Geometric Modeling and Processing 2024 18TH

Real-time Collision Detection Between general SDFs

Pengfei Liu[1], Yuqing Zhang[1], He Wang[2], Milo K. Yip[3], Elvis S. Liu[3], Xiaogang Jin[1]

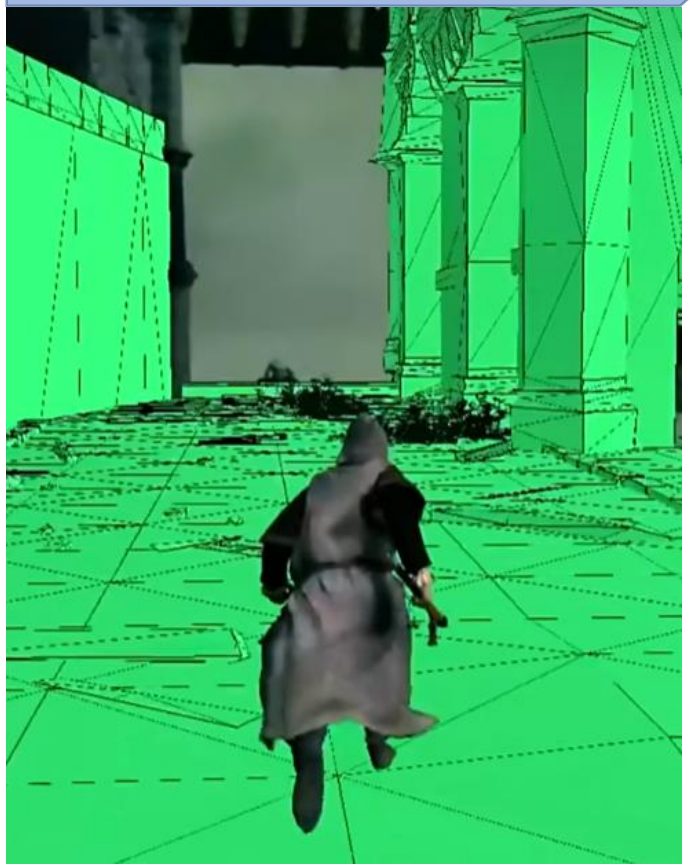
[1]State Key Lab of CAD&CG, Zhejiang University
[2]School of Computing, University of Leeds
[3]Morefun Studios, Tencent

Co-organizers：

Introduction

Collision detection is a basic subject…

Video Games



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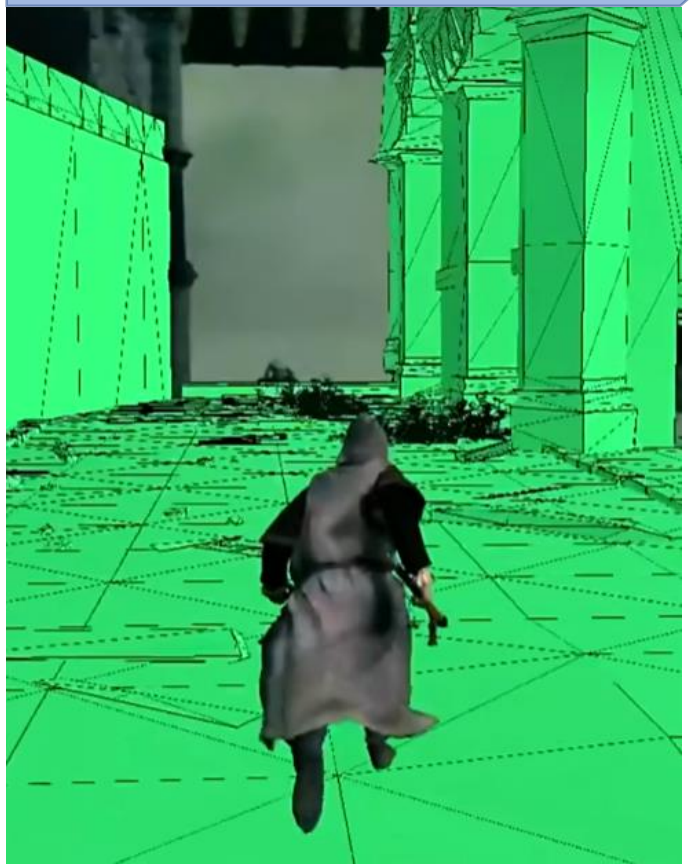
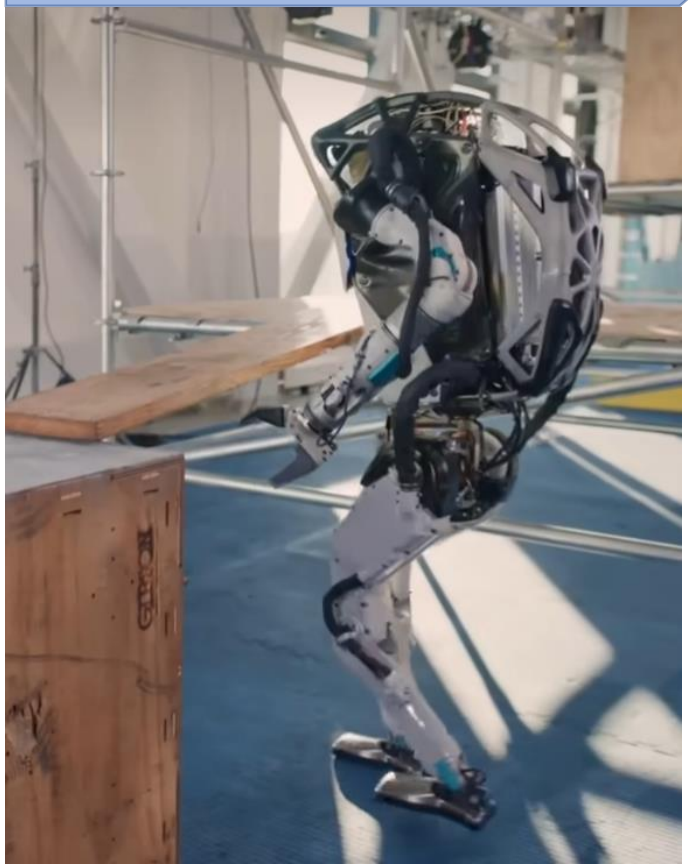


Robotics



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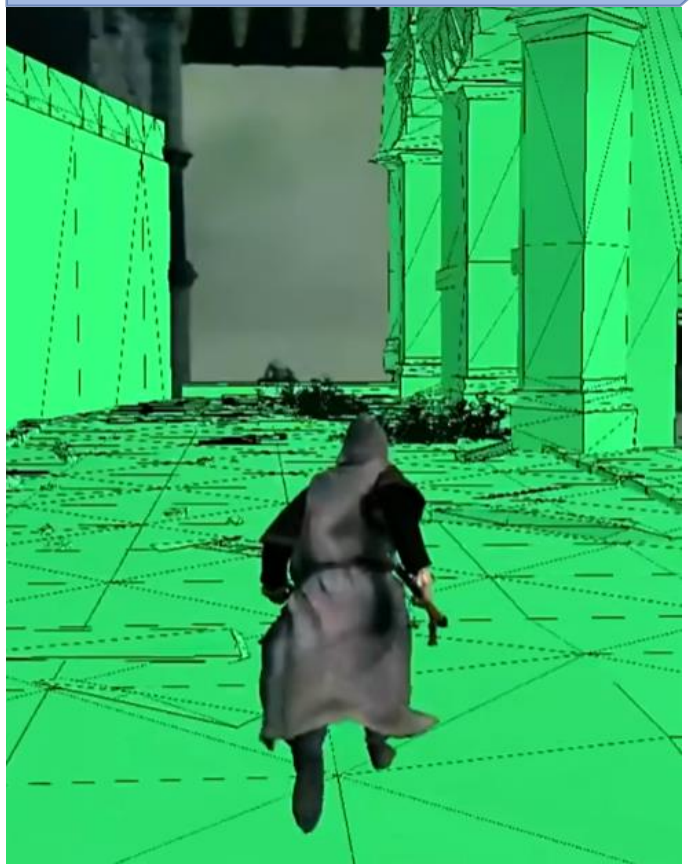
Video Games



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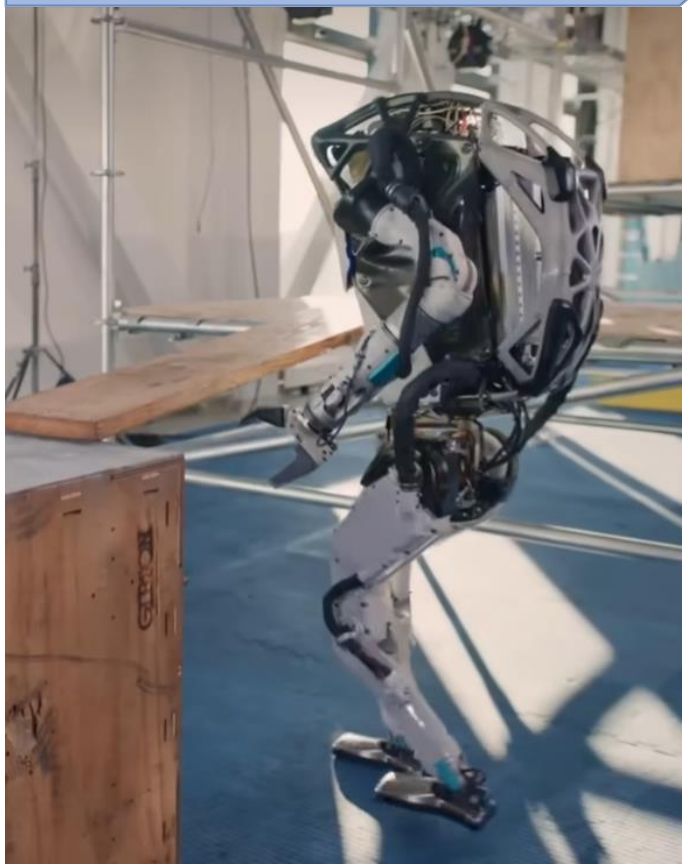
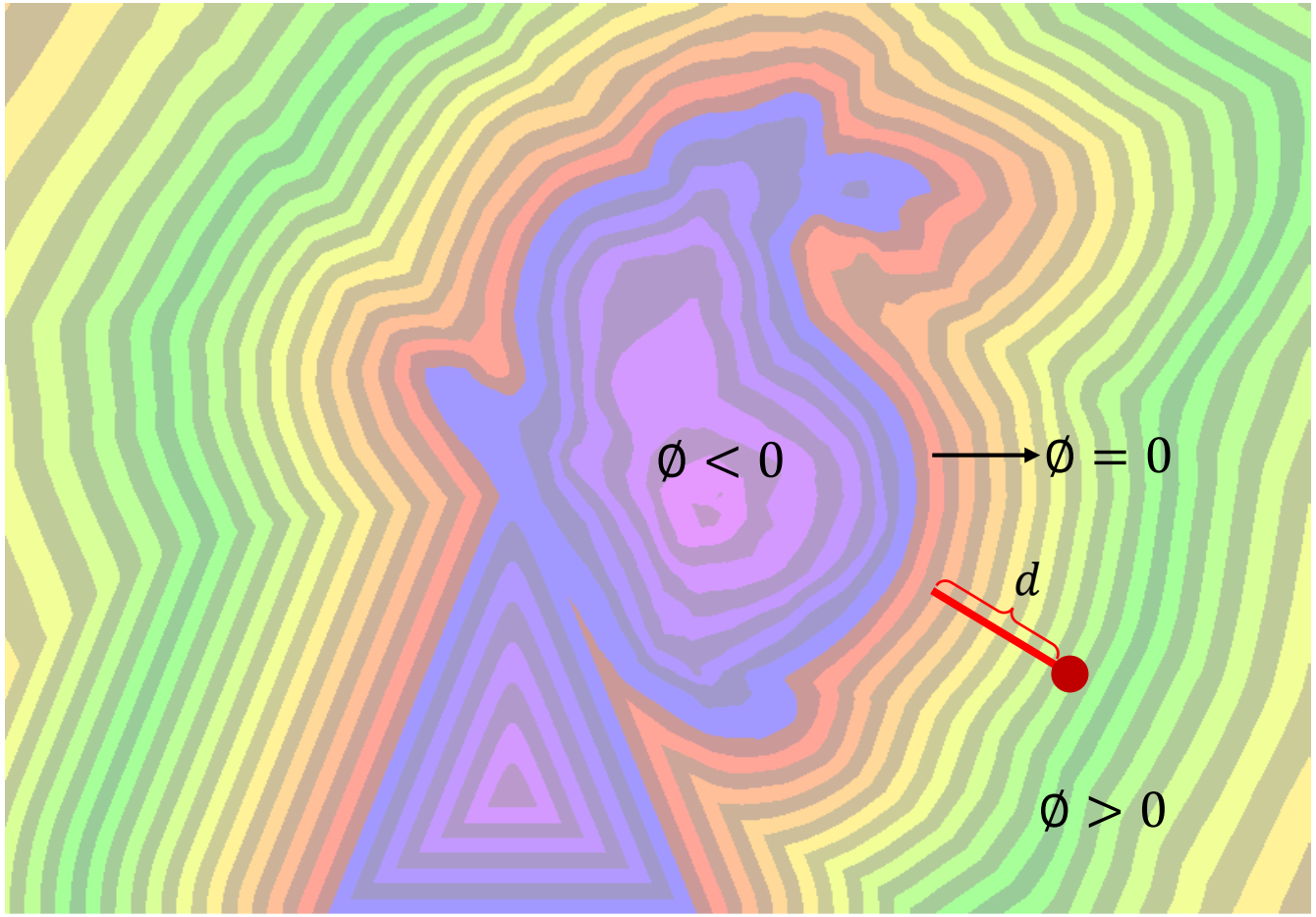
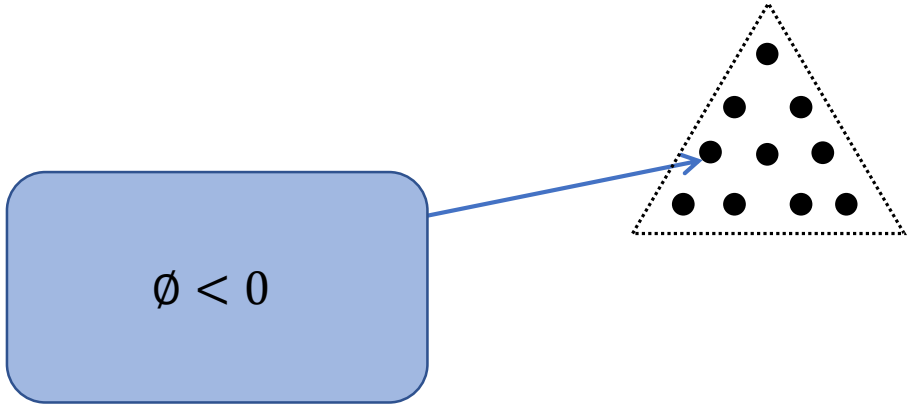


