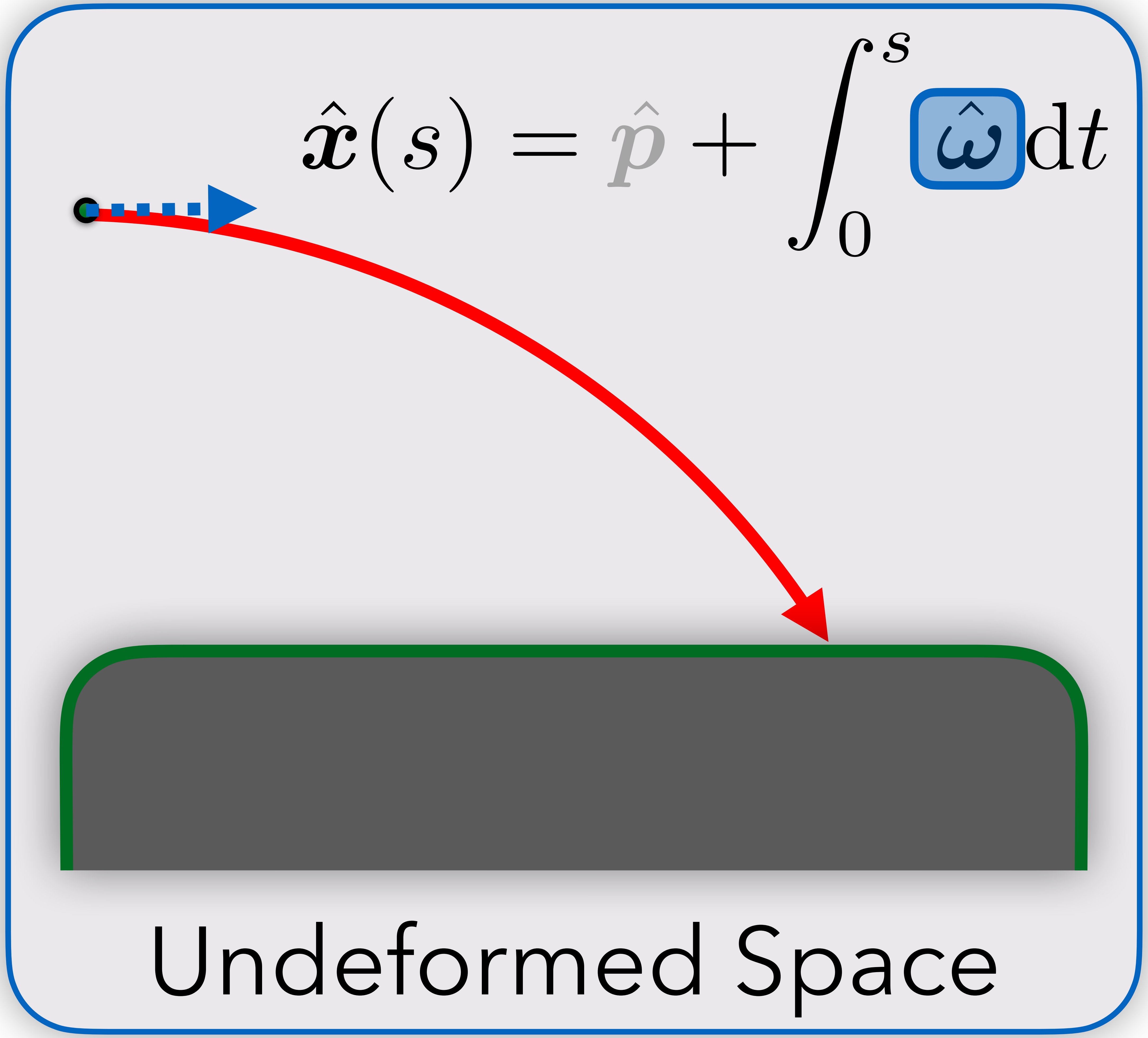


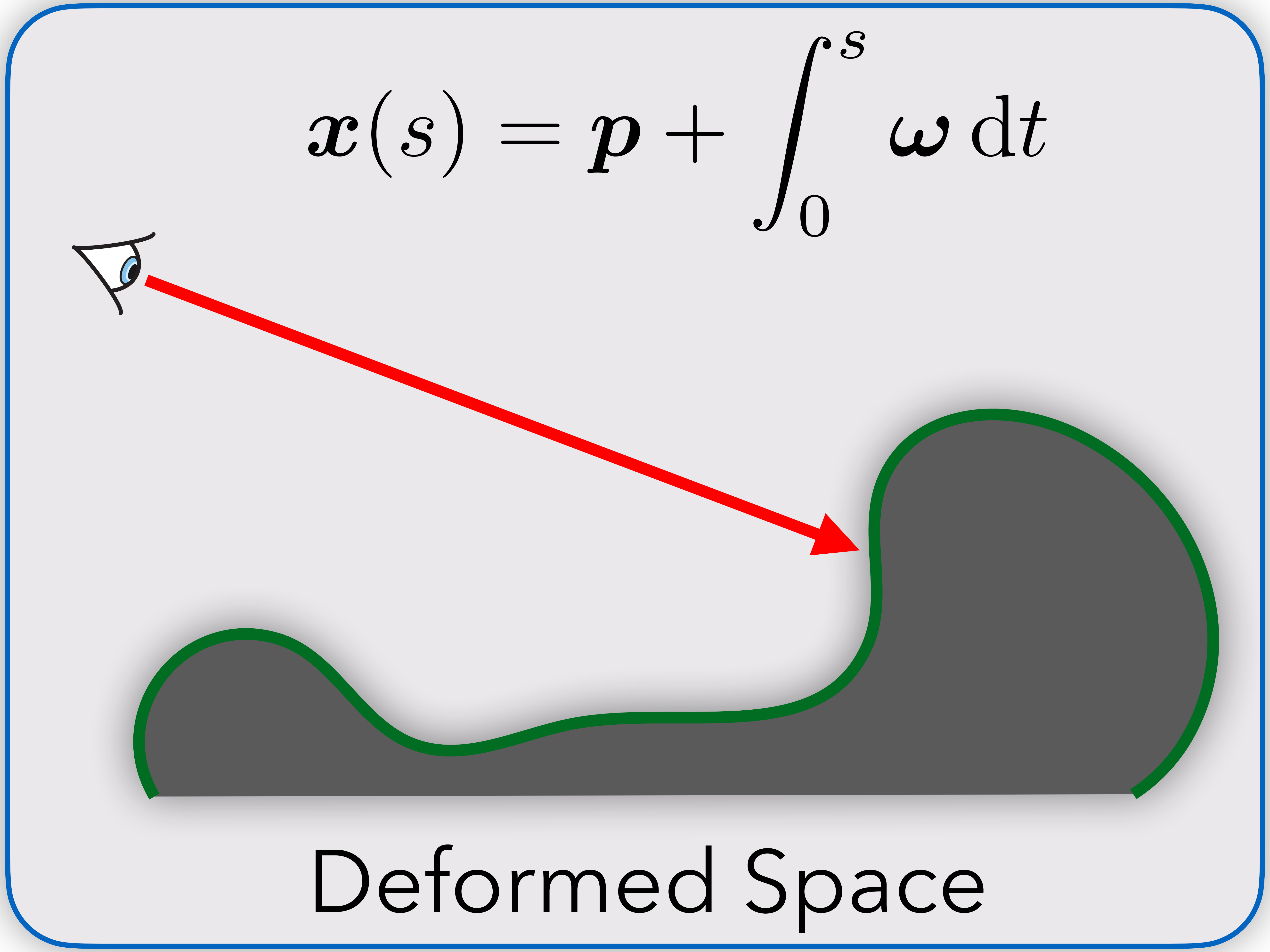
Undeformed Space

$$\boldsymbol{x}(s) = \boldsymbol{p} + \int_0^s \boldsymbol{\omega}\, \mathrm{d}t$$

Deformed Space

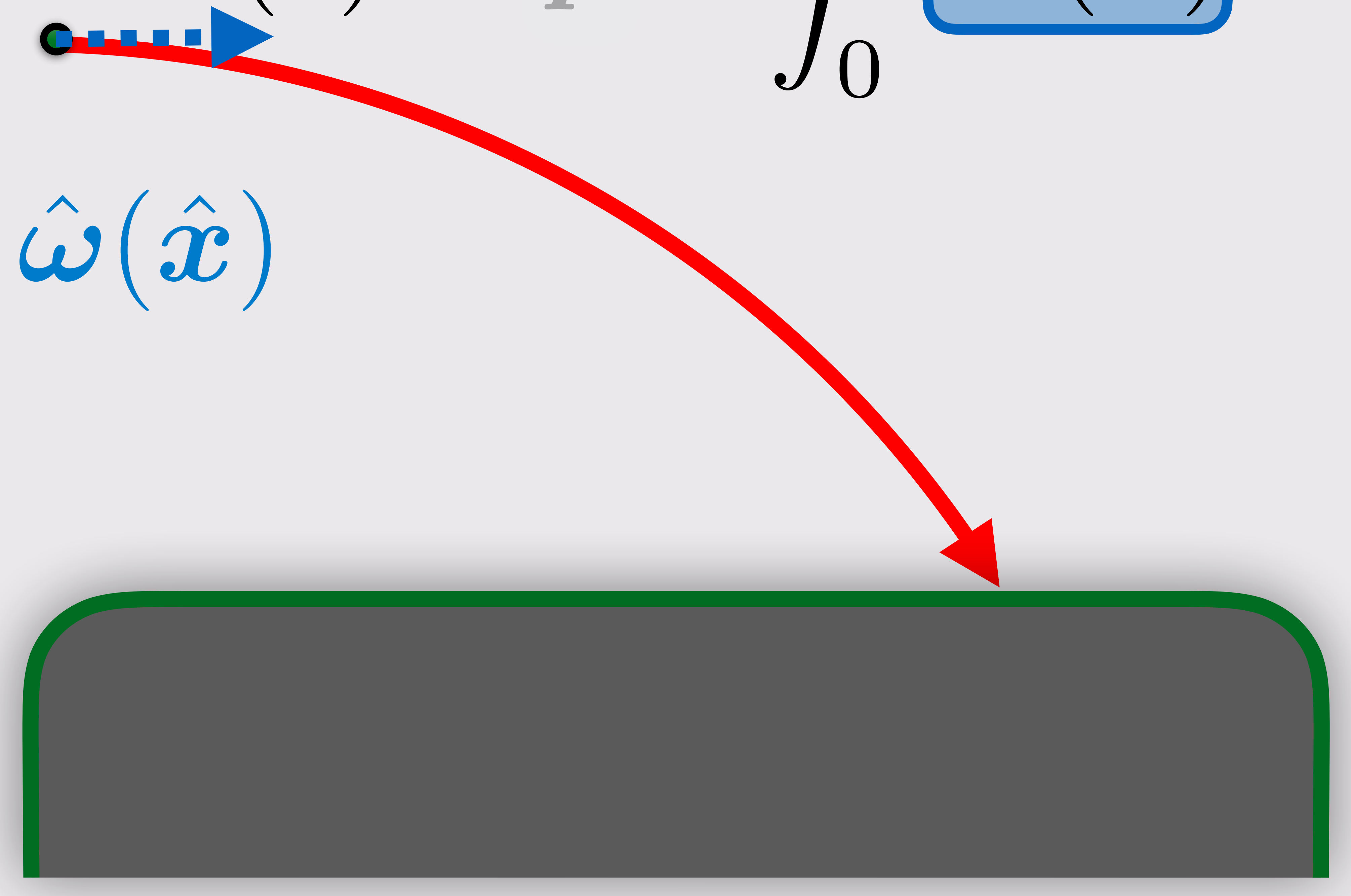
Line integrals to the rescue!





