Differentiable Rendering: A Survey

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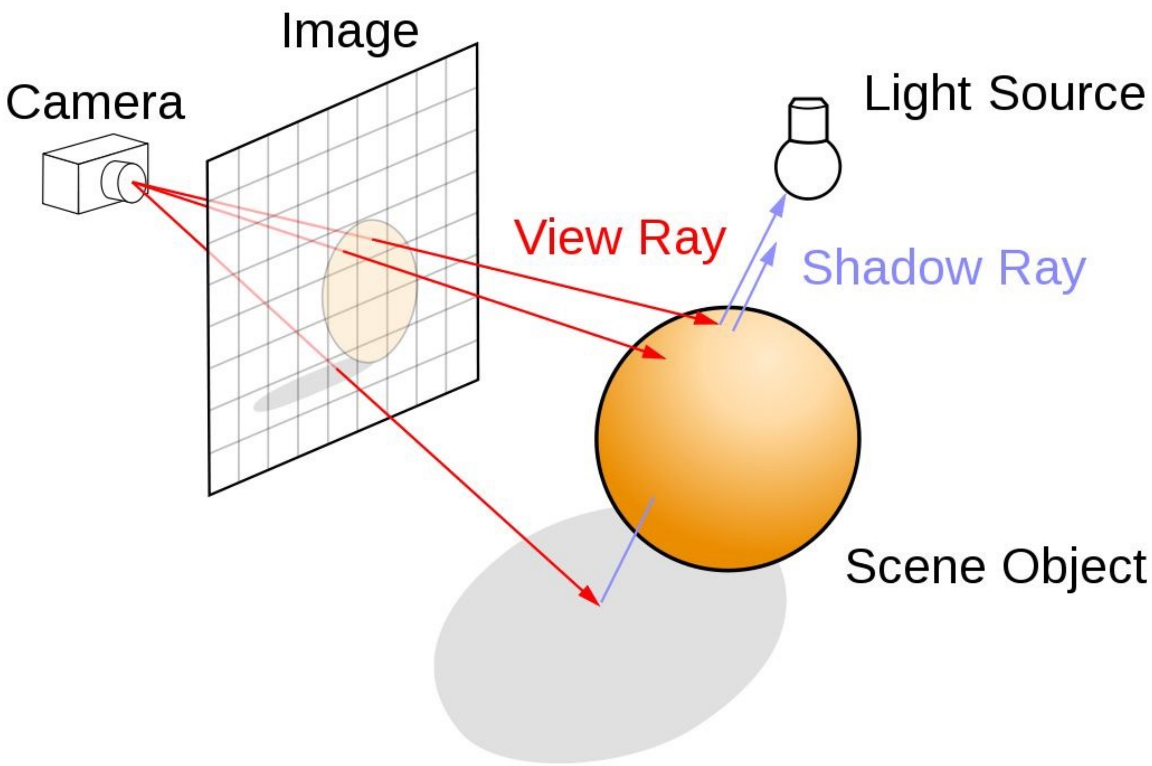
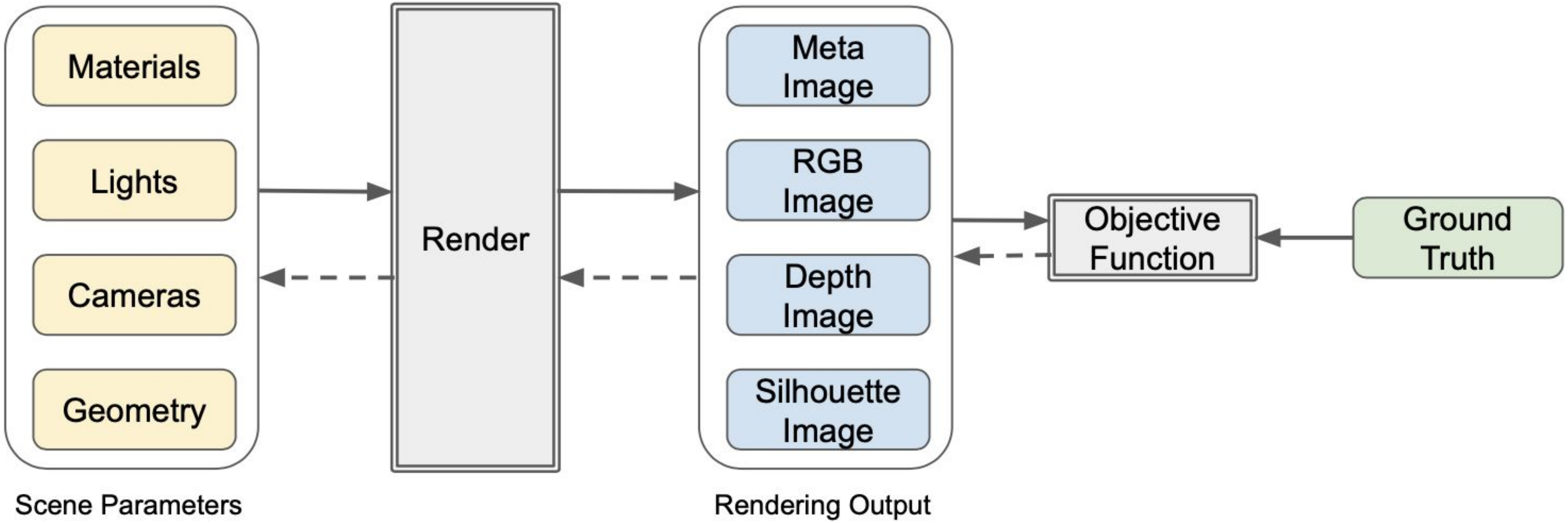
Motivation and Main Problem



Rendering is the process of generating images of 3D scenes defined by geometry, materials, scene lights and camera properties.

