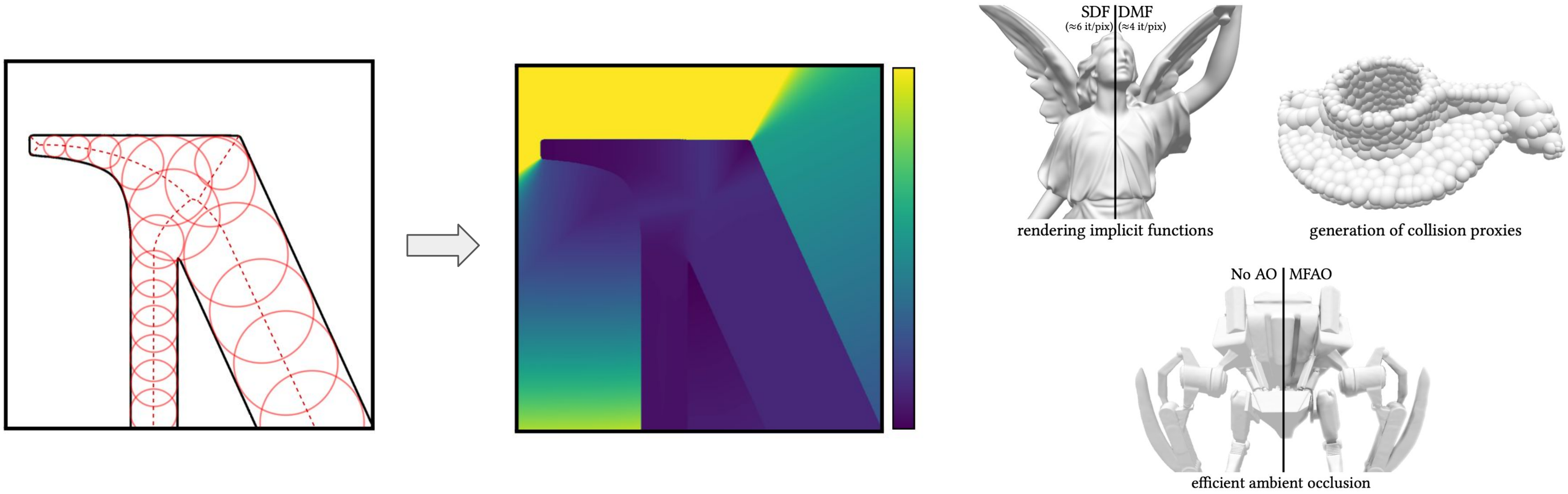
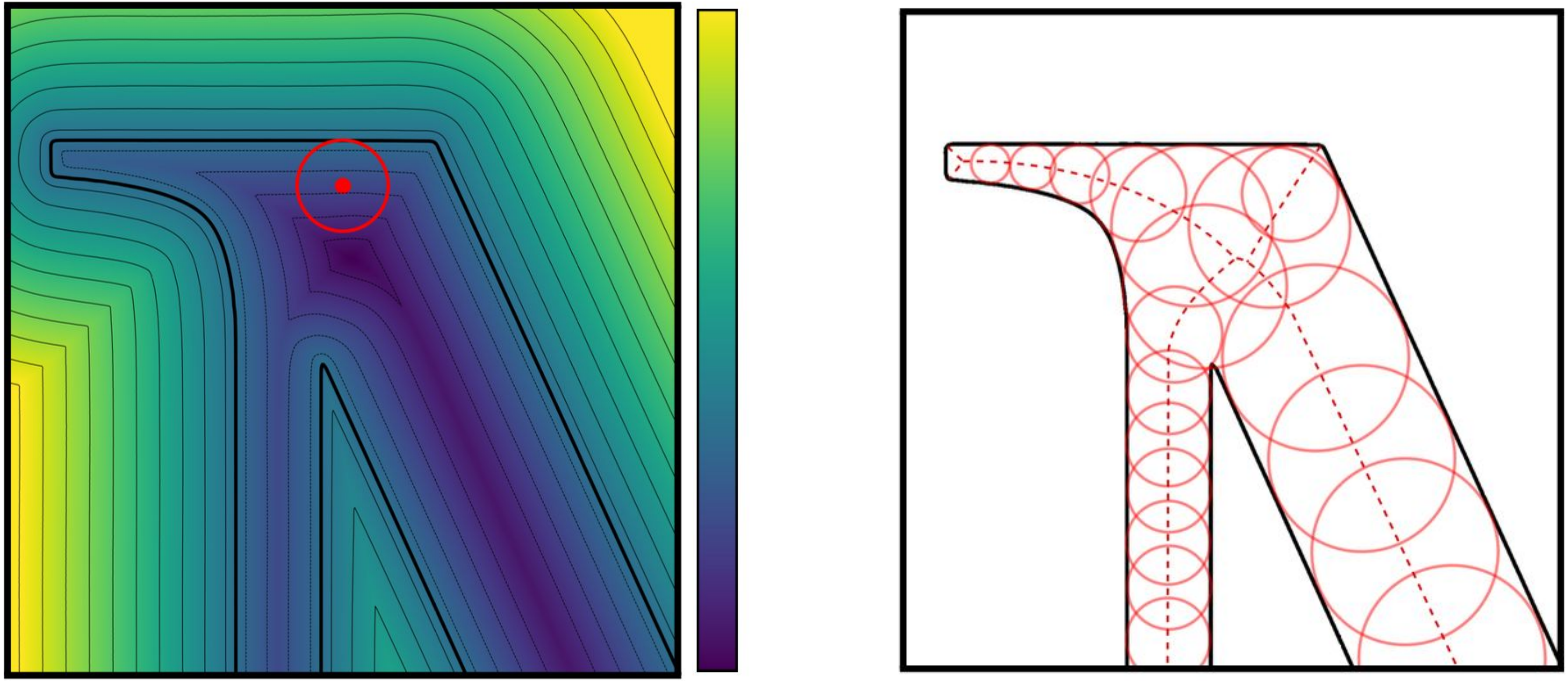
Deep Medial Fields



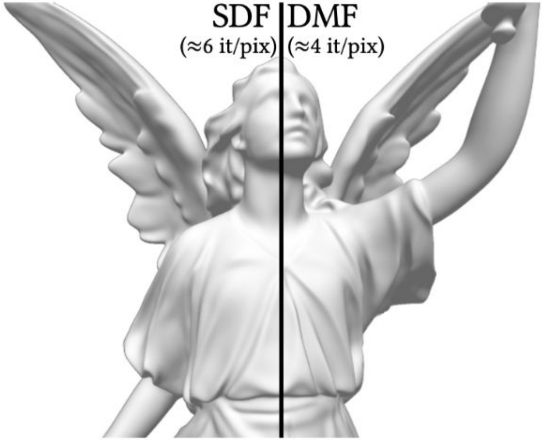
D. Rebain K. Li V. Sitzmann S. Yazdani K. Moo Yi A. Tagliasacchi