Finding the Tangent

$$\hat{\boldsymbol{x}}(s) = \hat{p} + \int_0^s \hat{\boldsymbol{\omega}}(\hat{\boldsymbol{x}})\,\mathrm{d}t$$

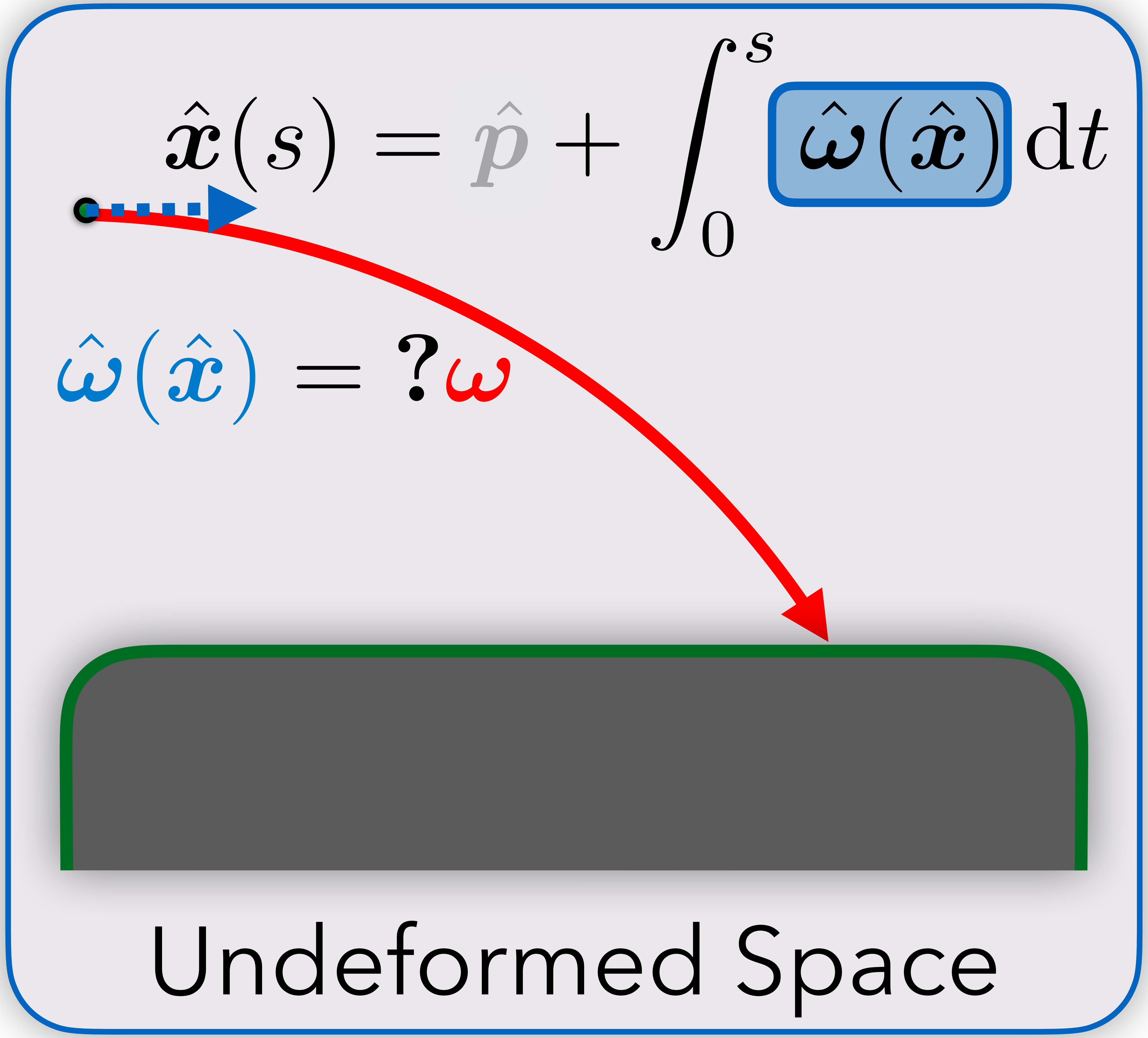


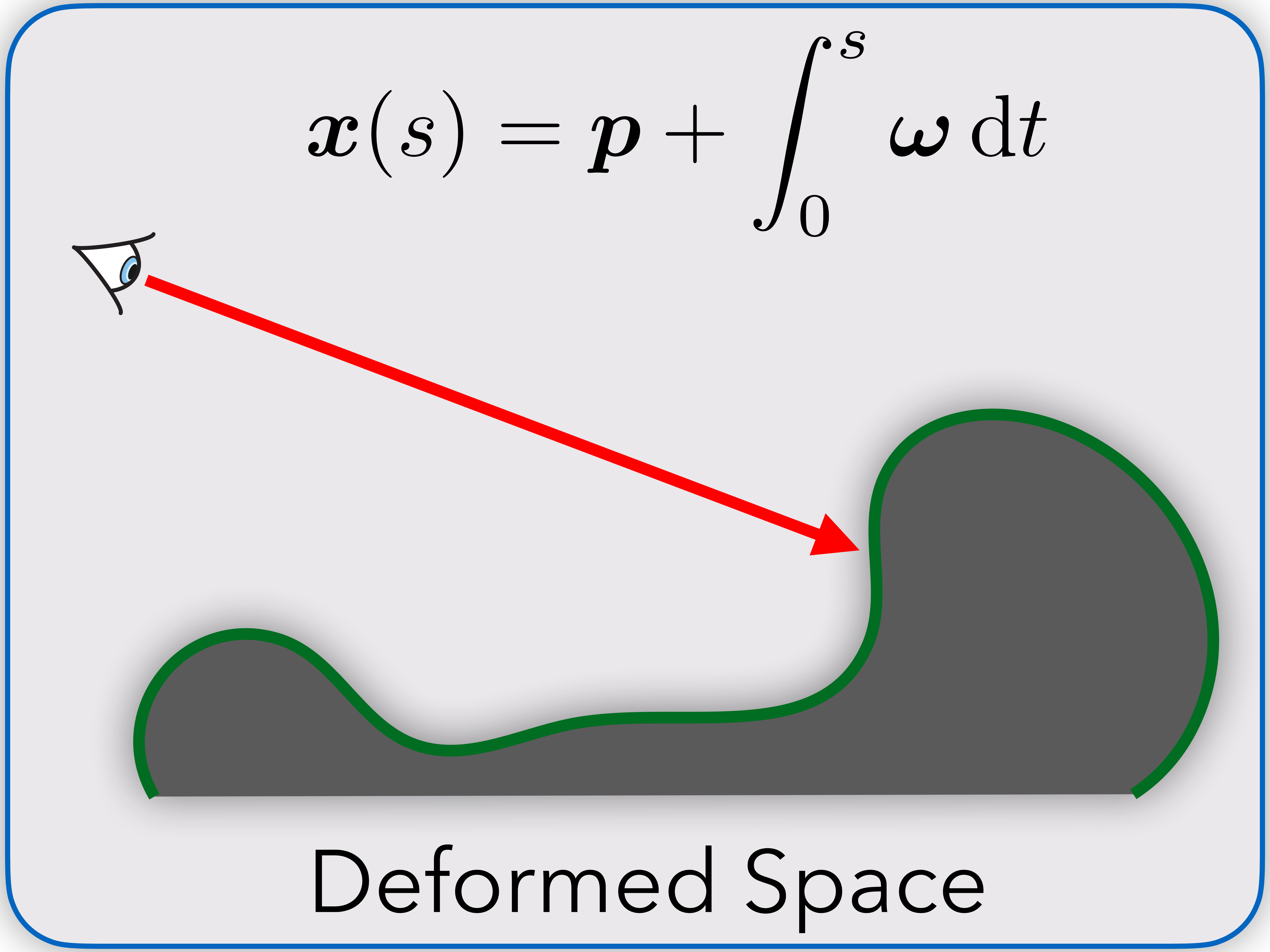
Undeformed Space

$$\boldsymbol{x}(s) = \boldsymbol{p} + \int_0^s \boldsymbol{\omega}\,\mathrm{d}t$$