Motivation and Main Problem

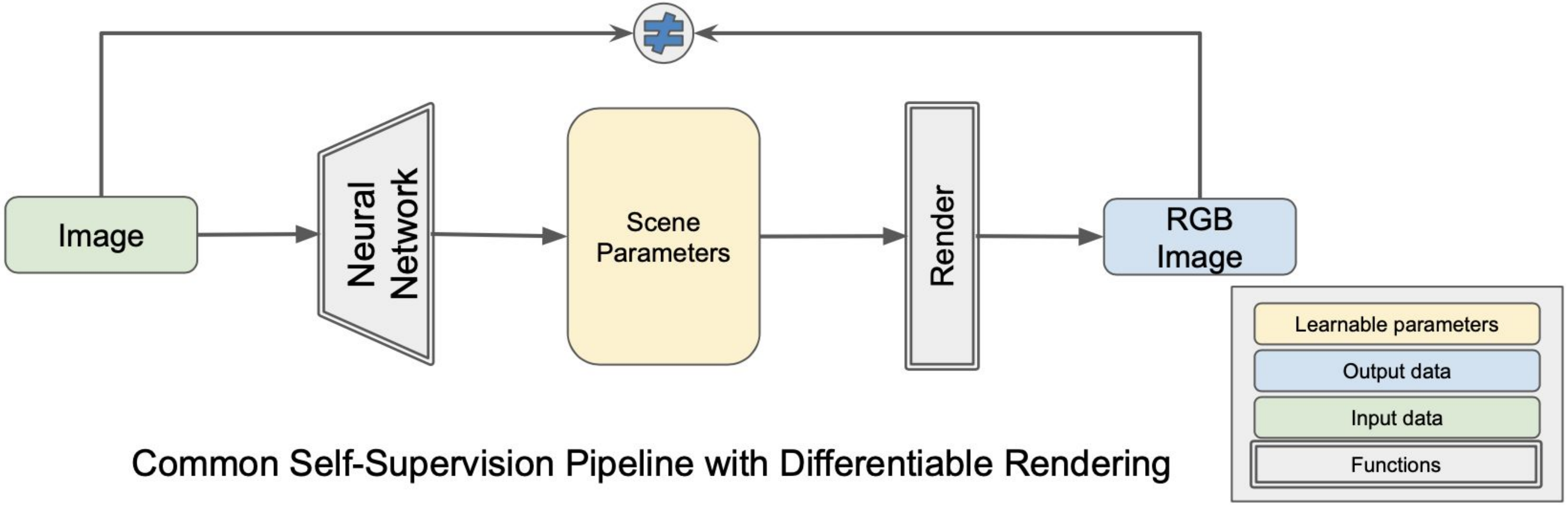
- Optimizing 3D scene parameters:



Optimization using a Differentiable Renderer

Motivation and Main Problem

- 3D self-supervision pipeline:
  - Image-based training of 3D object reconstruction.
  - Human/hand pose estimation.
  - face reconstruction, etc.



Common Self-Supervision Pipeline with Differentiable Rendering

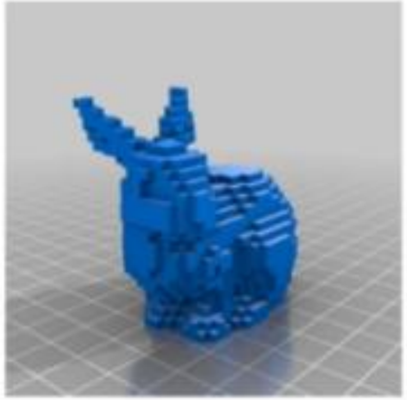
Contributions

Review the following aspects of differentiable rendering (DR):

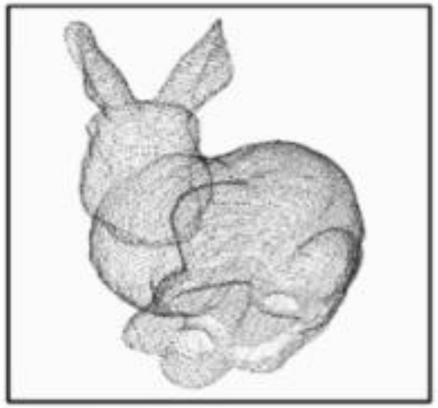
- **DR's mechanisms:** understanding which methods are suitable for addressing certain types of problems.
- **Evaluation methodology:** in order to choose or develop novel DR method.
- **Applications and usage:** in order to use DR in novel task.
- **DR libraries:** facilitate real-time applications or embedded devices.