Signed Distance Fields

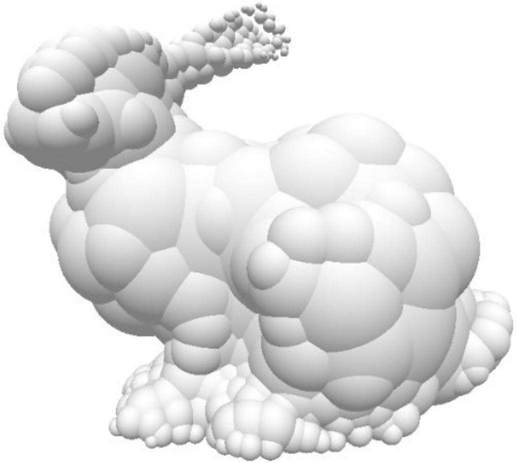
Medial Axis



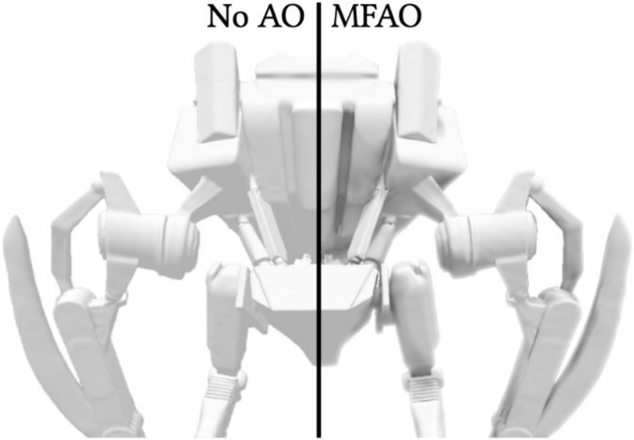
Applications



sphere tracing

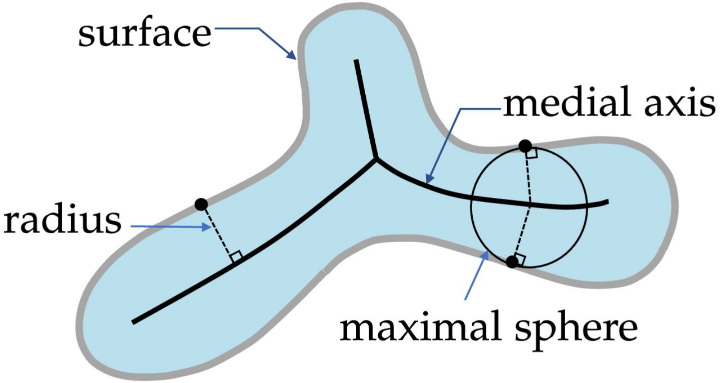


collision proxy



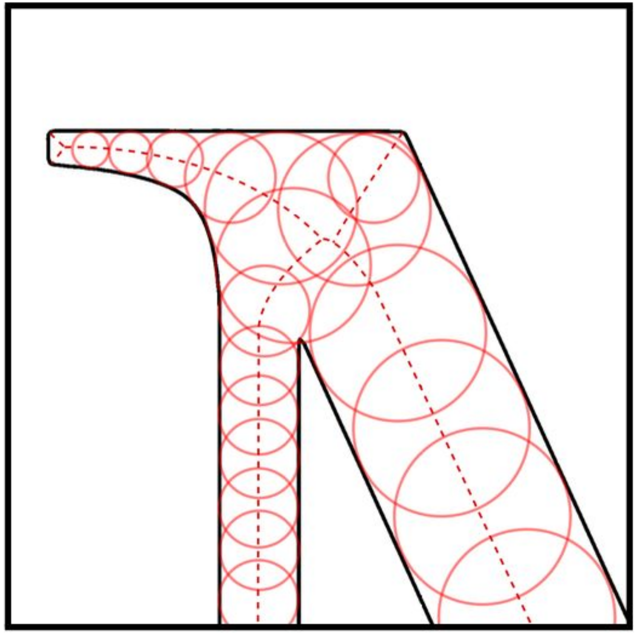
ambiant occlusion approximation

Medial Axis

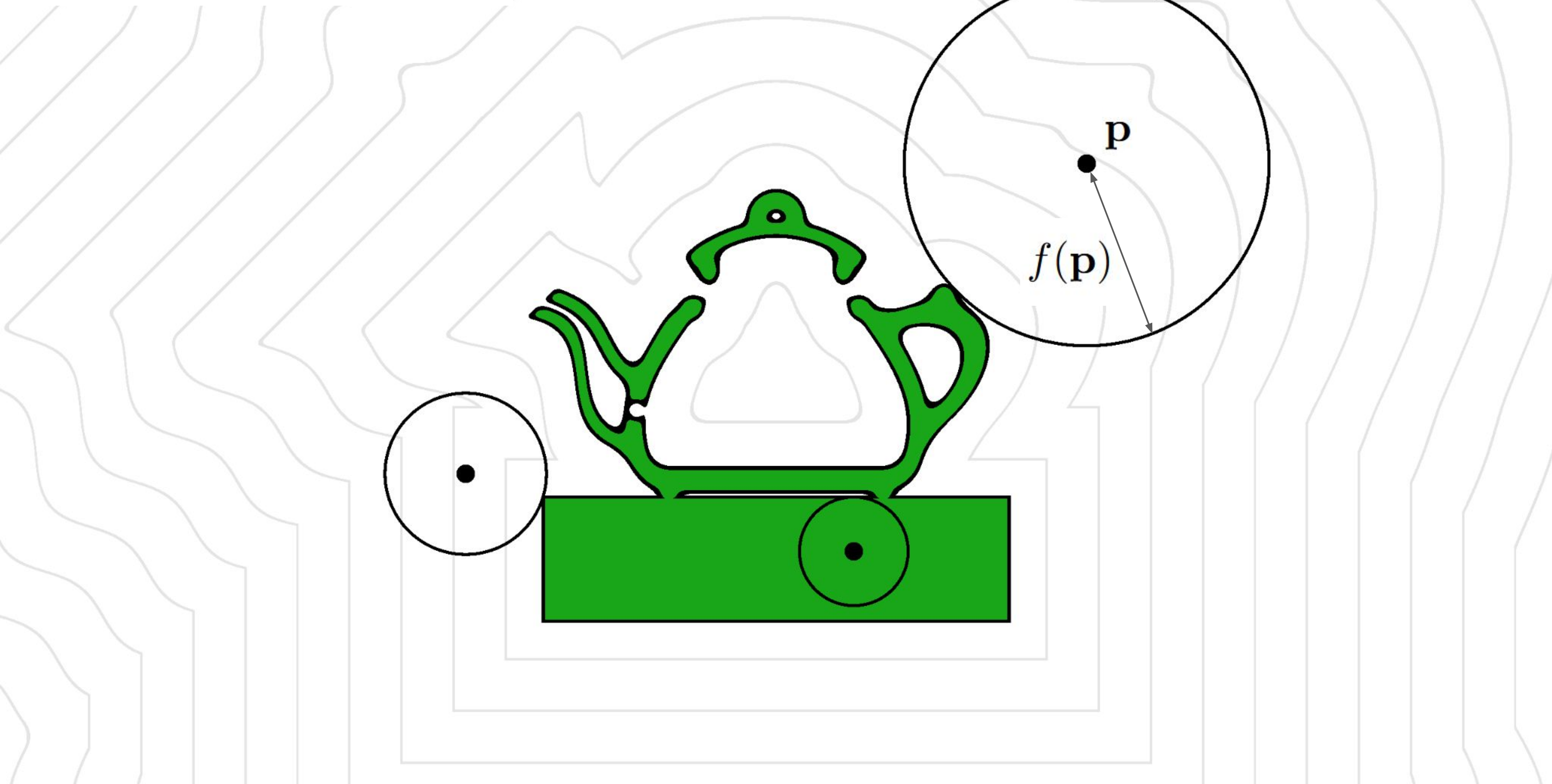


(a)

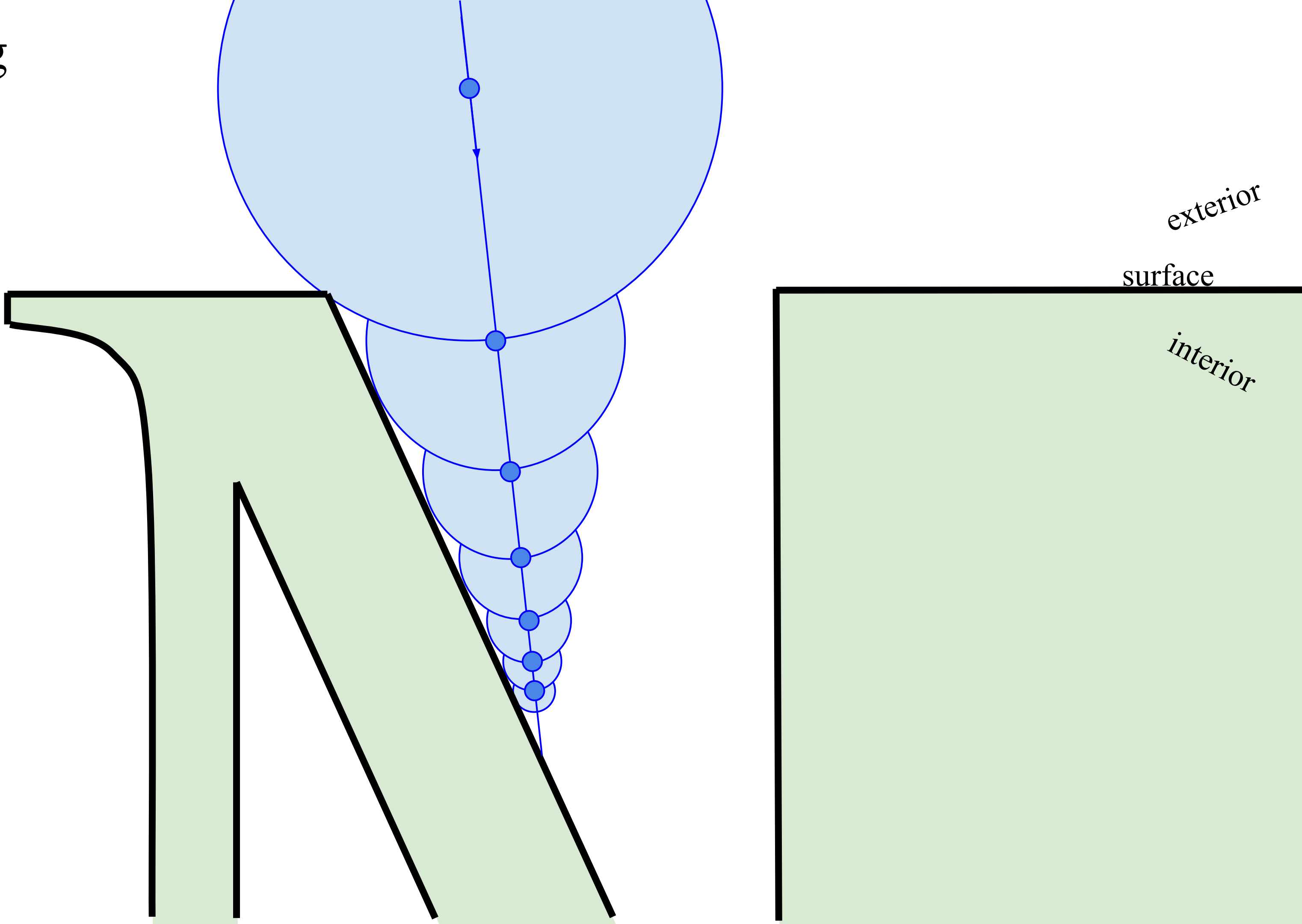
(b)