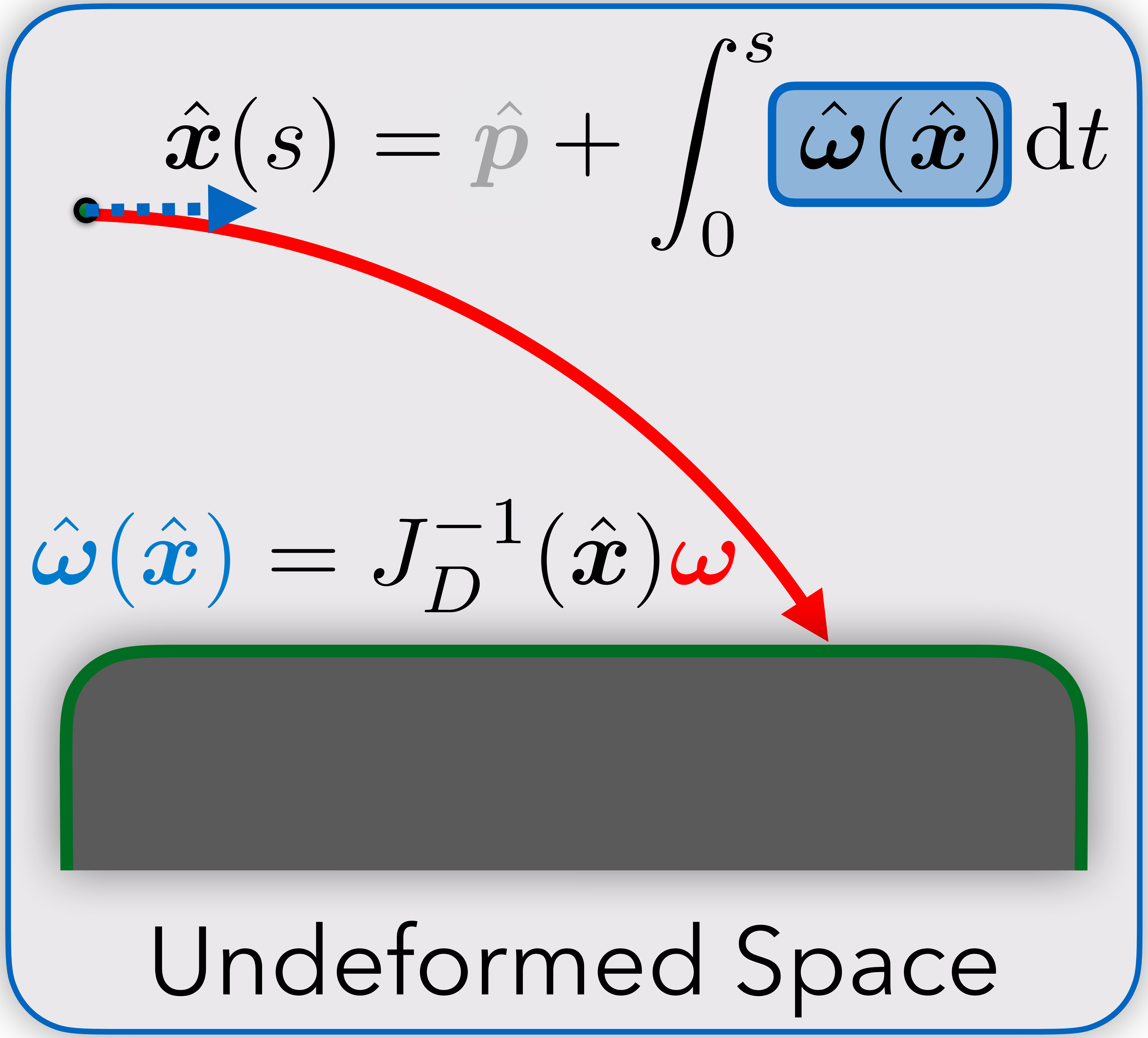
Deformed Space

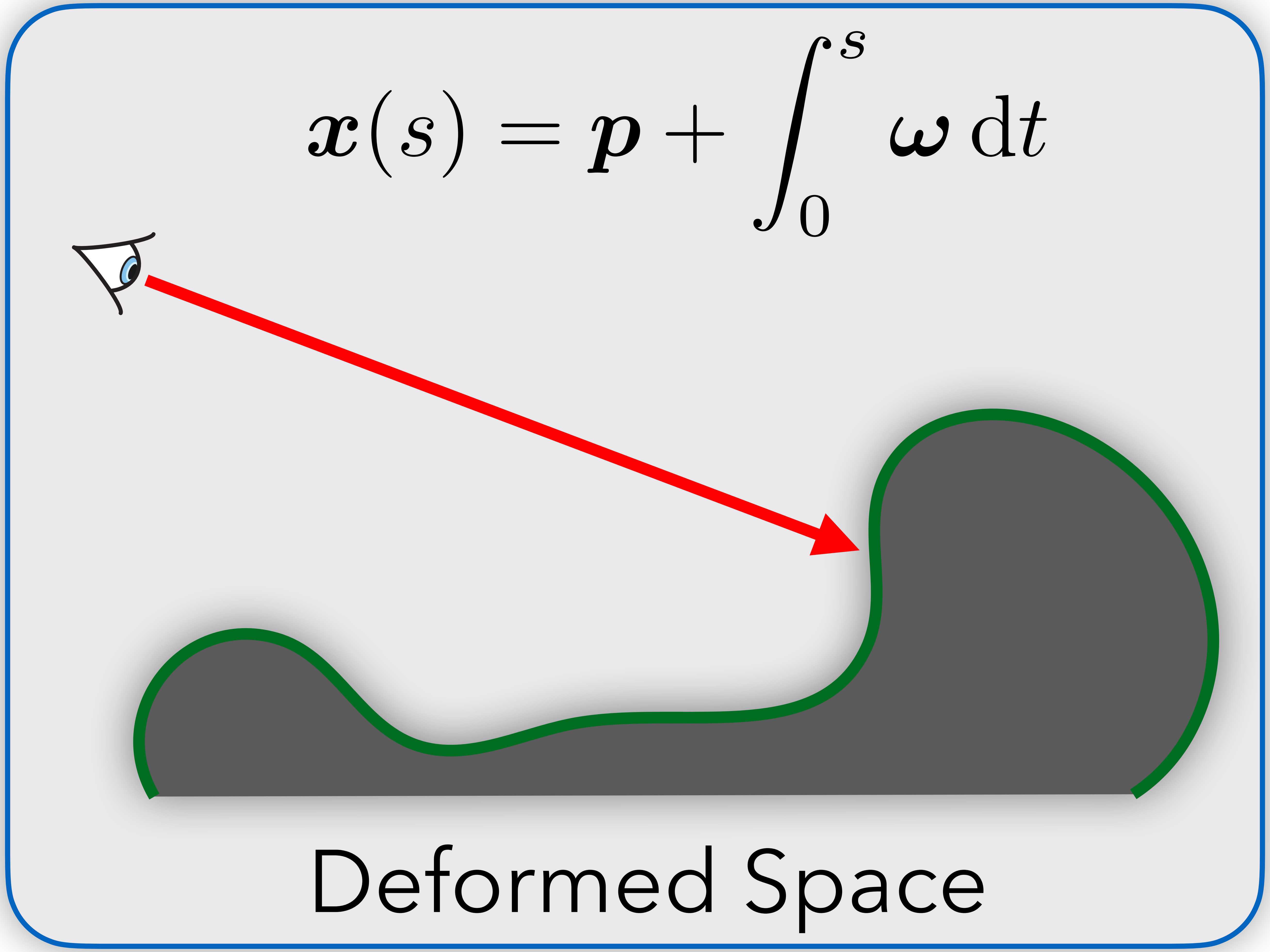
Finding the Tangent





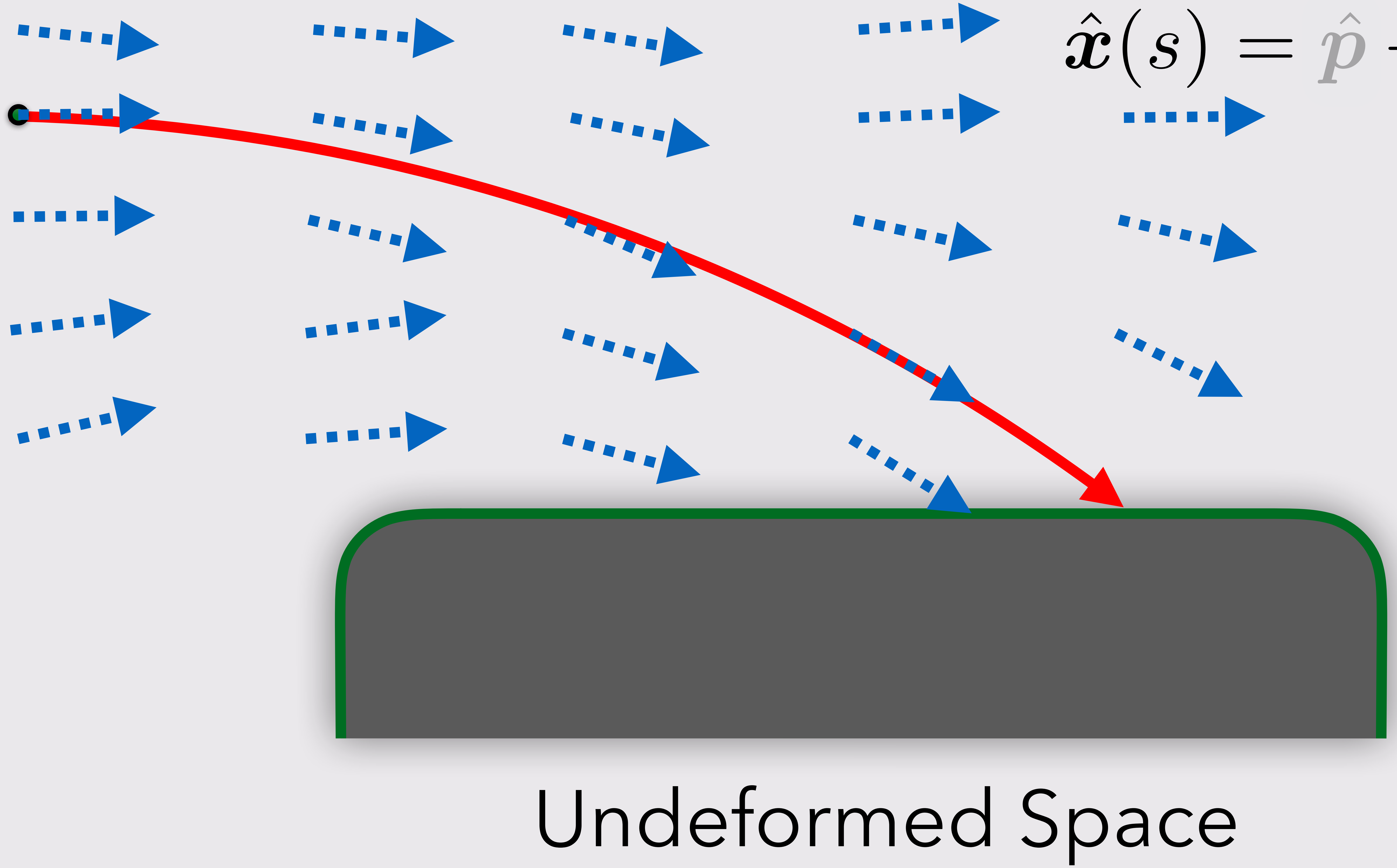
Finding the Tangent



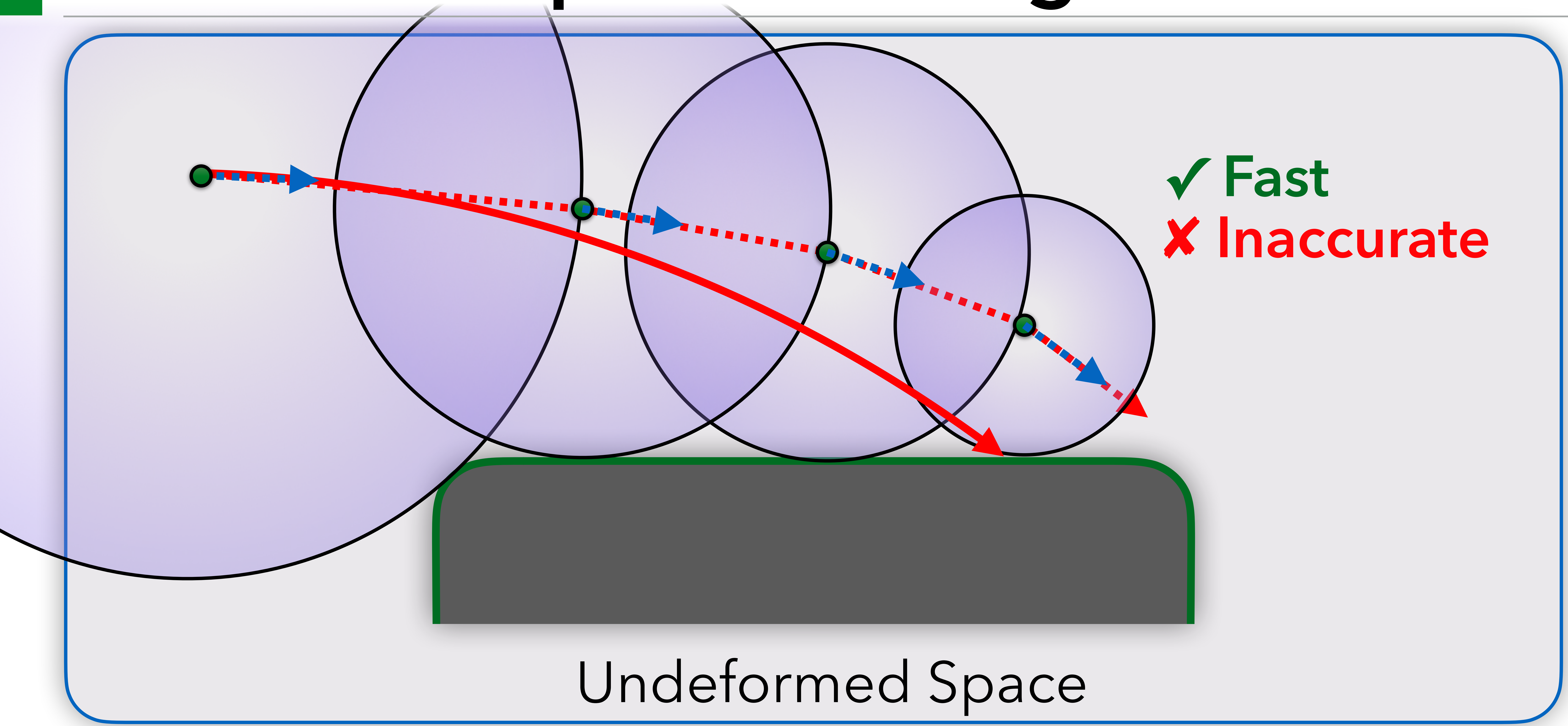


Numerical Integration

$$\hat{\boldsymbol{x}}(s) = \hat{p} + \int_0^s \hat{\boldsymbol{\omega}}(\hat{\boldsymbol{x}})\,\mathrm{d}t$$



