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学术论文

基于GPU的代数自适应有向距离场
Algebraic Adaptive Signed Distance Field on GPU

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Introduction

Signed distance fields (SDFs) are commonly used in solid modeling and physically based animation.
However, how to develop high-performance sparse data structures for signed distance field construction and boolean operations is challenging.
Our motivation is to develop a representation for adaptive signed distance fields that allows fast construction and boolean operations between any two SDFs, named as the algebraic adaptive signed distance field (AASDF).

Methodology

Boolean operation:

The analytic definitions of boolean operations are:

$$\phi_3 = \phi_1 | \phi_2 = min(\phi_1, \phi_2), \quad \text{union}$$
$$\phi_3 = \phi_1 \& \phi_2 = max(\phi_1, \phi_2), \quad \text{intersection}$$
$$\phi_3 = \phi_1 \backslash \phi_2 = \phi_1 \& (-\phi_2), \quad \text{difference}$$

Eikonal Equation:

The signed distance field $\phi(x)$ defined on the whole metric space $\boldsymbol{X}$ is:

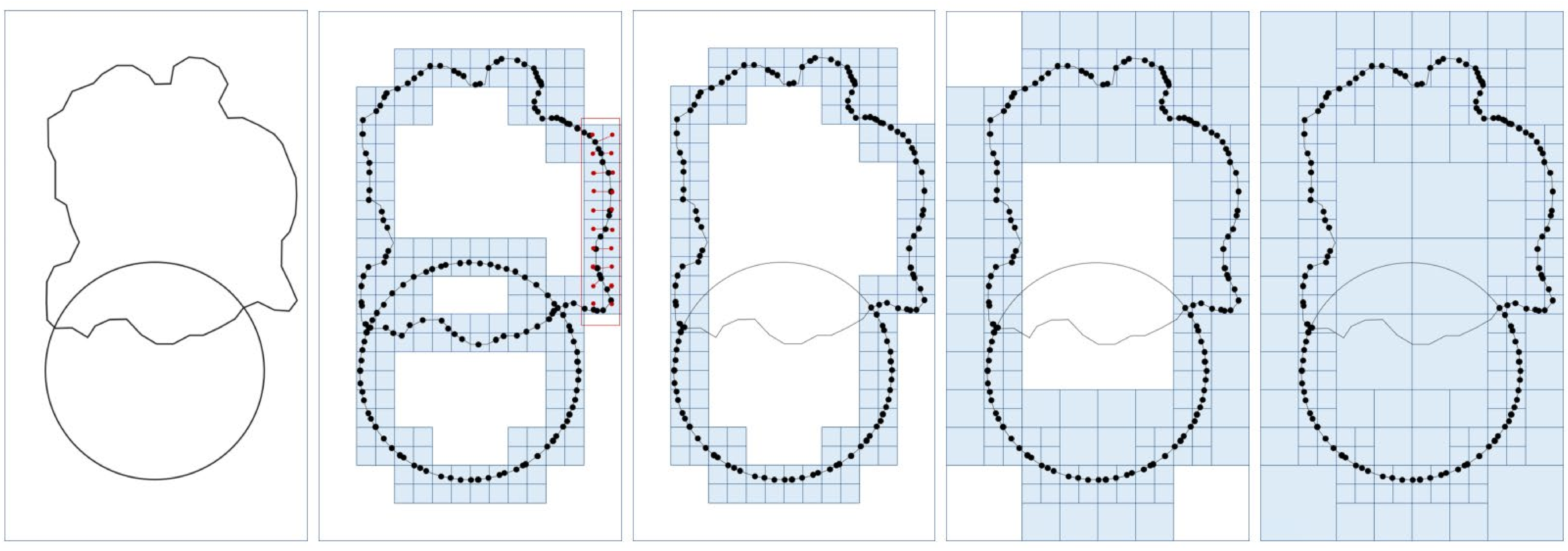
$$\phi(\mathbf{x}) = \begin{cases} d(\mathbf{x}, \partial\Omega) & if \ \mathbf{x} \in \Omega \\ -d(\mathbf{x}, \partial\Omega) & if \ \mathbf{x} \in \mathbf{X} \backslash \Omega \end{cases}$$