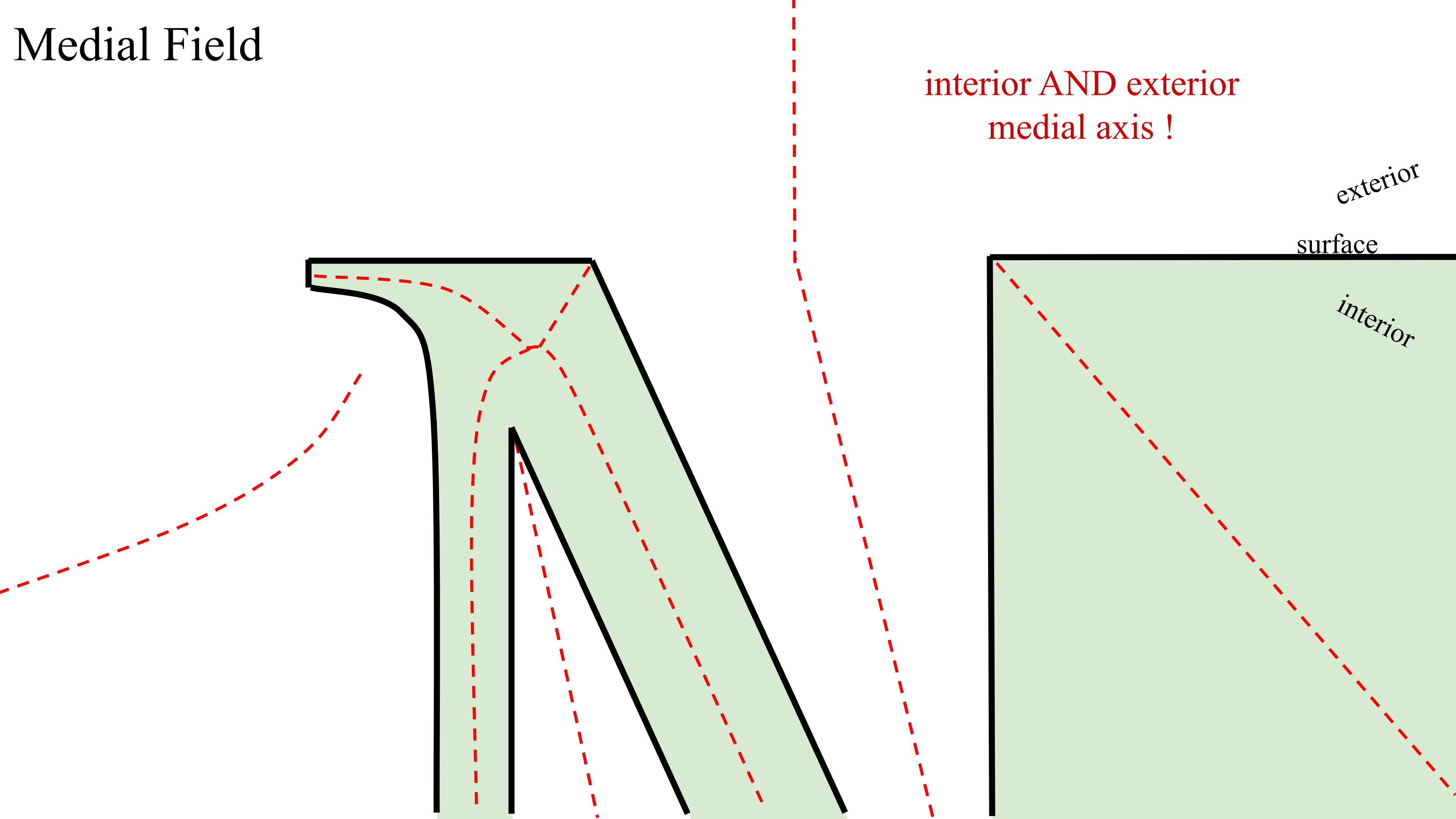
Signed Distance Fields



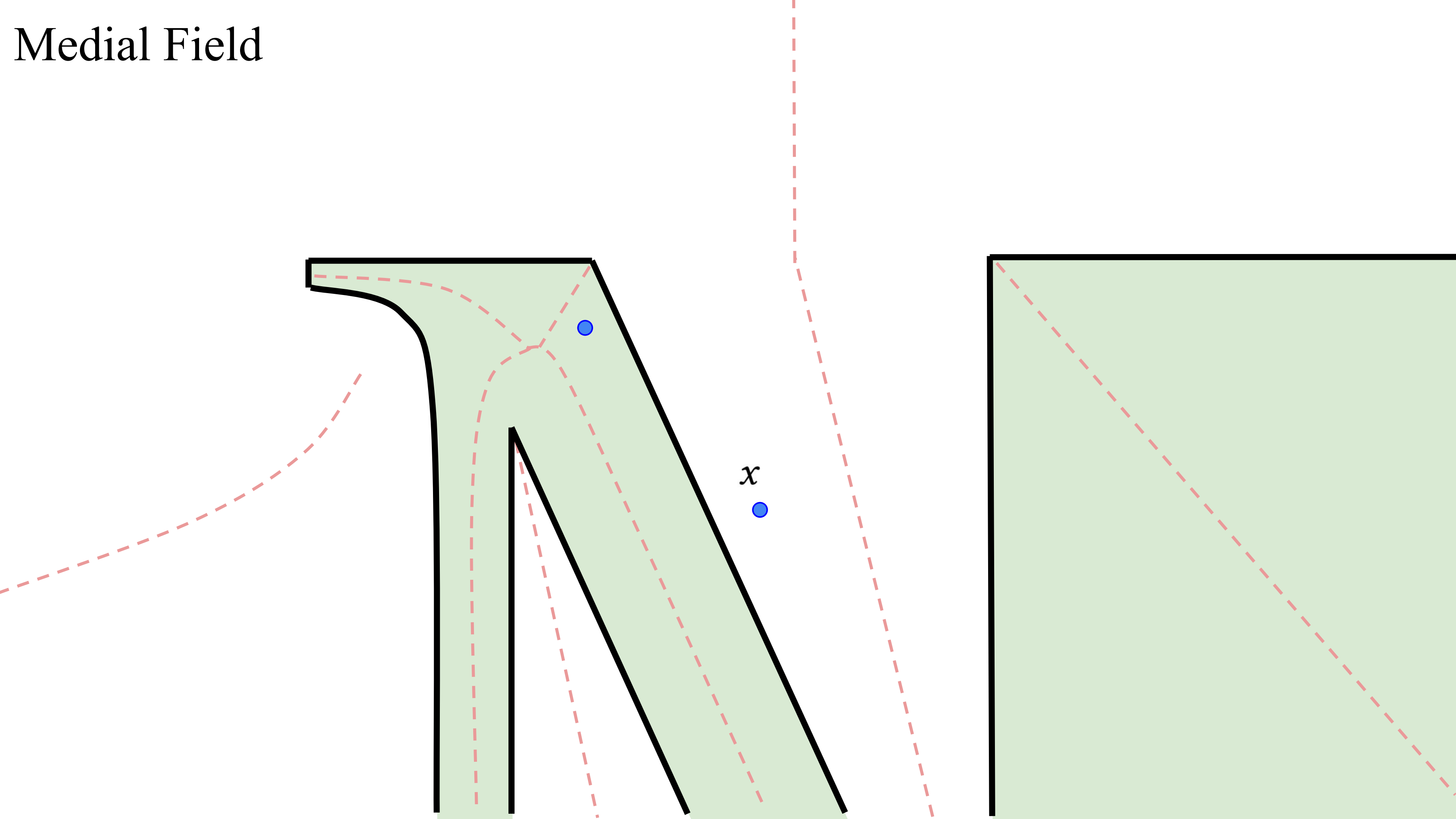
Sphere Tracing



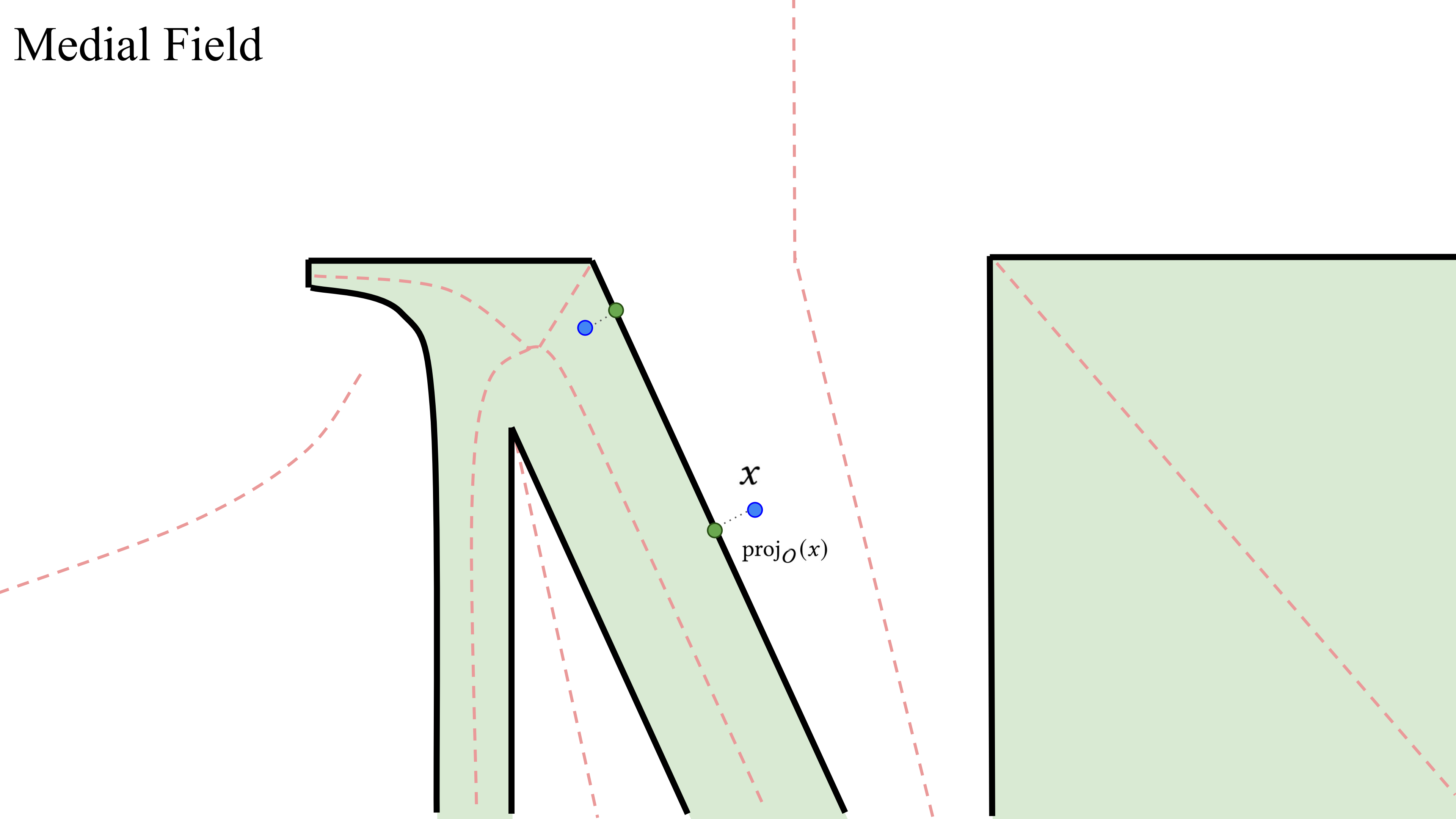
Medial Field



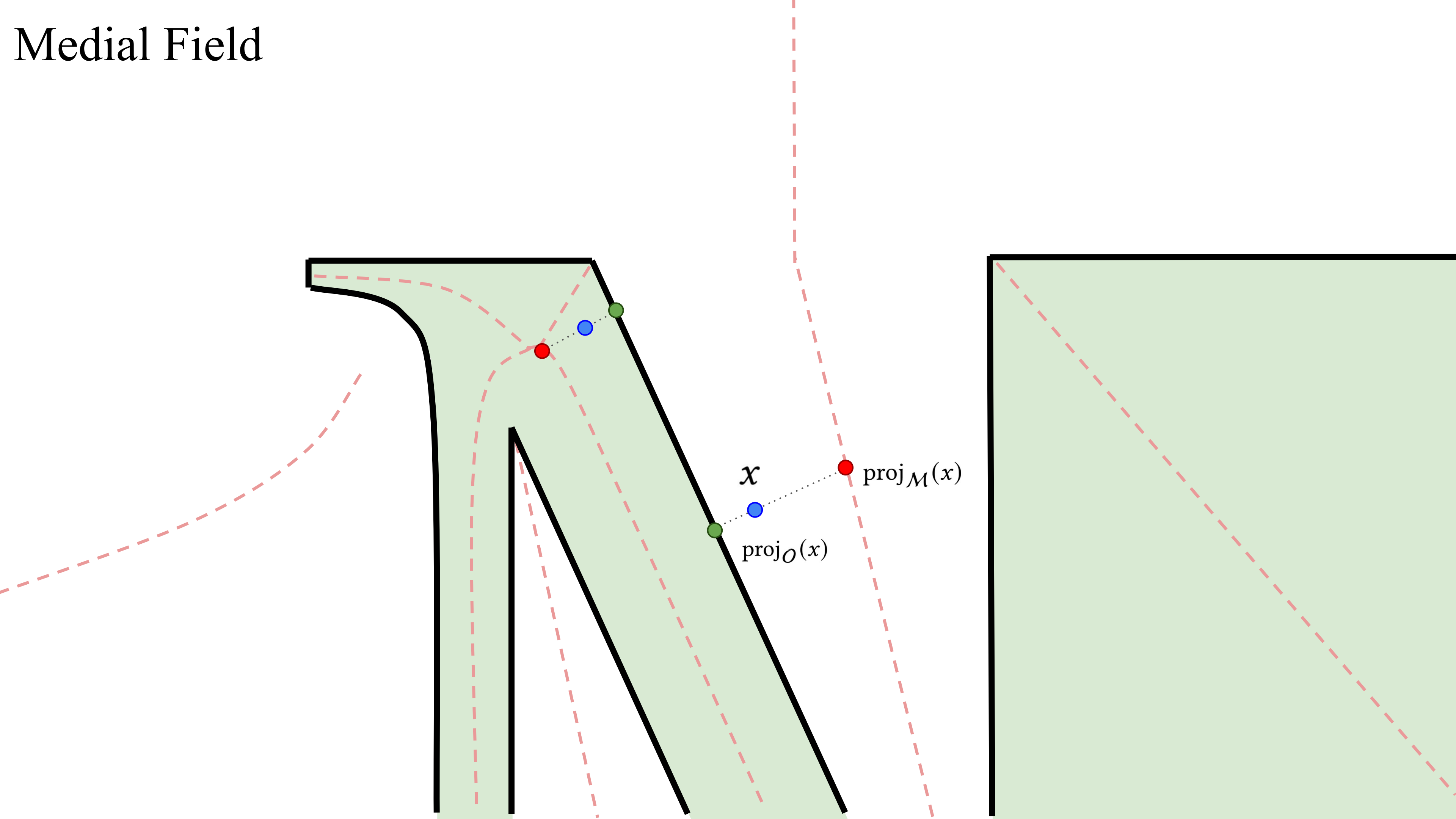
Medial Field



Medial Field



Medial Field