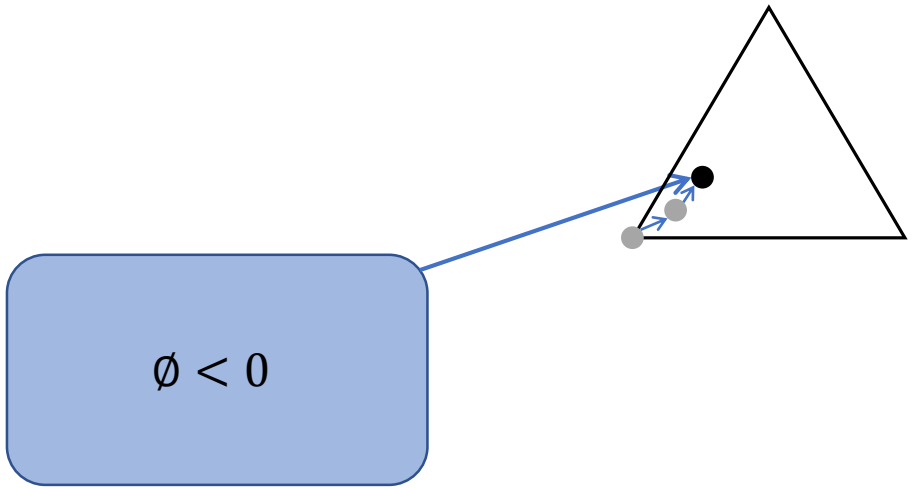
VR / AR

SDFs have been widely used in collision detection…





Point-SDF detection[Basu et al. 2015]

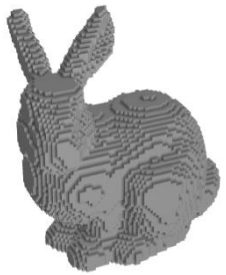


Surface-SDF detection[Miles et al. 2020]

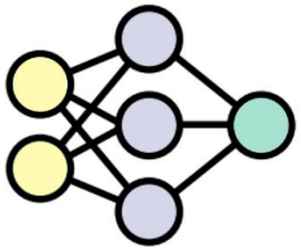
Collision detection between SDFs

$$\phi_c(\mathbf{p}) = \| \max(\mathbf{q}, 0) \|_2 + \min(\max(\mathbf{q}_x, \max(\mathbf{q}_y, \mathbf{q}_z)), 0),$$
$$\mathbf{q} = |\mathbf{p}| - \frac{1}{2}s.$$

Analytic distance functions



Voxels



Neural networks

Collision detection between SDFs

$$\phi_c(\mathbf{p}) = \| \max(\mathbf{q}, 0) \|_2 + \min(\max(\mathbf{q}_x, \max(\mathbf{q}_y, \mathbf{q}_z)), 0),$$
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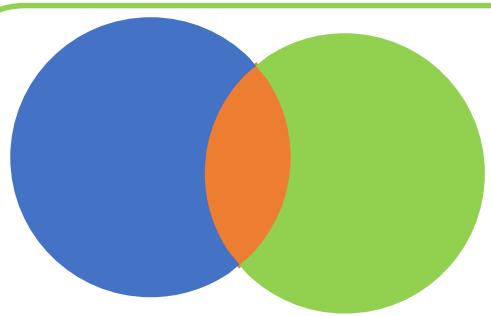
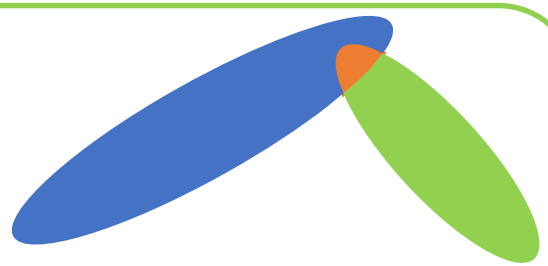
Analytic distance functions

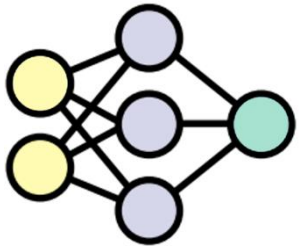


Sphere collision



ellipsoid collision

Voxels



Neural networks

Collision detection between SDFs

$$\phi_c(\mathbf{p}) = \| \max(\mathbf{q}, 0) \|_2 + \min(\max(\mathbf{q}_x, \max(\mathbf{q}_y, \mathbf{q}_z)), 0),$$
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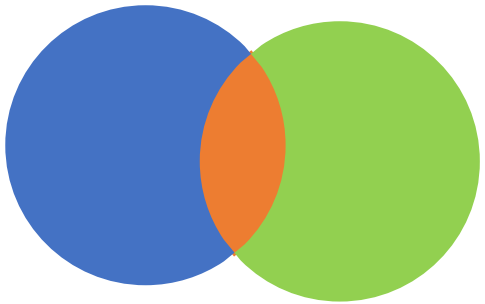
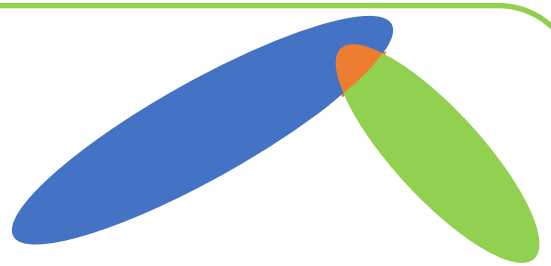
Analytic distance functions

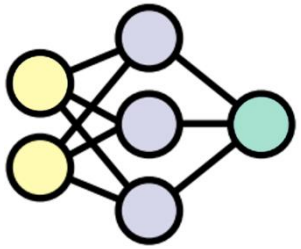


Sphere collision



ellipsoid collision

Voxels



Neural networks

?

Contributions

SDF-SDF Collision detection

The first real-time and accurate general SDF-SDF collision detection method.

Testing the intersection of analytic distance functions

A novel method for testing the intersection of analytic distance functions.

Estimating contact information

An accurate method for estimating contact information for SDF-SDF collision response stages.

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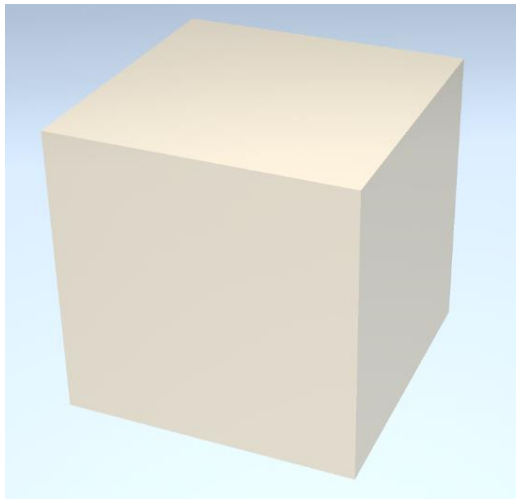
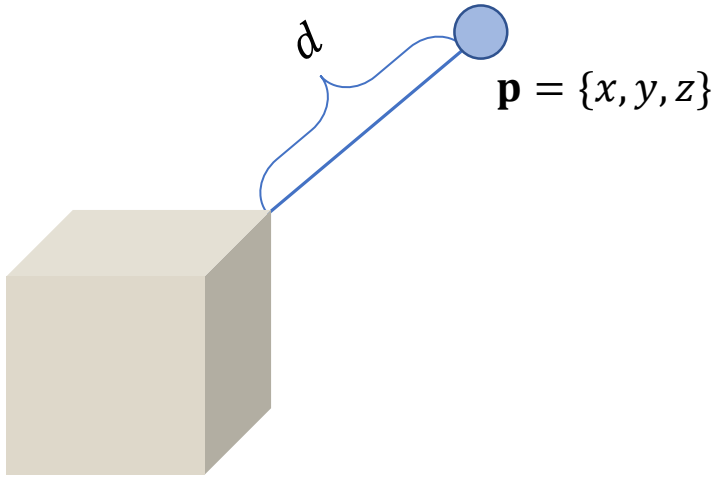
Intersection of analytic distance functions

From point query to Interval query





Point query:

$$\phi_c(\mathbf{p}) = \| \max(\mathbf{q}, 0) \|_2 + \min(\max(\mathbf{q}_x, \max(\mathbf{q}_y, \mathbf{q}_z)), 0),$$