Non-linear Sphere Tracing



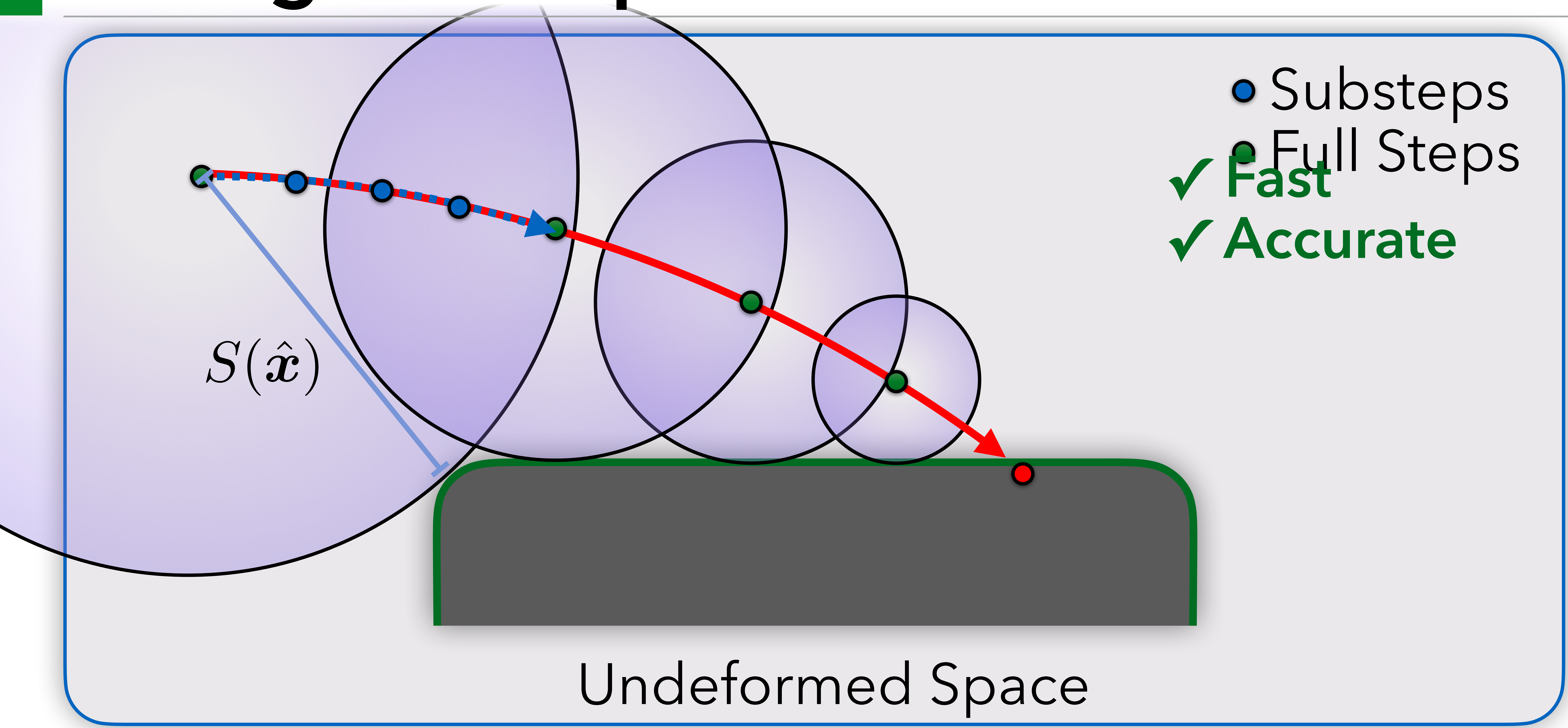
Non-linear Sphere Tracing

Conflict!

Sphere Tracing ⟷ **Integration**

Speed ⟷ *Accuracy*

Taking Substeps



✓ **Fast**
✓ **Accurate**

Integration – Summary

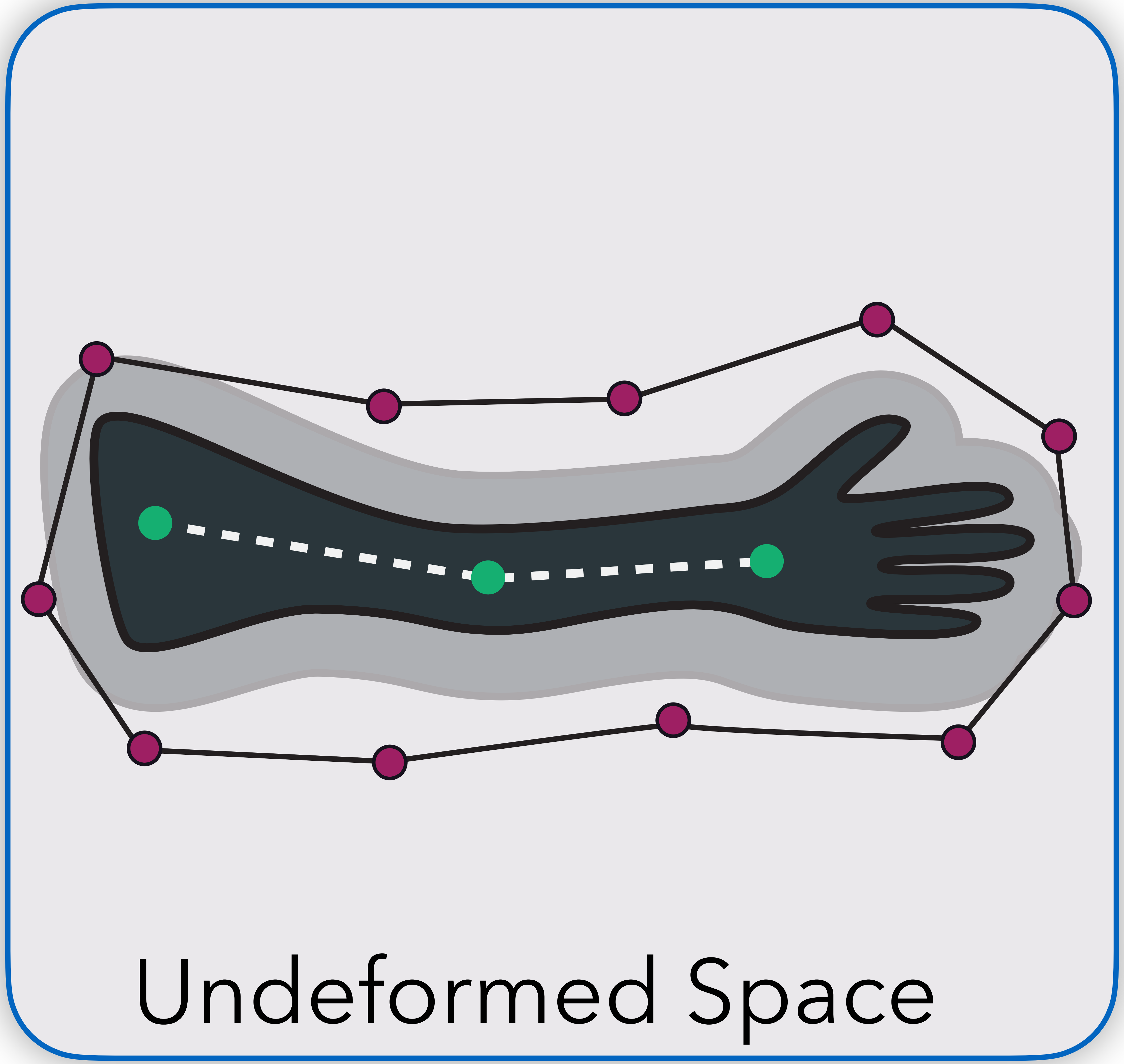
$$\hat{\boldsymbol{x}}(s) = \hat{\boldsymbol{p}} + \int_0^s \hat{\boldsymbol{\omega}}\, \mathrm{d}t$$