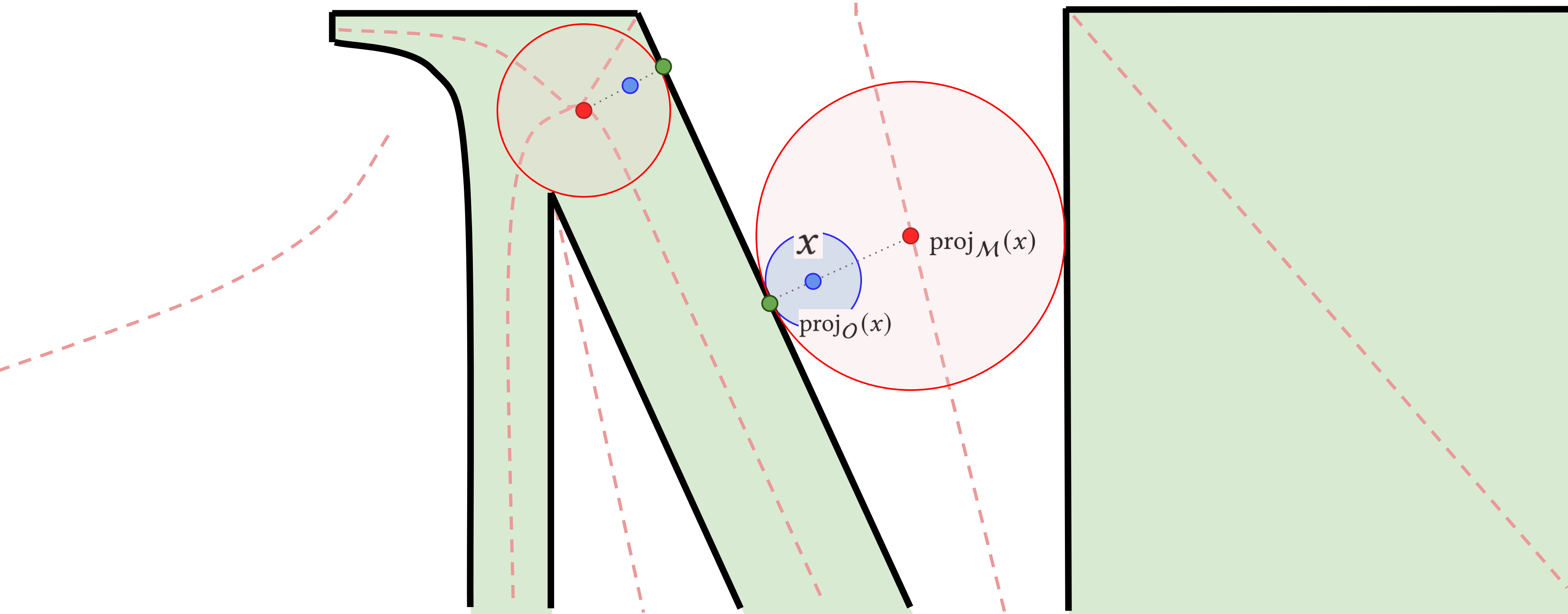


Medial Field

SDF

$$M(x) = |\Phi(\text{proj}_{\mathcal{M}}(x))|$$

Medial Field



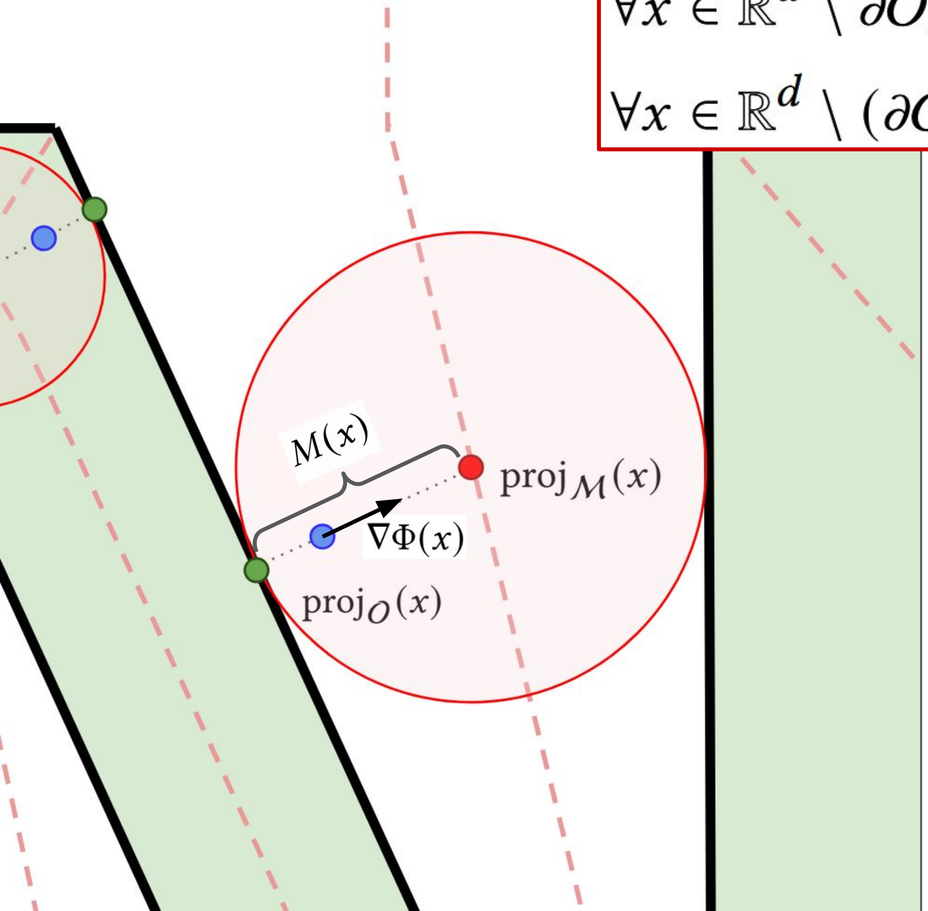
Medial Field

$$\forall x \in \mathbb{R}^d \setminus \partial\mathcal{O}, \qquad M^*(x) \geq |\Phi(x)| \,,$$