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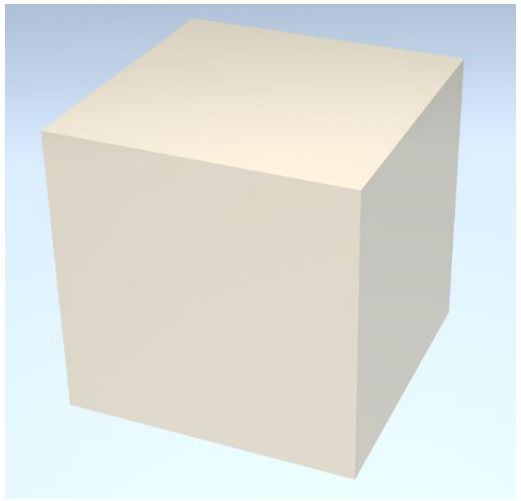
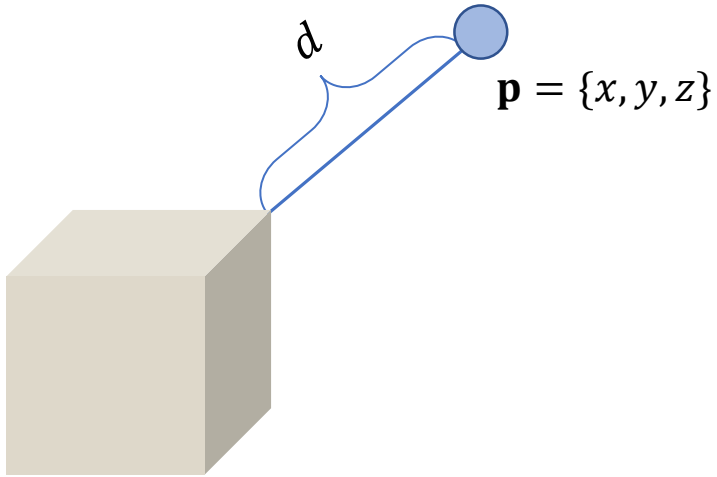
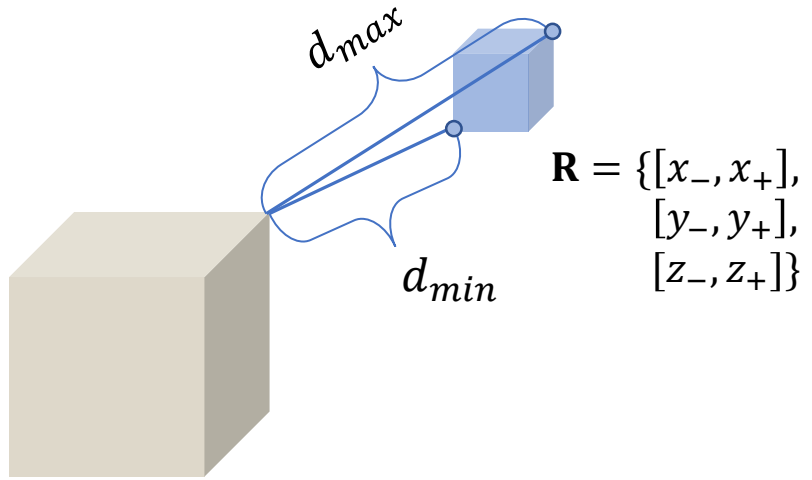
From point query to Interval query







Point query:

$$\phi_c(\mathbf{p}) = \| \max(\mathbf{q}, 0) \|_2 + \min(\max(\mathbf{q}_x, \max(\mathbf{q}_y, \mathbf{q}_z)), 0),$$

$$\mathbf{q} = |\mathbf{p}| - \frac{1}{2}s.$$

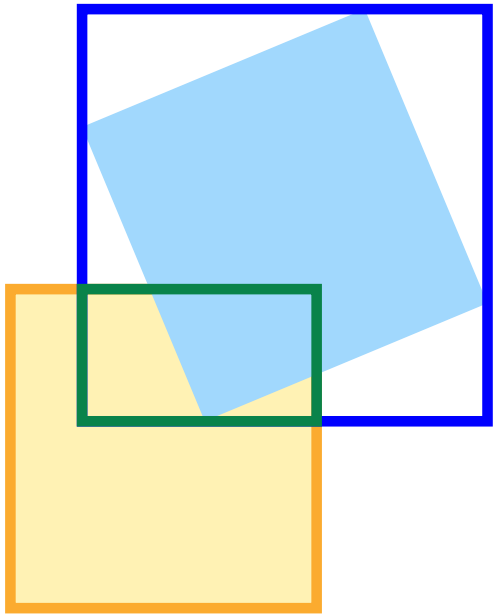
Interval query:

$$[d_{min}, d_{max}] = \phi_c(\mathbf{R}^p),$$

$$\phi_c(\mathbf{R}^p) = \| \mathrm{Max}(\mathbf{R}^q, 0) \|_2 + \mathrm{Min}\left(\mathrm{Max}\left(\mathbf{R}_x^q, \mathrm{Max}\left(\mathbf{R}_y^q, \mathbf{R}_z^q\right)\right), 0\right),$$

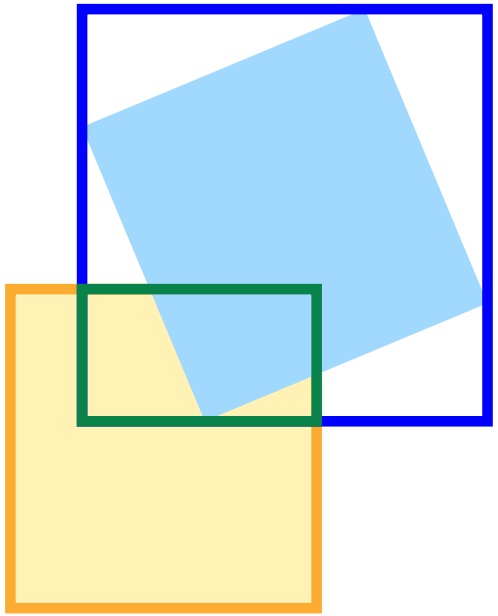
$$\mathbf{R}^q = |R^p| - \frac{1}{2}s.$$

From point query to Interval query

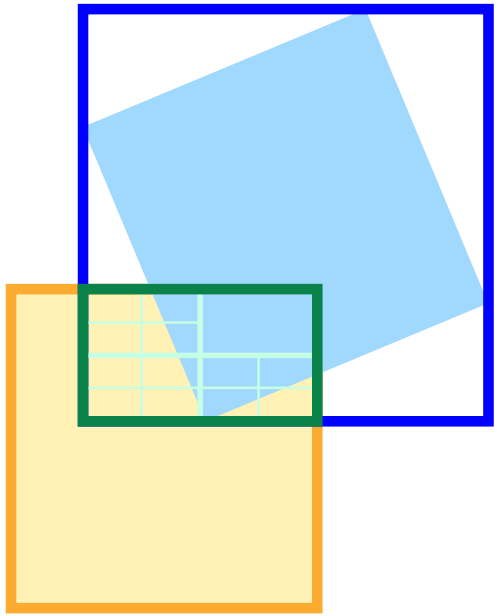


AABB detection

From point query to Interval query

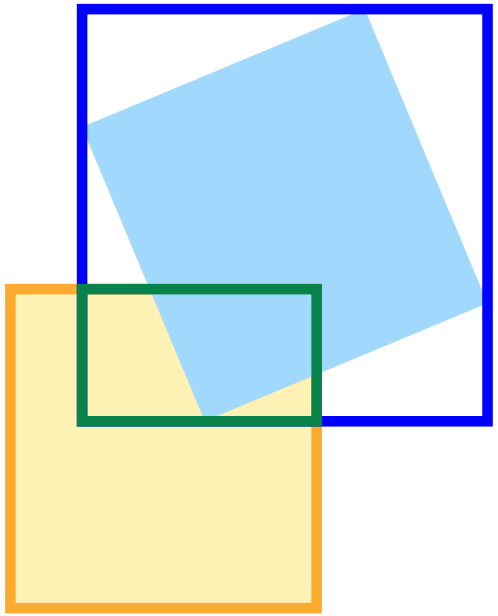


AABB detection

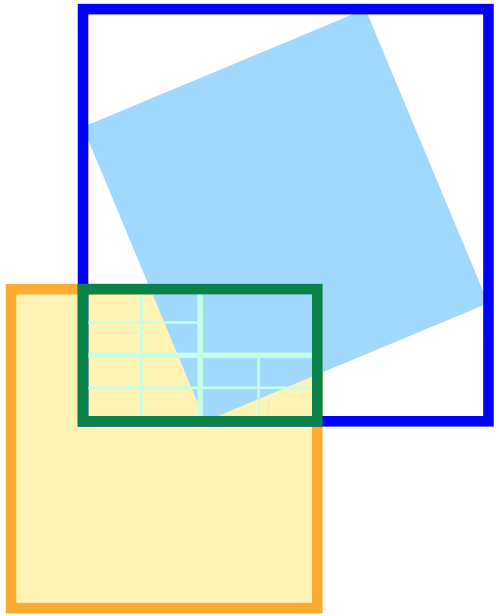


Octree subdivision

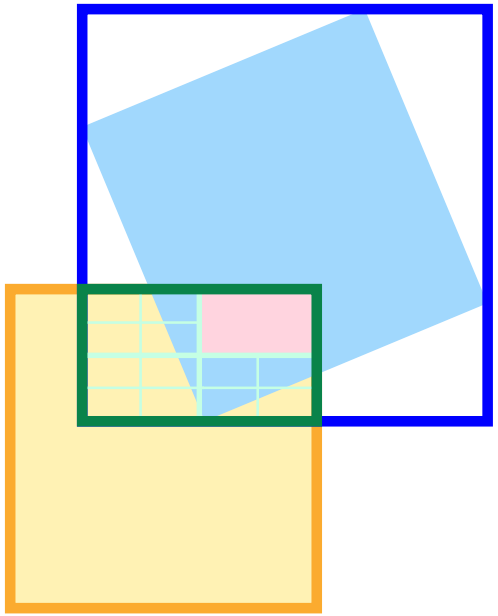
From point query to Interval query



AABB detection

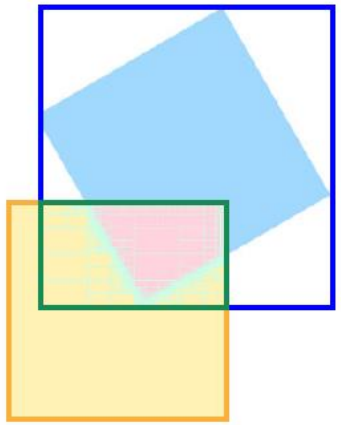


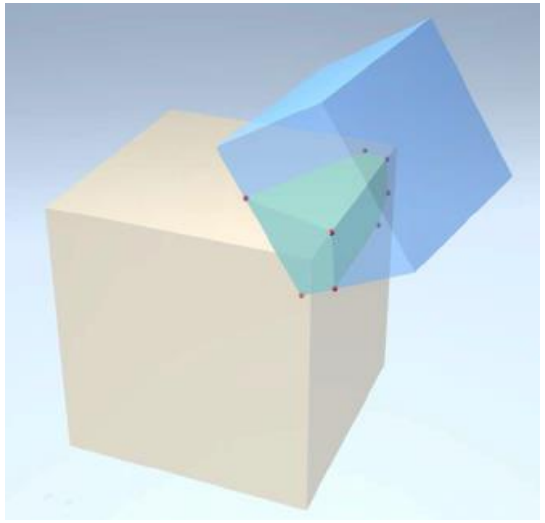
Octree subdivision

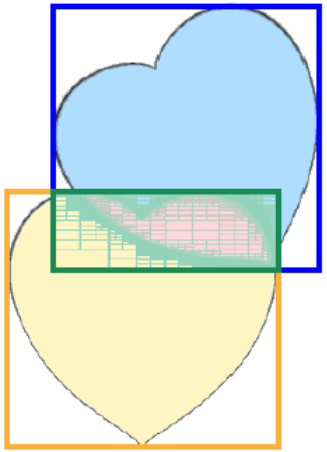


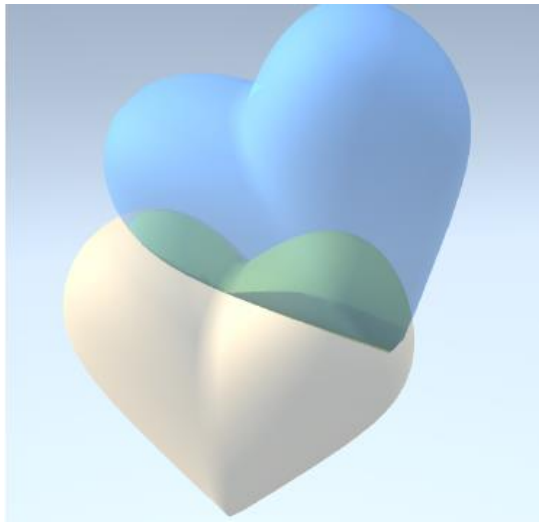
Find intersecting regions

From point query to Interval query









How to represent general objects ?