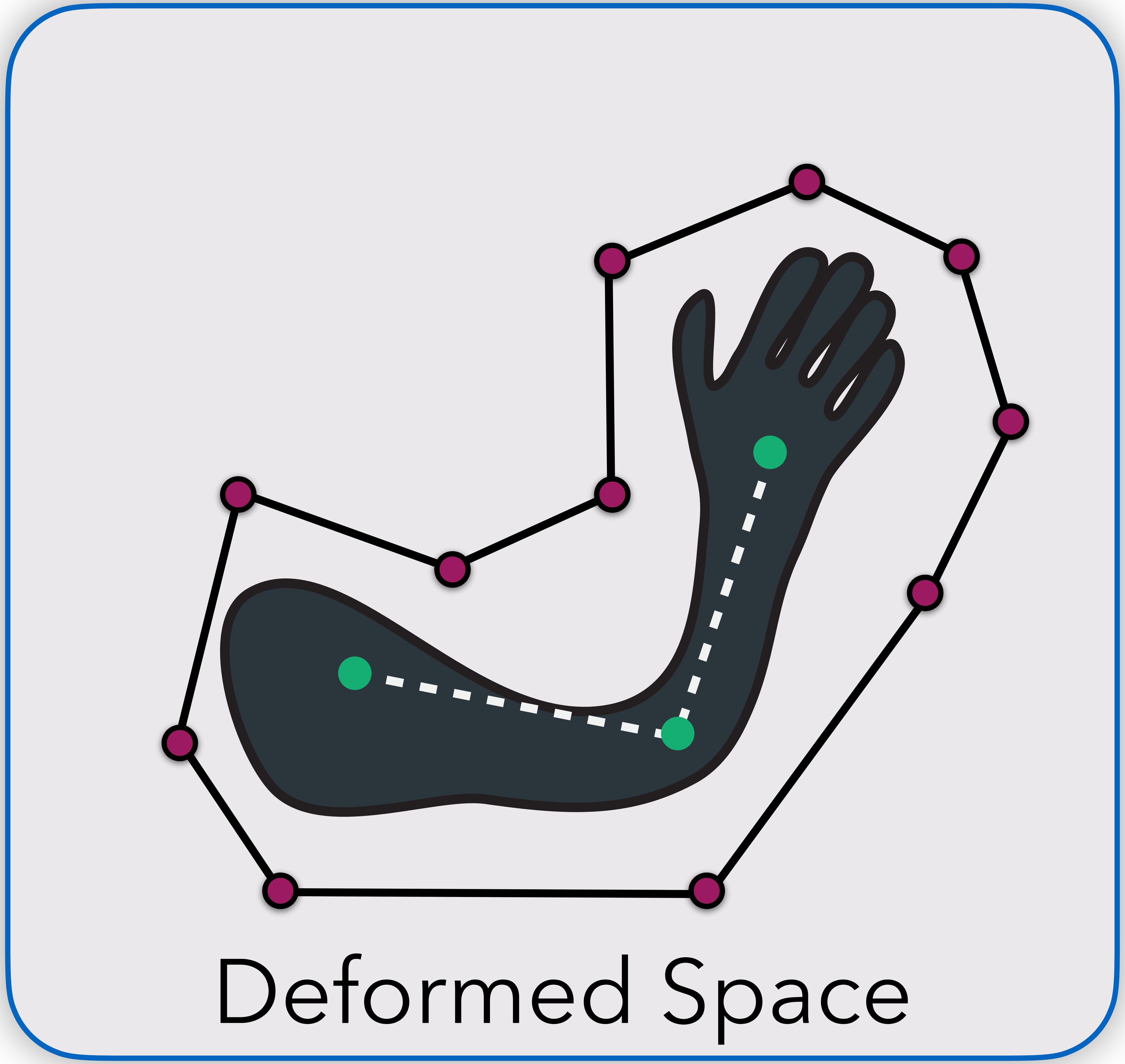
Integration – Summary

$$\hat{\boldsymbol{x}}(s) = \hat{\boldsymbol{p}} + \int_0^s \hat{\boldsymbol{\omega}}\,\mathrm{d}t$$

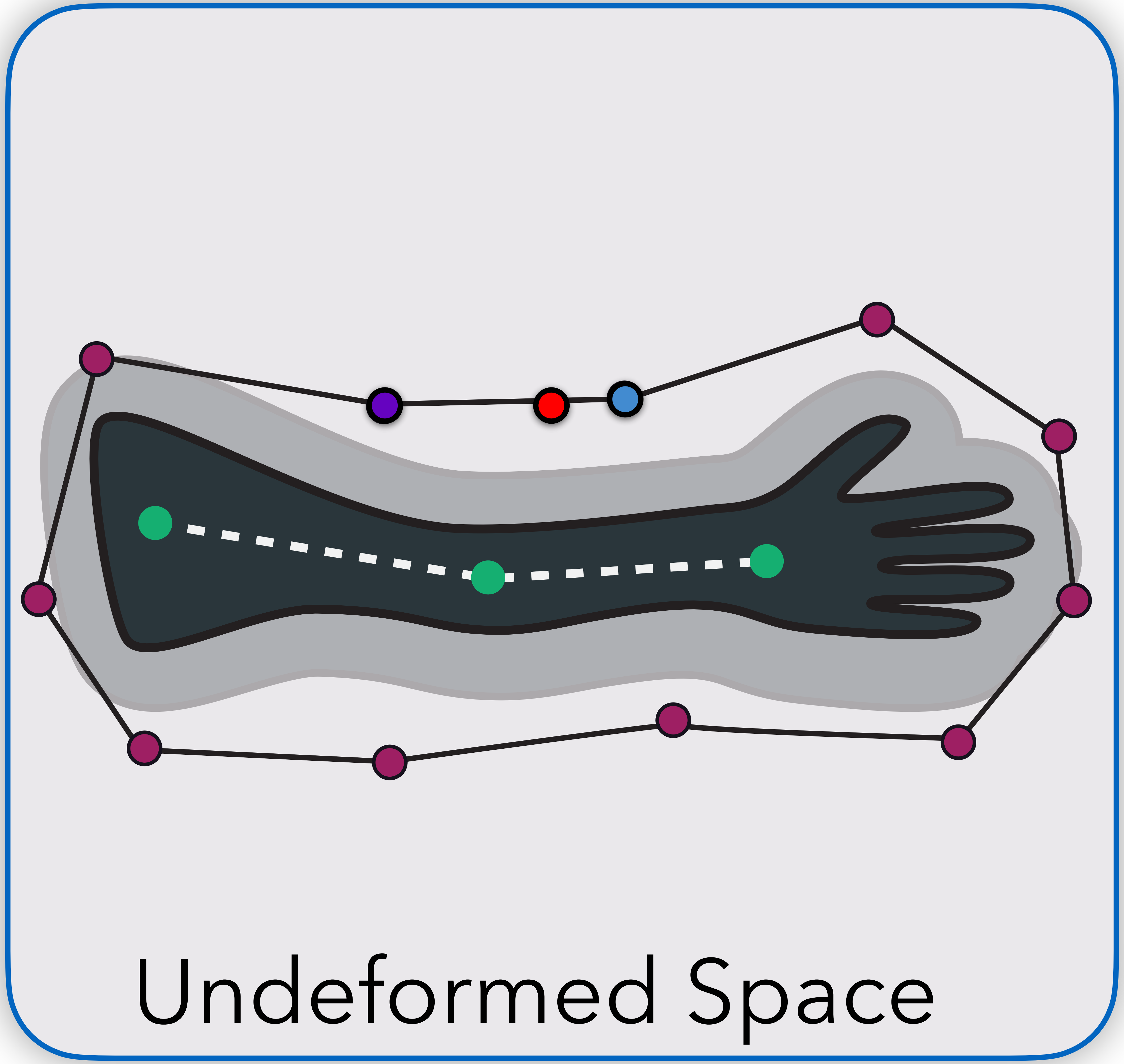
$$\hat{\boldsymbol{p}} = D^{-1}(\boldsymbol{p})$$