If the boundary is smooth, the gradient of $\phi(x)$ satisfies the Eikonal equation:

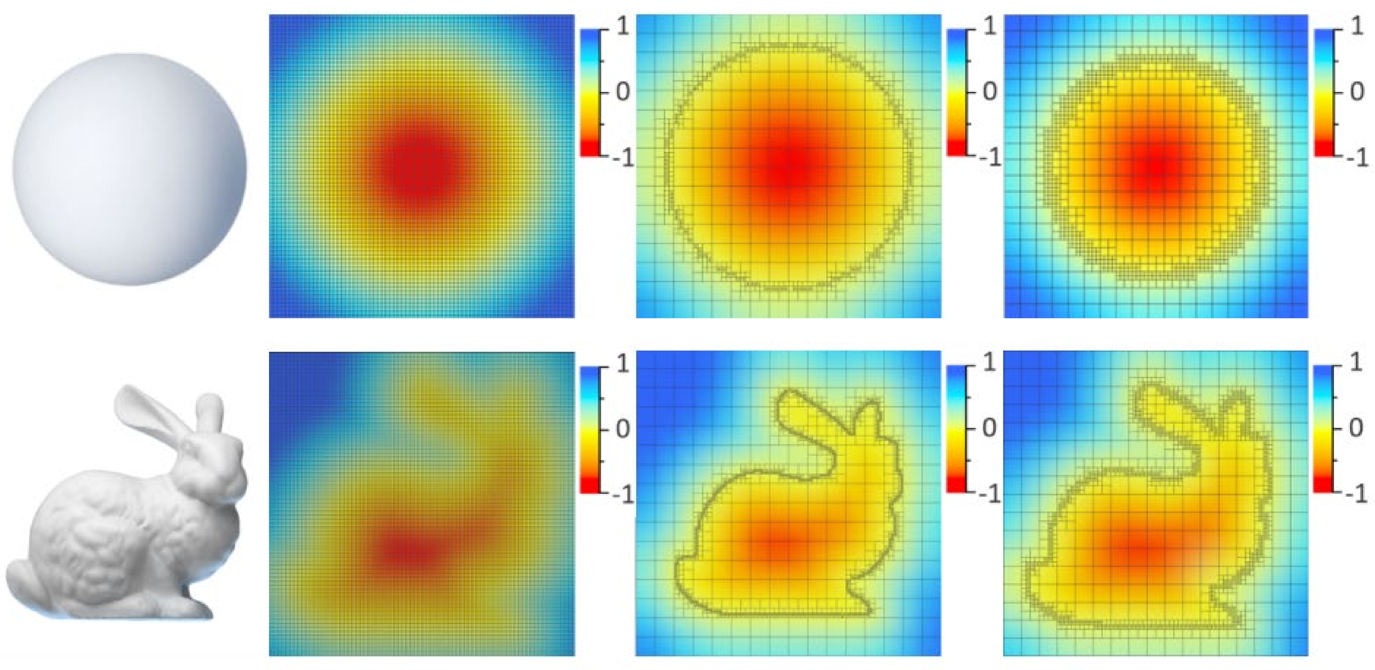
$$|\nabla \phi(\boldsymbol{x})| = 1$$

Construction Pipeline:

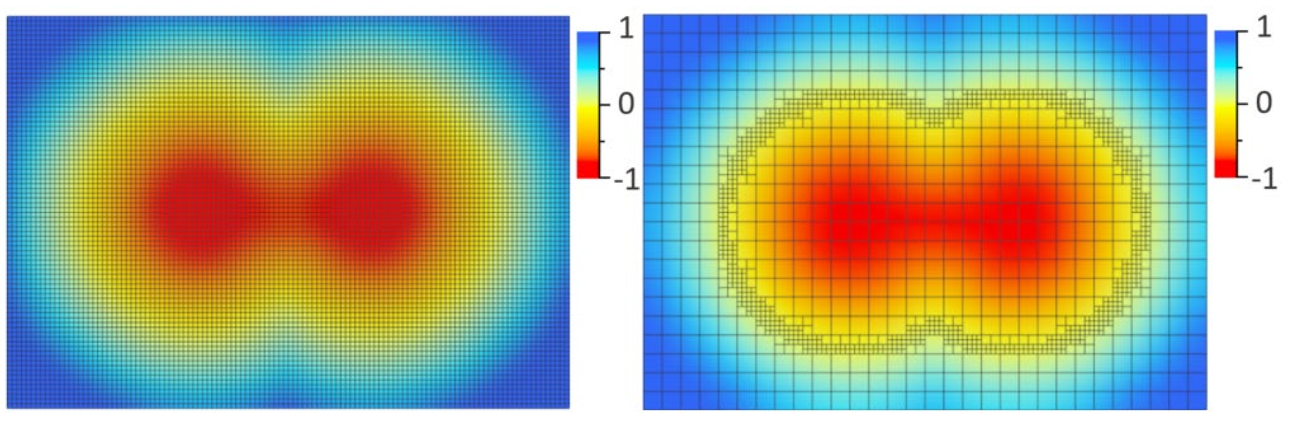
- Constructing nodes in the finest level.
- Boolean operations in the finest level.
- Constructing nodes in the intermediate levels.
- Constructing nodes in the top-most level.