General Background

- Object representation

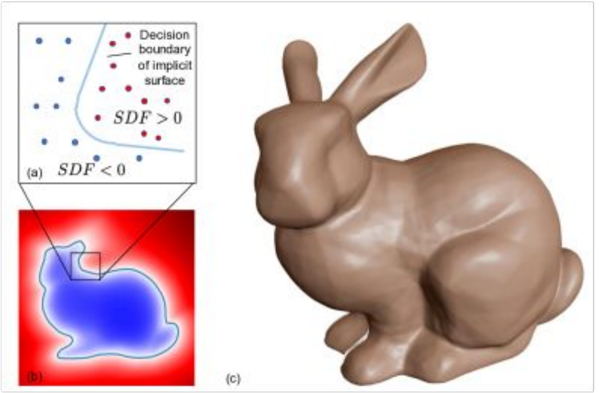


Voxel



Point Cloud

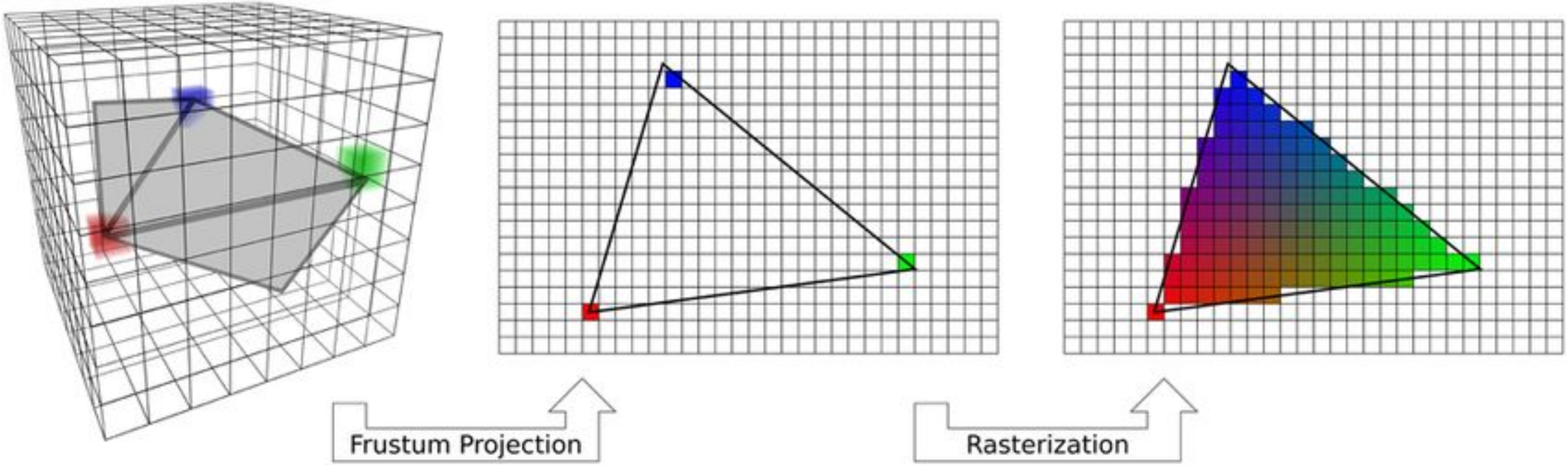
Mesh



Implicit Surface

General Background

- Rendering step

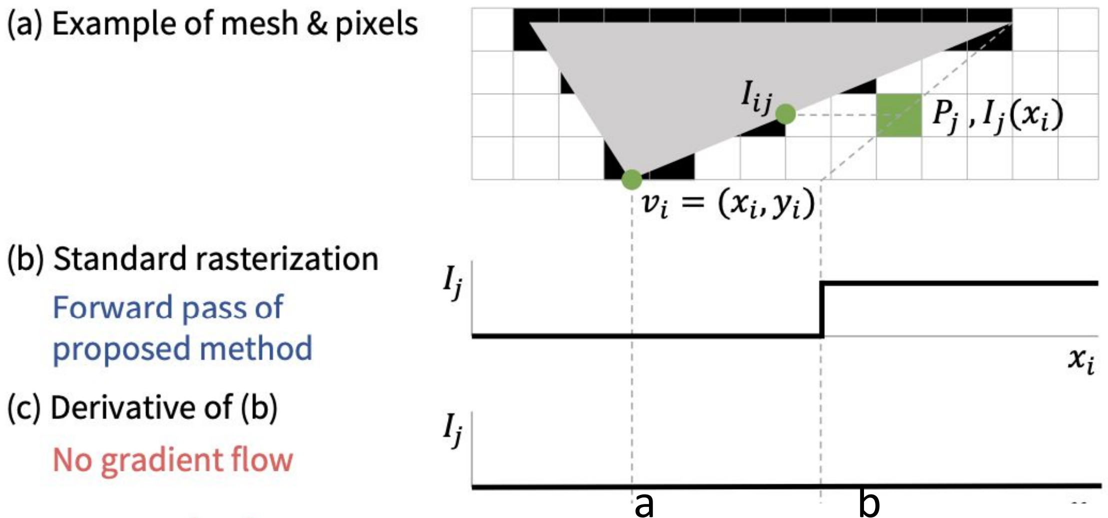


✓ differentiable

✗ non-differentiable

General Background

- Rasterization
  - assigning a triangle to the pixel
  - computing the pixel color based on the assigned triangle’s vertices’ colors.