General shapes

Intersection of general SDFs

General SDFs Pipeline

Preprocessing

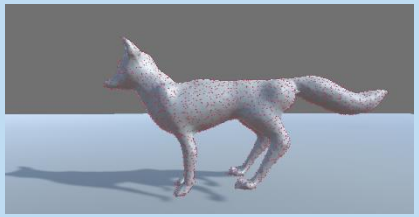
Input SDF/SDF gradient

Axis-aligned bounding box(AABB) generation

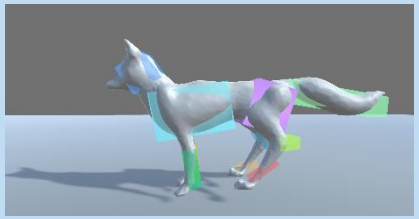
Automatic cuboid bounding boxes generation

Saving SDFs and their gradient in cuboid bounding boxes

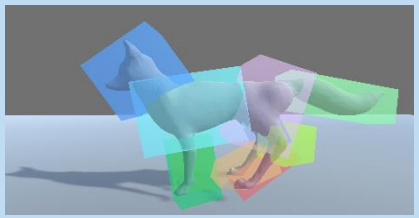
Sampling points / normal



Cuboid abstraction



Cuboid expansion



General SDFs Pipeline

Preprocessing

Input SDF/SDF gradient

↓

Axis-aligned bounding box(AABB) generation

↓

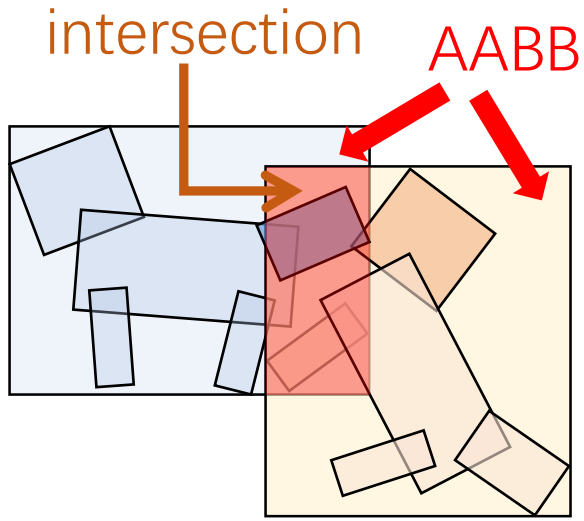
Automatic cuboid bounding boxes generation

↓

Saving SDFs and their gradient in cuboid bounding boxes

Collision detection

AABB collision detection



General SDFs Pipeline

Preprocessing

Input SDF/SDF gradient

Axis-aligned bounding box(AABB) generation

Automatic cuboid bounding boxes generation

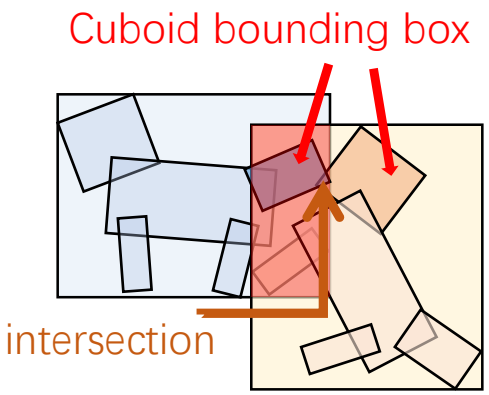
Saving SDFs and their gradient in cuboid bounding boxes

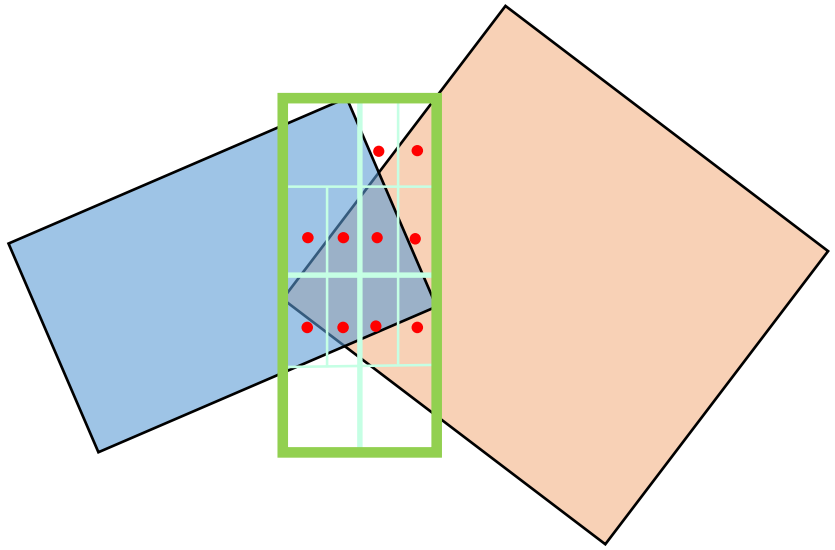
Collision detection

AABB collision detection

Detection points generation

Construct octree to generate intersection





General SDFs Pipeline

Preprocessing

Input SDF/SDF gradient

Axis-aligned bounding box(AABB) generation

Automatic cuboid bounding boxes generation

Saving SDFs and their gradient in cuboid bounding boxes

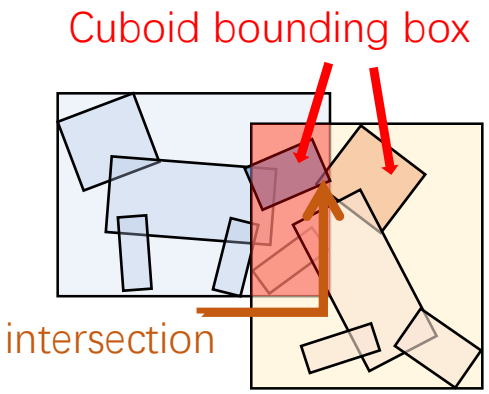
Collision detection

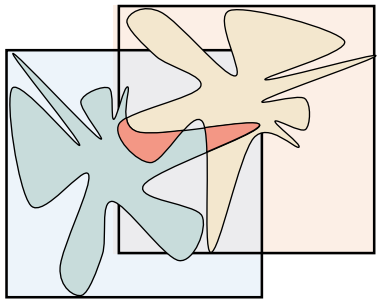
AABB collision detection

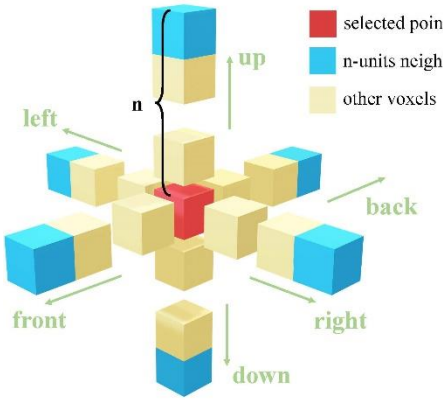
Detection points generation

Construct octree to generate intersection

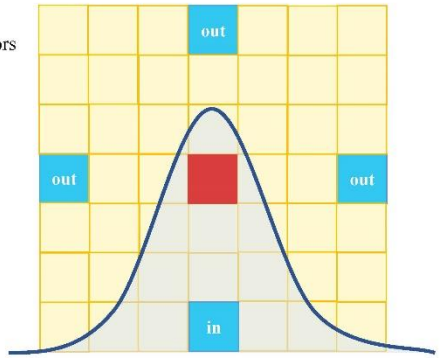
Traverse the SDF to find the convex part







(a)



(b)

General SDFs Pipeline

Preprocessing

Input SDF/SDF gradient

Axis-aligned bounding box(AABB) generation

Automatic cuboid bounding boxes generation

Saving SDFs and their gradient in cuboid bounding boxes

Collision detection

AABB collision detection

Detection points generation

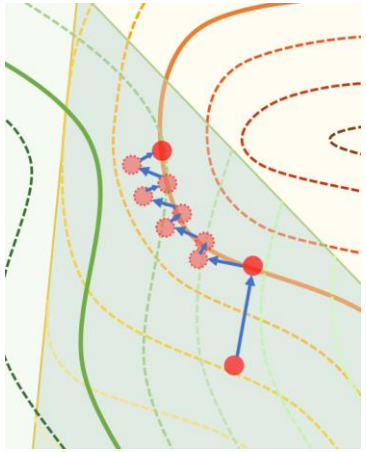
Construct octree to generate intersection

Traverse the SDF to find the convex part

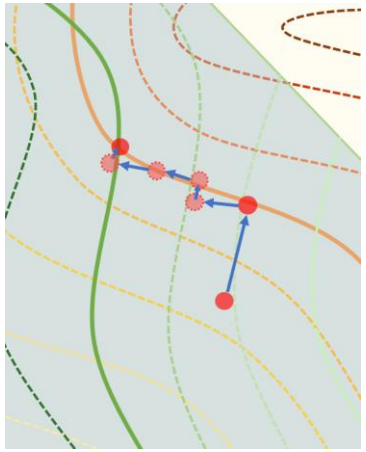
SDF collision detection

Projected gradient descent to find intersection point

Collision free



Collision detected



General SDFs Pipeline

Preprocessing

Input SDF/SDF gradient

Axis-aligned bounding box(AABB) generation

Automatic cuboid bounding boxes generation

Saving SDFs and their gradient in cuboid bounding boxes

Collision detection

AABB collision detection

Detection points generation

Construct octree to generate intersection

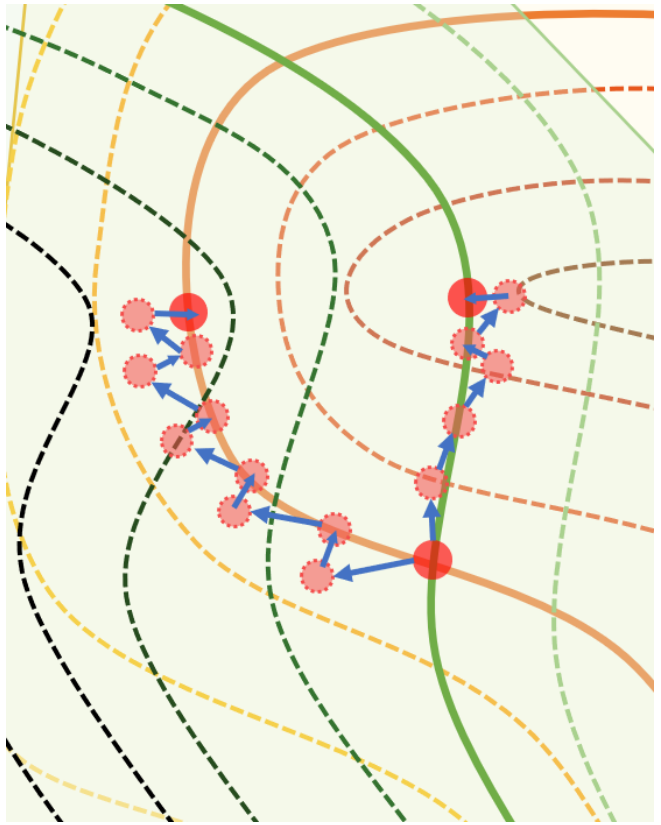
Traverse the SDF to find the convex part