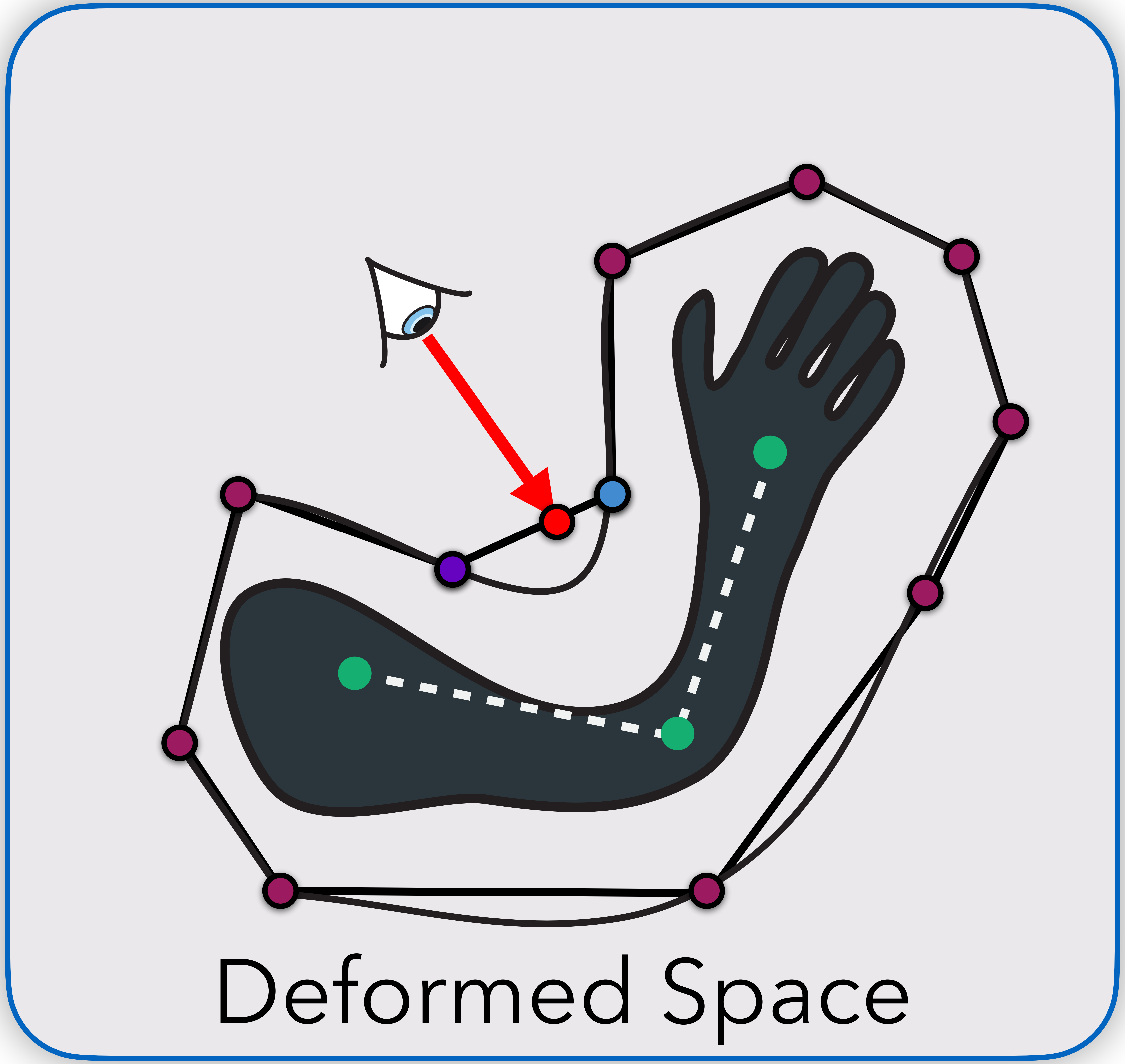
Finding the Start Point



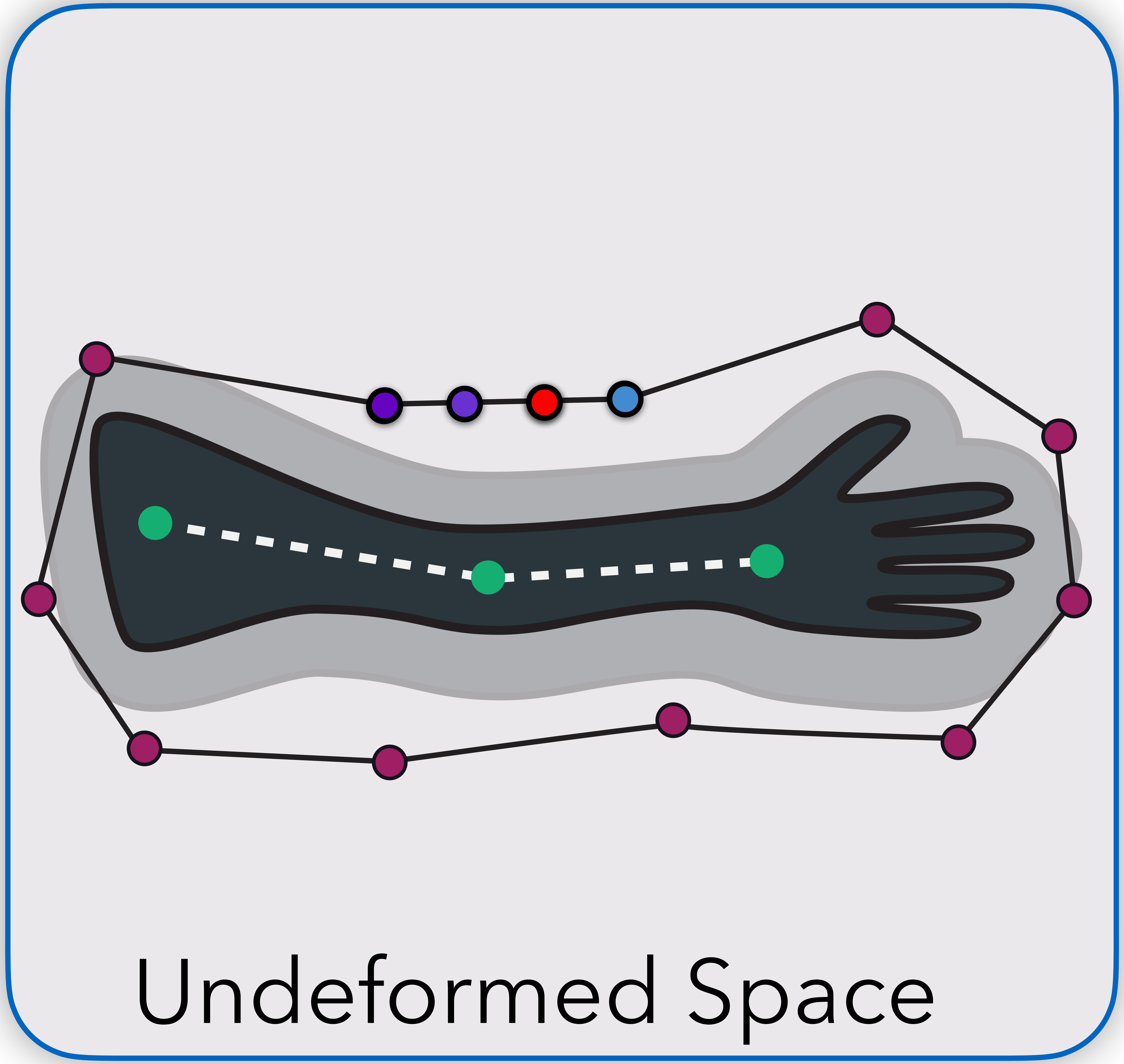


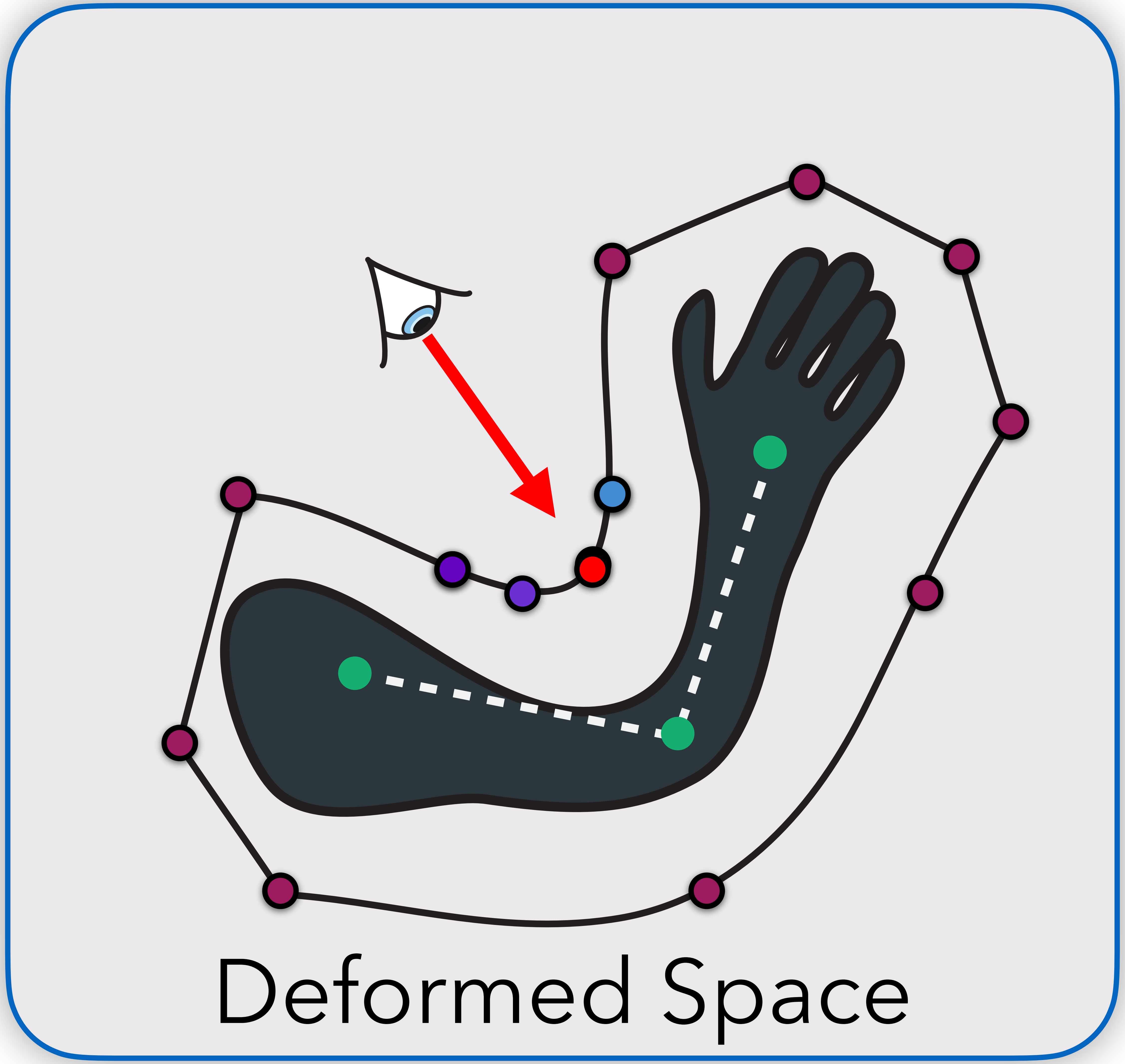
Finding the Start Point





Subdividing the Hull





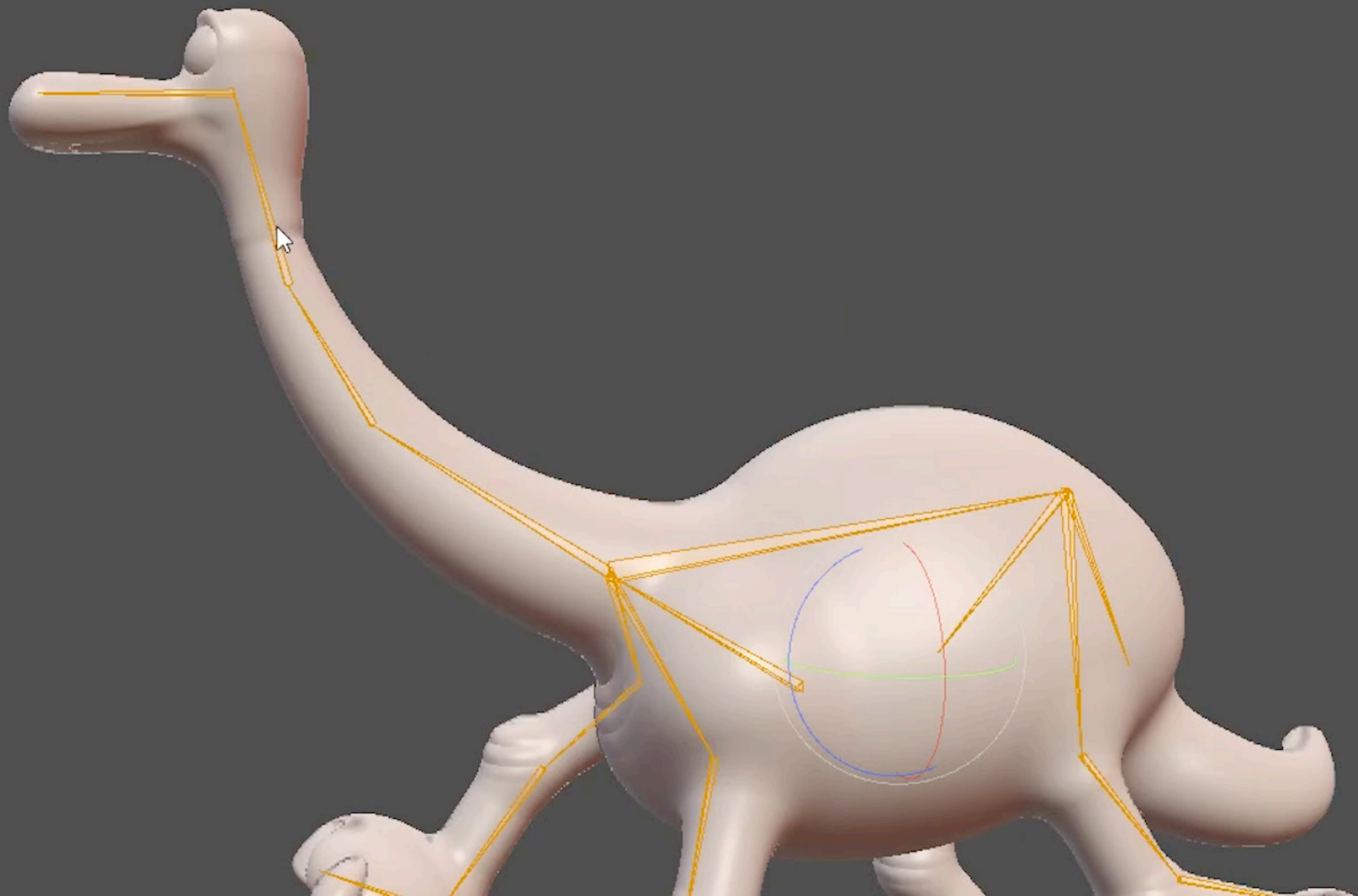
Problem Statement - Solved!