❌ Rasterization is non-differentiable

Problem Setting

- **Input:** Shape, Camera, Material, Lighting parameters $\Phi_s, \Phi_c, \Phi_m, \Phi_l$

Output: Rendered RGB image I_c or depth image I_d

Rendering function: $R(\Phi_s, \Phi_c, \Phi_m, \Phi_l) \rightarrow I_c, I_d$

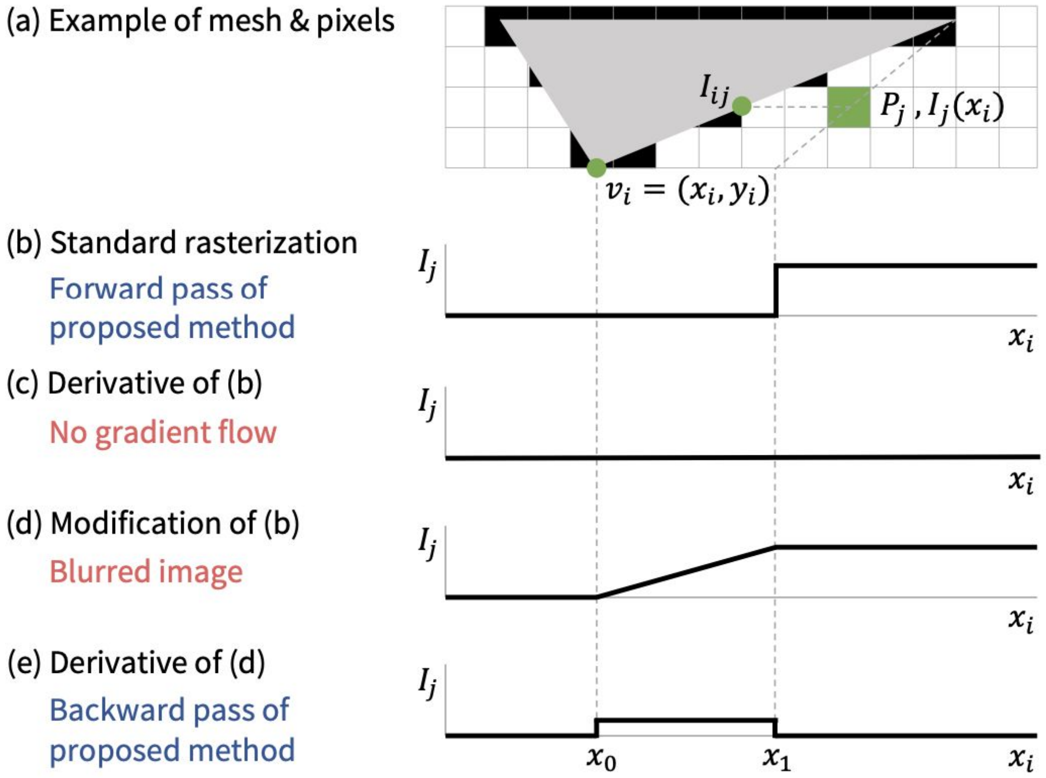
Problem: compute gradients of output image w.r.t. input parameters

$$\frac{\partial I}{\partial \Phi}$$

The computation of the gradients can be approximate, but should be accurate enough to minimize the objective function.

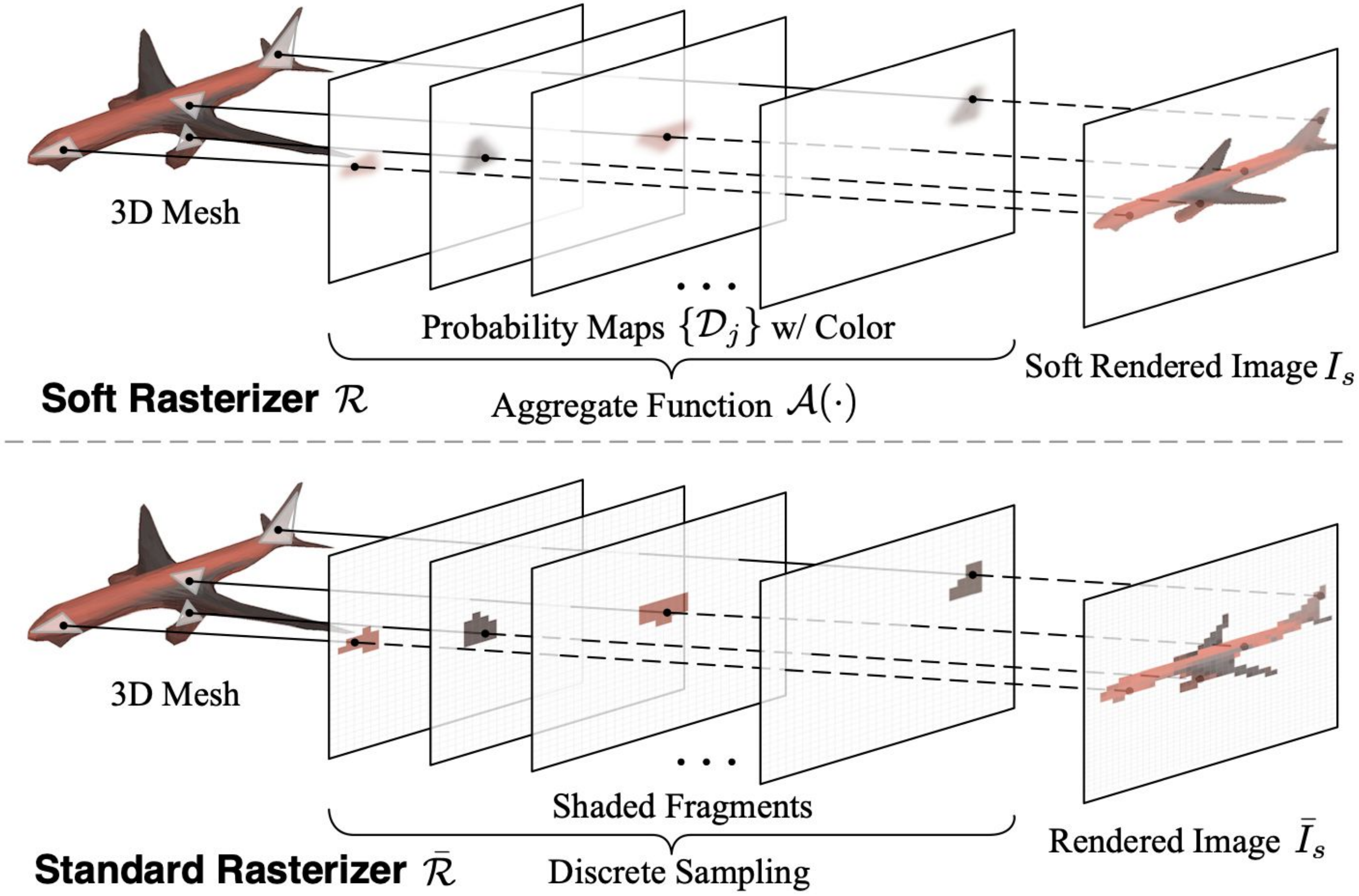
Approach (Mesh)