SDF collision detection

Projected gradient descent to find intersection point

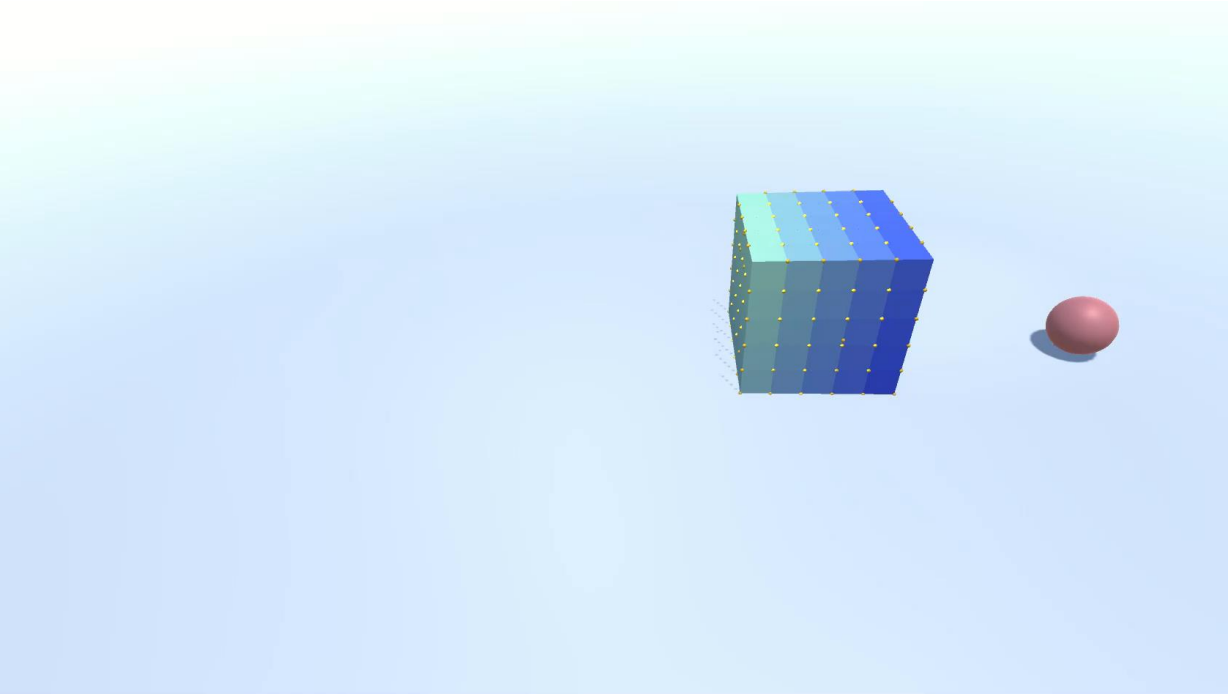
Contact generation

Intersection point

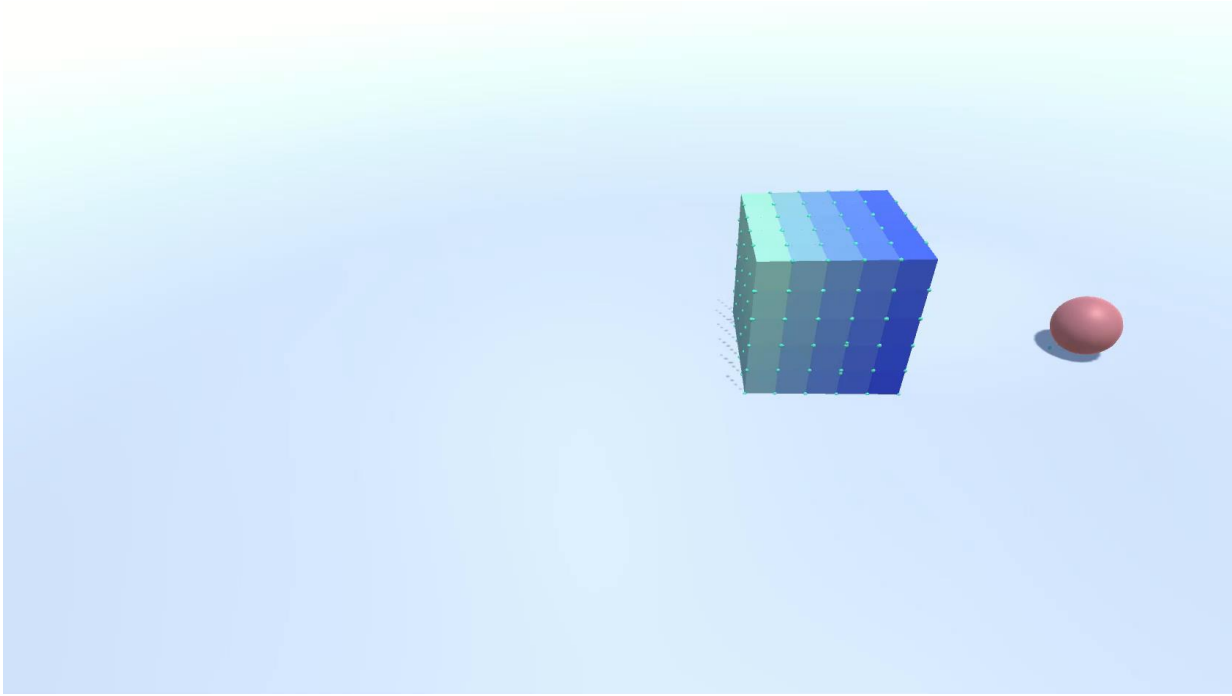


Results

Detection Precision



The accurate result

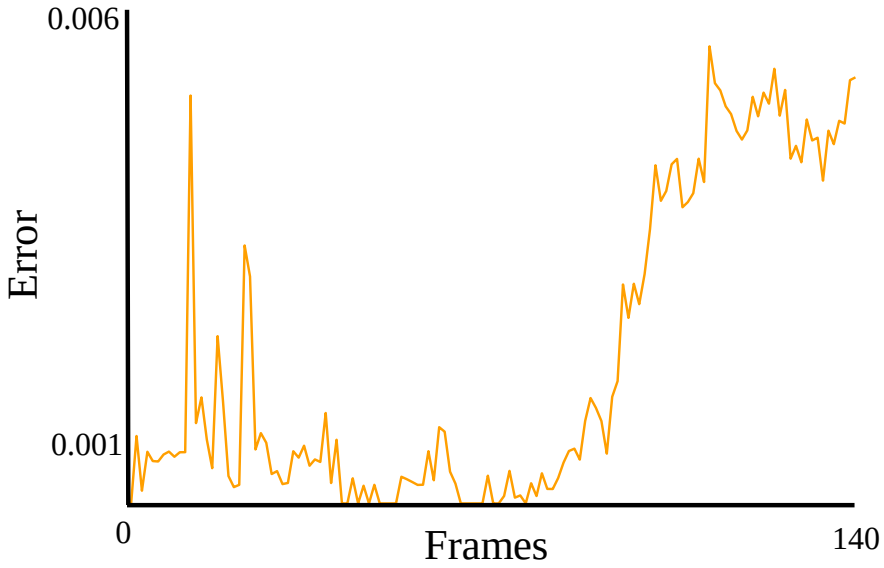


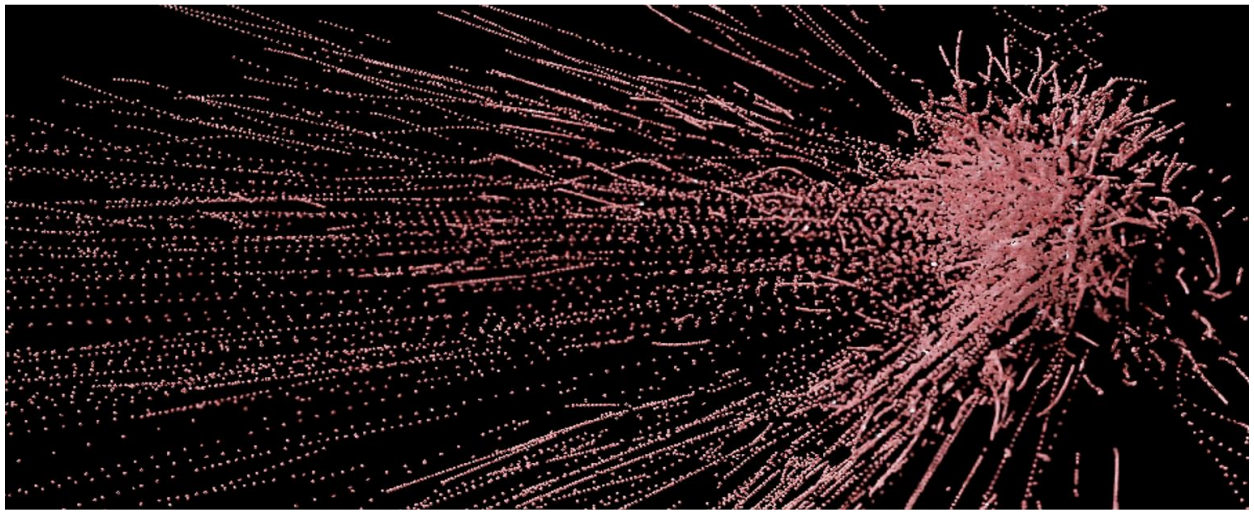
Our result

Detection Precision

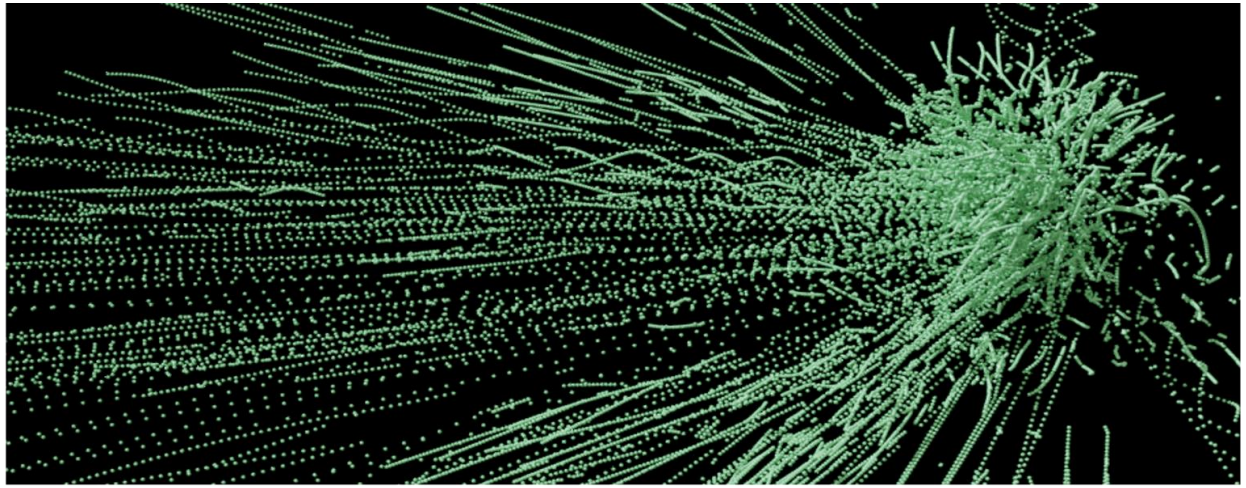
The number of cubes: 126

The number of contact points: 70381



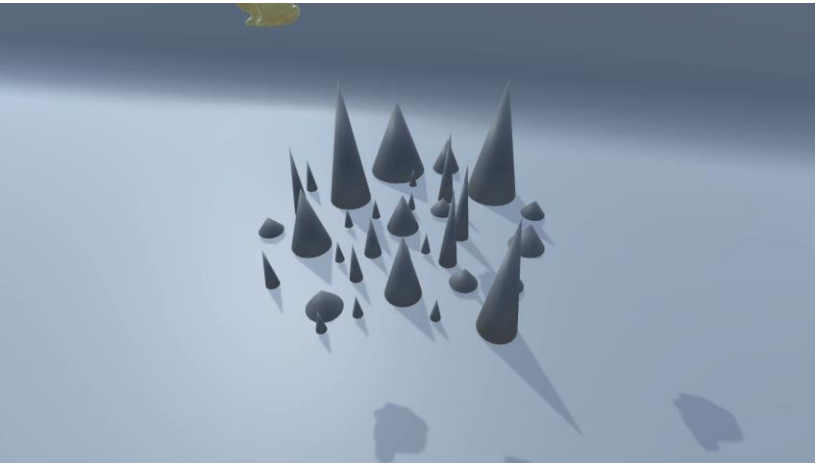


contact points distribution of accurate result

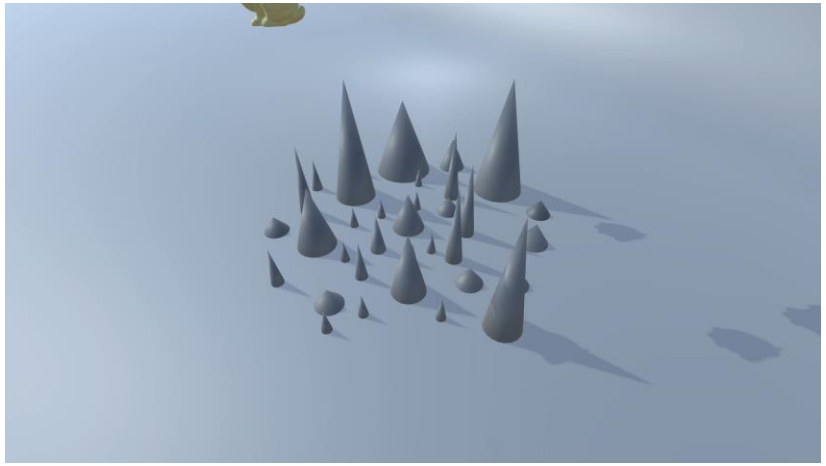


contact points distribution of ours($\varepsilon = 10^{-5}$)