Use **conventional deformation techniques** ✓ to directly render deformed **implicit surfaces** ✓

Results

Regularized Kelvinlets, Fernando de Goes and Doug L. James

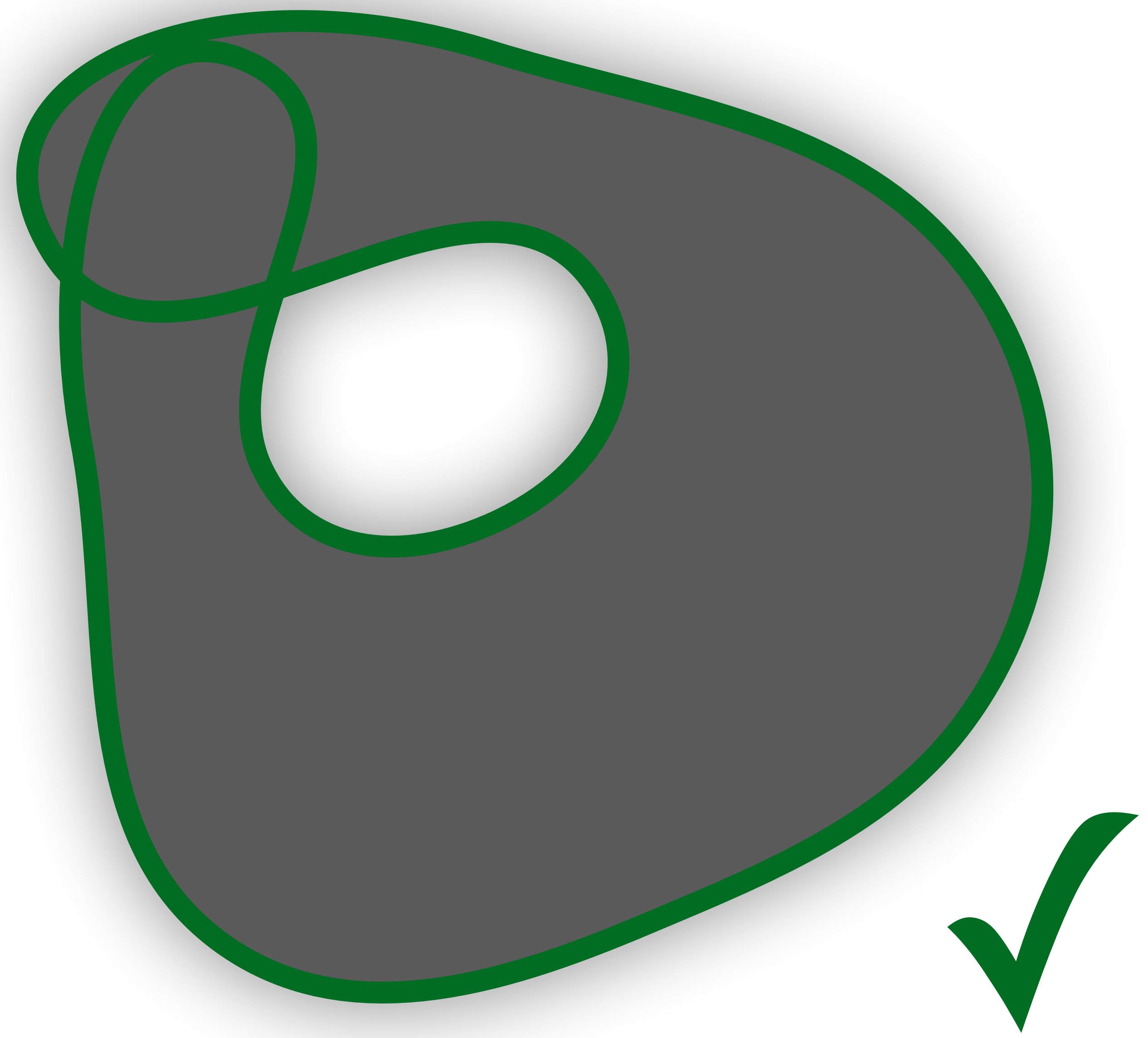
Linear Blend Skinning



The hull makes large scale deformations possible.

Limitations

- **Geometry**: Signed distance function
- **Deformation**: *Locally* foldover free



Future Work

- **Generalize** to all implicit surfaces

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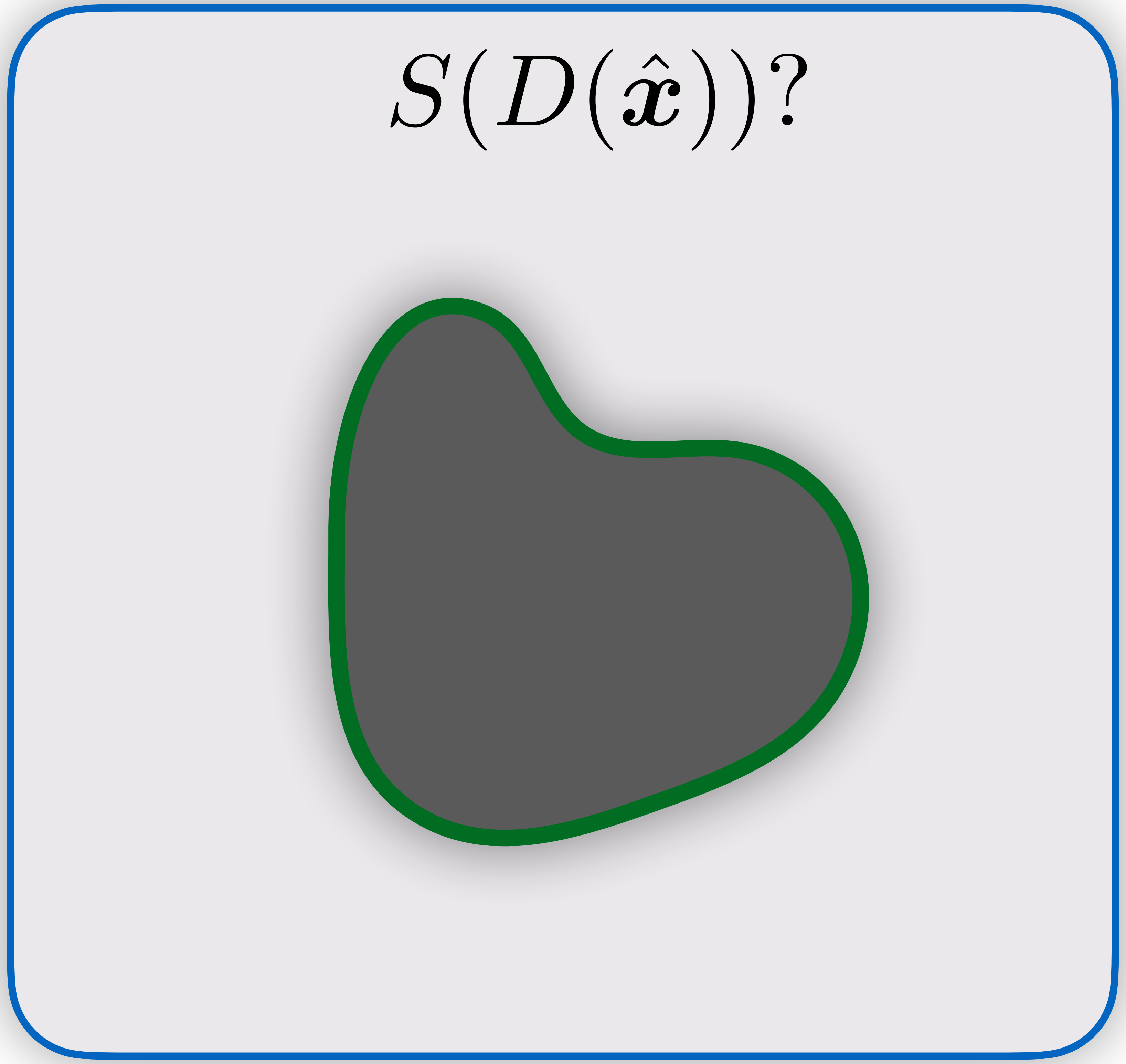
- Support **cheap layering** of deformations

Undeformed FFD FFD + Kelvinlet

Future Work

- **Generalize** to all implicit surfaces
- Support **cheap layering** of deformations
- Evaluate **deformed** SDF



Thank you!

Please visit

dartgo.org/nlst

for the full paper and supplemental material

Scan Me!