- Approximated Gradients: Neural 3D Mesh Render, OpenDR, etc.



Approach (Mesh)

- Approximated Rendering: Soft Rasterizer, DIB-R, etc.

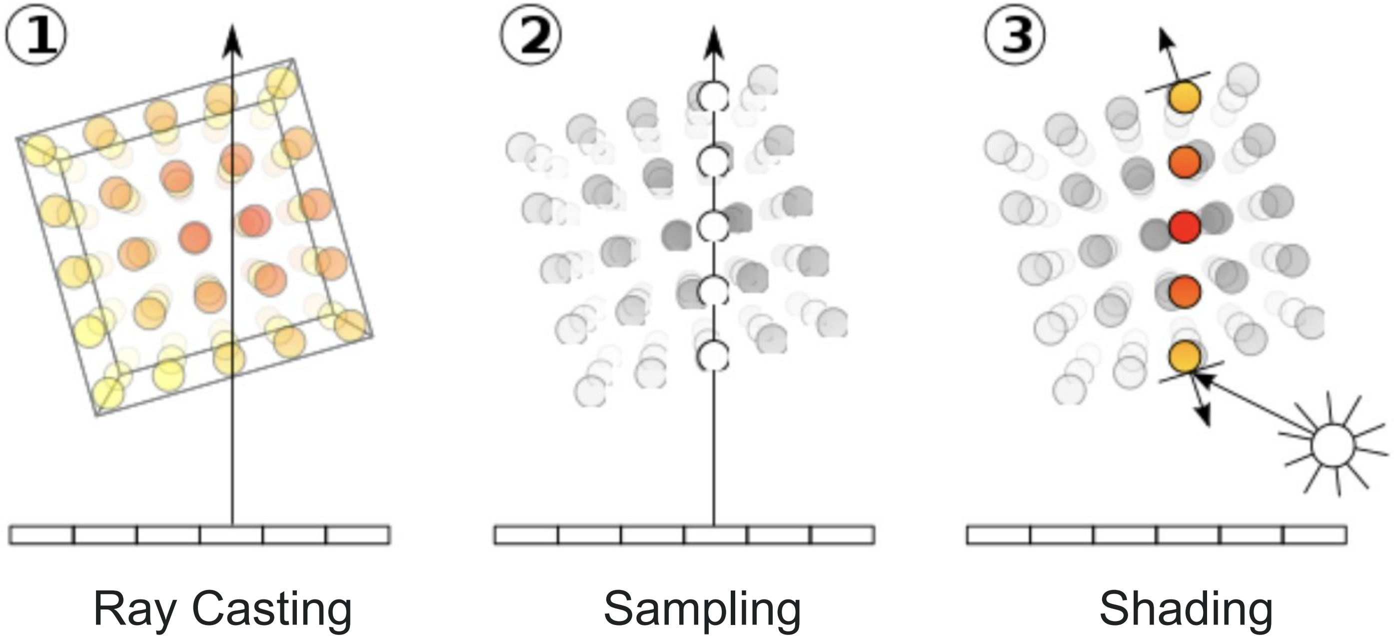


Approach (Voxel)

- Perspective transformer nets
- Differentiable Ray Consistency
- Neural volumes
- SDFDiff
- …

Ray Marching Pipeline:

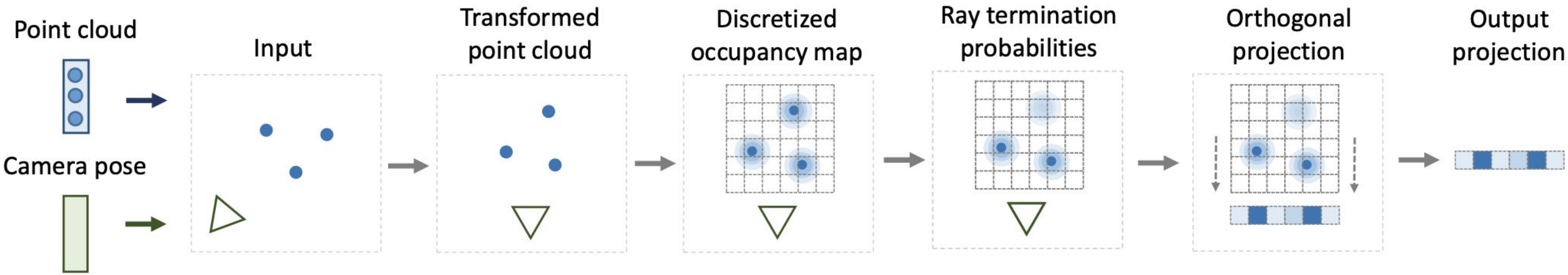
1. Collecting the voxels that are located along a ray
2. Aggregating voxels along a ray