$$\forall x \in \mathbb{R}^d \setminus \partial\mathcal{O}, \qquad M^*(x) = |\Phi(\mathrm{proj}_{\mathcal{M}^*}(x))| \,,$$

$$\forall x \in \mathbb{R}^d \setminus (\partial\mathcal{O} \cup \mathcal{M}), \qquad \nabla M^*(x) \cdot \nabla\Phi(x) = 0 \,.$$

$$\mathrm{proj}_{\mathcal{M}}(x) = x + \nabla|\Phi(x)|(M(x) - |\Phi(x)|)$$



Deep Medial Field

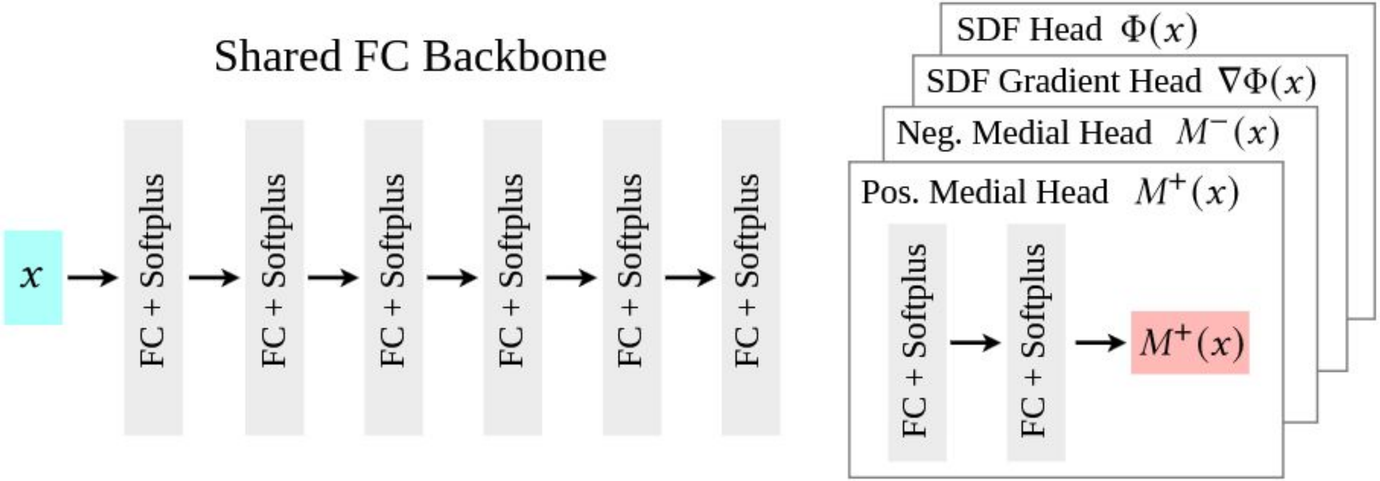
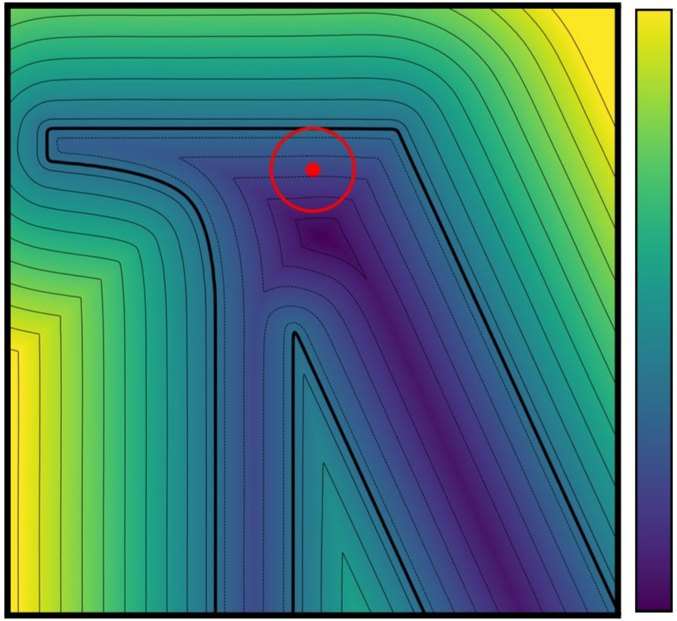
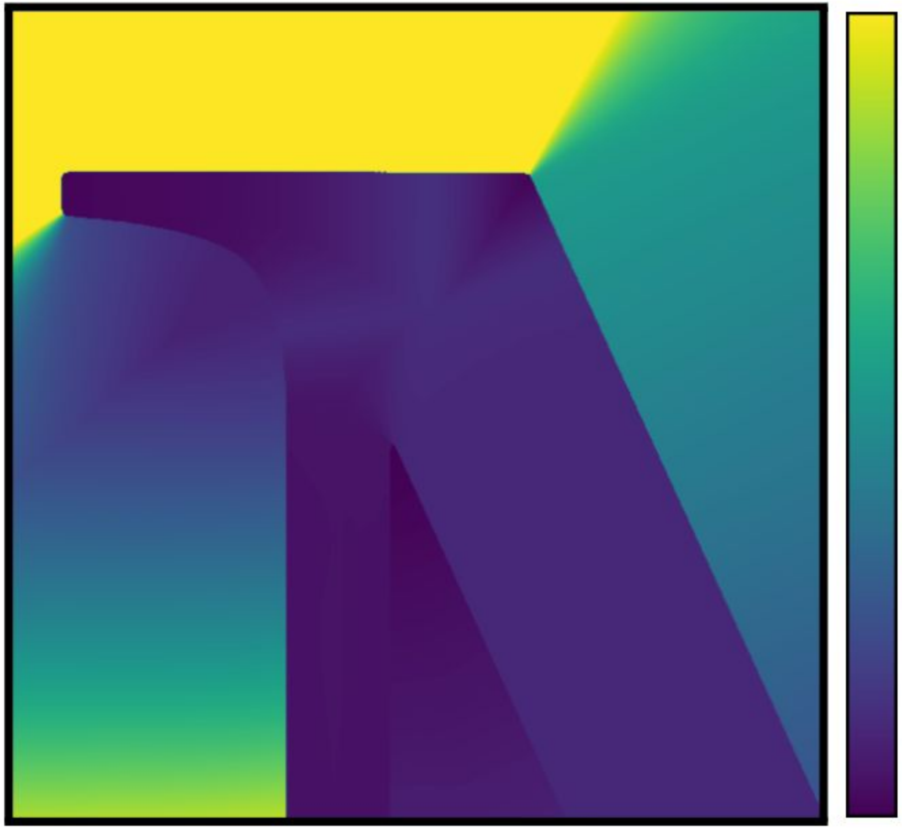


Fig. 9. **Architecture** – A block diagram of our network architecture. A shared fully connected backbone (left) embeds a world coordinate into a learned feature, which is then decoded into $M^+(x)$, $\Phi(x)$, $M^-(x)$ and $\nabla\Phi(x)$ by four separate, fully connected heads.

Medial Field

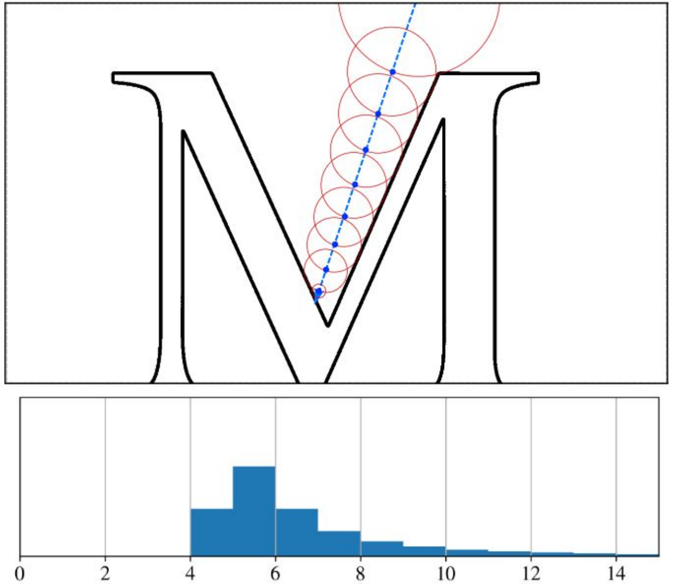


Signed Distance Field



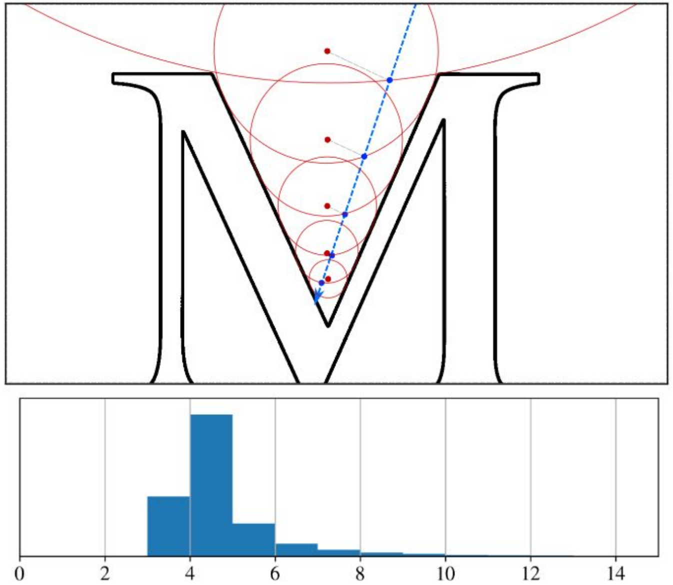
Medial Field

Applications - Sphere Tracing



Input: Ray direction d and origin o
Output: Position x of the ray intersection with ∂O
$x = o$
repeat
$x \leftarrow x + \Phi(x)d$
until $|\Phi(x)| < \epsilon$;