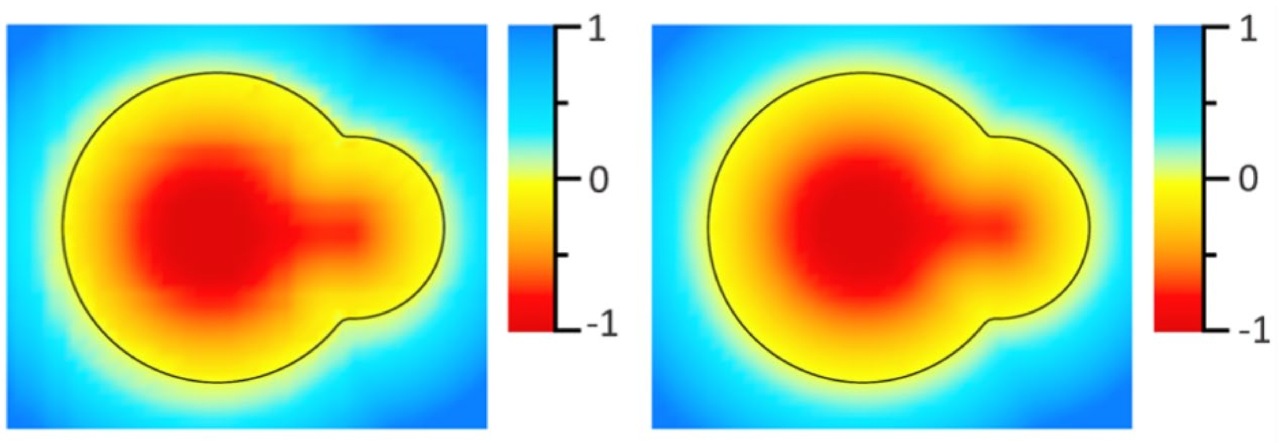
Results



Construction



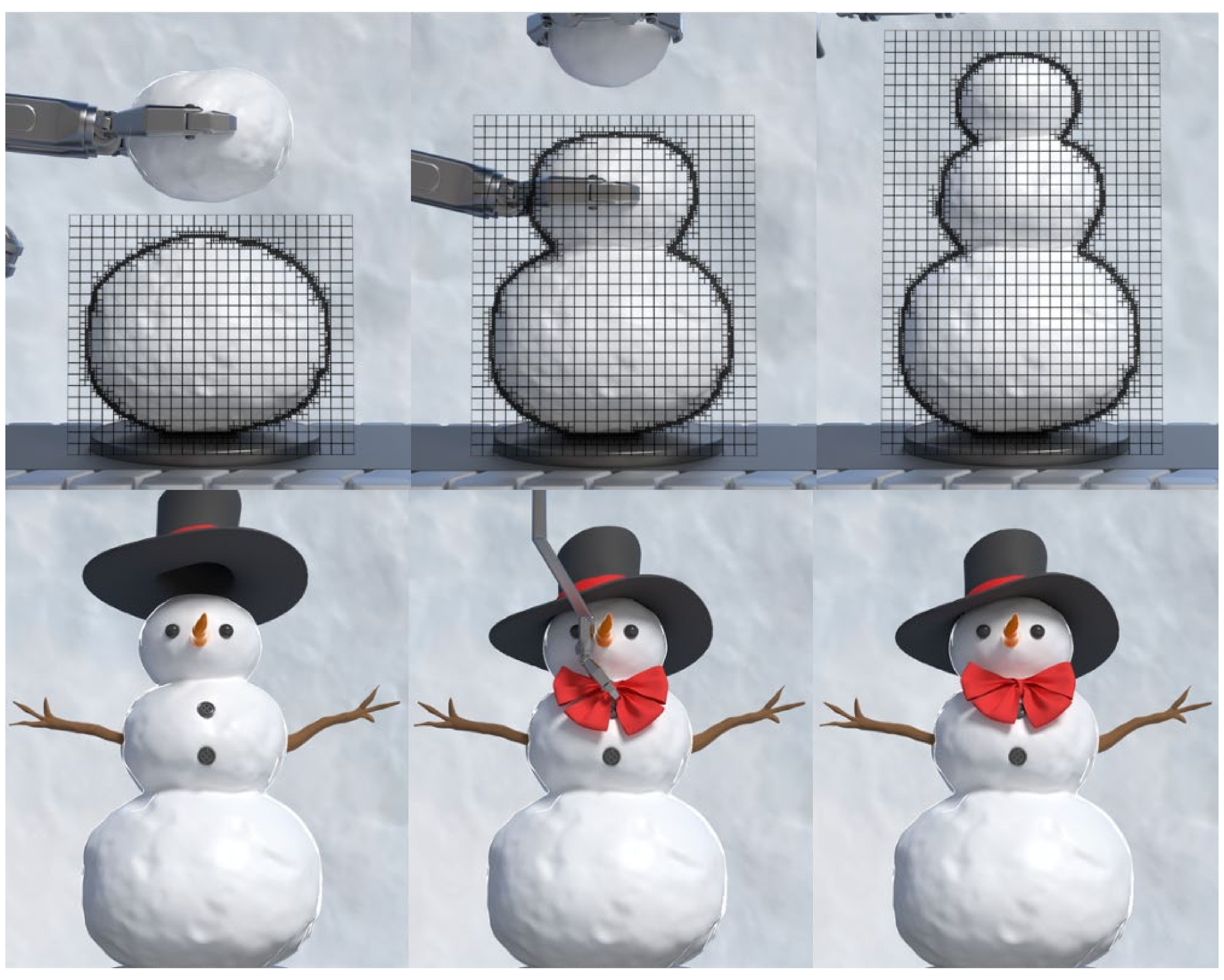
Boolean Operation



Access

Applications

AASDFs serve as the boundary for fluid simulation



AASDFs are used to construct complex models and used for fabric simulation

Contribution

Properties of AASDF:

- **Adaptivity:** The signed distance field maintains a sparse data structure that can dynamically refine the grid resolution to the regions of interest.
- **Completeness:** Boolean operation between any two SDFs produces a new SDF that maintains a sparse data structure fulfilling the adaptivity requirement.
- **Parallelizable:** All steps in the construction of SDFs and boolean operations have a high degree of parallelization.

Contribution:

- A hierarchical sparse octree that can be used to construct an algebraic system of AASDFs.
- A bottom-up fast iterative method to construct each element of AASDFs in parallel on GPU.
- A bottom-up algorithm to do boolean operations between two AASDFs in parallel on GPU.

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