Approach (Point Cloud)

Rendering Pipeline:

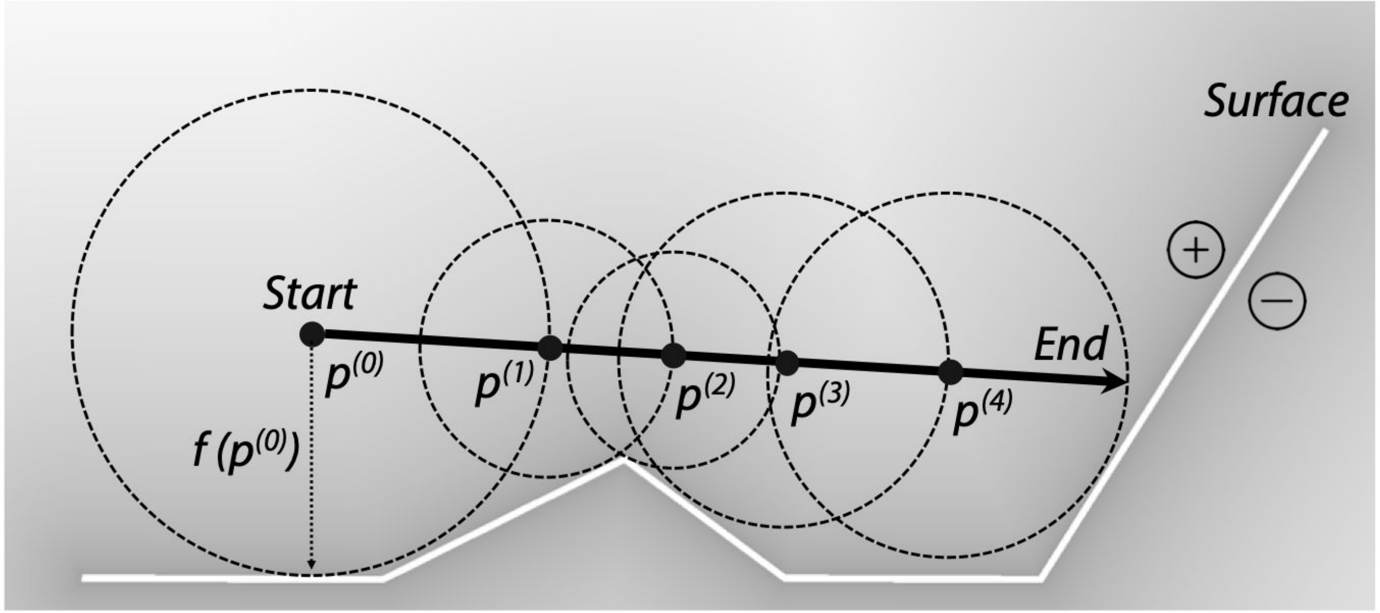
1. 3D point world coordinate -> screen space coordinate
2. Compute influence of 3D point on target pixel’s color
3. Aggregate based on influence and z-values



Approach (Implicit surface)

Similar to voxel-based methods, include:

- Sample points along ray (this is challenging because of infinite resolution)
- Check intersection points.