Sphere Tracing



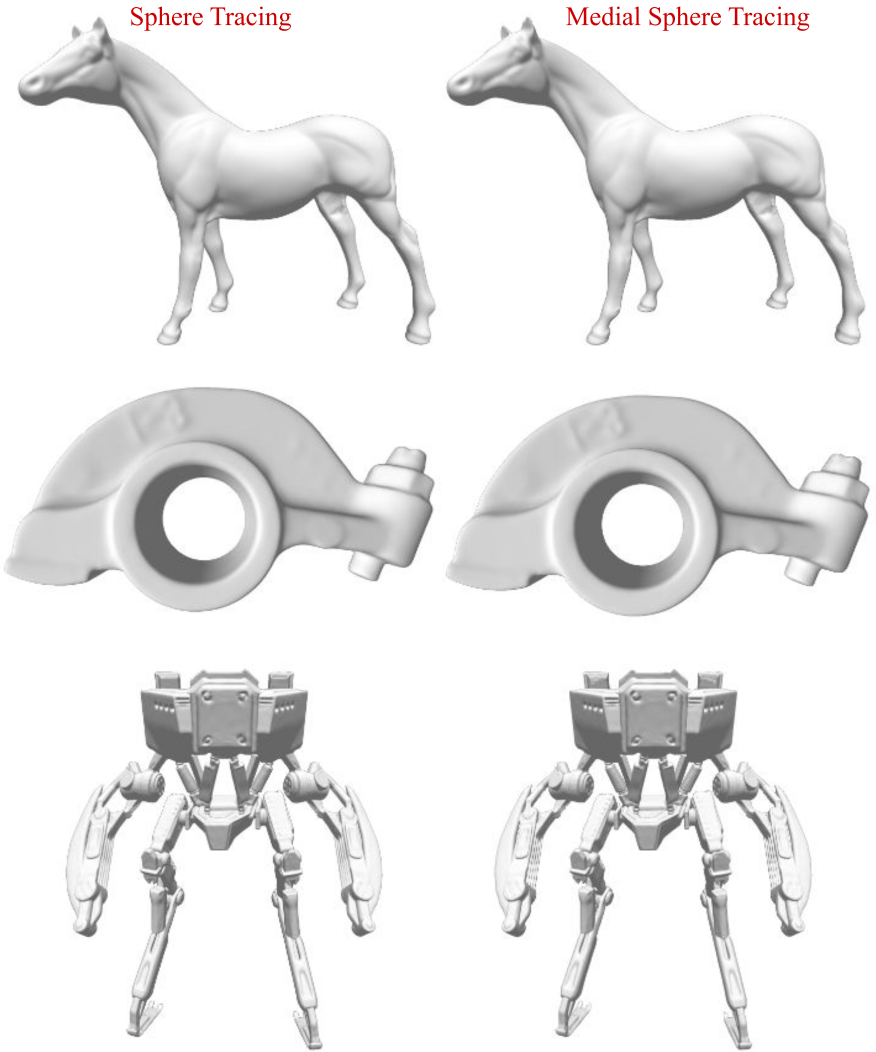
Input: Ray direction d and origin o
Output: Position x of the ray intersection with ∂O
$x = o$
repeat
$\mathrm{proj}_{\mathcal{M}}(x) = x + \nabla|\Phi(x)|(M(x) - |\Phi(x)|)$
$\beta = (\mathrm{proj}_{\mathcal{M}} - x) \cdot d$
$\alpha = \sqrt{\beta^2 - (||\mathrm{proj}_{\mathcal{M}}(x) - x||_2^2 - M(x)^2)}$
$s = \alpha + \beta$
$x \leftarrow x + sd$
until $|\Phi(x)| < \epsilon$;

Medial Sphere Tracing

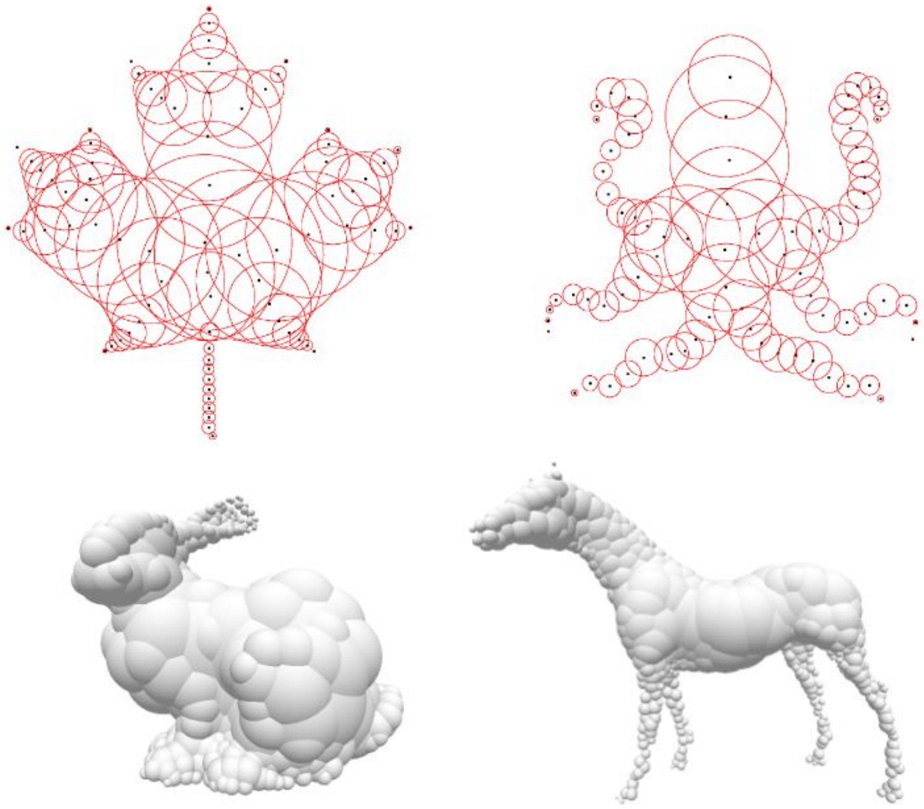
Applications - Sphere Tracing

Scene	Naive Sphere Tracing			Medial Sphere Tracing		
	Mean	Min	Max	Mean	Min	Max
armadillo	7.1	6.5	8.2	4.7	4.3	5.1
bunny	7.4	6.7	8.3	4.5	4.2	4.8
horse	6.5	6.0	7.3	4.1	3.8	4.5
lucy	6.1	5.6	6.9	4.1	3.8	4.5
mecha	6.9	6.3	7.8	4.8	4.4	5.2
rocker-arm	6.0	5.6	6.5	3.7	3.5	4.0

Average number of tracing iterations



Applications - Physics Proxies



Furthest sphere sampling. To create physics proxies we propose an algorithm that could be understood as a generalization of the furthest point sampling [Mitchell 1991], but for spherical data. We start by placing N points randomly throughout the volume and for each of these points finding a corresponding point on the medial axis, in constant time using the medial projection operation in (5). We then draw $M<N$ sample points x_n^* through an iterative sampling:

$$x_n^* = \arg\max_{x_n} \min_{x_m} \underbrace{||x_n - x_m||/(r_n + r_m + \epsilon)}_{\text{normalized separation}} . \tag{12}$$

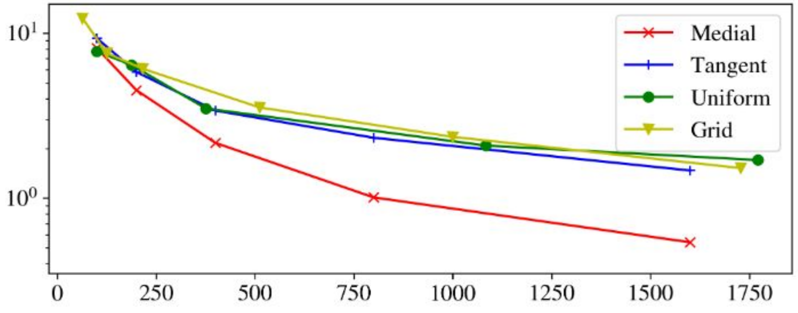


Fig. 7. **Physics collision proxies** – Spherical (circular) shape approximation computed by the medial field in 2D (top) and in 3D (middle). We also quantitatively analyze a variety of collision proxies, revealing the corresponding memory/accuracy trade-off in percentage MAE vs memory in # of floats (bottom).

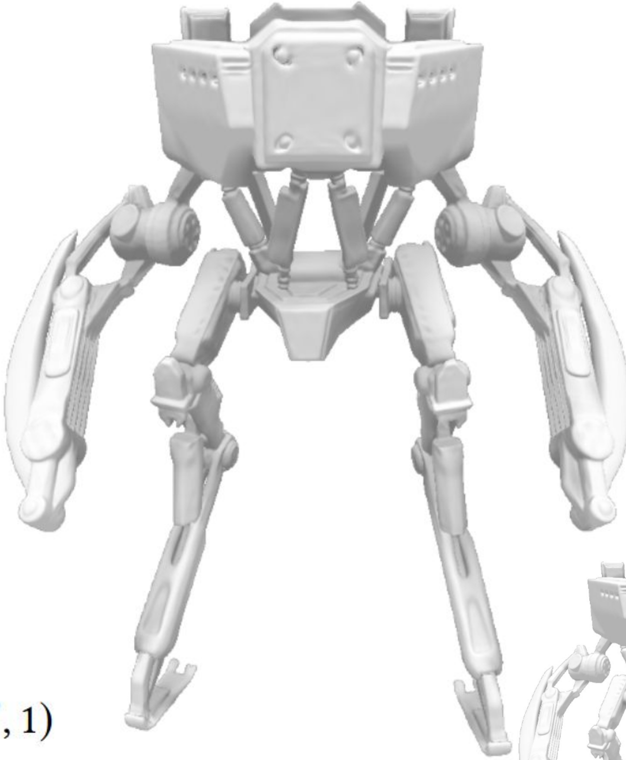
Applications - MFAO

The Medial Field **M(x)** measures the local thickness of both the shape and its complement space.