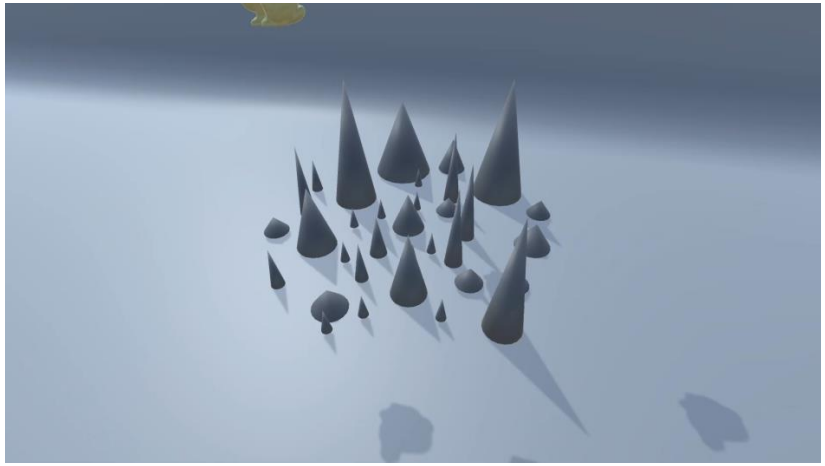
General SDFs



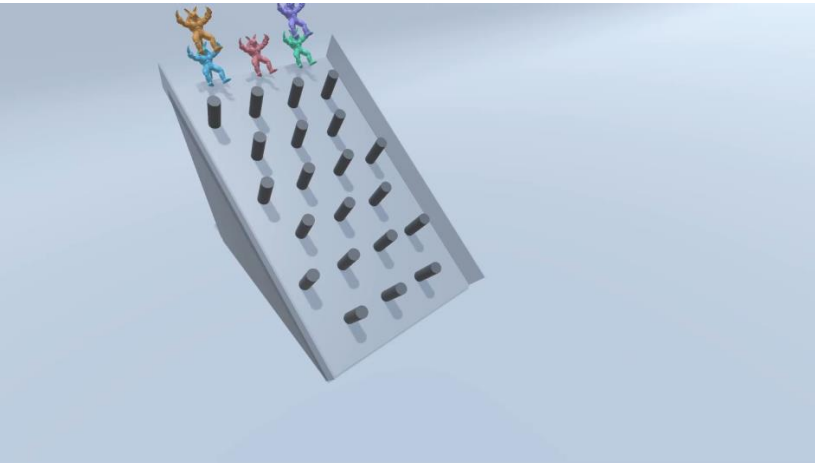
Fully mesh-based method



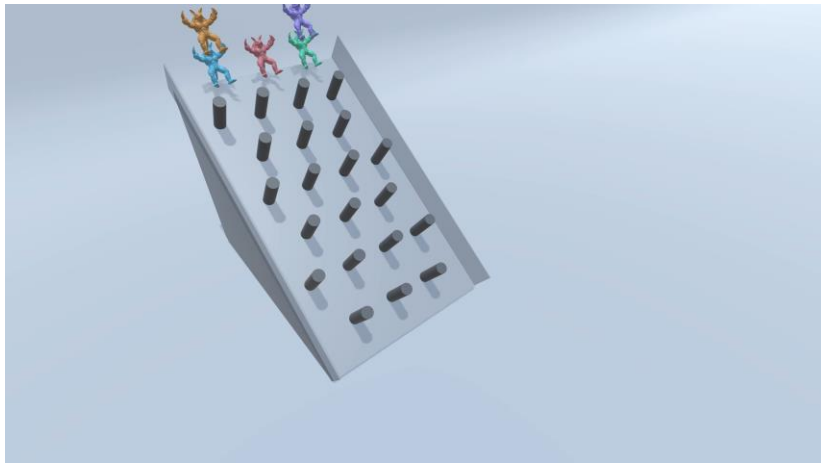
Mesh-SDF method



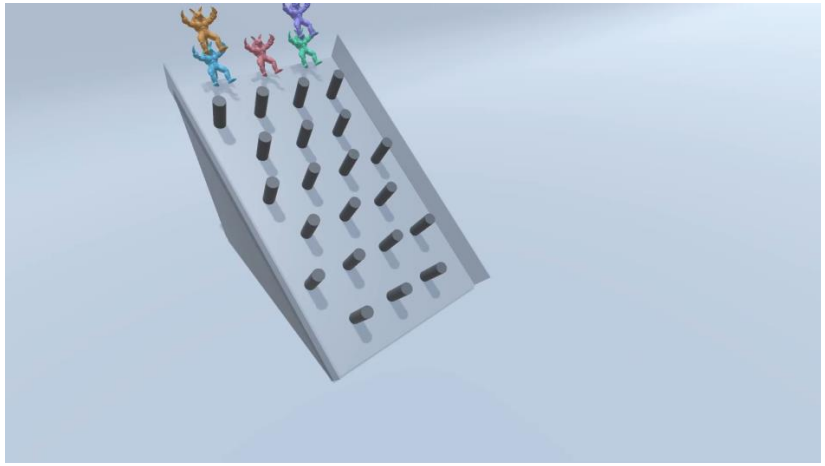
Our proposed method



Fully mesh-based method

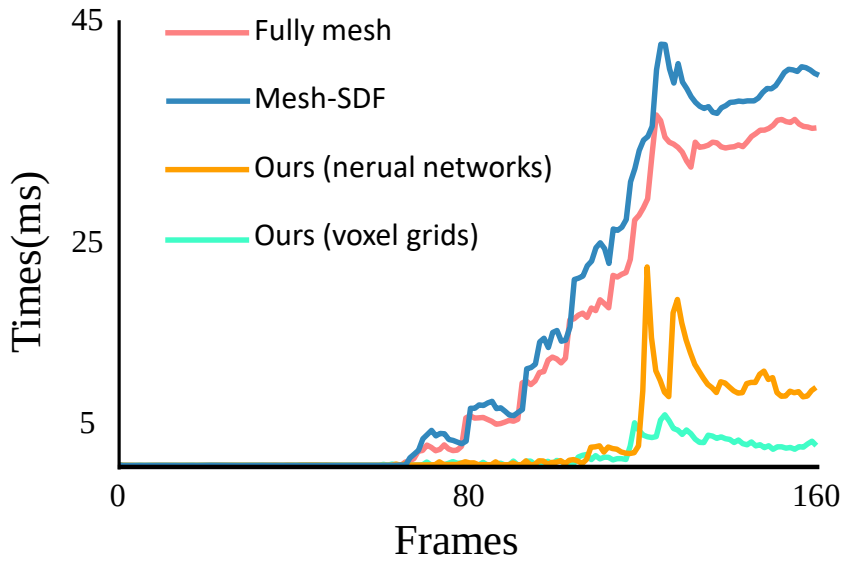


Mesh-SDF method

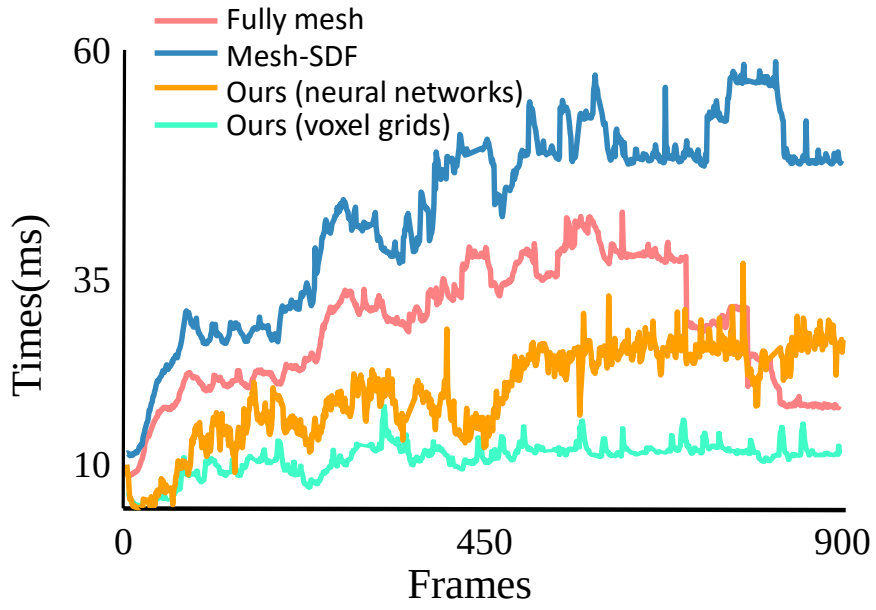


Our proposed method

General SDFs

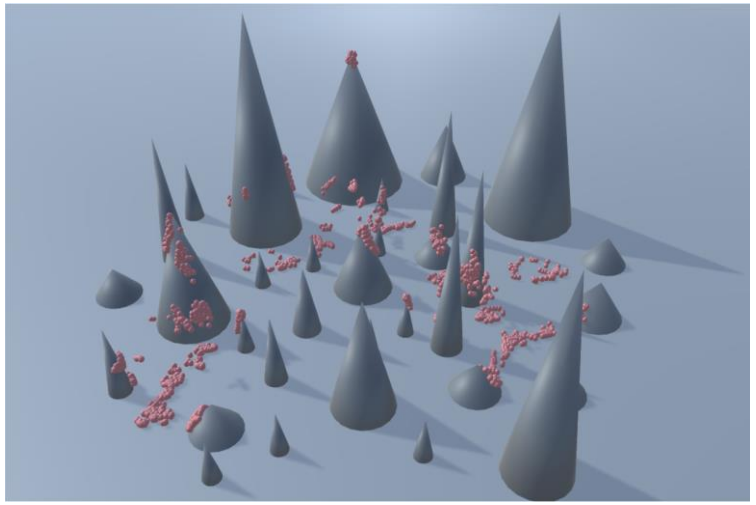


Bunnies and cones

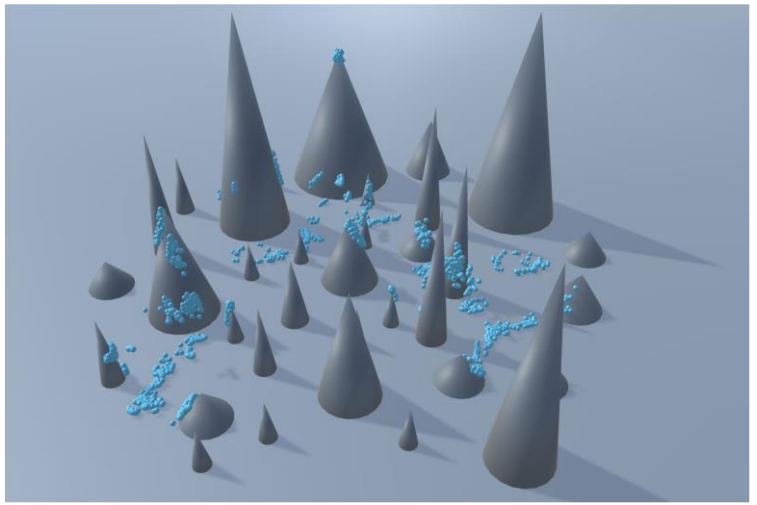


Armadillos and cylinders

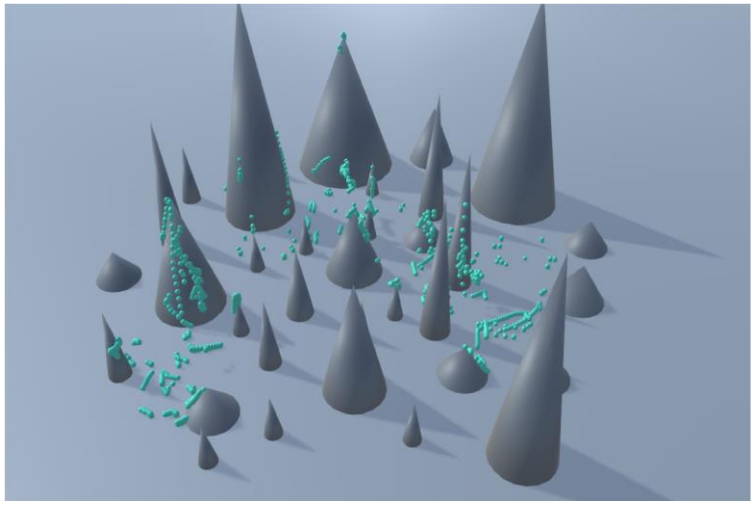
Contact points distribution



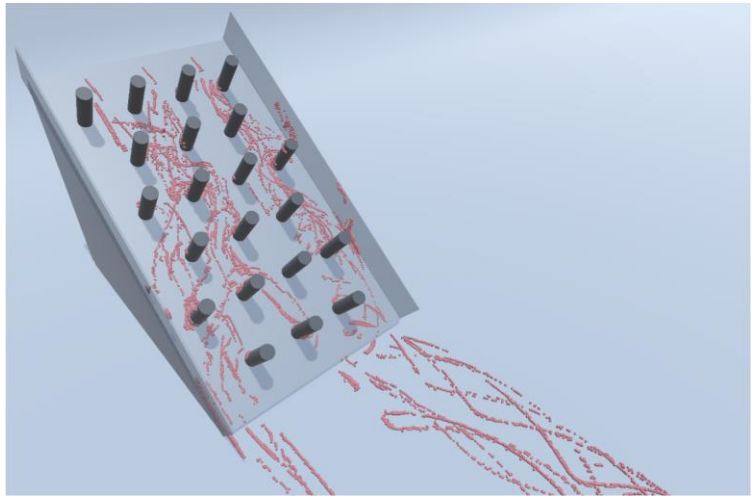
Fully mesh-based method



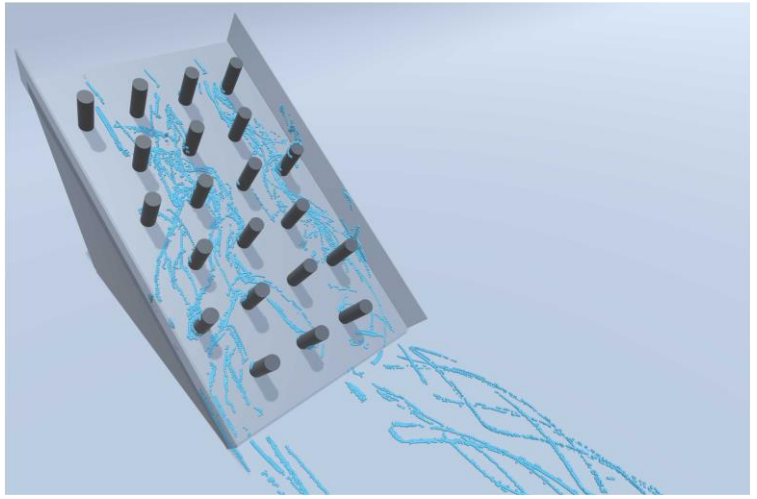
Mesh-SDF method



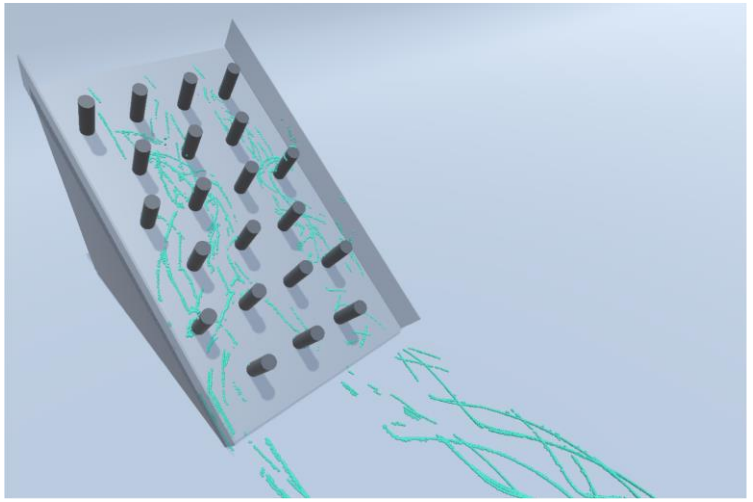
Our proposed method