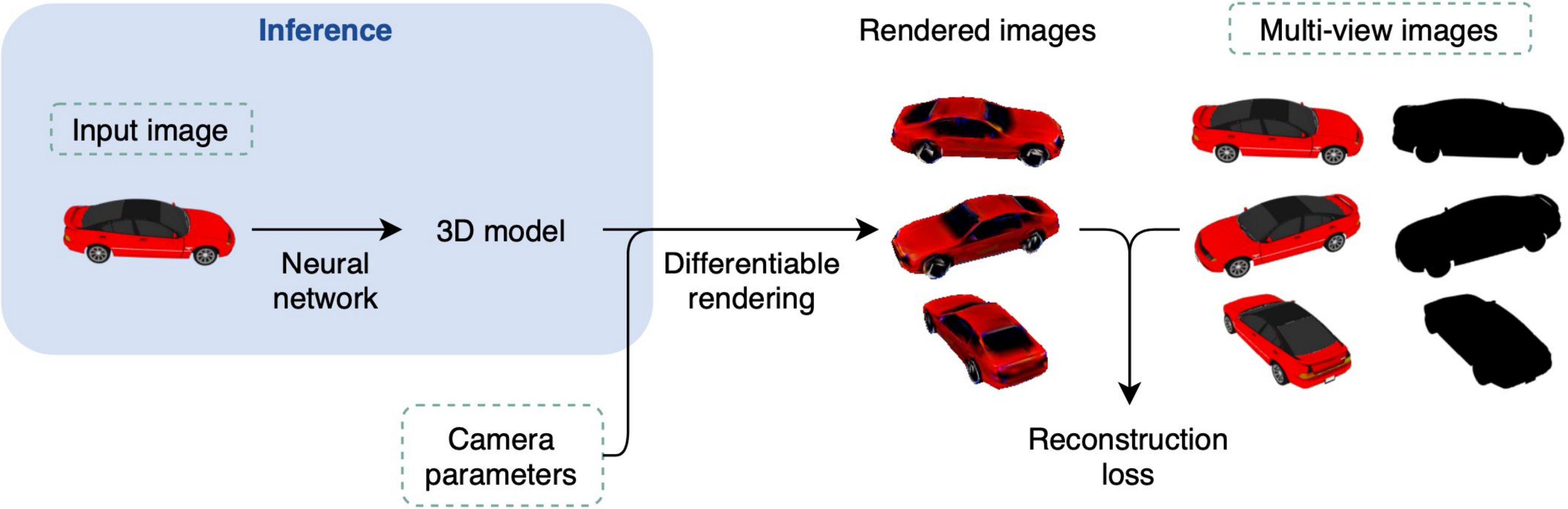
Sphere tracing is efficient

Evaluation Metrics

- Direct gradient evaluation:
  - Lack a common dataset.
  - Some papers focus on approximated gradients.
- Visualization gradients and analyze convergence efficiency.
- Evaluate optimized scene parameters:
  - Lack a common dataset.
- Evaluate 3D reconstruction accuracy.
- Computation time, especially for ray tracing based renderer.