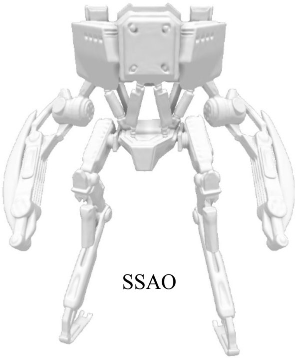
$$MFAO(x) = \min(aM(x + \nabla\Phi(x)\epsilon)^p, 1)$$

- no noise
- view-independent

MFAO



MFAO



SSAO

SSAO

Backface Distance Fields: Relaxing Signed Distance Fields

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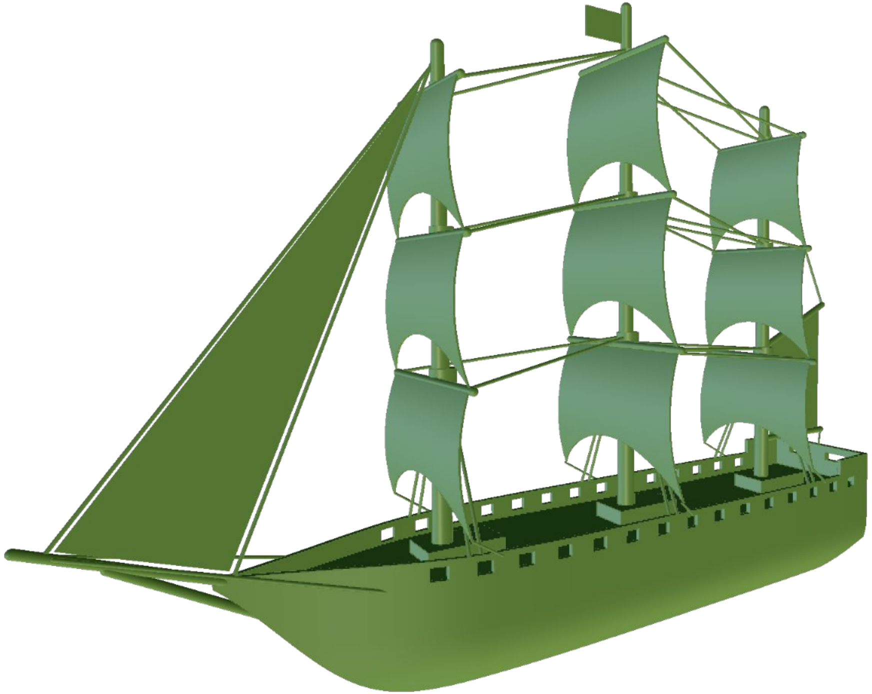
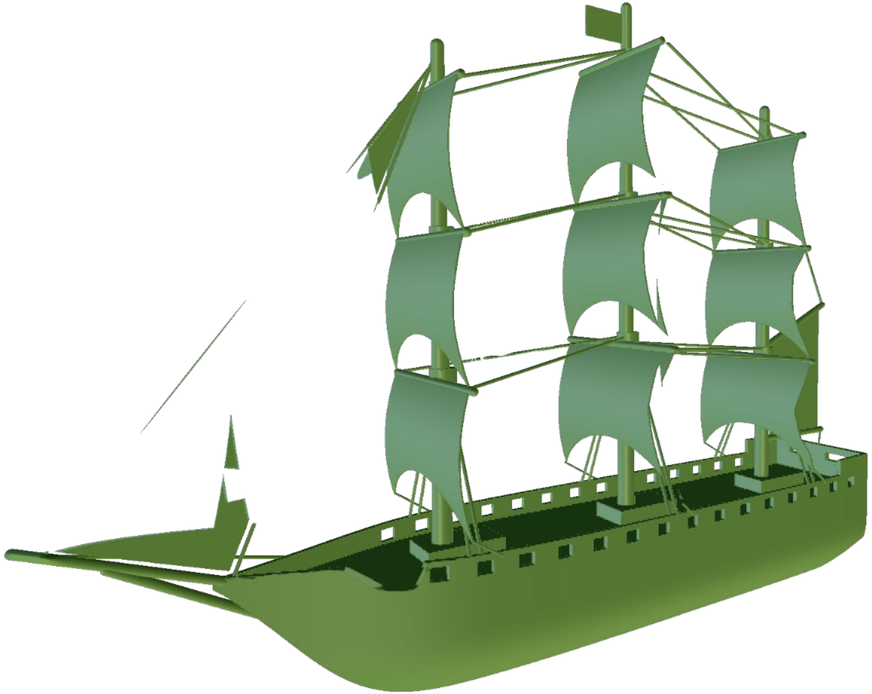
Keywords: Sphere Tracing, Signed Distance Fields, Ray-Surface Intersection, Unbounding Spheres, Safety Volumes.

Abstract: We propose backface distance functions, an implicit volume representation that improves the convergence rate of sphere tracing. We employ the closest signed distances to backfacing surface points, introducing a relaxed representation of signed distance functions. The backface and signed distance functions coincide within the volume. For external points, we prove that a backface distance-sized step is the largest direction-independent step along a ray that does not pass through the volume boundary more than once. We show analytic and discrete realizations of our concept. We present a discrete backface distance field generation method to construct exact and approximate fields from triangular meshes and procedural implicit scenes. We employ generation-time processing and correction steps in the discrete case to ensure robust surface visualization in combination with GPU filtering. We validate the proposed discrete and analytic representations empirically as well by comparing their performance to basic, relaxed, and enhanced sphere tracing and demonstrate that it generally outperforms the other methods.