Fully mesh-based method

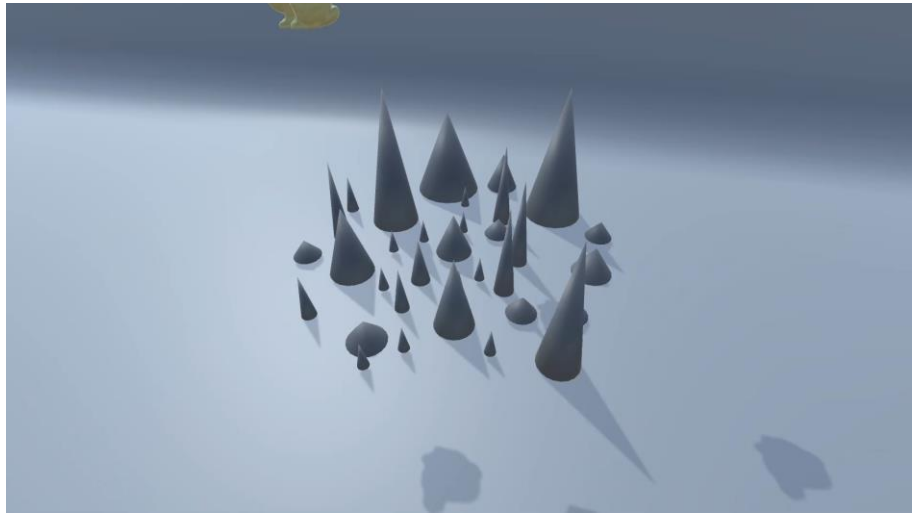


Mesh-SDF method

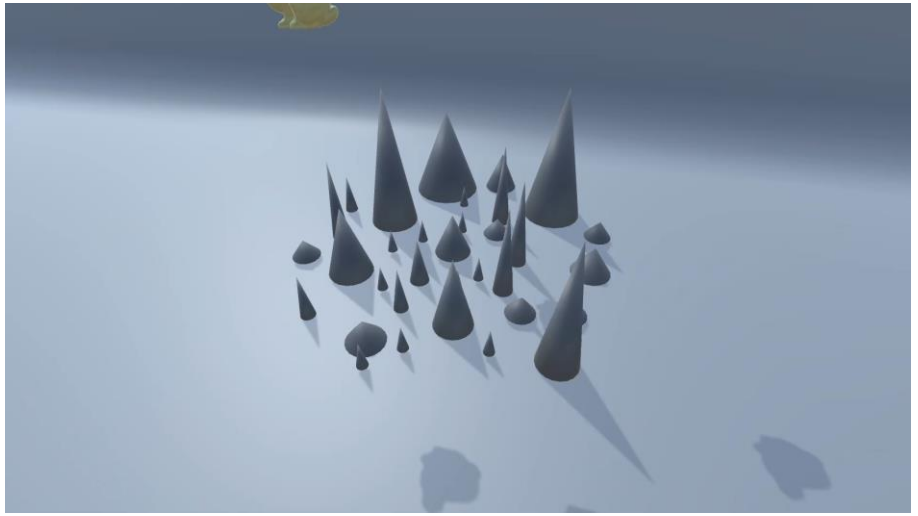


Our proposed method

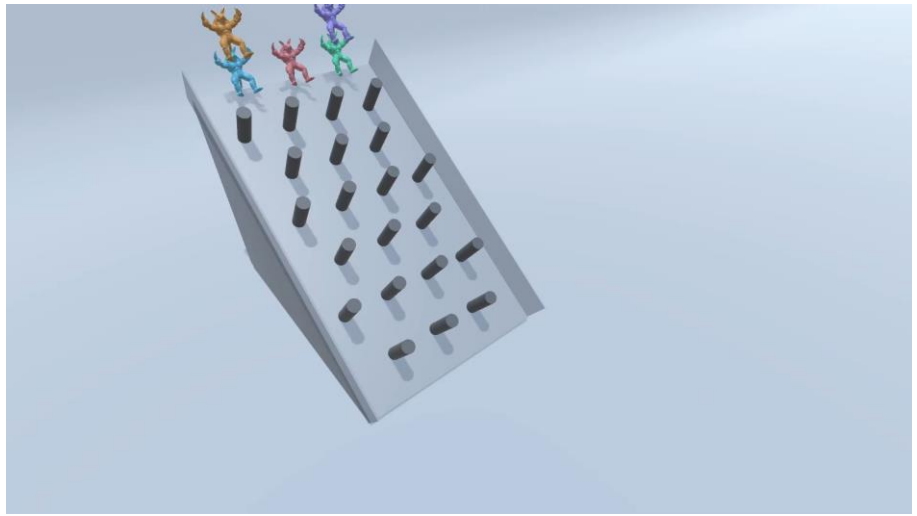
Ablation study



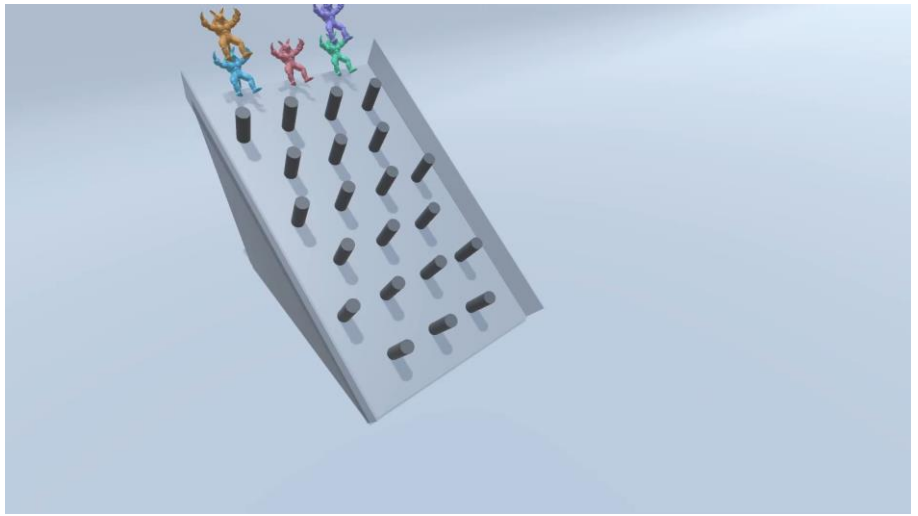
Bunny with SDF decomposition



Bunny without SDF decomposition

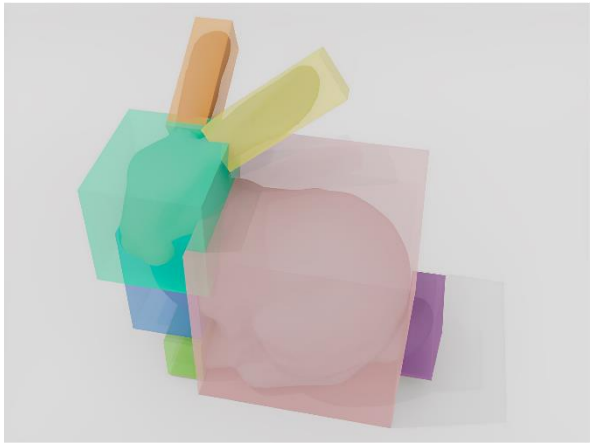


Armadillo with SDF decomposition

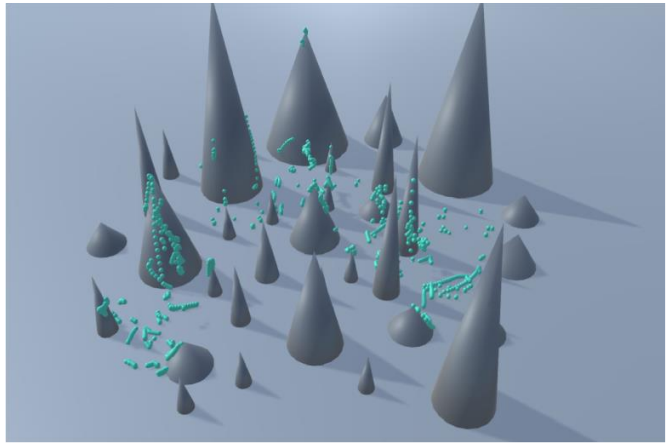


Armadillo without SDF decomposition

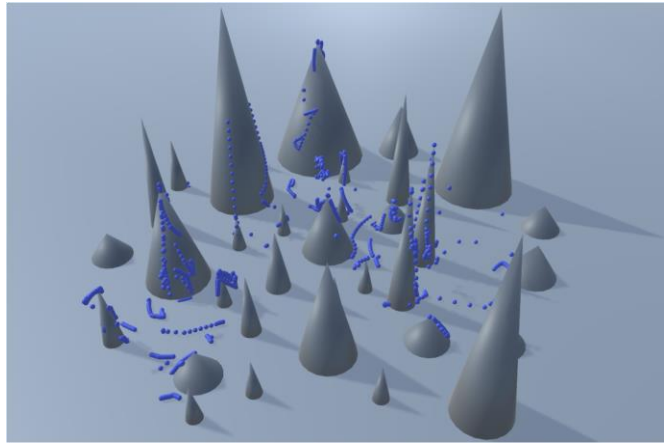
Contact points distribution



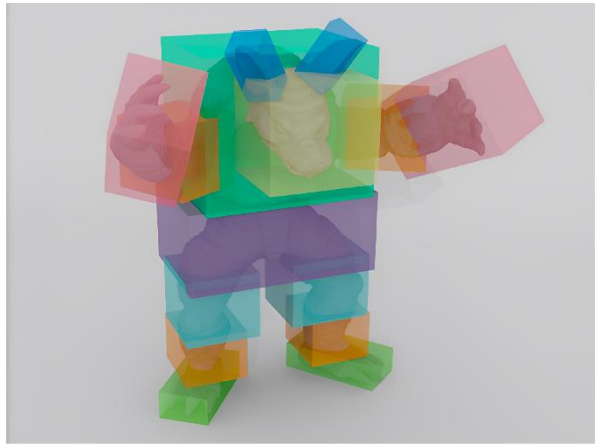
Cuboid bounding box for convex part



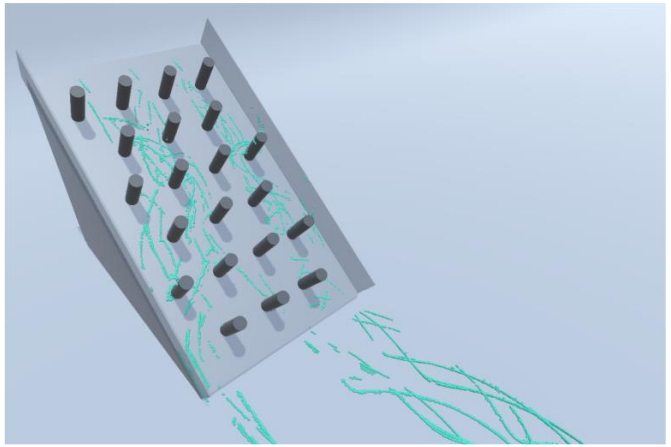
Bunny with SDF decomposition



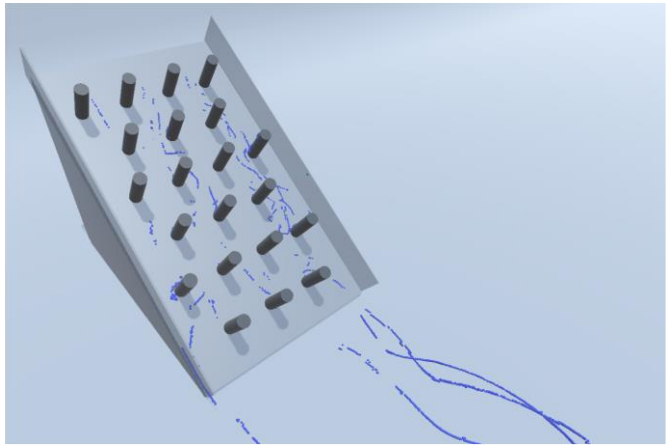
Bunny without SDF decomposition



Cuboid bounding box for convex part