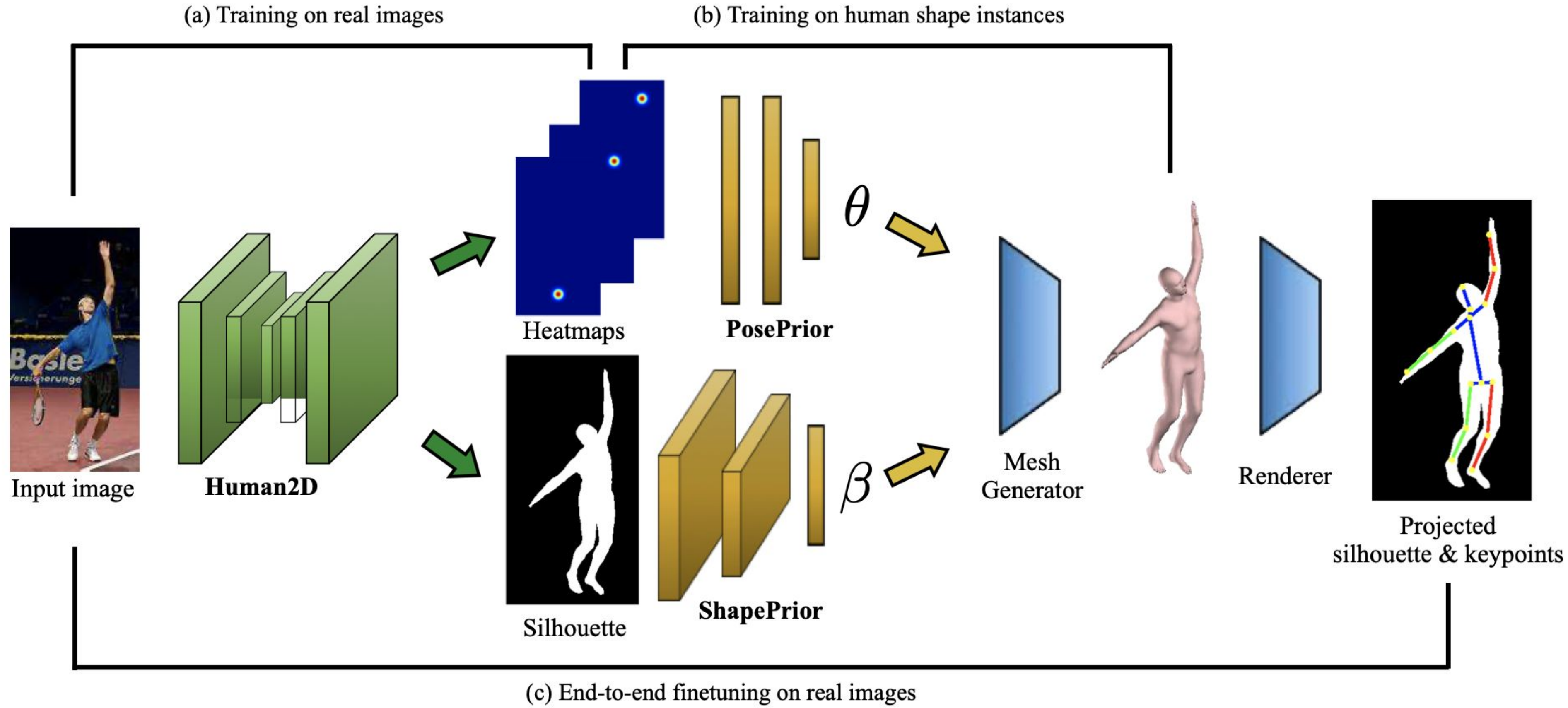
Applications

Object Reconstruction



Applications

Human Reconstruction



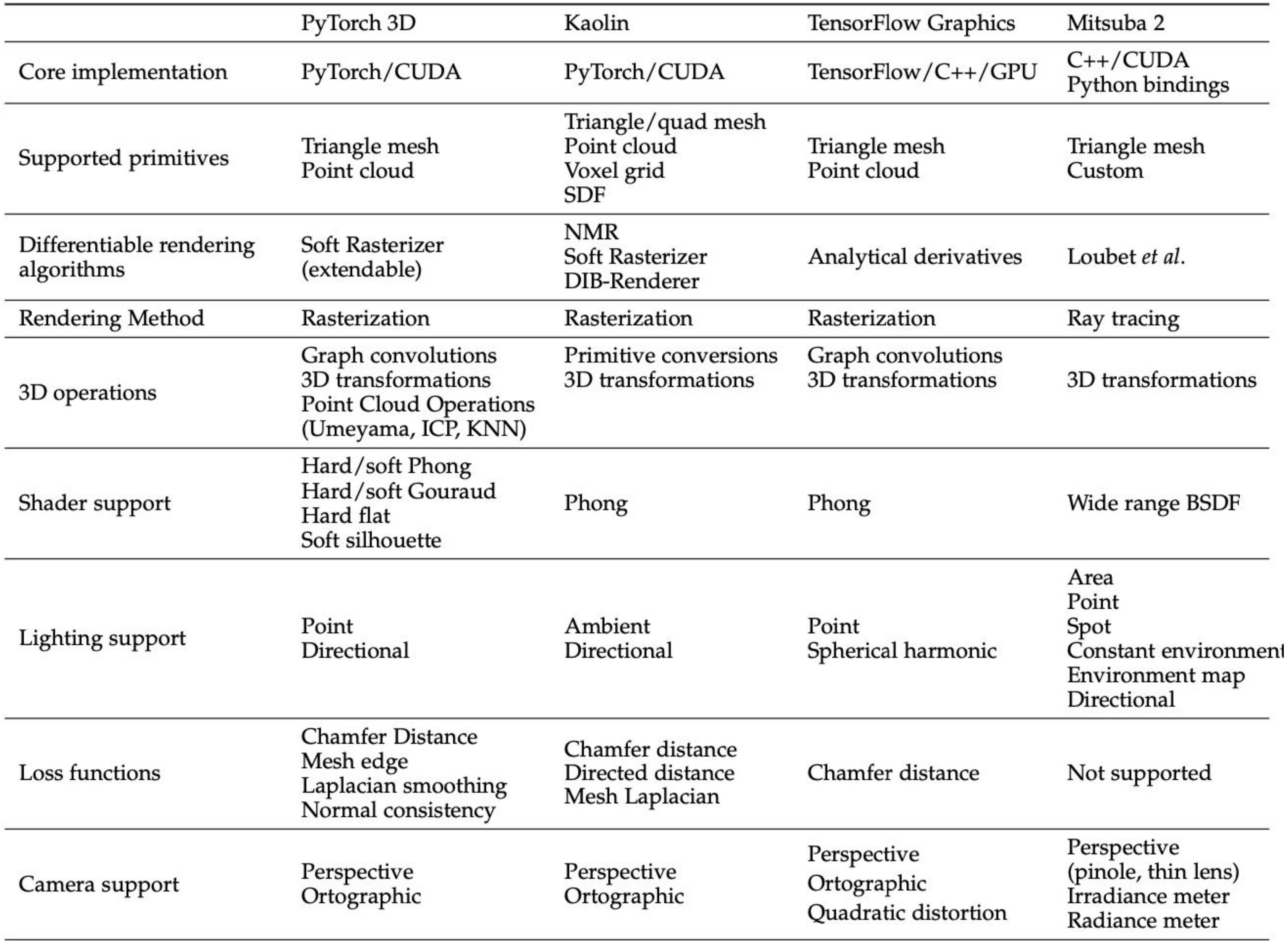
Libraries

DR library:

- *TensorFlow Graphics*
- *Kaolin*
- *PyTorch3D*
- *Mitsuba 2*

Non-DR library:

- Direct3D
- OpenGL
- Vulkan
- Unity
- Unreal Engine



	PyTorch 3D	Kaolin	TensorFlow Graphics	Mitsuba 2
Core implementation	PyTorch/CUDA	PyTorch/CUDA	TensorFlow/C++/GPU	C++/CUDA Python bindings
Supported primitives	Triangle mesh Point cloud	Triangle/quad mesh Point cloud Voxel grid SDF	Triangle mesh Point cloud	Triangle mesh Custom
Differentiable rendering algorithms	Soft Rasterizer (extendable)	NMR Soft Rasterizer DIB-Renderer	Analytical derivatives	Loubet *et al.*
Rendering Method	Rasterization	Rasterization	Rasterization	Ray tracing
3D operations	Graph convolutions 3D transformations Point Cloud Operations (Umeyama, ICP, KNN)	Primitive conversions 3D transformations	Graph convolutions 3D transformations	3D transformations
Shader support	Hard/soft Phong Hard/soft Gouraud Hard flat Soft silhouette	Phong	Phong	Wide range BSDF
Lighting support	Point Directional	Ambient Directional	Point Spherical harmonic	Area Point Spot Constant environment Environment map Directional
Loss functions	Chamfer Distance Mesh edge Laplacian smoothing Normal consistency	Chamfer distance Directed distance Mesh Laplacian	Chamfer distance	Not supported
Camera support	Perspective Ortographic	Perspective Ortographic	Perspective Ortographic Quadratic distortion	Perspective (pinole, thin lens) Irradiance meter Radiance meter

Open Issues

- The graphic model is naïve compared to natural image generation, cannot produce photorealistic images.
- Differentiable rendering of videos. The integration of a physics simulator is preferred.
- Incorporating learning-based methods into differentiable rendering is also worth considering.

Contributions (Recap)

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