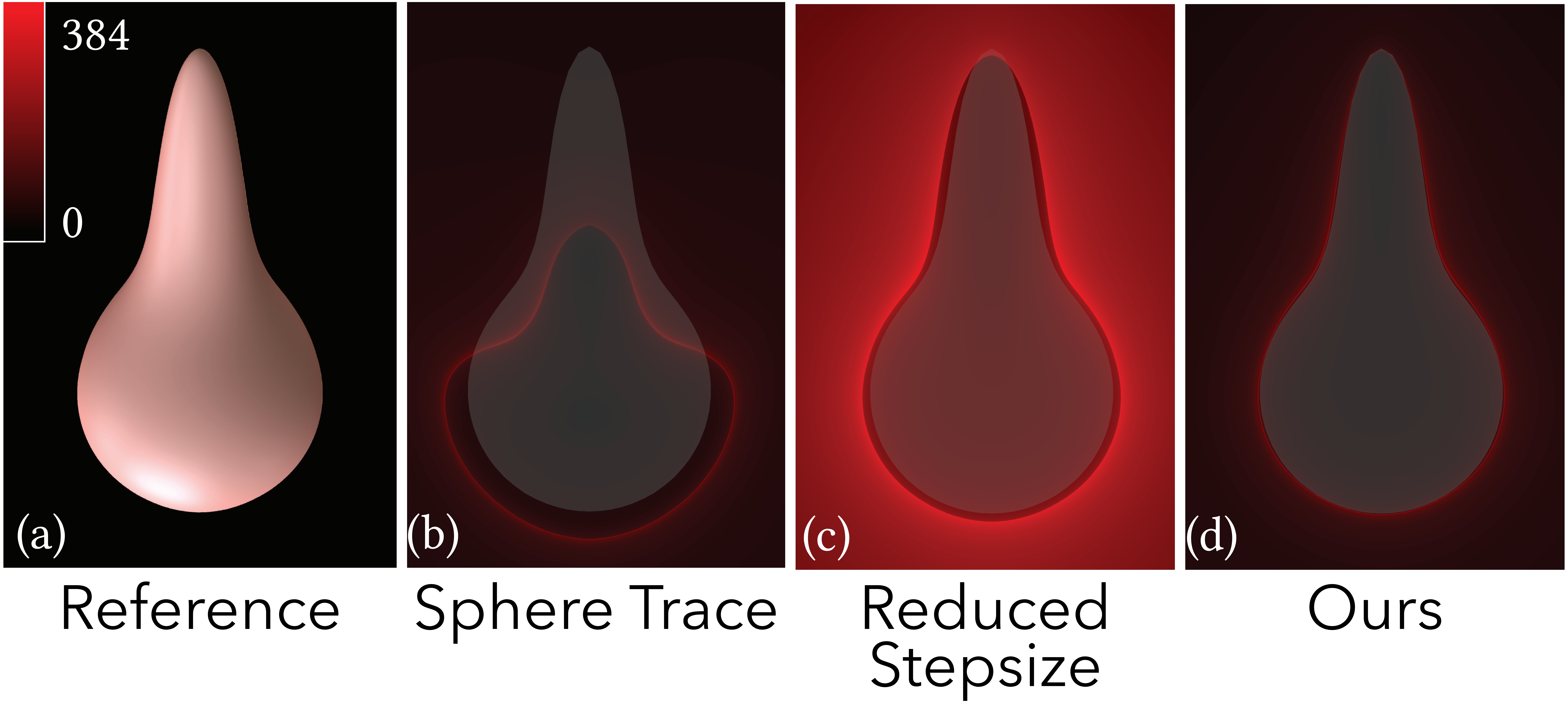
Dario Seyb
dario.r.seyb.gr@dartmouth.edu

Alec Jacobson
jacobson@cs.toronto.edu

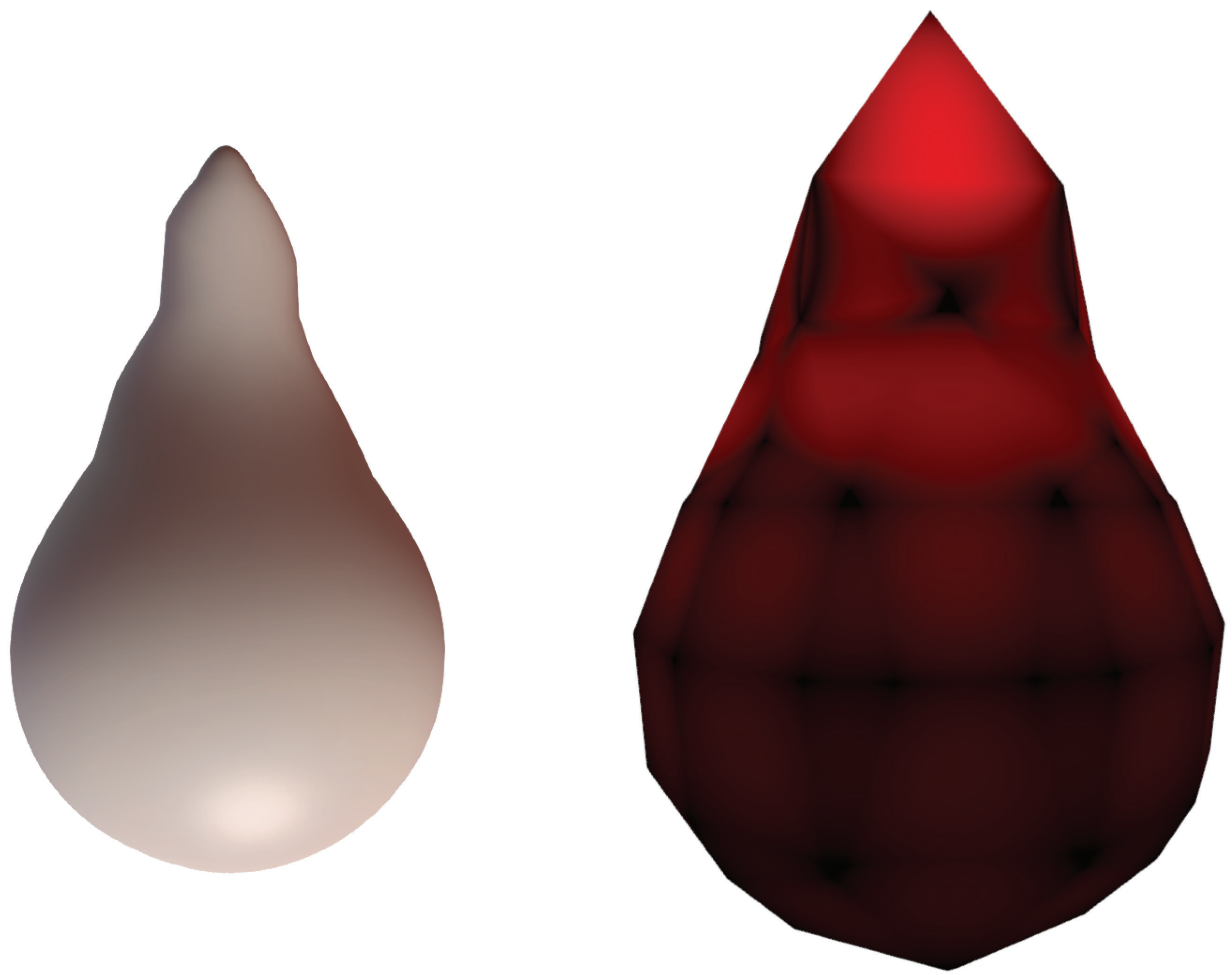
Derek Nowrouzezahrai
derek@cim.mcgill.ca

Wojciech Jarosz
wojciech.k.jarosz@dartmouth.edu

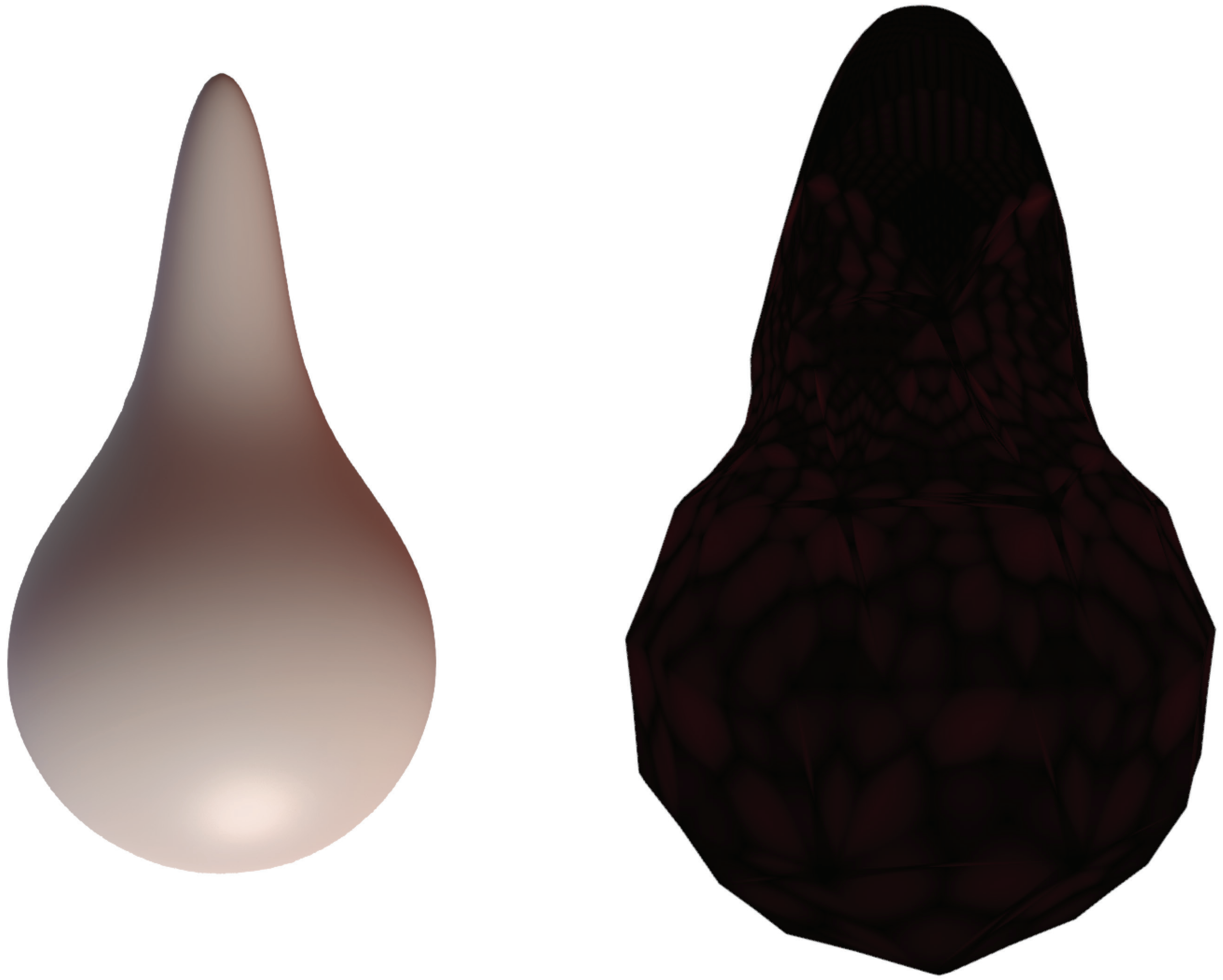
Integration – Comparison



Hull Subdivision – Results



No Subdivision



With Subdivision

Results - Error Control