Standard Sphere Tracing

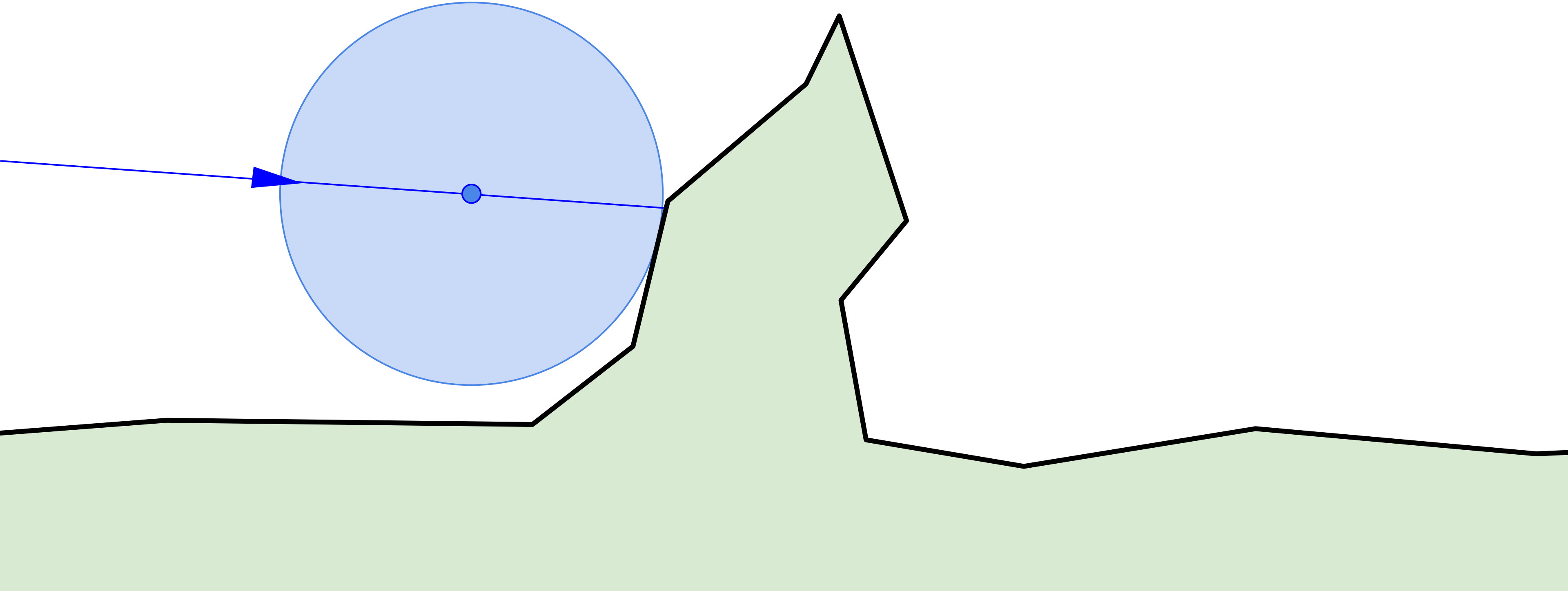


Underestimated distance

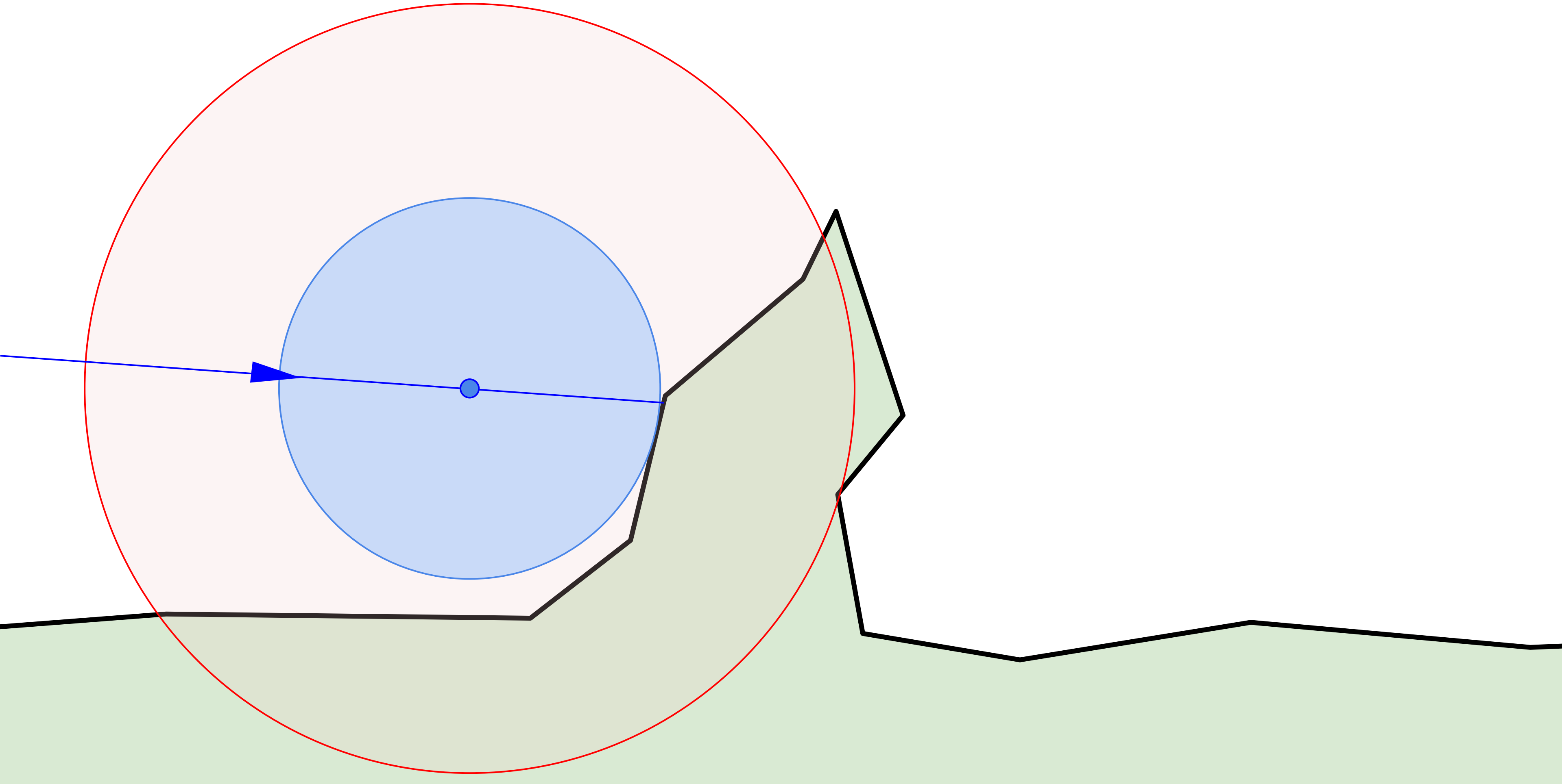


Overestimated distance

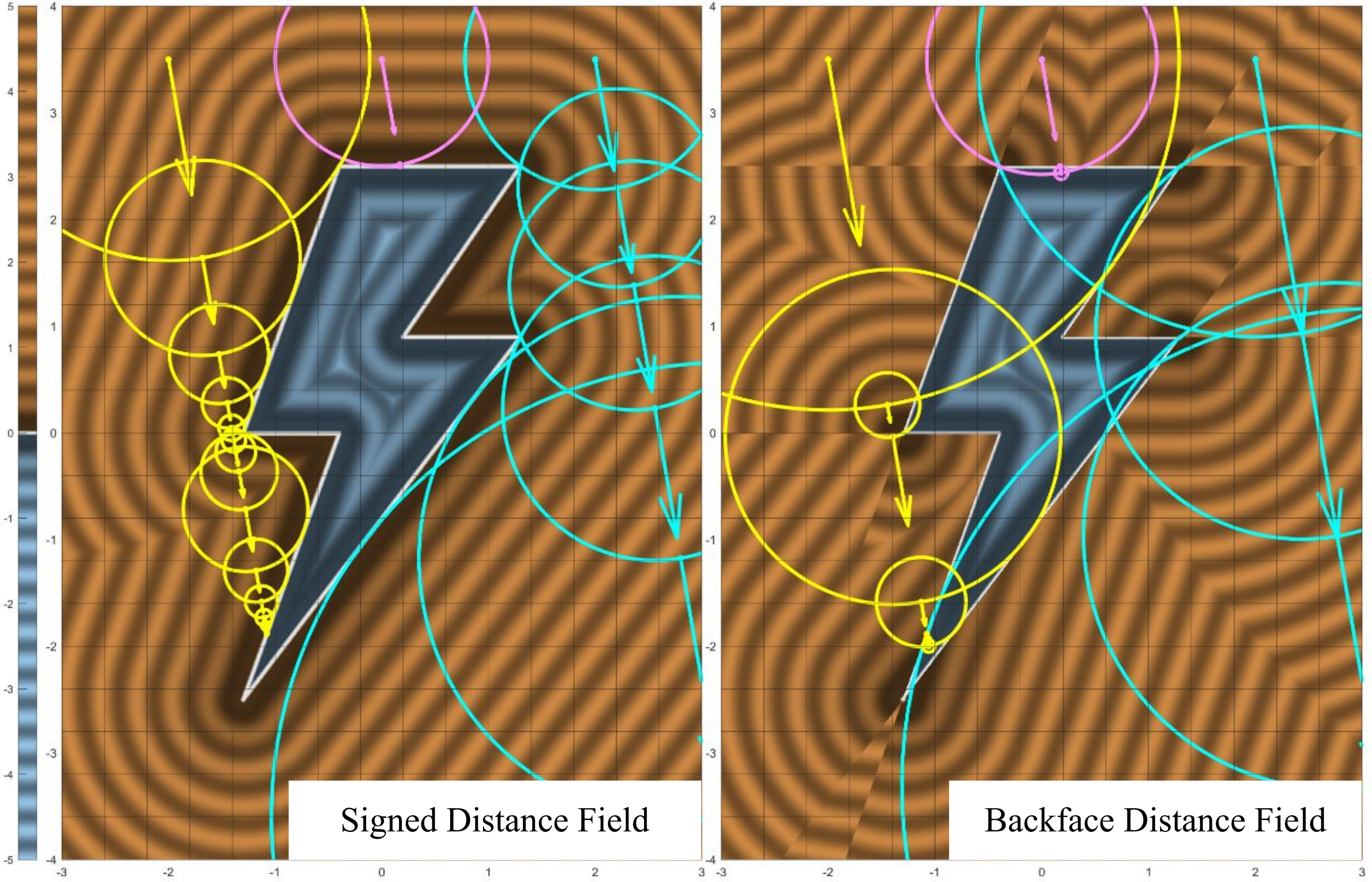
Standard Sphere Tracing



Backface Sphere Tracing



Backface Sphere Tracing



Backface Sphere Tracing

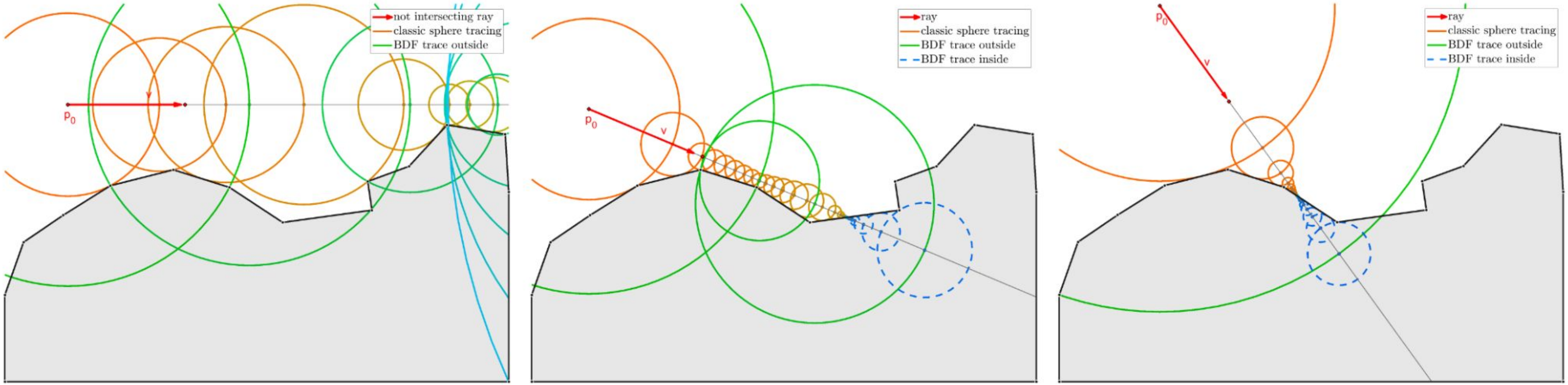


Figure 5: Three cases of tracing the SDF (in red) and the BDF (in green and blue) are displayed. On the left, the ray diverges to infinity, and our method leaves the frame in half as many steps. On the middle and the right, the ray intersects the surface, the BDF tracing steps inside and performs sphere tracing backwards to the root, rarely taking more steps (right).

Backface Sphere Tracing

Scene	Steps	Shadows: off				Shadows: on			
		ST	RT	ET	BDF	ST	RT	ET	BDF
Spheres	32	0.43	105%	109%	**86%**	0.66	105%	114%	**85%**
	1000	0.77	92%	93%	**77%**	1.14	87%	89%	**75%**
Gears	32	0.28	104%	104%	**89%**	0.39	103%	105%	**87%**
	1000	0.37	92%	89%	**86%**	0.5	90%	90%	**84%**
Mountain	32	0.36	100%	106%	**78%**	0.55	93%	104%	**75%**
	1000	0.49	86%	96%	**71%**	0.67	84%	96%	**72%**
Bunny mesh	32	0.25	100%	100%	**88%**	0.33	101%	102%	**86%**
	1000	0.32	92%	**86%**	**86%**	0.39	92%	90%	**85%**
Skull mesh	32	0.23	104%	104%	**91%**	0.31	106%	106%	**90%**
	1000	0.45	84%	**82%**	89%	0.51	**88%**	94%	90%