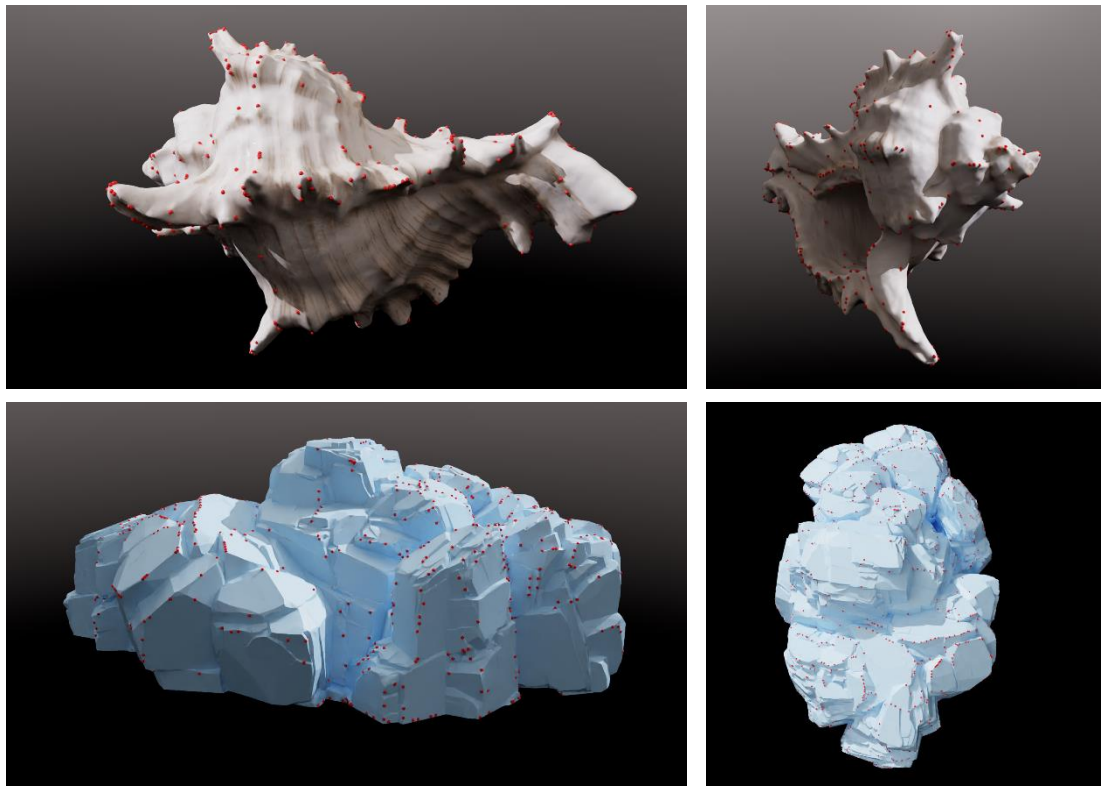


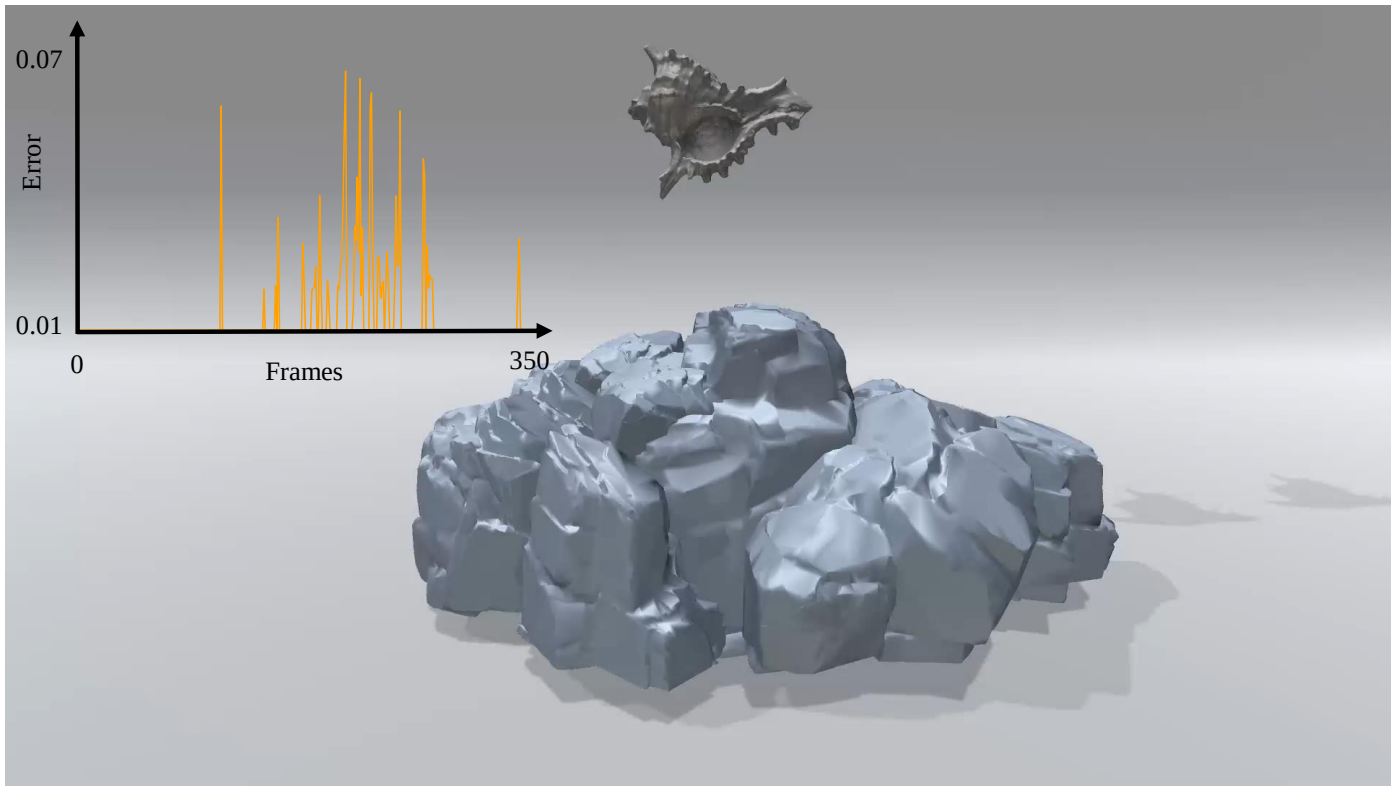
Armadillo with SDF decomposition



Armadillo without SDF decomposition

The Optimization of GPU Parallelization





Summary

Summary & Limitation

A general SDF-SDF collision detection method.

- We need a large number of detection points for multiple detections, which causes a lot of resource consumption.
- The query efficiency of SDFs varies depending on the representation.
- The method’s parameters must be manually adjusted according to the scene.

Geometric Modeling and Processing 2024

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THANKS!

Co-organizers：

山东大学 SHANDONG UNIVERSITY

青岛科技大学 Qingdao University of Science & Technology

山東財經大學 Shandong University of Finance and Economics